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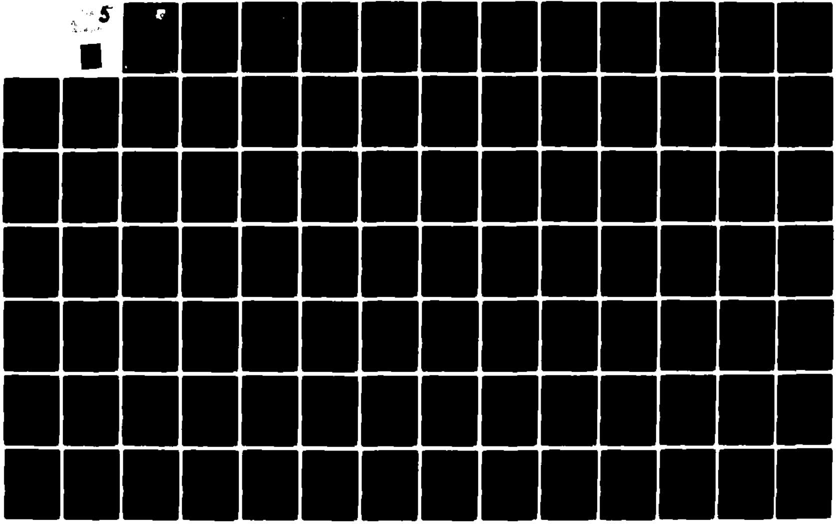

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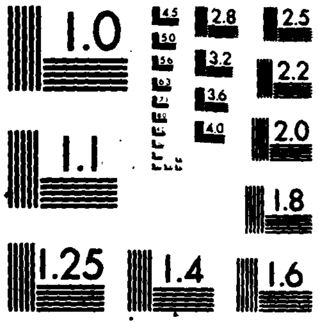

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AFWAL-TR-80-3075

THE COMPUTER IMAGE GENERATION Applications Study

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Final Report for Period February 1979 — July 1980

Approved for public release; distribution unlimited.

FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICE

This report has been reviewed by the Office of Public Affairs (ASD/PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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Visual Simulation
Display Systems
Visual Cues
Computer Graphics

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Computer Image Generation (CIG) systems in flight simulation are evaluated and future trends discussed as they pertain to full mission simulation. Primary consideration is given to the research and development environment, secondary to the training environment.

Recommendations are made on specifying and utilizing CIG features and capabilities.

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PREFACE

The authors would like to express their gratitude to all those individuals and groups who, without recompense, gave of their time and energies for the good of this report. A particular note of thanks must go to Dr. Conrad L. Kraft and Michael L. Cyrus as well as their associates at the Boeing Aerospace Company (Seattle, WA 98124) for their invaluable assistance and the depth of their knowledge.

This work was performed under Contract Number F33615-79-C-3600 and Job Order Number 24030106.

The study was initiated by the Air Force Wright Aeronautical Laboratories (AFWAL), Flight Dynamics Laboratory (FI), Flight Control Division (FIG), Control Synthesis Branch (FIGD), Wright-Patterson Air Force Base, Ohio 45433. The Principal Investigator for Logicon, Incorporated (Inc.) was Robert K. Gullen. The Software Analyst for Logicon, Inc. was Charles S. Cattell. The Psychologist for Logicon, Inc. was Richard K. Overton, Ph.D. The Simulation Group Leader for FIGD was Major William R. Brandt Ph.D. The Program Manager for FIGD was James A. Eicher.

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GLOSSARY OF CIG TERMS
(From Sutherland et al., 1974)

Back Edge	A Back Edge is one that cannot appear in the environment being rendered because it lies on the side of an object away from the observer.
Back Face	A "back face" is a face that cannot appear in the picture by virtue of being on the side of an object away from the observer.
Clipping Cull	The clipping cull is the process of initially removing edges that are not visible because they are on back faces or edges that lie outside the boundaries of the viewing window.
Cluster	A cluster is a collection of faces that can be treated as a group for some special reason.
Color or Shading Rule	This algorithm relates the appearance of a face in its visible location.
Computing the Plane Equation	For vertices v_i - (x_i, y_i, z_i), the components a, b and c are found as: j = (if i=n, then 1, else i+1) $a = (y_i - y_j)(z_i + z_j)$ $b = (z_i - z_j)(x_i + x_j)$ $c = (x_i - x_j)(y_i + y_j)$
Contour Edge	A Contour Edge is an edge that forms part of the outline of an object as seen by the observer.
Edge	The edge in this definition is defined as the delimiter of a surface. Therefore, at the junction of two surfaces we would encounter two edges.
Edge Intersection	Edge intersection has to do with calculating the visibility of an edge. A calculation is made whenever two edges intersect to determine which edge is in front of the other.

Environmental Coordinate System	The total coordinate system used to relate all objects to the viewer. All objects would be transformed to this system to determine their placement and their visibility.
Eye Coordinate System	The coordinate system relating the position of the eye and its viewing direction.
Face	A face is a polygon, usually planar, bounded by straight lines.
Implied Edge	The edge generated at the intersection of two faces.
Linearly Separable	Two clusters are linearly separable if a plane can be passed between them.
Minimax Test	These tests allow for a quick rejection of objects that do not obscure one another. It involves testing the maximum values in x and y of one face as it relates to the minimum x and y of another face.
Non-planar	A face that does not totally reside in a plane.
Object Coordinate System	The object coordinate system relates the surfaces of a particular object to one coordinate system. This allows the object to be repeated and/or moved very easily.
Penetration	The intersection of any two faces that exist in an environment.
Perspective Transformation	The transformation that produces the illusion of depth on a flat screen of the environment.
Planar	When the plane of the face and the face coordinate triples match, the face is said to be planar.
Plane	A surface of such nature that a straight line joining any two of its points lies wholly in the surface.
Plane Equation	The equation used to define the location and orientation of the plane of the face.

Scene Coordinate System	The coordinate system that relates the viewer's scene presentation to the viewer.
Segment Comparisons	Segment Comparisons are performed in the x-z plane. The segments are defined by the number of edge intersections. In each segment a search is made of all visible edges to determine the closest to the viewer and the rest are eliminated.
Sorting	Sorting is an operation that orders a set of records according to a selected key.
Surface Normal/Face Normal	A surface normal is an outward-pointing vector, normal to the surface of the object.
Surrounding Polygons	The Surrounding Polygon is a test used to determine if a polygon obscures a point or not.
Transformation	The act of rotating or mapping one configuration into another in accordance with some function.
Use of Plane Equations	The plane equation is used for many things in hidden surface removal. By substituting the values of another plane the relationship to the original plane may be established. The z values can be arrived at and provide distance to the viewer and the face normal may be calculated for back face removal.

List of Symbols, Abbreviations and Acronyms

A/A	Air-to-Air
A/G	Air-to-Ground
A/S	Air-to-Surface
ACM	Association for Computing Machinery
AF SIM SPO	Air Force Simulator System Program Office
AFHRL/ASM	Air Force Human Resources Laboratory/Advanced Systems Division
AFHRL/FT	Air Force Human Resources Laboratory/Flying Training Division
AFWAL	Air Force Wright Aeronautical Laboratories
AIAA	American Institute of Aeronautics and Astronautics
ASD/SD24E	Air Force Simulator System Program Office, Engineering Division
ASPT	Advanced Simulator for Pilot Training
ATS	Advanced Technology Systems
AVRADCOM	Army Research and Technical Laboratory
AWAVS	Please see VTRS
BITE	Built-In Test Equipment
BRS	Bibliographic Retrieval Services, Inc.
BW	Bandwidth
Bit	Binary digit
C	Candela
C/MOS	Complementary symmetry metal oxide semiconductor
CA	California
CCTV	Closed Circuit Television
CGI	Computer Generated Image
CIE	Commission Internationale de l'Eclairage
CIG	Computer Image Generation
COS/MOS	Complementary symmetry metal oxide semiconductor
CPU	Central Processing Unit
CSC	Computer Science Corporation
CT3	Continuous Tone 3
CT5	Continuous Tone 5
DDB	Digital Data Base
DDC	Defense Documentation Center
DEC	Digital Equipment Corporation
DIALOG	Lockheed Data Service
DIG	Digital Image Generation
DMA	Direct memory access
DMAAC	Defense Mapping Agency Aerospace Center
DMS	Differential Maneuvering Simulator
DRLMS	Digital Radar Land Mass Simulation
E	Illuminance
E&S	Evans and Sutherland
ECL	Emitter coupled logic
EL	Edge List Memory

List of Symbols, Abbreviations and Acronyms (Cont)

FC	Frame Calculator
FI	Flight Dynamics Laboratory
FIG	Flight Control Division
FIGD	Control Synthesis Branch
FIT	Fault Isolation Tests
FLOLS	Fresnel Lens Optical Landing System
FOCI	Farrand Optical Company Incorporated
FOV	Field of view
GE	General Electric
GP	General Purpose
HUD	Head-Up-Display
ICs	Integrated circuits
INSPEC	Institute of Electrical Engineers
IR	Infrared
JTCG	Joint Technical Coordinating Group
LA	Los Angeles
LCC	Life Cycle Costs
LLLTV	Low light level television
LOD	Level-of-detail
Link	Singer Corporation, Link Division
MECL	Motorola emitter coupled logic
MIT	Massachusetts Institute of Technology
MOS	Metal oxide semiconductor
MTBF	Mean Time Between Failures
MTF	Modulation transfer function
MTTR	Mean Time to Repair
NASA	National Aeronautics and Space Administration
NIAC	NASA Industrial Applications Center
NOE	Nap-of-the-Earth
NOSC	Naval Ocean Systems Center
NTC	Naval Training Center
NTEC	Naval Training Equipment Center
NTIS	National Technical Information Service
PIO	Pilot induced oscillation
PM TRADE	Army Project Manager of Training Devices
Pixel	Picture Element
R&D	Research and development
REIL	Runway end identifier lights
SAAC	Simulator for Air-to-Air Combat
SATD	Simulators and training devices
SI	Scan Line Intersection Computer
SEL	Systems Engineering Laboratories
SIGGRAPH	Special Interest Group on Computer Graphics
SMS	Shuttle Mission Simulator
SP1	Special Purpose 1
SP2	Special Purpose 2
STG	Synthetic Terrain Generator

List of Symbols, Abbreviations and Acronyms (Cont)

TAC	Tactical Air Command
TAWC	Tactical Air Warfare Center
TF	Terrain Following
TSIS	Total Systems Integration Simulator
TTL	Transistor to transistor logic
TV	Television
UCSD	University of California at San Diego
USC	University of Southern California
VASI	Visual approach slope indicators
VG	Video Generator
VLSI	Very large scale integration
VPU	Vector Processor Unit
VTRS	Visual Technology Research Simulator
bbn	Bolt, Beranek and Newman
cp	Candlepower
lm	Lumen
log BLMTFA	log Band Limited Modulation Transfer Function Area
lx	Lux
sb	Stilb

SUMMARY

This report describes an evaluation of Computer Image Generation (CIG) Systems as they may apply to flight simulation. Future trends are discussed as they pertain to full mission simulation. The current state of the art in CIG systems is reviewed in general, with specific emphasis placed on what CIG features are required to satisfy the needs of the U.S. Air Force, Wright Aeronautical Laboratories, Control Synthesis Branch (AFWAL/FIGD), Wright Patterson Air Force Base, Ohio.

A major portion of the study relates to comparisons of CIG system features available currently and in the future. The results are directly proportional to the amount of information provided by manufacturers. Due to the proprietary nature of CIG, certain necessary information is not available.

A review of the Table of Contents, major section titles will give the outline of subjects discussed in this report. Sections 1-3 give background, scope and goals. Sections 4-24 give details on CIG systems, with specific characteristics. General Conclusions are given in Section 25 with Specific Conclusions and Recommendations as they apply to AFWAL/FIGD Research and Development mission tasks given in Section 26.

In the appendices A, B and C are given a tabulation of our CIG questionnaire as well as a CIG research road map.

This study does not make a recommendation of one particular CIG system over another, nor whether to buy now versus waiting for the next generation. Today's CIG systems can accomplish a good part of AFWAL/FIGD mission task requirements if scaled down goals are set. However, the future for CIG systems promise significant advancements such that the original goals may be met.

SECTION 1

CIG STUDY INTRODUCTION

The Air Force Wright Aeronautical Laboratories, Control Synthesis Branch (AFWAL/FIGD) at Wright-Patterson Air Force Base, Ohio 45433, has the responsibility for conducting flight control research and development (R&D) on existing and future aircraft. To properly fulfill this obligation it must maintain an up to date test facility. The AFWAL/FIGD, recognizing this responsibility, generated a five-year plan that outlines the steps to maintain and improve the facility such that it will be properly equipped to accomplish its charter.

One of the improvements listed in the five-year plan is to modernize the existing simulators and add one additional simulator The Total Systems Integration Simulator (TSIS). A major portion of the modernization is the addition of a Computer Image Generation (CIG) system that will provide visual information to all the simulators (existing and new).

The AFWAL/FIGD currently has various types of visual display systems from camera/model to raster CIG systems. The new CIG system will augment or replace these existing systems.

SECTION 2

CIG STUDY GOALS

The goals of this study were to produce information concerning the requirements which CIG must meet in order to satisfy the AFWAL/FIGD full mission task. Additional information on the current state-of-the-art and future trends in CIG is provided. As much direction as possible is given for the writing of a statement of work, the evaluation of proposals and acquisition of a CIG system to be incorporated into the AFWAL/FIGD as an R&D tool.

It is the hope of the authors that impartiality has been maintained throughout the study period and within this report. When manufacturers names are given they appear in alphabetic order with no implication of merit being intended or applied.

SECTION 3

SCOPE OF THIS REPORT

The thrust of this report is to relay to the AFWAL/FIGD the information that was gathered during the study period. Because of the full mission task requirements of the AFWAL/FIGD, the study was directed toward raster scan CIG.

Because of the time involved, there were no actual tests or experiments done on the various CIG systems. The information gathered and used was provided by the manufacturers of the systems, users, CIG experts and currently available published material.

Since a major portion of the study relates to the comparison of CIG systems available currently and in the future, some of the results are directly proportional to the amount of information provided by the manufacturers.

Because of the nature of the subject specific conclusions are drawn throughout the report. These conclusions are synopsized in the Specific Conclusions and Recommendations section of this report (Section 26).

Various systems have unique advantages and disadvantages and total evaluation of each is required to make valid comparisons between manufacturers. Unfortunately due to the proprietary nature of CIG, some necessary information was not available. Though the report is exhaustive it is not absolutely complete. Different sections are explored to different depths because of the level of information available.

The study will use terms such as edges and polyhedrons. We do not suggest that the techniques that utilize these forms are the best or worst. We are using them because they currently have the broadest usage and understanding.

SECTION 4

CIG FAMILIARIZATION

4.1 LITERATURE SEARCH

A computer literature search was performed at three different facilities:

(a) The University of California at San Diego (UCSD).

(b) The National Aeronautics and Space Administration (NASA) Industrial Applications Center (NIAC) in Los Angeles (LA), California (CA).

(c) The Defense Documentation Center (DDC) in LA.

At UCSD the Bibliographic Retrieval Services, Inc. (BRS) as well as the DIALOG (Lockheed) Data Service were utilized. The National Technical Information Service (NTIS) (1964 – present) of the United States (U.S.) National Bureau of Standards, Springfield, Virginia (VA) and the Information Services Division of the Institute of Electrical Engineers (INSPEC), London, England data bases were accessed through BRS and "DIALOG."

Within the INSPEC data base the physics, computer in control, as well as electrical and electronic abstracts were searched.

At NIAC the NASA data base (1962 – present) was searched.

At DDC the DDC data base as well as technical reports (past work), work units (current work in progress), and program planning (future work) were searched.

The key words and phrases for the search are shown in Tables 1, 2, and 3. Table 1 contains the Computer Image Generation key phrases. Table 2 contains the perception key phrases. Table 3 contains sensor simulation key phrases. The lists are not complete but are meant to show the approach taken.

The results of the literature search took the form of titles and abstracts. Each title and abstract was evaluated. Table 4 shows the evaluation technique used. All documents with a score of 1 were acquired. Because of the volume of the material no lower scoring documents were evaluated.

4.2 COMMUNICATIONS WITH USERS, MANUFACTURERS, AND KNOWLEDGEABLE SOURCES

Table 5 lists all the contacts made during the course of this report. It includes those facilities to which trips were made as well as telephone and letter contacts.

4.3 TRIPS

Table 6 lists all the trips made during the course of this report.

Table 1. CIG Key Phrases

Flight Simulation
Flight Simulators
Control Simulation
Landing Simulation
Training Simulator
Visual Simulation
Computer Generated Imagery
Computer Generated Images
Computer Generated Image
Computer Generation of Images
Computer Image Generation
Computer Image Generators
Computer Image Generator
Computer Images
Digital Images
Digital Image Generation
Digital Image Generators
Computer Graphics
CIG
CGI
DIG

Table 2. Perception Key Phrases

Perception
Cue
Cue
Texture
Time Discrimination
Time Response
Distance
Velocity
Attitude
Position
Altitude
Visual Perception
Human Performance
Space Perception
Pattern Recognition
Pilot Performance
Sensory Perception
Visual Cues
Visual Perception
Visual Signals

Table 3. Sensor Simulation Key Phrases

Forward Looking Infrared
FLIR
FLIR Detectors
Simulation
Simulators
Low Light Level Television
LLTV
Radar Images
Infrared Detectors
Infrared Images

Table 4. Selection of Technical Reports

(1) Definitely of Interest
(2) Probably of Interest
(3) Maybe of Interest
(4) Foreign Language
(5) Of Possible Interest to the AFWAL/FIGD
(6) Of No Interest

Table 5. Communications Table

Advanced Technology Systems (ATS), Engineering Department,
Fair Lawn, NJ 07410.

Air Force Human Resources Laboratory/Advanced Systems
Division (AFHRL/ASM), Wright-Patterson AFB, OH 45433.

Air Force Human Resources Laboratory/Flying Training Division
(AFHRL/FT), Advanced Simulator for Pilot Training (ASPT),
Williams AFB, AZ 85224.

Air Force Simulator System Program Office (AF SIM SPO),
Engineering Division (ASD/SD24E), Wright-Patterson AFB,
OH 45433.

Air Force Wright Aeronautical Laboratories (AFWAL),
Flight Dynamics Laboratory (FI),
Flight Control Division (FIG),
Control Synthesis Branch (FIGD),
Wright Patterson AFB, OH 45433.

American Airlines, Flight Academy/Simulator Engineering,
Fort Worth, TX 76125.

American Institute of Aeronautics and Astronautics (AIAA),
New York, NY 10019. AIAA Working Group on Training
Simulation, Daytona Beach, FL.

Army Project Manager of Training Devices (PM TRADE),
Aviation Division, Naval Training Center (NTC),
Orlando, FL 32813.

AWAVS - See Visual Technology Research Simulator.

Boeing Aerospace Corporation, Crew Systems and Simulation
Technology, Seattle, WA 98124.

Boeing Aerospace Corporation, Flight Training, Seattle,
WA 98124.

Chrysler Corporation, Defense Engineering Division, Detroit,
MI 48231.

Defense Documentation Center (DDC), Los Angeles, CA 90045.

Table 5. Communications Table (Cont)

Department of the Army, Aeromechanics Laboratory,
Army Research and Technical Laboratory (AVRADCOM),
Ames Research Center, Moffett Field, CA 94035.

Evans & Sutherland (E&S) Computer Corporation, Simulation
Systems, Salt Lake City, UT 84108.

Experimental Computer Simulation Laboratory, Code 974,
Naval Training Equipment Center (NTEC), Orlando, FL 32813.

Farrand Optical Company Incorporated (FOCI), Valhalla, NY 10595.

FB-111, Detatchment 3, Platsburgh AFB, NY 12903.

FB-111, Tactical Air Command (TAC) Headquarters, Directorate of
Fighter Reconnaissance Operations, Simulator Branch,
Langley AFB, VA 23665.

FB-111, Tactical Air Warfare Center (TAWC), Surface Attack
Simulator Directorate, Eglin AFB, FL 32542.

FB-111, Trainer Division, Hill AFB, UT 84056.

General Electric (GE) Company, Advanced Simulator for Pilot
Training (ASPT), Air Force Human Resources Laboratory/
Flying Training Division (AFHRL/FT), Williams AFB, AZ 85224.

General Electric (GE) Company, Air Force Simulation Systems,
Daytona Beach, FL 32105.

General Electric (GE) Company, Video Display Equipment Operations,
Syracuse, NY 13221

Gould Incorporated, Simulation Systems Division, Melville,
NY 11746.

Grumman Aerospace Corporation, Research Department, Bethpage,
NY 11714.

Honeywell Incorporated, Training Systems and Research Division,
Minneapolis, MN 55413.

Magicam, Hollywood, CA 90038.

Marconi Radar Systems, Limited, Control and Simulation Division,
New Parks, Leicester, England LE3 1UF.

Table 5. Communications Table (Cont)

Massachusetts Institute of Technology (MIT)/Manned Vehicle
Laboratory, Cambridge, MA 02139.

McDonnell Douglas Electronics Company, Simulation Marketing,
St. Charles, MO 63301.

National Aeronautics and Space Administration/Shuttle
Mission Simulator (NASA/SMS), Flight Simulation Division,
Johnson Space Center, Houston, TX 77058.

National Aeronautics and Space Administration (NASA),
Engineering Laboratory, Johnson Space Center,
Houston, TX 77058.

National Aeronautics and Space Administration Industrial
Applications Center (NIAC), Los Angeles, CA 90007.

Northrop Corporation, Aeroscience Laboratory, Hawthorne, CA 90250.

Redifon Simulation Incorporated, Arlington, TX 76011.

Systems Engineering Laboratories (SEL), Advanced Simulator
for Pilot Training (ASPT), Air Force Human Resources
Laboratory/Flying Training Division (AFHRL/FT),
Williams AFB, AZ 85224.

The Singer Corporation, Link Division, Binghamton, NY 13902.

The Singer Corporation, Link Division, Sunnyvale, CA 94086.

University of California, Lawrence Livermore Laboratory,
Livermore, CA 94550.

University of California at San Diego (UCSD), San Diego, CA 92093.

University of Southern California (USC), Information Sciences
Institute, Marina del Rey, CA 90291.

Visual Technology Research Simulator (VTRS), previously known as
Aviation Wide Angle Visual System (AWAVS),
Naval Training Equipment Center (NTEC), Orlando, FL 32813.

Table 6. Trips

Magicam — A wholly-owned subsidiary of Paramount Pictures, Los Angeles, California. Magicam has developed a technique of color keying video information using a computer-controlled camera slaved to a master camera. This system utilizes an advanced synchro-servo system which displays a very high level of positional accuracy.

UCSD — This facility provided on-line access to the B.R.S. and Dialog Data Services.

NIAC — This facility provided access to the NASA Data Base.

DDC — This facility provided access to the DDC Data Base.

AIAA — Working Group on Training Simulation. This conference provided information pertaining to CIG.

GE facility, Daytona Beach, Florida — A walk through was taken and a demo of texture was seen.

USC — Information Sciences Institute. Discussions were held on current and future CIG technologies.

E&S facility, Salt Lake City, Utah.

Boeing — A GE Compu-Scene system was evaluated and discussions were held on current and future CIG technology.

NASA/SMS — The Link CIG System was evaluated and discussed.

NASA/Engineering Laboratory — The E&S CIG System was evaluated and discussed.

Experimental Computer Simulation Lab — Discussions were held on current and future CIG technology.

PM TRADE — Discussions were held on current and future CIG requirements.

VTRS — A GE Compu-Scene system was evaluated and discussions were held on current and future CIG systems.

Singer-Link facility, Sunnyvale, California — An F-111 was demonstrated and evaluated. Discussions were held on current and future CIG technology.

ASPT — A GE system was evaluated and discussions were held on current and future CIG technology.

Northrop Corporation — Discussions were held on current CIG technology and Northrop requirements.

AFHRL/ASM — Discussions were held on future CIG and display technology.

AF SIM SPO — Discussions were held on CIG data base considerations.

4.4 CIG THEORY OF OPERATION

4.4.1 CIG Concept

Computer Image Generation (CIG) or Computer Generated Image (CGI) or Digital Image Generation (DIG) is the technology (art) of portraying a visual scene using computers, special purpose hardware, and a digitally stored visual data base which has been previously built for the purpose.

The following sections will be used to bring the neophyte CIG user up to a level of understanding that will allow him/her to comprehend the impact of some of the figures and limits discussed later. The advanced reader may skip this section and proceed to Section 5.

The computer-generated picture is produced very much like that of a newspaper or magazine picture. If either one of these pictures were magnified, it would become apparent that the picture was composed of many small dots. In the case of colored pictures the dots would be colored (usually RED, BLUE, GREEN). This technique using dots to produce a picture may be thought of as a quantitized representation of the visual scene. The point being made here is that a quantitized representation of a scene can look almost as real as the actual scene itself. The number of dots, the size of the dots and the distance from the picture all contribute to its fidelity.

Now that we agree that a picture can be made of many small dots, the next step is to provide motion to the scene created either by the motion of objects in the scene and/or the motion of the viewer. This is done by creating a new scene at a given rate (the rate may vary but 30 Hertz is the standard U.S. TV update rate, known as the frame rate). If we can put a group of dots on a screen to form a picture and then create a new picture with these dots within 33.3 milliseconds (30 Hertz), we can produce what appears to be a moving picture. If we display alternate halves of the frame 60 times a second (60 Hertz), or every 16.7 milliseconds, we can eliminate flicker. Each half frame is known as a field.

The following discussion will show how a scene is transformed from its real world representation to its elementary parts (dots). At this time, let's make the conversion to the standard graphics terminology by calling the "dots" picture elements or pixels. A picture element or pixel is the smallest discrete unit on which the hue and/or tonal value can be controlled.

The "world" is first transformed into objects that can be defined by mathematical equations and characteristics (i.e., tree = cylinder, brown + cone, green). See Figure 1.

Now that the world has been defined, the viewer is allowed to proceed through it. The simulation system rather than the CIG system controls the world and where moving models are placed. Therefore, the simulation system provides position and change rate information to the CIG system on a continuing basis (this is known as the simulation update rate). The CIG system uses the position and altitude and attitude information to determine the possible visual sphere (i.e., east end of L.A. International looking west), Figure 2A, 2B, 2C.

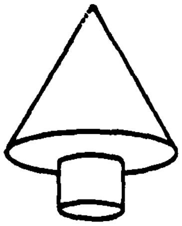

Figure 1. Representing a Tree

The next step is to reduce the amount of visual data to only that visible through the windows of the simulated vehicle, 2C to 2D. Once this has been done, the three-dimensional scene must be put in perspective and converted to a two-dimensional scene for presentation, Figure 2D to 2E. We know that the picture is made up of a matrix of dots or pixels; therefore, our next step is to take the 2D picture and subdivide it into lines of picture elements (pixels/dots), Figure 2F. Now we calculate each picture element of that line to determine its attributes (shade or color), Figure 2G, 2H. Now begins the construction of the actual picture. The picture element data is fed to the display device and the new picture is constructed, Figure 2J. All of the preceding calculations are done within 33 milliseconds (up to 1,000,000 picture elements).

4.4.2 CIG Basic Approach

The following discussion is a description of the basic functions of today's typical CIG system. It is necessary to understand these basic functions to appreciate the problems involved in presenting an acceptable computer image.

Many of the anomalies unique to a raster-type presentation are consequences of the way the picture is constructed and therefore an understanding of this construction is important.

Various systems use slightly different approaches, but basically they are all very similar to the one described.

4.4.2.1 Data base creation. See Figure 3. Normally in a motion picture production the scenes are recorded on film and then developed to enable presentation. In a CIG system the act of photographing is done by an artist/engineer (in whatever order you want). He first analyzes many pictures, drawings, and in some cases the actual scene, and then he constructs the model. The model must be as realistic as possible but must be drawn using the most efficient CIG methods (i.e., as few edges as possible). Once he has finished his drawing, he transfers the model into the CIG data base. This is similar to the photographer taking the pictures and is done by converting the model into a number of polygons. These polygons will have attributes such as color, position, relationship to other polygons, etc. All this information is

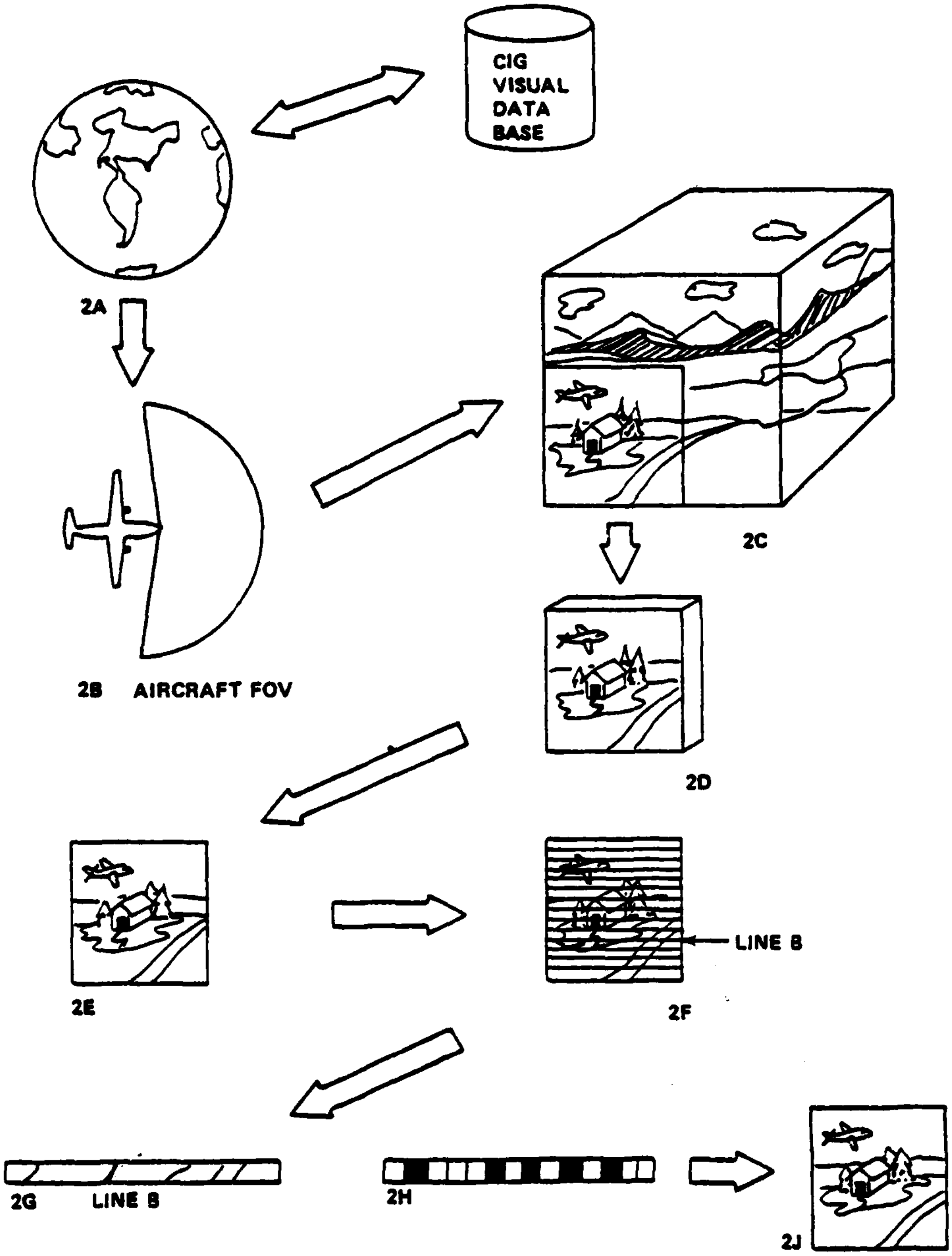

Figure 2. CIG Scene Creation

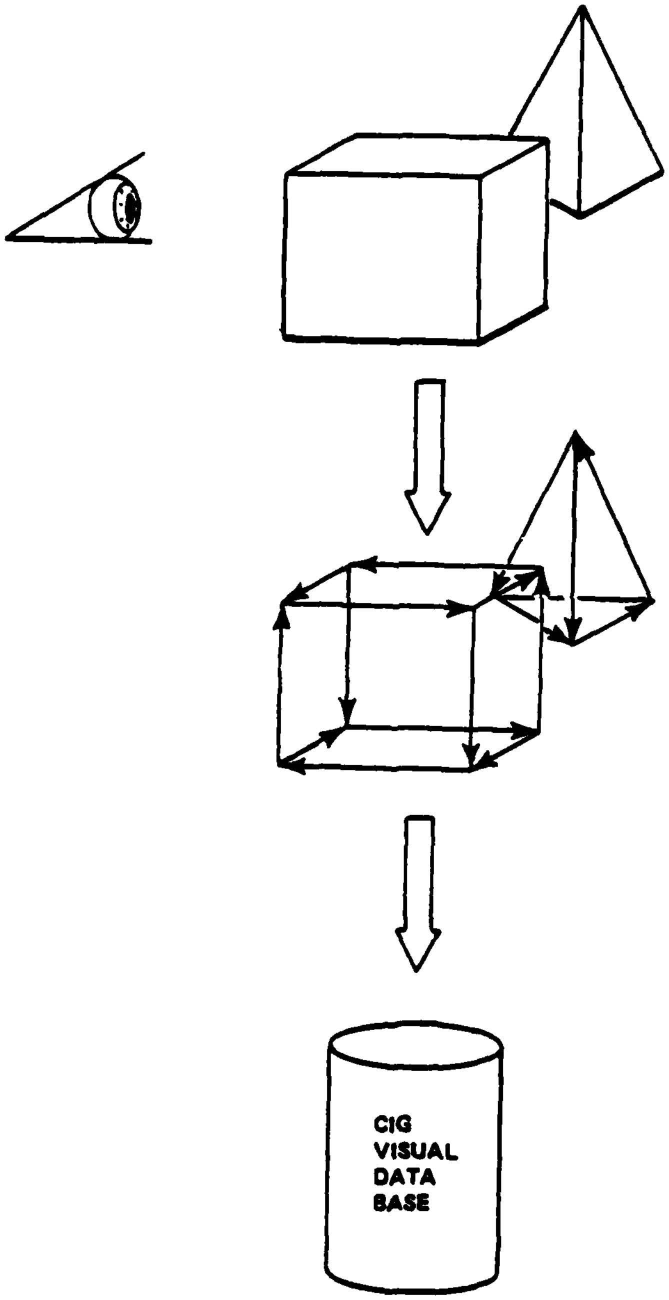

Figure 3. CIG Data Base Creation

converted into a digital representation that is stored in the CIG data base. Some of the problems encountered in this area are:

(a) Possible size of the data base

(b) Ease of modeling the scene in the CIG system

(c) Commonality between various CIG data bases (Simulator to Simulator), Sensor and CIG.

The CIG Data Base Manager processes information about the scenery of the gaming area. It does so by storing the mathematical description (of the objects in the scene) in the proper files. This is similar to the processing of exposed motion picture film to produce projectable motion picture film.

Once processed the film can be run through a projector and the scene is recreated on the screen. In a similar fashion the data files produced by the CIG Data Base Manager are processed by the CIG real-time programs to recreate the scenery on the CIG screen.

4.4.2.2 Determining orientation. At this point the recorded scenes are stored in the data base. They now are in a digitized usable format for the real-time CIG system to use. The real-time processing can be likened to the projection of a movie film.

Once the gaming area has been recorded, the problem is to provide for the CIG viewer. The viewer must be able to proceed through the CIG visual environment in any way desired. To do this the real-time CIG system must be able to construct scenes from any viewing reference and lighting conditions. Allowing the viewer to interact with the visual scene is where the CIG system departs somewhat from the normal movie. The following discussion will explain how the real-time presentation is accomplished.

The first thing that has to be done is to establish where the viewer is in this expansive gaming area. See Figure 4. Since the gaming area (On-Line Data Base) may be as large as 500 by 500 nautical miles, a sphere, cone or cube of possible visual data must be established which is a subset of the total gaming area. The size of the visual sphere is controlled by the field-of-view provided to the viewer. This sphere of possible visual data is also referred to as the "Active Data Base". This data resides in the CIG memory for fast and easy access.

The active data base is of interest because it represents the available scenery that can be shown at any one instant. If the active data base is exceeded (i.e., the vehicle moves so fast that the area of visible scenery has moved out of the active data base) then the scene will obviously deteriorate.

The next bit of information positions the projector in our movie analysis. This information is the position attitude and change rates provided by the simulation program. This information is used to position the spot where the eye is viewing the outside world. The active data base information is rotated into the viewer's coordinate system to allow for follow-on processing.

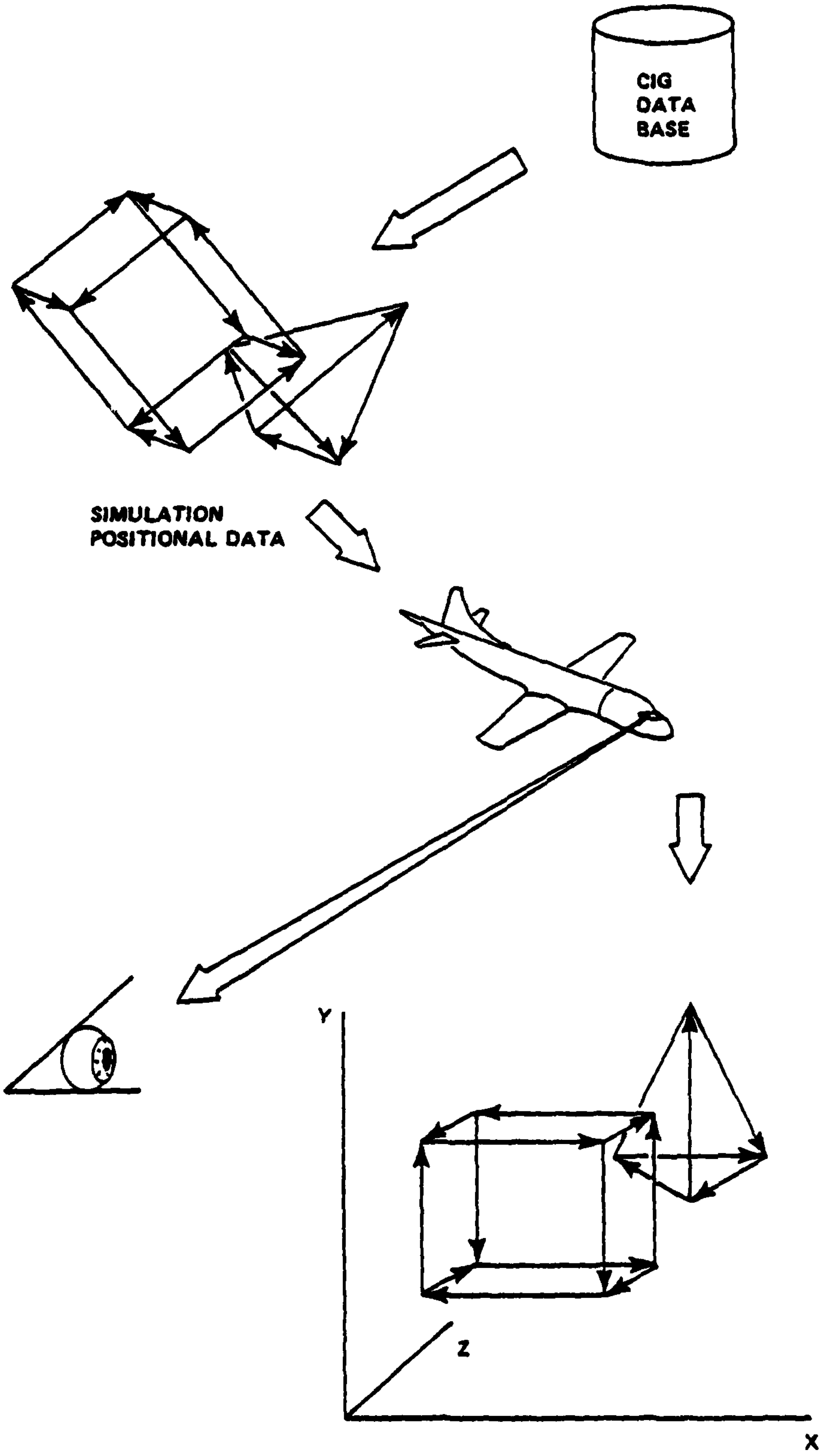

Figure 4. Orientation of Presentation

4.4.2.3 Determining what is visible. The problem now is to calculate the visual information that is actually visible to the viewer. See Figure 5. For this example, we will assume that the CIG projection system is a mosaicked CRT presentation. (That is, the field of view is made up of multiple CRTs butted together to provide a total scene.) The continuing discussion will now concentrate on the CIG system's presentation of a scene on one of these CRTs. The same technique is used for the remaining CRTs. The example here is directed at a mosaicked system but could be a view from other windows or instructor viewpoints, etc.

An imaginary window the size of the CRT is placed between the viewer and the outside world. Then the scenery, including moving models, is projected onto the imaginary window plane. The visual information that is not required is clipped away so that the remaining data left to process is that area that is formed by the CRT WINDOW and its Z extension away from the viewer. The objects are put into perspective size, dependent upon their distance from the viewer. At this point, the level of detail (LOD) of the model has been determined. LOD may be defined as a concept which allows a CIG system to present the simplest view of an object consistent with its range from the viewer. The purpose of having different LODs is to limit CIG system loading by presenting only the detail which the viewer can discern. To implement the LOD concept, an object which is to be depicted must be modeled separately for each LOD (currently 3-8 levels) from most simple to most complex. These related models reside in the CIG data base and an algorithm implemented in the CIG system selects which one to display by considering range, system loading, and object priority.

At this stage the objects within the window of the scene have been defined by:

(a) Levels of visibility — the visible range affected by fog, rain, haze, dust, etc.

(b) Their priority (i.e., who is behind whom)

(c) The object's proper level of detail.

Note: The distance a person can see is dependent on many variables. Fog, rain, dust, etc. reduce the visible range. If we can use these factors in realtime scene creation it will speed the processing required to build a scene. The speed is increased by the elimination of elements in the visual scene which would be beyond the visible range and therefore need not be processed.

4.4.2.4 Creation of the two-dimensional scene. See Figure 6. The next step is the creation of a two-dimensional scene. This means that all of the objects that have faces that cannot be seen from the viewpoint will be dropped from consideration. What is left is the list of potentially visible object faces (i.e., those facing the viewer are only potentially visible because other faces, which would occlude or occult them, may be between them and the viewer).

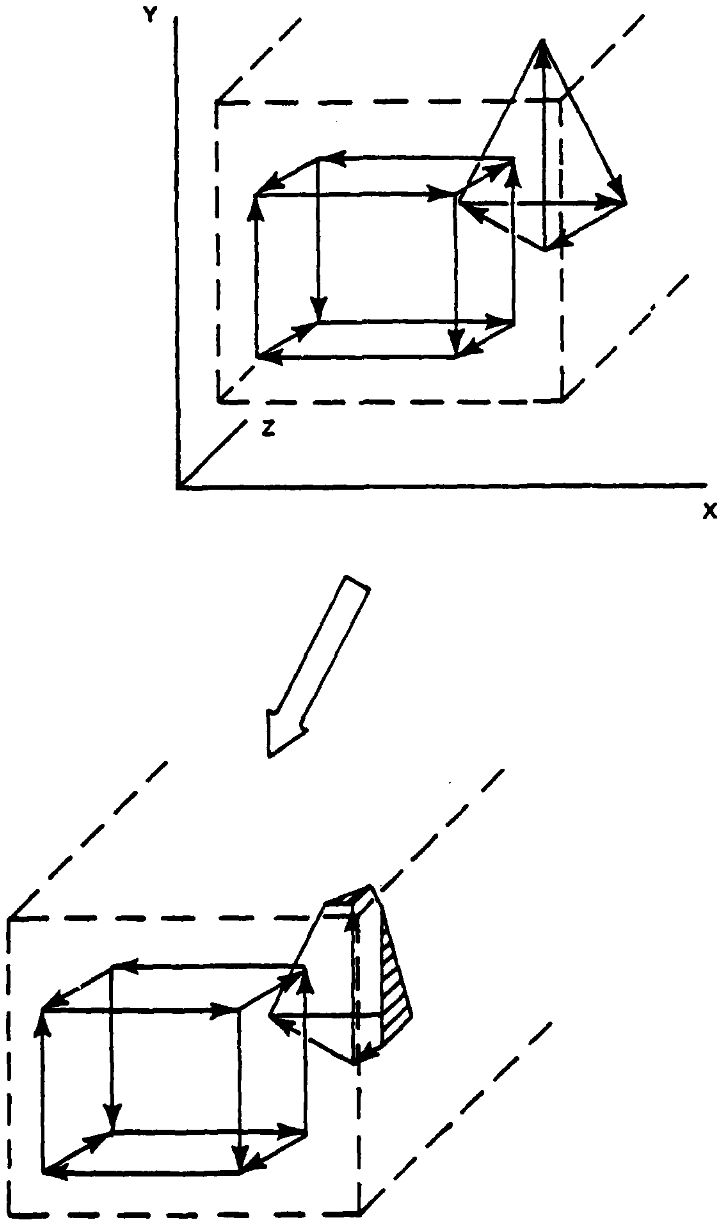

Figure 5. Determining What Is Visible (Clipping)

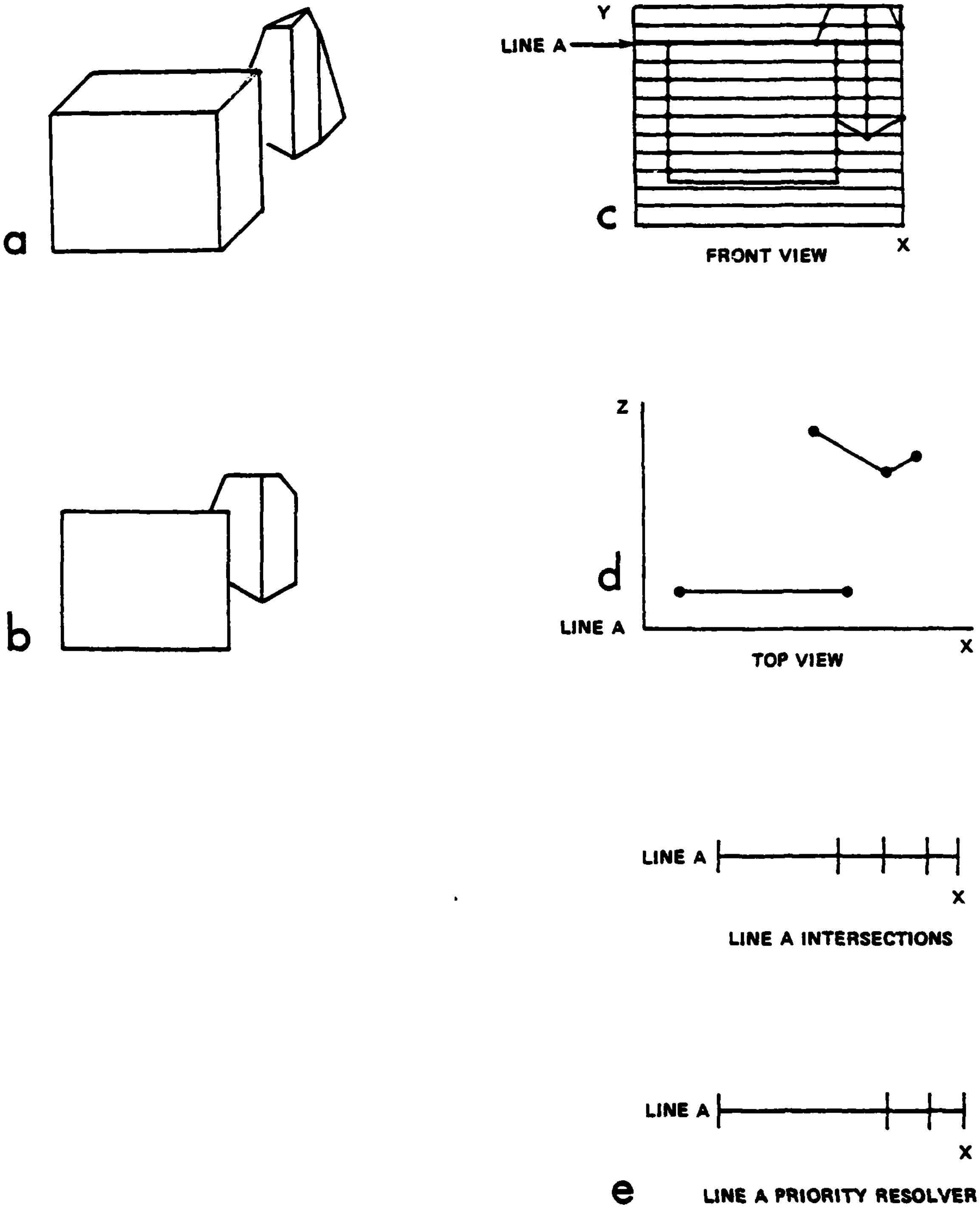

Figure 6. Creation of the Two-Dimensional Scene

Now the remaining visual volume will be dissected by passing a number of horizontal (could be vertical) planes through the scene. This will produce the raster scan lines of the scene. The number of the cuts or lines is dependent upon the screen resolution which represents the CIG picture. Currently, that range approaches 1024 scan lines. Now that we have the scene dissected into many lines, the next process determines the composition of the scan line. Figure 6b shows what the screen looks like from a point in front of the screen. In Figure 6d, a slice of the dissected scene is rotated such that the view is from the top or X,Z plane. As you can see, some of the faces fall behind others in this figure. The priority processing determines which of these faces (which are now lines because we are only looking at a slice through the Y-axis) are in front of the others. This is done using a subdivision algorithm which looks for the start points and stop points of line segments. These start and stop points are generated when the edge of a face crosses a scan line. The number of priority calculations done on a scan line becomes important when the "edge-crossings-per-system-scan-line" figure is discussed. The magnitude of these calculations is related to the number of edges that cross the scan line. The algorithm tries to reduce the lines encountered in the X,Z plane to one continuous scan line along the X-axis eliminating the occulted line segments. The system scanline is a combination of one scan line from each channel in a multi-channel system.

When this processing has been accomplished, a scan line is complete with the highest priority segments represented across the scan line as in Figure 6e. The next processing phase will deal with the subdivision of the scan line into pixels. This processing defines the final hue and/or tone of each individual pixel.

Now we have broken the picture down to its smallest part and the next process sends these out to the proper display channel for presentation by the display system.

For additional information on the "HOW" of CIG, refer to:

(a) Newman & Sproull, 1973

(b) Sutherland et al., 1974

(c) Bennett, 1975

(d) Raike, 1976

SECTION 5

CIG FEATURES AND CAPABILITIES

5.1 CIG FEATURES TABLE

Table 7 is broken down into seven CIG feature categories. They are:

I General Features
II Image Quality Requirements
III Astronomical Phenomena
IV Atmospheric Phenomena
V Terrain and Cultural Objects
VI Airborne Maneuvering
VII Light Types

No current system contains all the features listed; however, all the features listed are applicable to one or more of the AFWAL/FIGD mission tasks. Consequently, these features define a fully implemented generic CIG system.

5.2 SELECTED CIG FEATURES DISCUSSION

The following is a discussion of some specific CIG features from Table 7 which require amplification. With the exception of the channel count, only GE considers specific CIG features to be options. E&S as well as Link offer few options and tend to include all the features their system is capable of generating as part of the standard package. There is a difference in approach philosophy here. Future manufacturers also appear to offer a few potential options.

(a) Level-of-Detail

LOD is used in two manners within a CIG system.

(1) It is used to schedule the point at which additional detail in an object should become apparent during approach. This scheduling allows the maximum utilization of system capacity without overload. It has been found that a 2 to 1 ratio in complexity of the models used for various levels of detail is optimal (Bunker and Pester, 1979). The transitions should take place each time the distance to the object is cut in half. Eight levels of detail work well for this technique. It should be noted that using this approach, however, doubles the on-line

Table 7. CIG Features

I. General Features

(1) Occultation, Multiple levels of

(2) Level of detail (multiple), with blend at transition. Object priority and channel priority designation and slant range determine transition.

(3) System capacity
  a) Displayable (potentially visible) data base
  b) Active data base
  c) On line (available) data base

(4) Edge crossing capacity (see II.1)

(5) Multi-channel operation

(6) Stereo - left eye/right eye (dual eye point) calculations

(7) Head/eye slaved eye point calculation - six degrees of freedom

(8) Support multiple simultaneous simulations

(9) Support simultaneous sensor simulation - using common data base

(10) Automated data base building

Table 7. CIG Features (Continued)

II. Image Quality Requirements and Scene Anomaly Correction

(1) Overload avoidance

(2) Overload Management

(3) Anti-aliasing features (spatial)

(4) Anti-aliasing features (temporal)

(5) Vertical edge smoothing

(6) Horizontal edge smoothing

(7) Field rate updating or non-interlaced 60 Hz frame

(8) Non-restricting roll, pitch, yaw and mach rates

(9) Transport delay

Table 7. CIG Features (Continued)

III. Astronomical Phenomena

(1) Sun image — remains at ∞ but is moving object

(2) Moon image — remains at ∞

(3) Stars images — remain at ∞

(4) Day illumination continuously variable with sun angle, and visibility

(5) Dusk/Dawn illumination continuously variable with sun angle, and visibility

(6) Night illumination (horizon glow)

Table 7. CIG Features (Continued)

IV. Atmospheric Phenomena

(1) Haze (variable)

(2) Fog

(3) Light points

(4) Horizon glow

(5) Scattered clouds (moving object approach and penetration possible)

(6) Broken clouds (moving object approach and penetration possible)

(7) Overcast (approach and penetration possible) internal illumination should vary with position

(8) Thunderstorms (moving object and penetration)

(9) Lightning (in cloud only)

(10) Rain on windscreen

Table 7. CIG Features (Continued)

V. Terrain and Cultural Objects

(1) Modeling of two as well as three dimensional features

(2) Shading (fixed smooth) unlimited with no impact on system capacity

(3) Shading (sun variable smooth) unlimited with no impact on system capacity

(4) Texture (2D)

(5) Texture (3D) real world analog

(6) Shadows

(7) Circle and elliptical features

(8) Reflections

(9) Transparency

(10) Translucency

(11) Color, muted subtle gradations

(12) Four seasons portrayal (i.e., winter, spring,. . .)

(13) Own aircraft occulting FOV

(14) Time variable effects (sea state)

(15) Ship wake (bow and stern)

Table 7. CIG Features (Continued)

VI. Airborne Maneuvering

(1) Collision detection

(2) Sun glint

(3) Models, multiple moving

(4) Contrails (real time data base building)

(5) Tracers follow trajectory

(6) Ordnance impact (bomb and shellburst)

(7) Deletion of destroyed models

(8) Smoke or dust

(9) Flares (projected lights)

(10) Grayout/blackout of scene (G force related)

(11) Glare

(12) Attackers gun flash

Table 7. CIG Features (Continued)

VII. Light Types

(1) Lights (omnidirectional, directional and dynamically [temporally] variable)

(2) Own aircraft landing light patterns

(3) Rotating beacons

(4) Approach Lighting Systems Simulation*

Standard approach light system with sequenced flashers	ALSF-1
Standard approach light system with sequenced flashers & CAT II mod.	ALSF-2
Simplified short approach light system	SSALS
Simplified short approach light system with sequenced flashers	SSALF
Simplified short approach light system with runway alignment indicator lights	SSALR
Medium intensity approach light system	MALS
Medium intensity approach light system with sequenced flashers	MALSF
Medium intensity approach light system with runway alignment indicator lights	MALSR
Runway end identifier lights	REIL
Lead-in lighting system	LDIN
Visual approach slope indicators	VASI

*Includes both steady burning and sequenced flashlights with definable vertical and horizontal coverage.

Note: Description of lighting systems may be found in FAA Handbook 6850.2.

Table 7. CIG Features (Continued)

VII. Light Types (Continued)

(5) Runway lighting systems simulation

High intensity runway lights	HIRL
Medium intensity runway lights	MIRL
Touchdown zone and centerline lights	TDZ/CL

Note: Description of lighting systems may be found in FAA Handbook 6850.2

(6) No entry for 6

(7) STROBE lighting (controllable intensity)

(8) Taxiway lighting (controllable intensity)

(9) Own aircraft rotating beacon in cloud

data base requirement. For example, a model using 1000 edges in its highest level-of-detail would use 500 edges in the next level of detail, 250 edges in the next, 125 in the next, 62 in the next, 31 in the next, 15 in next, and 7 in the last. This totals to 1,990 edges and should be contrasted with the highest level of detail model which required 1000 (Bunker and Pester, 1979). Doubling the data base size doubles the effective cost of modeling an object. Currently, the transitions between levels of detail are abrupt changes and can be quite disturbing. Methods of blending at the transition point are available and should be implemented to alleviate this problem. One technique currently implemented only at VTRS utilizes translucent surfaces to accomplish this blending.

(2) The level-of-detail can be controlled for overload management purposes. Going to lower levels of detail to prevent or alleviate overload is a universally applied current practice. It is not a trivial task, as the lower level of detail objects must be prioritized by importance and position in the field of view. If the object is in the periphery of the observer's field of view, going to a lower level of detail can be inobtrusive. If the same object appeared at the point of fixation or was the target which the pilot had been tracking, its change would be quite disturbing. See Section 17.2.2.6, CIG Weaknesses, for further discussion. Blending during LOD transitions caused by overload management may not be practical because of the time available to reduce overload.

(b) System Capacity

The CIG system capacity can be described with three different approaches:

(1) Figure 7 shows the E&S polygon approach in which a 2-dimensional convex (no re-entrant or internal angle >180°) patch with vertices V1 through V4 define the basic unit.

Figure 7. Polygon (E&S)

(2) Figure 8 shows the display edge concept utilized by General Electric.

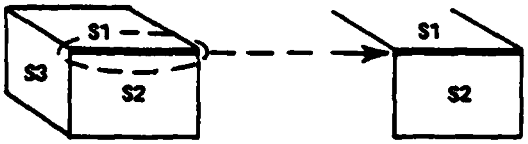

Figure 8. Display Edge (GE)

In this approach the edge created by the junction of two surfaces (S1 and S2) is the basic unit of measure. Currently this concept is the most widely utilized.

(3) Figure 9 illustrates the face boundary concept, until recently, utilized by Link. Here the junction of two faces is defined with two edges. Link currently uses the display edge concept illustrated in Figure 8.

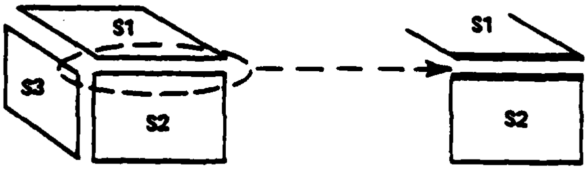

Figure 9. Face Boundary (Link)

Table 8 gives data comparing the three different approaches. A conversion factor is given to convert polygons or face boundaries to display edges. The Navy, utilizing a slightly more complex model of a house as a standard for conversion, has come up with a multiplier of 2.67. A potentially visible edge is any edge bounding a surface, the normal of which makes an acute angle with the line of sight. Potentially, visible edges may or may not be occluded by other objects appearing in front of them.

Table 8. Polygon, Display Edge, and Face Boundary Conversion

Concept	Count	DE Conversion Factor Multiplier
Polygons	3	3 (NAVY = 2.67)
Display Edges (DE)	9	1
Face Boundaries	12	.75

The displayable data base is that simulation data which is being presented at any instant in time. Changes in this data base may cause overload.

The active data base is the data base which is accessible immediately and could be called up because of a rapid change in roll, pitch or yaw. It is resident within the CIG system core or solid state read/write memory.

The on-line (available) data base is that data base which is resident in a mass storage device and contains visual information defining the entire gaming area.

Currently the maximum displayable data bases are averaging approximately 8000 edges. Active data base storage runs as high as 6 times the displayable data base. The on-line edge capacity is a function of the storage media. One simulator visited (ASPT) had the potential to store 300 million bytes of data. At ASPT, the maximum amount of data per environment is 16 million bytes. The typical amount of data per environment is 4 million bytes.

Typical data bases currently run as follows. At NASA the Evans and Sutherland Continuous Tone 3 (CT3) data base for Edwards Air Force Base uses 856 polygons, 178 of which are for the runway and 16 of which are utilized to portray a truck sitting at the edge of the runway. An A-7 aircraft at VTRS required approximately 700 display edges, while a MIG on the Link F-111 system uses 800 display edges and a camouflaged FB-111 uses 2000 display edges. The FB-111 gaming area is 600 by 600 nautical miles and is comprised of 250,000 display edges total. The Plattsburg Airport gaming area is 2 nautical miles by 3 nautical miles and is made up of approximately 5400 display edges. A lower detail surround is used with the Plattsburg Airport and it is 6 miles on a side, comprising city and highways made up of 2,500 edges. There are 15 edges per square mile in the corridors. Outside the corridors there are 1 to 2 edges per square mile. See Stark et al. (1977) for a full breakdown of an airport scene.

Table 9 shows the VTRS/GE on-line data bases by edge count and point lights. These data bases are held in mass storage while parts of them are used to create the active and displayable data bases.

(c) Edge Crossings Per System Scan Line

The concept of a system scan line is important. When edge crossing figures are considered, they must be given in both channel and system totals. The edge crossings per system scan line total may or may not be the sum of the channel edge crossing restrictions. In systems with high channel counts, a large proportion of the visual scene will be made up of the sky. Consequently, while individual channel edge crossing restrictions may be high, the total will be lower than the sum of the channels. Systems that do not have an edge crossing per scan line restriction may have a polygon per channel restriction to consider (E&S). Current systems range from 256 edge crossings per system scan line (Link FB-111) to 340 per system scan line (GE Compu-Scene, Boeing) to 1024 edge crossings per system scan line (GE-ASPT) to no edge crossings per system scan line restriction whatsoever (E&S CT5). It is interesting to note that the ASPT system capacity is currently 2500 edges and soon to be 5000 edges with the 1024 edge crossings per system scan line capacity. This works out to 20% of the displayable edge capacity. ASPT did not report an edge crossing overload problem. Other current systems go as low as 3.2%. See 17.2.2.1.

(d) Multi-Channel Operation

Multi-channel operation is one of the few features which are considered to be options by all CIG manufacturers. Current systems range up to seven channels (ASPT) per system with nine (GE-2360 and 2363) becoming available in the near future.

(e) Stereo

Stereo operation must be considered as it may provide missing cues. See section 7.1.1(a), 7.2.5.5, 15.7 and 25.1.2.6 for full discussion of stereo.

(f) Head/Eye Slaving (Area-of-Interest Displays)

Head/eye slaved eye point calculation with six degrees of freedom must be considered. This feature could provide two capabilities:

(1) Area of Interest (AOI)/Field-of-View (FOV) displays - which allow concentration of edge detail and consequently more efficient use of available edge capacity. See 14.1.8, 14.3.3 and 14.4.

(2) Monocular movement parallax could be provided by sensing changes in head position and doing succeeding CIG calculations from the

Table 9. VTRS/GE Online Data Base

	Total Edges	Total Number of Point Lights
NATO Air Field	4655	1914
Meridian Airfield	4060	3010
TA4J Aircraft	1059	7
T62 Tank	759	0
Lexington Carrier	1485	19
Sea Scape	600	1680
Fresnel Lens Optical Landing System (FLOLS)	20	0
Meatball	9	0
T37 Aircraft (LOD#3)	424	0
Data Bases		
Meridian Contains: Meridian Airfield TA4J Aircraft T62 Tank	5878	3017
Lexington Contains: Lexington Carrier Landscape FLOLS Meatball T37 Aircraft	2538	1699
NATO	4655	1914

new eye point. See also 7.1.5.5 for definition of monocular movement parallax.

(g) Multiple Simulations

Support of multiple simultaneous simulations is necessary. Simultaneous simulation requires the calculation of one eye point for each simulation. Simultaneous simulations divide the available displayable edge capacity between the simulations. Consequently they may only be utilized when the combined edge count of each simulation makes a total which is less than the displayable edge count of the system. This implies a requirement for "edge/information poor" scenes.

Because of the impact of shared system edge capacity on scene content Boeing found that compatible scheduling of simultaneous simulation was a major problem.

(h) Overload Avoidance

Unused capacity is inefficient and consequently expensive; however, it must be considered as part of a system if the effects of inadequate overload management are unacceptable.

Displayable data base buffering of 20% – 400% may be required depending on:

(1) The effectiveness of the Active Data Base Management scheme for overload protection. (See 17.2.2).

(2) The number of channel boundaries and the effect of truncating edges on edge count. (See 17.2.2.2).

(3) System efficiency requirements determined by cost/utility.

Preferably there should be no limit on the number of allowable edge crossings per system scan line. If the CIG approach dictates that there must be a limit on the number of allowable edge crossings per system scan line, this limit should exceed 20% of the displayable edge capacity (e.g. 8,000 edge system 1,600 edge crossings per system scan line possible).

(i) Overload Management

Overload management must be very sophisticated. In multi-channel systems the occurrence of overload can cause the loss of all video information to the display channels following the channel which overloaded. Inadequate overload algorithms can cause the loss of key targets as well as cues.

(j) Spatial Anti-Aliasing

Spatial anti-aliasing features are currently able to correct most of the position-dependent anomalies created by the quantitizing process. See 17.2.1.1.

(k) Temporal Anti-Aliasing

Temporal anti-aliasing is currently in its infancy. These time-related phenomena are not specific to CIG but are characteristic to all raster scan technology including broadcast television (see 17.2.1.2). For further discussion of both types of anti-aliasing, please see CIG Weaknesses, Section 17.2.1.

(l) Field-Rate Updating or Non-Interlaced Frame

Field-rate updating or non-interlaced 60 Hz frame rate updating is required to correct certain scene anomaly problems. See 7.2.1.2(a) and (b). Currently field-rate updating is available in CIG systems. However, it decreases the displayable data base system capacity by 50%. A non-interlaced 60 Hz frame rate is to be preferred over even field-rate updating (see 7.2.1.2[b]). However, it would require doubling the bandwidth of the system and, indeed if it were possible, would further limit system capacity and cause even higher cost.

(m) Non-Restricting Attitude Rates

Non-restricting roll, pitch and yaw rates are facilitated by adequate active data base storage. A non-restricting mach rate capability is attained by high data transfer rates between the on-line storage device and the active data base. Depending on data base optimization data transfers from the on-line data base to the active data base can range from 8% to 40% of the maximum active data base capacity per second.

(n) Transport Delay

Transport delay is currently an open question. If stated as a fixed number, it is almost meaningless. Not unless actual aircraft dynamics are considered can transport delay take on a meaningful role in simulation. Please see Section 17.2.6 for full discussion.

(o) Haze

Haze should be variable. Haze creates aerial perspective through which more distant objects lose contrast thereby aiding distance judgment. Objects with a slant range exceeding the selected visibility should not impact the displayable edge count. Haze is an absolutely essential part of CIG simulation. Without it, the cues to aerial perspective are lacking and roll as well as distance judgments will be incorrect. Please see Section 7.1.5.4, for further discussion.

(p) Light Points

Light points should be attenuated with distance.

Some compensation must be made for the apparent oversized CIG representation of light points at infinity. See 7.1.1(d) and 17.2.12. To do this it may be possible to attenuate the light point's intensity, thereby decreasing its contrast and increasing its apparent distance. This technique can be used during closure to the distance where the light point represents the correct angular size and intensity. Closure, after that point is reached, should be portrayed in a real-world manner by increasing both intensity and size of the light point. These increases should continue as long as slant range continues to decrease and should not terminate at any specific slant range. (See 17.2.12).

Subjective evaluations have determined that 6,000 light points are adequate to represent a night runway scene (Rivers, 1977).

(q) Clouds

Clouds are available from all current manufacturers of CIG systems. They lack realism but can be penetrated and flown within. Specification of their dimensions, position, top and bottom level is available.

(r) Texture

Texture is just becoming available in rudimentary form (see 7.2.10.) It should be considered essential for all mission tasks which include low level flight within the flight envelope. (See 7.2.7).

Texture must follow certain rules if it is to function successfully in a CIG system environment. Texture must follow all geometric rules: texture cannot be truncated (i.e., simply end or abut a different form of texture) unless it corresponds to the scene boundaries; it must stick to the ground and not appear to float; it must follow the contours of the terrain which it covers; it must be compatible with smooth shading; and, most importantly, it must resemble the real world in some fashion.

If texture is not an analog of the real world, the cues it provides to the pilot, although they may allow for the maintenance of flight, may cause the pilot to adopt a control strategy different from that of the actual aircraft. Texture which appears to be an analog of the real world should give the pilct minimal problems with scaling.

(s) Shadows

Shadows can be used to root objects such as trees and tanks to terrain. Without shadows, objects may seem to float above the terrain. Shadows may also be used to give cues on the rate of closure and height above the ground of an airborne target (Lewandowski, 1979). (See 8.2.6).

(t) Circles and Elliptical Features

Circles and elliptical features are currently available. An argument can be made for the efficiency of their use and the addition they make to realism (Bunker and Ingalls, 1978). Estimates of hardware required to add 256 circular features appear to account for 5% to 15% of the total hardware (Bunker and Ferris, 1977). Bearing this in mind, the additional cost may not be justifiable. In an edge-oriented system, it may never be practical to add circle arc generation to gain capacity. Only systems which are innately different from edge and polygon approaches may be able to make cost effective use of this feature.

(u) Transparency

Transparency depicts the passing of light through a clear or colored medium such as the glass windows of a building. Only the apparent position and/or the color of objects seen through the medium may be altered. Algorithms are currently being developed to do this; they work well in non-real- time. Transparency's possible applications in flight simulation oriented CIG is unclear at this time.

(v) Translucency

Translucency has been demonstrated by both GE and Link and has been used for level of detail transitions by GE at VTRS as well as in laboratory experiments (Bunker and Pester, 1979). Translucency could also be used for a realistic representation of bomb burst on target as well as shadow creation.

(w) Color

Color is currently a debated topic. Its inclusion, however, is recommended as its cost impact on the CIG system is minimal. Display considerations may be the deciding factor, however. Please see Section 7.2.6 for a complete discussion of color considerations and findings.

(x) Time Variable Effects

Time variable effects, such as sea state in which whitecaps appear and disappear temporarily, can give strong cues in the low altitude regime of flight.

(y) Wakes and Contrails

Ship wakes as well as contrails, smoke and dust can be difficult to generate as they may require real-time data base building.

(z) Collision Detection

Collision occurs when the simulated flight brings the aircraft in contact with other aircraft, building, trees, terrain, etc. Collision detection is offered by all current CIG manufacturers. GE and Link both utilize either the eye point or a simple box surrounding the aircraft to determine contact. Earlier E&S systems used this same approach. Currently, E&S has a very sophisticated approach which returns information to the host Central Processing Unit (CPU) concerning the vertices as well as the slope of the surface closest to the aircraft so that contact calculations may be made for surfaces other than horizontal. This has application in the helicopters approaching irregular surfaces for a landing.

(aa) Moving Models

Multiple moving models are possible with current CIG systems; their generation, however, taxes these systems rather severely. ASPT currently has one moving element and has a goal of eight. VTRS added another general-purpose CPU at the front end in order to go from one to six. The NASA SMS has a goal of 38 moving elements. Please refer to Section 17.2.9 for a further discussion of this subject.

(ab) Glare

Glare is of significance because no current display approach can give a sun image of sufficient intensity to hamper the pilots ability to perform the required tasks (see 14.2.4).

SECTION 6

REALISM

6.1 REALISM — REASONABLE AND ADEQUATE

Because realism and CIG's current ability to produce it, are debatable issues it is necessary to consider just what realism is and how important it may be to simulation.

The concept of reality could be perceived as having two dimensions:

a. Raw physical events

b. Man's interpretation of those events.

In some cases "fidelity in simulation" may require a close correspondence between the physical events and the simulation of that event. In other cases, what is required of the simulation is the creation of an illusion which will allow the observer's perception of the event to be proper (Wood, 1977). An example is necessary for clarification. If a person were given the task of simulating a motion picture, he would first consider the raw, physical process of moving film through a gate, stopping it long enough to allow a shutter to cause light to pass through the film frame twice, and then moving it on to bring the next frame into the gate. Man's interpretation of this event is continuous motion. If the motion picture image to be simulated is that of a car driving down a road, the simulation could be accomplished by having the observer view an actual car driving down an actual road. The perceived effects of the interpretation of the event would be the same. However, the raw physical events would differ significantly.

Man is a symbol-processor; his interpretation of reality is derived from references to previously catalogued perceptual information. If this catalogue can be indexed and the observer stimulated into using it properly, less demands may be placed on the visual system.

Absolute realism is, and will forever remain, unattainable, through simulation. Simulation is the exact, or not so exact, antithesis of realism. A simulated object is not, nor can it ever be, the object. A photograph is considered to be the epitome of pictorial realism, yet a photograph of a real-world scene is an abstraction of that scene, just as any CIG image is an abstraction of the real world it is meant to represent. With this fact in mind, it must become apparent that no CIG scene may ever become the real world. Consequently, a decision must be made as to what is adequate scene detail and what is required scene detail, since under all conditions the scene portrayed will be an abstraction. Rephrasing this concept: All CIG is abstract. A decision must be made as to what degree of abstraction is reasonable and adequate. There is no single answer to this question. What is reasonable and what is adequate changes with mission task and desired goal.

6.1.1 What is Reasonable Realism?

What is reasonable must be that which is in the realm of CIG to produce. An attempt to totally match human perceptual characteristics would be unreasonable. For example, at optimal light levels and spatial frequencies, the human eye can detect movement down to 10 arc-seconds of displacement. A display with a square field of view covering only 20° x 20° would require 7,200 lines of resolution in each direction, and at 30 frames per second the required band width would be one gigahertz, using conventional approaches (Tyler, 1978). Not only is this band width over 30 times that of the maximum currently available, but the CIG system would be required to do calculations for over 50 times the number of picture elements. Clearly human perception limits are an unreasonable requirement.

Orlansky and String (1977) have pointed out that "The development of visual displays for flight simulators is driven strongly by what can be done and not particularly by what is needed in a display to make it cost effective for training purposes." While Stark (et al., November, 1977) points out that "they [visual systems] have almost always provided cueing information defined more by their own unique capabilities and limitations than by the needs of students of varying levels and kinds of abilities." Again clearly, some balance between the hardware realities and R&D simulation requirements must be met.

Basinger and Ingle (1977) look forward to future realism to add a "component of fear" as an "authentic confusion factor" for low-level flight. Presently fear and confusion apply only to the would be specifier of CIG systems.

6.1.2 What Is Adequate Realism?

What is adequate is directly proportional to the difficulty of the task and the level of performance required. Numerous low-fidelity and non-fidelity simulations have met with success. At ASPT, it was found that in some cases, teaching a maneuver in reverse order is more efficient than teaching it conventionally. For example, if a task such as landing or weapons delivery is segmented, and the last part, then the middle, then the first part are taught in that order, students reach proficiency faster. It was found that low-fidelity simulation could produce significant transfer effects to a specific aircraft for the air-to-ground tasks. Although this is a training environment vis-a-vis R&D, the implication is that segmenting the R&D tasks may be an effective tool, yet diverge from absolute realism.

Rivers (1977) found that "total fidelity throughout the flight envelope was not achieved by any of the devices evaluated;. . . ." Because of the weaknesses of current visual systems, researchers have come up with numerous methods to provide minimally adequate cueing. Ritchie (1977, 1978) reports a technique which he calls "representing reality." He tells of a problem with a CIG system in which the lack of resolution restricted the pilots from lining up on a carrier deck at the proper distance. Normally, the carrier deck landing area is black with 1 foot wide white edge markings. By changing the landing area to white and outlining it in grey, the pilots were able to successfully line up.

Bunker (August, 1978) discloses how the Navy 2F90 visual system at Kingsville, Texas, was providing insufficient resolution to depict the Fresnel Lens Optical Landing System (FLOLS) at the normally expected acquisition point (slant range). "The solution — it was made less realistic. It's modeled size was made a function of its distance from the pilot — larger than life at a distance and decreasing to actual size at close distances. Result — satisfactory training." Bunker also describes an early attempt to model a scene in which the scene elements were randomly placed for realism but scene content was minimal. Pilots were unable to maintain their glide path. By remodeling the scene and making all fields square and roads parallel, they took the naturalness out and this fixed the problem. In describing this early system, the problem Bunker solved was that of inadequate edge capacity.

"The pilot will probably want the real world, even though there is evidence that he can land his airplane if we provide him with as little as three dots of light, properly oriented on the ground" (Flexman). "There seems little reason to build systems with the highest possible fidelity without knowing of whether or not they are needed. . ." (Cohen, February, 1979)

Stark (et al., November, 1977) points out that a chalked outline of a runway on a blackboard has been used successfully in T-6 aircraft training. By manually tilting the blackboard, the trapezoidal shape of the runway was depicted for the students.

At the Simulator for Air-to-Air Combat (SAAC), it was found that a checkerboard pattern of one-half-mile squares allowed pilots to maintain control to altitudes below 1,000 feet by visual reference alone. Geographical orientation is aided by 8 unique symbols which are inset into the squares. From these it is possible for pilots to extrapolate the heading of enemy aircraft when those aircraft are not within the field of view. "The subjective realism of the STG [Synthetic Terrain Generator in SAAC] picture is relatively low, but its utility in supporting ground reference, air-combat maneuvers is very high." (Stark, 1976). See also 7.2.4.1.

All these quotes may seem bewildering, however, one conclusion can be drawn: if no attempt is made to train perceptual skills, fidelity to the real world can remain a secondary concern. Proper pilot response is of primary concern. To get it anything goes: reversing the logical order of events, reversing gray tone representations, exaggerating size, providing unnaturally regular terrain, providing only three dots of light for a landing, a white line trapezoid for a runway or 1/2 mile squares for terrain.

Although the preceding examples were taken from the training environment, they do imply that much can be done with low-fidelity and non-fidelity in the visual scene.

6.1.3 Subjective Evaluation of Adequate Realism

Because pilots integrate cues from various sources, such as the motion base, with cues from the visual system in order to come to a perceptual understanding of their situation in space, their judgment may be distorted by any disparity that arises. ". . . The response to stimulation that is being given may be distorted or differ from that which would occur under more natural circumstances. Thus, the subjective impressions of an experienced pilot may not be an ideal criteria for judging the accuracy or adequacy of a visual display in the absence of other cues upon which he has come to depend on as complements of the visual inputs." "Some of the refinements of the simulation which make it seem highly realistic in appearance to someone seated in the pilot's seat may be of little real consequence with respect to the job of controlling the device. These elements may be extremely important for nuturing the illusion of reality at a superficial level but could conceivably give rise to relatively favorable, subjective evaluations of a device, certain fundamental aspects of which were seriously incorrect." (Brown, 1975)

6.1.4 Who Uses What?

"The deletion of cues will be most disturbing to the skilled pilot, who may have learned to recognize the effects of his control on each varying scene element or in scene elements which are not used by other pilots or instructors as reference." (Stark et al., November, 1977)

Palmer and Petitt (1976), in their paper on the difference thresholds for judgments of sink rate during the flare, point out that pilots differed significantly in their ability to judge sink rate from the cues provided by the visual system. Since each of the pilots must be considered to have been equally qualified, the only assumption that can be drawn is that each uses different cues in the real-world situation. The consequence of not providing the cues used by a particular R&D test pilot becomes obvious when this is borne in mind. See 7.2.5.4.

Barnes (1970) postulated the concept of a visual threshold which had to be exceeded prior to the initiation of action by a pilot. Reaching this visual threshold occurs by passing through a dead band during which no action can take place. This dead band increases with increasing uncertainty, caused by degradation of fidelity. Degradation does not necessarily have a linear effect on performance, however. "Pilots continue to perform quite satisfactorily up to some point where there may be an abrupt breakdown in performance. The implication is that the pilots are able to compensate within fairly wide limits. Their ultimate breakdown results when a limit of compensation is reached, and breakdown cannot be attributed to the specific item of information which is eliminated just prior to breakdown." (Brown, 1975)

6.1.5 Going Too Far Towards Simplicity

Ritchie (1977) unwittingly demonstrates that low fidelity can be carried to excess. He describes an experiment which he finds both intriguing and troublesome. This experiment, done by Ryan and Schwartz (1956, 1969, 1960-69), had test subjects determine the orientation of a hand which was depicted in four different ways:

(a) A black-and-white photograph

(b) A shaded drawing

(c) A line drawing

(d) A cartoon-type, simplified drawing.

Ritchie states that "The subjects could make the response quickest and most accurately with the cartoon-type, simplified drawing. Let me leave you with the thought that sometimes we make it the most useful picture by deliberately departing from fidelity in perhaps many yet-to-be-determined ways." What Ritchie fails to point out is the fact that although the orientation of the hand could be determined most quickly and accurately from the cartoon-type, simplified drawing, the reason was that it was the least ambiguous of the four depictions. The manner in which the hand was positioned and illuminated may have led to confusion and illusion even in the real-life situation. In this case, the cartoon may have given clarity where the real-world situation would not.

6.2 EFFECTS OF INADEQUATE REALISM

Basinger and Ingle (1977) state that "Current and near-future requirements for CIG realism are sufficient image content and image detail to allow the pilot to perform his tasks in the simulator the same way as in the aircraft, but without real-world appearance of images." They go on to say that future requirements will be for "complete, real-world appearance." If this is a requirement at all, it is a requirement today, as well as for the future, but one which cannot currently be met. As Basinger and Ingle rightfully point out, identical task performance between the aircraft and the simulator is significant and may well be critical to the successful completion of the R&D task.

When system limitations, such as restricted field of view, inhibit the application of normal techniques and procedures, as was found by Rivers (1977), realism or fidelity must be considered to be inadequate. In the SAAC system when the entire field of view was filled with one square, ". . . the scarcity of task-relevant, visual cues in the display forced the pilots to adopt a control strategy different from that used in the aircraft." (Stark, 1976) This concept cannot be over emphasized.

The danger that a modified control strategy presents in a research environment is that changes made in order to improve aircraft characteristics may, in actuality, be simply changes required to improve the simulator characteristics (Staples, 1978). In addition, "When a simulator is used to investigate the feasibility of certain design characteristics or as a basis for ascertaining whether a pilot can fulfill the role which is planned for him in some vehicle still on the drawing boards, then there may be no way of ever knowing with assurance whether negative conclusions drawn from simulator work are valid." (Brown, 1975.)

6.3 RESEARCH AND DEVELOPMENT SIMULATION VERSUS TRAINING SIMULATION

Heintzman and Shumway (1976) point out that simulation may be broken down into five categories, two in research and three in training: (See Table 10).

Table 10. Types of Simulations

Engineering research
Training research
Undergraduate training
Transition training
Continuation training.

Each type of simulation places varying emphasis on the type of visual information to be presented. Engineering may require total flexibility and the ability to measure performance to a very critical level. Training may require absolute fidelity in cockpit configuration and instrument presentation, while allowing minimal fidelity or non-fidelity in visual presentation.

In the training environment, motivation must be considered and involving the student is essential to success. A simulation which does not make the student feel that he is "really flying" may be unsuccessful for this reason. Motivation is not as much of a problem in the R&D environment.

In the final analysis, the question is one of performance versus learning. The R&D task requires the measurement of performance for evaluation, while the training task requires learning on the part of a student. In training realism should not be the issue. What should be the issue is whether or not the simulation makes the real world "easier to handle" (Cohen, February, 1979). No such requirement exists for the R&D simulator.

6.4 MEASURING REALISM

As has been previously stated, subjective judgments of realism, correlations between visual information and performance, as well as the simplification of cues, are extremely hazardous techniques to use when evaluating realism. Brown (1975) suggests seven potential indices of flight performance in reference to landings. (See Table 11).

Table 11. Potential Indices of Flight Performance During Landings

Rate of descent or sink rate in feet per second
Vertical component of acceleration
Point of touchdown
Glide path slope
Rate of lateral motion
Precision of longitudinal control
Overall coordination of flight.

Palmer and Petitt (Visual Space Perception on a Computer Graphics Night Visual Attachment, 1976) evaluated five perceptual tasks to determine which of them, if any, could be used for a measurement of simulator realism (see Table 12).

Table 12. Perceptual Tasks and Simulator Realism

Objective-size judgments
Angular-size judgments
Shape judgments
Slant judgments
Distance judgments.

They found that "only the angular-size judgment task proved to be of potential use as a measure of simulator realism."

6.5 REAL REQUIREMENTS

Until recently, the only simulation requirements model being utilized was the "substitution model." This model, which applies to training, originated in the concept that the greater the fidelity of simulation, the better the chances of effective training transfer. This implementation realized in the hardware of a simulator caused the simulator to be utilized simply as a substitute for the aircraft and did not capitalize on capabilities that a simulator could have which an actual aircraft would not.

More recently, the "training objectives model" has been suggested. This model, utilizing the concept of a "skill differential," has the basic premise that desired skill levels must be established as a goal prior to the specification of a simulator (Thorpe).

While the "substitution model" requires an attempt to obtain absolute fidelity, the "training objectives model" could conceivably utilize low fidelity or non-fidelity. These authors would like to suggest a third model to be utilized in R&D applications. This model, the "pilot-response fidelity model," would permit the calibration of the simulator so that experimental results would be meaningful. What is suggested is that a series of runs be made in actual aircraft with measurements taken of performance characteristics. The same runs would then be flown in the simulator, which has been programmed to emulate the actual aircraft. The runs to be flown would be flown by the same pilot or pilots. In this manner, data relating to control responses may be correlated between actual flight and simulation. Once a correlation is established between actual flight and simulation, that correlation may continue to be used. However, because pilots differ, each pilot to fly the simulator must be calibrated for the specific maneuvers he is to execute. In addition, because pilots learn how to fly simulators with practice, periodic recalibration for each pilot would be necessary. Of greatest importance is that a control strategy different from that of the actual aircraft not develop. If it is unavoidable, it must be both recognized and compensated for in the final results of any experimentation.

In the final analysis, the greatest realism is required on the part of the user when specifying a CIG system. Pictorial realism and total fidelity may be considered as potentially the ultimate goal for R&D simulation. However, <u>much can be done short of that goal</u>.

SECTION 7

PERCEPTION AND CUES

No definitive study has specified all the cues necessary for all possible AFWAL/FIGD mission tasks. Numerous researchers over the past decade have called for such work. Only now at ASPT and VTRS are these studies beginning. See Appendix C for an overview of this research.

What follows in this section on cues is a synopsis of what the authors feel is currently pertinent information. The information given on perception should be used in conjunction with the section on display hardware (Section 14 and particularly 14.5).

In order to establish the requirements for a simulation system using visual cues, it is necessary first to understand human visual capabilities. Total evaluation of human visual perception is very complex and goes beyond the scope of this report. Its most significant aspects, however, are detailed in the following paragraphs. Two reference documents proved to be of exceptional value and should be utilized for further reference.

(a) "The Design Handbook for Imagery Interpretation Equipment," is edited by Farrell and Booth (1975)

(b) "Perception of Displayed Information," is edited by Biberman (1973).

The act of perceiving visual information may be broken down into two functions:

(a) Reception

(b) Correlation and interpretation.

7.1 VISUAL PERCEPTION – RECEPTION

Human reception of visual information utilizing the eye and its associated musculature can be evaluated in a number of ways such as static acuity, factors reducing static acuity, sensitivity to movement and depth perception.

7.1.1 Measurements of Static Object Acuity

Acuity is a measurement of the ability to discriminate objects in a scene. Four types of acuity measurement follow (Farrell and Booth, 1975). See Figure 10.

(a) Minimum Separable Acuity.

Minimum separable acuity (resolution) is the ability to differentiate a gap between two closely spaced objects. The average viewer will detect a gap between the two objects, 50 percent of the time, if they are separated by more than 40 to 60 seconds of arc (Keesey, 1960; Helmholtz, 1866).

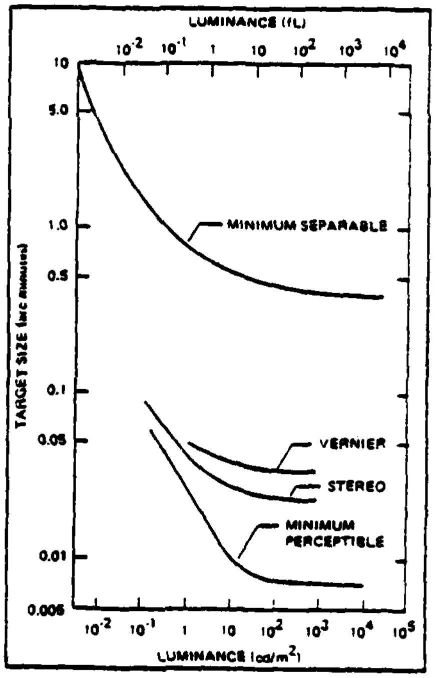

Figure 10. A Comparison of Acuity Measures
(Reproduced from Farrell & Booth, 1975)

(b) Minimum Vernier Acuity.

Minimum vernier acuity (lateral) is the ability to perceive sideways displacement. If two identical objects are placed, one above the other, and one of the objects — say the lower one — remains fixed in place while the upper object is moved laterally to one side, the minimum displacement which can be made before detection of displacement occurs is approximately 2 seconds of arc. Vernier acuity is also known as lateral acuity. It is important to note that the objects are of identical size and equal distance from the viewer at the beginning of the test.

(c) Minimum Stereo Acuity.

Stereo acuity can best be defined as an observer's ability to determine that one of two identical objects is closer to him than the other. In testing stereo acuity, the observer views two identical rods — one placed above the other. The lower rod remains fixed, as the upper rod is moved toward the observer. For the average viewer, when the two rods are noticeably different distances from each other, they are separated by 2 seconds of arc (Berry, 1948). The experiments used to determine this figure utilized two identical objects which were placed very close together, thereby causing direct comparisons to be made. The ability to judge relative depth decreases as the reference object is moved laterally away from the test object. Other terms which are equivalent to stereo acuity are stereoscopic acuity, stereopsis and depth perception. For a broader discussion of these terms, please see Sections 7.1.4 and 7.1.5 below, dealing with depth perception.

Stereo cues, theoretically, can give range information out to 1300 meters (via retinal disparity) (Staples, 1978).

(d) Minimum Perceptible Acuity.

Minimum perceptible acuity (detection) is the ability to detect the presence of a dark object against a light background. Two factors determine detectability. One is level of illumination and the second is the contrast between the object and the background. Given sufficient illumination and contrast, the average observer can detect a thin, dark object against a light background 50 percent of the time if that object subtends a visual angle of 0.5 seconds of arc (Hecht and Mintz, 1939). This phenomenal sensitivity corresponds to the capability to detect a wire less than .2 inches in diameter, 1 nautical mile away.

It is important to note that when the observed object is an intense light source against a dark background the visual angle subtended by the light source does not define detectability. An actual point source of light (i.e. a distant star) would be invisible to the unaided eye if it was a non-radiating object. A point light source is visible because the light energy it emits stimulates the retina.

What is perceived is a dot of light that represents a visual angle of approximately 1.25 minutes-of-arc. This effect of expanding what would otherwise be an imperceptibly small light source is called the retinal spread function. In order to ensure that a simulated point light source, in a visual scene, is small enough to spread out to 1.25 minutes-of-arc (on the retina) it should be depicted as no larger than 0.8 minutes-of-arc on the display (Kraft, 1979).

7.1.2 Factors Affecting Acuity and Target Detection

The definition of 20/20 vision is the human eye's capability of identifying alphabetic lettering such as the letter C which subtends a visual angle of at least 5 minutes of arc or the eye's ability to recognize (50% of the time) the orientation of the gap in the C which represents 1 minute of arc. All types of visual acuity decrease in accuracy as the observed objects change from static to dynamic. All the preceding test data were taken from static targets. Many things affect visual acuity, in a negative way, and reduce these ideal findings. (See Table 13.)

Table 13. Factors Affecting Acuity

Reduction in luminance

Reduction in contrast

Reduction in time available to look at or search for the target

Introduction of a non-uniform background

Introduction of noise

Lack of experience with the viewing situation

Lack of knowledge about the target shape and orientation

Reduction in information about when a target will appear

Displacement of the target from the fixation point

Reduction in information about target location

Reduction of the rate at which the targets appear

Reduction in the reward for correct response relative to the penalty for reporting the wrong object, as a target

Target motion.

Figure 10 also illustrates the relative differences between the four types of acuity. Of greatest significance is the fact that one arc minute of resolution, which is the current target for numerous visual systems, does not even come close to approaching the human eye's ability to detect three of the four types of previously mentioned acuity.

Biberman (1973) published a table of factors influencing target detection and recognition, which was originally published by Self (1969). Biberman points out that "Not all factors listed in each group are independent of other factors under the same heading, and the list is neither systematic nor complete." However, Self's list is of interest, and it is reproduced as Table 14.

Table 14. Target Detection and Recognition

The scene (or total picture)

(1) The size of the picture or displayed image.

(2) Numbers, sizes, shapes, and scene distribution of areas contextually likely to contain the target object.

(3) Scene objects: numbers, shapes and patterns, achromatic and color contrasts, colors (hue, saturation, lightness), acutance, amount of resolved details, all both absolutely and relative to the target object.

(4) Scene distribution of objects.

(5) Granularity, noise.

(6) Total available information content and amount of each type of information. This is one way of summing up 1-5 plus other elements.

(7) Average image brightness or lightness.

(8) Contextual cues to target object location.

The target object

(1) Location in the image format.
(2) Location in the scene.
(3) Shape and pattern.
(4) Size, color, resolution(s), acutance, lightness or brightness
(5) Type and degree of isolation from background and objects.

The test subject (observer)

(1) Training.
(2) Experience.
(3) Native ability.
(4) Instructions and tasks briefing.
(5) Search habits.
(6) Motivation
(7) Compromise in speed versus accuracy
(8) Assumptions

Human perception is very poor at judging absolute brightness but is extremely sensitive to changes in relative brightness (contrast). Black-and-white contrast is so significant that for example, an object which is 11 arc minutes in size will be invisible to an observer if its contrast with the surround is 2.5% or less (Kraft, 1979).

7.1.3 Sensitivity to Movement

Tyler (April, 1978) lists five facts about human sensitivity to movement (see Table 15).

Table 15. Sensitivity to Movement

"Movement sensitivity can be extremely fine, with movement detected down to 10 arc-seconds displacement of the line."

"Movement sensitivity extends to high frequencies, at least 30 Hz for this moderately bright stimulus, with little diminution in sensitivity up to 20 Hz."

"Velocity sensitivity for the minimum detectable velocity (assuming the maximum velocity in the stimulus determines threshold) can be computed from these data to be only about 3 arc-min/sec."

"The peripheral retina is far less sensitive to movement than the fovea, at all temporal frequencies and equivalent velocities."

"The maximum sensitivity to movement occurs at about 2 Hz at all retinal locations, including the fovea."

7.1.4 Primary Factors Facilitating Depth Perception

Cues to depth perception, almost exclusively, give relative depth information rather than absolute range. Convergence [using binocular disparity] may be the only cue to absolute distance information (Kaufman, 1974).

Binocular vision allows the perception of depth through disparity. It is often evaluated in relationship to a number of factors. Information within quotes in this section, unless otherwise noted, is from Reynolds et al. (1978): "The three primary cues to depth perception are accommodation, binocular disparity, and convergence." Kaufman (1974) points out that accommodation is an effective cue to depth over a limited range, e.g., 1 or 2 meters.

7.1.4.1 Accommodation. Accommodation is the ability of the eye to adjust in such a manner as to bring an object into focus. The image of that object is focussed sharply onto the retina. Other objects at different distances have blurred images focussed onto the retina; therefore, relative distance of depth can be perceived for objects close to the observer."

According to Dr. C. L. Kraft (1979), it has been recently established that for the average person the resting state of accommodation is a balance between two neurological systems, which are antagonistic. For most people, the average is 1.7 diopters or about 24 inches away. This resting state is reached when the eye has no edge or object to focus on at infinity.

A good example of where this problem can manifest itself is a climb-out through an overcast on instruments. Breakout of the overcast in a climb and the observation of no objects in the bright blue sky ahead will allow the eyes to transition from accommodation for the instruments to resting state accommodation, without reaching focus at infinity. A call from the traffic controller, giving traffic at 12 o'clock, would require the observer to attempt to locate an aircraft at infinity while his eyes were focussed at approximately 24 inches.

There is no way to change the focus of the eye from its resting focus to infinity unless there is a visible edge at infinity to focus on. It takes only 20 seconds from being focussed afar until the eye drifts back to its natural resting state.

This time is directly proportional to age and becomes longer as age increases. Younger pilots who are flying on instruments and break out of a cloud into clear air or are flying on instruments at night will almost never be in focus at infinity. This is why, at times, an older pilot can beat a younger pilot to detect a very small target at a distance.

The time it requires for the eye to change from near focus to infinity focus is not only dependent upon age; it also is dependent upon the length of time working on instruments. The time can range from 3.25 seconds for a young pilot in his 20s to 8.5 seconds for a pilot in his 50s. Please see Figure 11, supplied by Dr. C. L. Kraft, which demonstrates this phenomena. Under minimum conditions, during an approach to a landing it can take as little as 14 seconds between the breakout of an overcast and the touchdown. It can be seen that for an older pilot this may leave very little time for perceptual judgments to be made following the completion of accommodation at infinity.

Stark (1976) quotes from Puig, who, in turn, quotes from the SCIENCE OF SEEING: "When an observer looks at a two-dimensional picture of a three-dimensional scene, such as a landscape, changes in accommodation not infrequently take place, as different parts of the picture would be in focus for the same accommodation." So it appears that, at least in certain instances, accommodation may occur in reverse.

7.1.4.2 Binocular disparity. "Binocular disparity, i.e., stereoscopic vision, is the condition of different retinal images existing in each eye when viewing an object in space. It turns out that binocular disparity, even in random patterns, is enough to indicate depths." See 7.1.1(c).

Theoretically, retinal disparity is functional up to a range of 1300 meters (Staples, 1978). The effects of retinal disparity have been demonstrated to be discernible at a distance of 580 meters (Stratton, 1898).

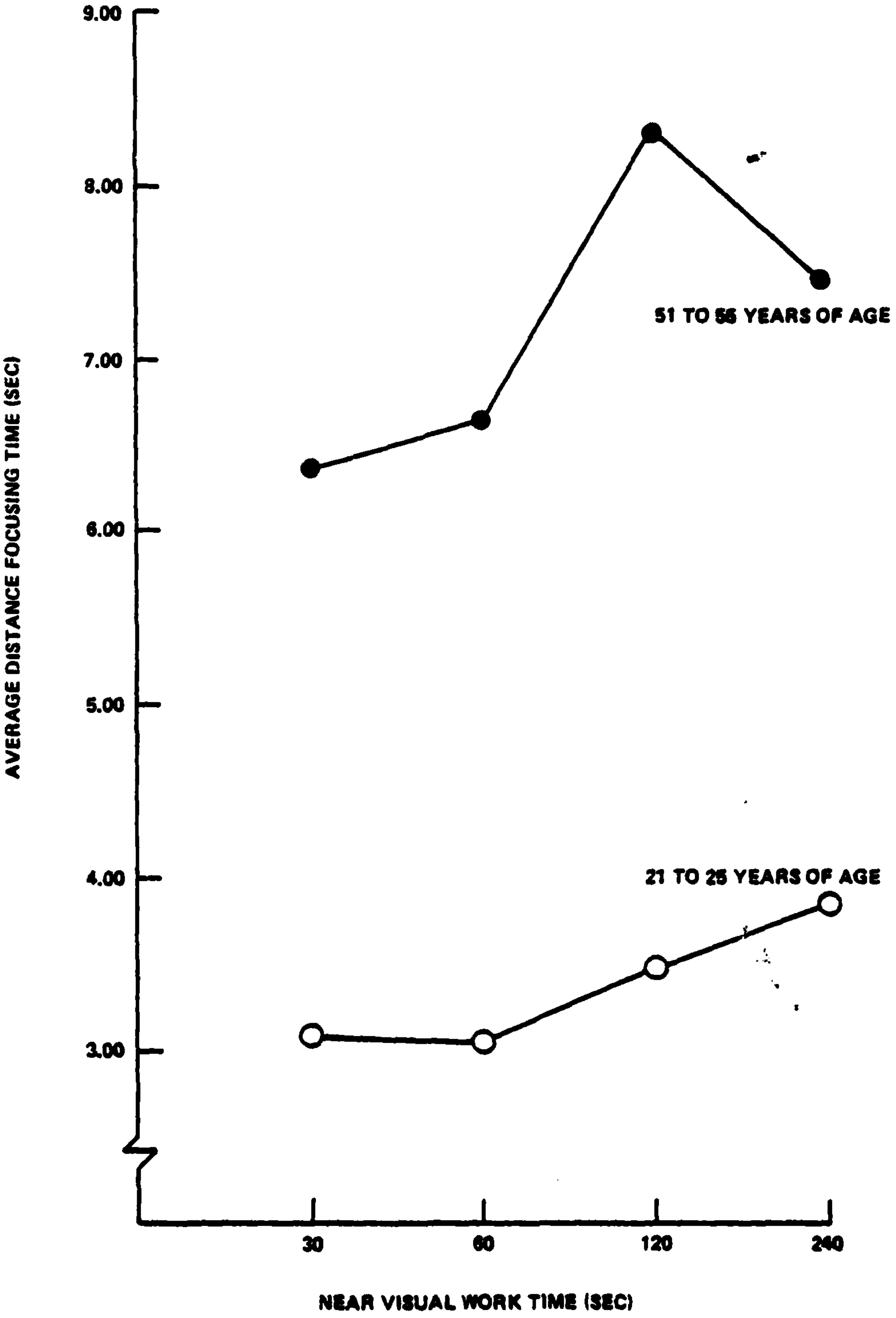

Figure 11. Accommodation Times (From Kraft, 1979)

7.1.4.3 Convergence. "Convergence is the rotation inward of two eyes such that each eye fixates on the same point. This is effective for distances of several meters."

According to Bunker (1978), "Gibson [1951] concluded that the primary source of distance information is the 'stimulus gradient' of horizontal surfaces, that this may be derived from any one or combination of a variety of stimuli and that among these are texture gradient and the gradient of convergence of parallel lines."

7.1.5 Secondary Factors Facilitating Depth Perception

According to Reynolds (1978), the traditional secondary cues to depth perception are: relative size of similar objects, interposition, linear perspective, aerial perspective, and binocular movement parallax. Unless otherwise noted, the following quotes are from Reynolds.

7.1.5.1 Relative size. "Relative size of retinal images of familiar objects are cues for determining a feeling of distance. Larger retinal images of objects in the same class usually indicate that the larger object is closer."

Roscoe (1978) states that ". . . the apparent size of objects well beyond the 6-meter, or 20-foot distance to 'optical infinity' change reliably with changes in the spatial distribution of textural stimuli to accommodation in the background visual scene. The greater the distance through empty space to resolvable texture, the larger the apparent size of centrally fixated objects, such as the moon or an airport runway. As the textural pattern extends downward or moves nearer, the central object fails to maintain a constant, 'apparent size.' As the pilot approaches a runway over water at night, his visual image of the runway grows, but not in perfectly inverse proportion to distance remaining.

"When no resolvable background texture is present, as when viewing the moon against a clear sky, the textureless moon provides an inadequate stimulus to distant accommodation and shrinks in size, as do the symbols of the head-up display when flying in clouds. Even a partially clouded sky apparently cannot hold distant accommodation to a textureless, collimated moon or display symbols. Thus, "moon illusion" is not manifested by a spuriously large moon on the horizon but rather by a perceptually shrunken moon overhead.

". . . Although no specific data are available, it would be expected that in the absence of visible texture in the near field pilots with extremely distant dark focus would be the ones who tend to make low approaches at night and occasionally land in the ocean." Roscoe goes on to state that experimental evidence does not support the assertion that collimating bold, well-defined symbology, such as with a Head-Up-Display (HUD), causes the eyes to go to a far accommodation distance. He suggests the use of a variable magnification CIG system to facilitate training.

The perceptual constancy phenomenon is the term used to define what an observer sees when an object's range changes while its size appears to remain the same, even as the corresponding retinal image changes. According to

Crawford et al. (1977), Postman and Eagen (1949) found that ". . . the relationship between distance and perceived size of a given object is actually a non-linear one." Crawford suggests that "When size is used as the primary cue to distance in CIG, it may be desirable to incorporate computer-processed corrections for the known non-linearity in the relationship." To the author's knowledge no CIG manufacturers are currently developing this feature.

7.1.5.2 Interposition. "Interposition is the overlapping of one object by a closer object. This information yields an ordering of objects. Not every visual flight simulator adequately solves this hidden surface, masking or occultation problem." There are limits placed on each current system to the number of occultations which are possible.

7.1.5.3 Linear [geometric] perspective. Linear perspective describes the condition that a constant distance between points subtends a smaller and smaller angle as the points recede from the observer. This is the common railroad effect as tracks converge toward the horizon."

Staples (1978) feels that "In the real world, perspective is the most important means of determining position [x,y,z] (as distinct from orientation), except, perhaps, near the ground. Because of other deficiencies, in the simulator it assumes relatively greater importance also near the ground."

Distortions induced by the display must be minimized, as they tend to change the perception of linear perspective.

While factors such as resolution, luminance, and color tend to vary in the real world with atmospheric conditions, there is always a direct, one-to-one correspondence between position, attitude and linear perspective. This correlation extends to the vestibular, kinesthetic and tactual sensory systems (Brown, 1975)

7.1.5.4 Aerial perspective. "Aerial perspective represents the case of viewing an object from a considerable distance through the atmosphere which both absorbs and scatters light. This obscures surface detail and visual contrast and causes an observer to report an object as far off. Smog and haze are excellent absorbers and scatterers of light."

It has been observed that the lack of aerial perspective in a CIG scene will cause an optical illusion in which the horizon line appears to be too high; adding aerial perspective eliminates the problem (Ritchie, 1977).

A simulation which does not incorporate the effects of aerial perspective may induce into pilots the feeling that they are rolling at a rate higher than their actual roll rate. This phenomenon occurs because the clarity of distant objects causes them to appear closer than their real-world counterpart. Adding a "haze function" substantially alleviates the problem (Stark, 1976).

Currently E&S, GE and Link include aerial perspective as a CIG feature but it may be omitted from the system when it is not desired, as was done by NASA on the SMS.

7.1.5.5 Monocular movement parallax. "Monocular movement parallax" occurs when a subject's eyes move with respect to the environment or conversely. When such movement occurs, there exists a differential, angular velocity between the line of sight of a fixated object and any other object in the field of view. This provides a means to discriminate between objects.

7.1.6 Peripheral Vision Cues

There is a difference between the perception of motion in depth and the perception of position in depth, without motion. Regan (et al., 1979) states that "Both changing image size and flow patterns are compelling cues to motion in depth, and both are available to one eye alone." Peripheral vision, although much lower in acuity than the foveal area, is a very strong source for the visual perception of motion in depth.

Although it may appear that there is a contradiction here, there is not. Earlier it was stated that peripheral sensitivity to individual objects moving in the observers FOV is low. What is being described here is the observer moving in relation to his environment.

Peripheral vision is particularly effective in detection of changes in velocity (Staples, 1978). Even though the human eye does not have strong acuity in the periphery, as far as moving stimuli are concerned detail helps significantly in producing the appropriate sense of motion, as well as spatial orientation. For this reason, wide field-of-view simulation may be most appropriate to giving adequate velocity and altitude cues in low-level flight (Buckland et al., 1979).

At Boeing, Kraft (1979) has found that large triangles placed on the surface in the airport environment sufficed to represent buildings when viewed only via peripheral vision. As previously stated, recent findings indicate that ". . . flow patterns are compelling cues to motion in depth. . . ." (Regan et al., 1979.)

7.2 VISUAL PERCEPTION – CORRELATION AND INTERPRETATION

To a certain extent, the function of the receptors, dealt with in the preceding sections, corresponds to the occurrence of the raw, physical event without regard to correlation and interpretation of what is being perceived. The brain functions as the mediator in this area. It performs data processing, object detection, object orientation, object recognition, object identification, rate judgments, angle judgments, time-to-go judgments, and, in certain cases, misinterprets the results of these judgments.

7.2.1 Human Data Processing

There are limits to the rate at which people can "through-put" information. A corollary which may follow from this fact is that there is no point in having a CIG system present the pilot with more information, disregarding redundancy, than he can through-put.

Information is defined as that which reduces uncertainty. Intuitively, the meaning of the definition is obvious. Mathematically, one may view uncertainty as a field in which a point is located; information is that which eliminates empty parts of the field; the more parts eliminated, the greater the information.

The accepted unit of information is the "bit." The word is a contraction of "binary digit." Although the term originated in engineering, it has a precise psychological meaning; one bit of information reduces the uncertainty by one-half. Figuratively, it eliminates half the field. A second bit removes one-half of the remaining uncertainty, leaving only one-fourth of the original, and so on.

"Through-put rate" is defined as the rate at which a person puts out information immediately after receiving it in another form. In the case of a pilot, it is the rate at which he transforms sensory information into control information.

After obtaining cues from the visual scene, a pilot must "through-put" information. In other words, he first receives the intended information through his sensors, and then he processes the data and makes his decisions (both appropriate and inappropriate), which he exhibits by means of his choice of actions (or the lack, thereof) in the guidance and control of his aircraft.

Some of the limitations on the rate at which a person can through-put information have been quantified as a result of previous research. Most basically, psycho-physiological factors set the limits on a man's through-put rate.

Man must process information through his neurons, which transmit information at slow rates (roughly 1-100 meters/second). They, therefore, limit man's performance.

Leshowitz (et al., 1974) found that it takes approximately 250 milliseconds for the processing of an item of visual information. He found that observers processed a piece of visual information using well defined principles. Subjects were presented with a test stimulus which was subsequently interrupted by an interfering or retroactive masking stimulus. When the masking stimulus followed the test stimulus too closely, it was found that there was a large loss of retention of the test stimulus. Some test subjects were affected more strongly than others, which implies that they had differing capacities for processing information. The results of these experiments, when considered in relationship to CIG technology, may explain why the degradation of an image during overload management is so disturbing to some observers.

A person requires in the order of 200 milliseconds to begin to make a simple reaction, i.e., to begin to make one response, which is predefined, to a clear, unequivocal stimulus. It has been found that the reaction time increases with the number of responses from which a person must choose. This extended reaction time is called "complex reaction time."

Data on complex reaction times provide an approach to the estimation of man's through-put rate. Unfortunately, there are reasons for doubting the validity of the approach. The salient reason is that man can process information in a parallel manner; in particular, his sensory neurons can be taking in new information while his motor neurons and muscles are still reacting to old information. Reaction time data generally come from experiments which do not take this fact into account. They do, however, provide one quantitative approach to the phenomena of man's finite rate of information processing. The present authors have used data on complex reaction times in a standard textbook (McCormick, 1976) to calculate the estimates of the human through-put rate limit. The data consistently show a limit of about five bits of information per second.

Overton (1968) made estimates of the through-put limit by calculating the rates at which people actually through-put information, while performing certain simple tasks. In some cases, such as typing ordinary English, the input signal is definitely redundant. In those cases, an estimate of the degree of redundancy was made, and its effects were removed to obtain the final result. The results are summarized in Table 16.

Table 16. Human Through-Put Rates

TASK	RATE
Participating in Reaction Time Experiments	8 bits/sec
Typing Nonsense Letters	8 bits/sec
Typing English	15 bits/sec
Simultaneous Oral Translation	20 bits/sec

It will be noted that the lower rates were obtained with the more artificial tasks. The differences may be explained by at least two factors:

(a) The redundancy of the natural tasks may have been under-estimated.

(b) The people in the more artificial situations were processing other information, such as assessing the general situation which did not show up in the experimental results.

Ritchie (1978) states that a human being can process about 16 bytes/second. He gives no reference and indeed mistakenly uses the term bytes instead of bits/second, but his point is interesting as it gives a possible upper limit for human data processing capabilities.

Considering all the estimates, a realistic limit for the rate at which information can be throughput is probably in the range of 5-10 bits/second.

The corollary to this should be repeated: Not counting the redundant information which may be present in a display, a CIG system probably has no need to present the pilot with more than about five or ten bits of new information per second.

There is additional waste involved in current CIG systems. Bunker (1979) feels that "Because of the eye's small region of sharp vision, most of this detail is wasted." In fact, according to one study [Diel, 1976], ". . . the human visual capability can be represented by about 130,000 resolution elements, provided that these elements are sized non-linearly according to the eye acuity function. . . ."

Both Bunker and Diel point out that some form of variable acuity which takes advantage of the eye's perceptual characteristics as well as the brain's data processing capabilities should be implemented in a CIG system through some form of area-of-interest image generation and display technique.

Galanter (1974) puts forth the conjecture that the rate of change of information just prior to touchdown is so great that it may be impossible for the pilot to use it to derive control information on orientation relative to the runway. This being true, the implication is that the pilot has committed himself to the landing at a distance from the runway and proceeds "more or less ballistically from that point onward." He states that the pilot may be exhibiting a capacity to plan the series of control force applications, including the flare, on what he has seen. If this is true, the implications are that a high level of detail (texture) would be neither required nor effective as cues during the last few seconds of a landing.

Interestingly Kraft (1979) found that the performance of pilots using instruments concurrently with CIG visual simulation was not as good as when they used the CIG visual scene alone. This seems to imply that the time sharing of CIG visual information with instrument derived information works to the detriment of pilot performance.

7.2.2 Measuring Human Data Processing

In comparison with the information transmission rates for electronic equipment, the throughput rates for people are astoundingly low. However, people normally respond to scenes which are highly redundant, with most changes being dependent on the context and the immediately previous scene. Therefore, a scene containing ten new bits of information per second might be quite realistic. The important question is: Where should those new bits of information go? In other words, what parts of a scene really carry the five or ten bits/second to which pilots respond? If we could answer this question fully, we could largely solve the problem of cue sufficiency.

There are at least three approaches to answering the question:

7.2.2.1 Experimental. The ultimate way to answer the question is through experimentation: take out features and observe the pilot's performance, add information and measure performance, and repeat the process until you have a display system which works. This is the approach taken by Ritchie (1978) and

Lewandowski (1979). The only difficulty is that it is terribly time consuming as well as expensive, and, as has been previously pointed out in the section on realism, it may not work. As a practical matter, some kind of guide to experimentation — guide to what to look for — is needed. Other approaches may provide such a guide.

7.2.2.2 Intuitive. The cartoon characters in "Peanuts" are rarely cited as scientific references, but they illustrate well the presentation of essential information. Using very few lines, the cartoonist projects a wealth of action and "feeling." Skilled cartoonists and characterists, taking advantage of their experience and artistic training, successfully use what we will call an "intuitive" approach to the identification of proper cues for at least some perceptions.

Cartoonists may be of little or no value in specifying the cues which are necessary in nap-of-the-earth flight. However, they have no monopoly on intuition. Some guidance may come from two other classes of people.

First, of course, one can ask pilots to name the cues to which they respond. Some useful information will probably be gained. However, suppose you were asked, "How do you ride a bicycle? What cues do you respond to, and how?" The cues would be difficult to specify in words, although one may feel or see them very well. The same thing may be true with pilots. They may not really know what cues are essential for low-level flight.

Second, perceptual psychologists have some general rules for identifying what will be seen in a scene, and what lines are most essential for generating what kinds of images. Some of these rules are subjective and intuitive, but some are more objective and therefore more useful.

7.2.2.3 Objective and mathematical. An observation, which dates at least from the days of Ivan Petrovich Pavlov, is that people tend to respond to change. Furthermore, change can be quantified when people are presented fairly simple functions (e.g., a clicking noise whose frequency is changing according to a certain function), the mathematical first derivative of the functions can be used to predict what the people will perceive and what they will fail to perceive. This was shown by Overton (1959). He also demonstrated that people exaggerate the features which contain the most change and, therefore, the most information. For example, if you ask a group of people to draw a square rapidly, most of them will draw squares whose angles are acute: the pointedness of the corners where the change, and the essential information lies, is exaggerated.

These findings offer an approach which is at least objective, and, at best, mathematical, for identifying the information-carriers in a CIG scene.

Also, basic geometry makes it clear that some cues are necessary. Specifically, there must be some indicator of scale. Some kind of texture or reference object must enable the pilot to scale the x and y axes (e.g., to know that he is looking at a 130-foot line from a certain distance rather than a 260-foot line from twice the distance), and aerial perspective or other cues must enable the pilot to scale the z axis. This is logically true, and it was shown experimentally to be true when the "3-D object" was found to be necessary during terrain following, by Lewandowski (1979).

Additionally the previously mentioned primary and secondary factors facilitating depth perception cannot be ignored. Any error of omission or distortion of these factors will more than likely induce illusions in the viewer.

7.2.3 Object Recognition

According to Ritchie (1978), when viewing a displayed visual scene, observers tend to see two things:

(a) Familiar objects

(b) What they expected to see.

Illusions occur not so much because of the raw data presented but because of the manner in which the observer correlates and interprets the data.

Ritchie states that "perception" is a set of habits which are used to structure information. The act of perceiving objects can lead to very powerful illusions. He gives as an example a drawing, reproduced here as Figure 12, of a human face with four eyes rather than two. Try as he might, the human observer cannot justify the disparity.

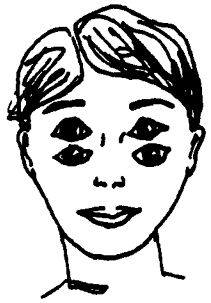

Figure 12. Observers Try to Organize Elements into Familiar Objects (Adapted from Ritchie, 1978)

7.2.4 Distance, Rate, Angular and Time-To-Go Judgments

7.2.4.1 Distance judgments. Distance judgments are subjective; they do not match real-world distances and, invariably, are overestimated. It has been found that the following equation may be applied in at least one experiment (Galanter et al., 1974).

$$\text{Perceived Distance} = \text{Range}^{1.24}$$

Crawford et al. (1977) also found that the judgment of distance tended to be greater than the actual distance. Their findings, however, showed a relatively accurate judgment at great distances (7 miles). They found that at the middle range of distances (between 30,000 feet and 5,000 feet) the difference appeared to remain constant between the perceived distance and the actual distance and averaged approximately 2 miles. The experiments were set up to evaluate how the perception of distance changed with changes in aerial perspective (haze) and texture. The 2 mile figure comes specifically from the haze experiments; however, it appears to apply as well to the texture experiments. For experienced pilots, second trials in both experiments seemed to imply that, although the pilots continued to overestimate distance, varying haze or texture did not appear to vary the overestimations significantly. It should be noted that the "texture" used in this experiment was, in actuality, a pattern of green rectangles of varying shades which were made up of overlapping stripes, 1,000, 2,000, or 3,000 feet wide. No highly detailed texture was utilized in this experiment nor could it have been expected that highly detailed texture would have shown any difference in results for distances greater than 1,000 feet. See 6.1.2.

7.2.4.2 Rate judgments. Rate judgments, according to Galanter (1974) are overestimated in a manner proportionate to the overestimation in distance judgments.

7.2.4.3 Angular judgments. Vagneur (1975) states that the pilot's ability to perceive acute angles should be investigated, as it holds the greatest potential for determining the visual cues on approach. He points out that the skills and accuracy necessary to control an aircraft during the approach and landing are transferrable from one aircraft type to another and could be accounted for by the visual technique of using multiple sighting points on the runway. These points would relate to specific altitudes on final approach. Pilots with monocular vision have successfully used this multiple-sighting technique.

7.2.4.4 Time-to-go judgments. Galanter (1974) reported that "all groups in all conditions tend to underestimate the time-to-touchdown." "The line fitted to these data has a slope of unity. This implies that the function relating judgments of time-to-touchdown to the actual transit time is linear."

Galanter (1974) concludes that "Taken all together, the results of this experiment lead to the conjecture that, although human observers overestimate distance, they also overestimate rate to the same extent so that psychological time, at least in the behavioral sense, is matched linearly with real time."

Time-to-go judgments may be the most important of all judgments in terrain avoidance during air-to-air combat, air-to-ground weapons delivery and terrain following, as well as touchdown.

7.2.5 Cue Requirements

Various cues are used by different pilots to perform the same tasks. Specific cues can undoubtedly be linked to particular tasks. However, numerous researchers — including Brown (1975), Vagneur (1975), and Cohen (February, 1979) have pointed out that, to date, no adequate studies have been done to define which cues do what. The following is a discussion of what is known or surmised. See Appendix C for current research.

7.2.5.1 Pilot control tasks. The pilot obviously derives perceptual information from his visual environment, which he uses to control the aircraft. Stark (et al., November, 1979) has defined the flight control situations, listed in Table 17, which utilize visual cues.

Table 17. Flight Control Situations

Attitude control
Spatial position control
Geographic position control
Ground velocity control
Flight path control
Altitude rate control
Closure rate control
Flight path control with respect to obstacles along the route.

To this list may be added attitude rate control, as well as numerous other control functions associated with target acquisition and weapons delivery which may or may not be directly linked to visual cues in the environment.

7.2.5.2 Real world cue functions. According to Stark (May, 1977), specific perceptual characteristics or cues facilitate the following functions:

(a) Attitude Control

Generalized visual cues, because of their magnitude, are effective in attitude control. Peripheral vision is very sensitive to relative motion.

(b) Geographic Orientation

Control of attitude, heading, and flight path during combat and aerobatic maneuvers are facilitated by generalized visual cues. Terrain surface provides heading, heading rate and terminal heading during all flight maneuvers.

(c) Contact Navigation

(1) Recognizable, real-world features correlated to maps

(2) Discrimination between similar features to avoid confusion

(3) Visual cues must support flight, including all functions associated with navigation such as flight control, communications, and planning.

(d) Ground Velocity/Flight Path

Take-off, pattern, and landing require relative motion of textural elements (motion parallax). Flight below 200 feet entails the recognition of details and detail motions.

(e) Altitude Rate

The cues to altitude rate vary with altitude.

Relative rates of foreground objects to background objects (near field, far field) and changes in apparent size, as well as surface detail, geometric cues, i.e., the shape of the runway, are all low-altitude cues.

Above 200 to 300 feet "changes in apparent sizes of terrain and cultural features provide gross cues to rate of ascent or descent up to, perhaps, 15,000 feet."

(f) Closure Rate

Relative motion between two aircraft flying formation is determined by changes in the observed aircraft image. ". . . the visibility and legibility of surface details provide information about relative position, range, and closure rate between the two aircraft."

(g) Obstacle Clearance

Object size and motion parallax as well as the velocity of surface features moving across the field of view give pilot cues to ground clearance.

(h) Approach to a Landing

Table 18, reproduced from Stark et al. (November, 1977) illustrates the relationship between scene elements, pilot tasks, and cue functions during an approach to a landing. Although dealing with CIG simulation of an approach the list is appropriate to real-world simulation as well.

During an approach to a landing, the runway outline is the most important cue at far to medium ranges to touchdown. The runway centerline becomes the dominant cue at near ranges (Roscoe, 1977).

Table 18. Landing Approach Cue Functions (Reproduced from Stark et. al., November 1977)

SCENE ELEMENT	PILOT TASKS	CUE FUNCTION
Ground	Maintain wings level; maintain pitch/power relations for optimum glide angle.	Horizon roll and pitch reference.
Runway	Maintain heading alignment; correct wind drift.	Runway shape defines alignment with centerline; shape and location in field of view define wind effects.
	Maintain glide path to runway touchdown point.	Rate of change in shape of runway and in length/width ratio define glideslope angle and touchdown location.
Taxiways	Identify aircraft position on approach path in limited and varying visibility; decide to continue or abort approach.	Airfield features provide cues to aircraft location when runway is momentarily obscured.
Buildings	Maintain glidepath to runway touchdown point; correct for wind drift.	Relative motion among scene elements provides cues to aircraft position, glidepath, and ground track; changes in building perspective provide cues to altitude.
Roads	Identify aircraft position on approach in limited and variable visibility; decide to continue or abort approach.	Scene elements surrounding this airfield provide cues to aircraft position when runway is momentarily obscured. Changes in relative position of off-airfield scene elements also provide information about position, flight path, and ground track in normal flight operations, permitting student to learn to perceive total situation.
Gravel	Control glidepath to runway touchdown point.	Surface detail defines terrain configuration and nature of terrain surface; relative motion among surface elements helps to define position of aircraft on approach path.
Grass Patches and Shadows	Maintain alignment with runway; control glidepath to runway touchdown point.	Changes in apparent shapes and relative motion among terrain surface elements provide cues to aircraft position and to location of touchdown point; off-runway surface details help student to learn to perceive total situation.
Approach Tower	Maintain alignment with runway; control glidepath to runway touchdown point.	Relative motion of top of tower, gravel, and runway surface provides cues to aircraft position on approach path; helps student to learn to perceive total approach and landing situation.
Individual Clouds	Maintain alignment with runway.	Relative motion between clouds and other scene elements provides cues to aircraft velocity and flight path.
Cloud Cover	Recognize aircraft position on approach, in limited and varying visibility; interpret flight status; decide to continue or abort approach.	Visibility effects help the student to learn to interpret minimal cues as they might be available in real-world flight operations.
Grooves, Tire Marks	Maintain minimum sink rate at touchdown.	Grooves and individual tire marks provide cues to absolute altitude and altitude rate, supporting practice in adjusting vertical velocity and flare height within acceptable limits.
	Control heading during rollout; reduce velocity to permit turn to taxiway.	Tire marks and blemishes provide cues to ground velocity used in predicting and controlling effects of rudder, brakes, reverse thrust in slowing to taxi speed, and in executing ground turns.
Hills	Maintain runway alignment during landing rollout; make smooth turns from driveway to taxiway.	Hills and other distant objects provide cues to heading, whose effectiveness is proportional to their distance from the pilot's point of view.

7.2.5.3 Cue simulation. Stark (May, 1977) states the following visual cue simulation requirements which relate to the previously mentioned real-world cue functions:

(a) Attitude Control

"Basic attitude control requires a horizon line and some differentiation between the terrain and the sky. Pitch and roll are controlled by comparing reference points on the aircraft with the horizon." Yaw is facilitated by a discrete reference on or below the horizon line. Peripheral cues to roll rate may require a horizon extending 90° to one side of the normal line of sight. Texture and haze giving normal cues to distance permit attitude rate control. Aerial perspective is required for accurate roll rate control. (See 7.1.5.4). Changes in size of terrain elements facilitates distance judgment.

(b) Geographic Orientation

Objects need not be identifiable but must contain unique elements to enable alignment of the aircraft on a specific heading, as well as provide points around which to perform maneuvers.

(c) Contact Navigation

Contact navigation requires recognizable terrain and cultural features. These features must be visible at realistic ranges and altitudes. Visibility and lighting must change their detectability and recognizability.

(d) Ground Velocity/Flight Path — Low Altitude

Cues to ground velocity and flight path may be provided by simple objects that change size and shape in appropriate manner as they are circumnavigated. Three-dimensional objects "provide additional cues in the form of enhanced motion parallax cues and mutual occlusion." Low altitude is defined here as between 200 and 2,000 feet. Below 200 feet ". . . gradually increasing clarity of details" provides cues.

Range and range rate information may be ascertained from scene elements of known size and the relationships between scene elements of known size.

(e) Altitude Rate

At low altitudes, familiar objects provide altitude rate cues. Detail and textural information are important. At high altitudes "simple, generalized shapes" are adequate.

(f) Closure Rate

Changes in the size of objects and increasing resolution of surface detail are two cues to closure rate. Additionally, rates of change of the foreground to the background provide closure rate information.

(g) Obstacle Clearance

"Three-dimensional objects of known size and shape having familiar surface details are required for training on obstacle clearance during taxiing and flight operations." During taxiing, surface markings help in control of velocity as well as turn radius. Wing-tip cues provide realistic judgment of clearance in maneuvering around obstacles.

(h) Range

"In formation flying, size, shape, and aspect cues are critical in providing information about relative distance and flight paths." Range and range rate cues can come from surface detail.

(i) Approach to a Landing

In night landing simulation, how well a pilot maintains the visual glide slope is entirely dependent upon the range at which the runway surface is acquired in respect to the runway lights (Kraft et al 1977 – 1979). See also 8.2.8 and 15.9

7.2.5.4 Cue simulation inadequacies. To a point, pilots will adapt to whatever cues they find available to them. They will trade one cue for another cue when specific cues which they would normally use are missing. Experienced pilots suffer most from the absence of preferred cues. Lower fidelity simulators might be quite adequate for certain types of training but could be totally inadequate as human factor test beds. When the number of cues is reduced, a greater emphasis and dependency is placed upon those which remain. While real-world visual cues are very redundant, CIG visual cues are not.

Stark et al. (November, 1977) correctly points out that the simulation of visual cues requires the programming of these cues with two purposes in mind:

(a) Eliciting Specific Responses

In order to support specific responses, specific information must be supplied, (e.g. horizon line allows maintenance of proper altitude, etc.)

(b) Avoiding Illusions

In order that illusions not be induced, sufficient cues must be provided, and those cues must not contradict one another or provide erroneous information themselves (e.g., lack of atmospheric perspective (haze) causing distant terrain to appear closer than it is meant to appear although the geometric perspective is correct). This fault, in turn, may induce the illusion of a higher than normal perception of roll rate as well as a horizon which is displaced upwards.

It is neither necessary nor desirable from a cost effectiveness standpoint to attempt to recreate all the real-world visual cues which are available to a pilot. Unfortunately, those which are essential have not yet been defined.

As previously mentioned (6.1.4), Palmer and Petitt (1976), in their paper on sink rate, credit Barnes (1970) with postulating the idea that weaknesses in the presentation of visual cues increased the visual threshold "which must be exceeded before the pilot can initiate action." This delay takes on the appearance of a dead band or transport delay in the control loop.

In the same paper, Palmer and Petitt put forward the allegation that during a landing, in an actual aircraft, pilots are either descending at the slowest rate of sink they can perceive or they are using some cue other than the threshold-to-sink rate.

7.2.5.5 Compensating for inadequacies. Numerous ploys have been employed in an attempt to give adequate cues for a simulator landing. Various CIG systems have had diamonds added next to the runway, or T-38 aircraft or fuel trucks, as well as skid marks on the runway. To date, no technique has been successful in producing a vertical velocity (sink rate) at touchdown as low as that found in the actual aircraft.

Comparisons made at NASA found no significant difference in sink rate between camera/model systems and CIG systems (Brown, 1975). Staples (1978) states that, in one study, it was found that the actual aircraft demonstrated a factor of 2 improvement in mean touchdown rate, "even though the field of view of the actual aircraft was severely restricted in comparison to the simulation. A factor of 3 improvement was found in standard deviation of bank angle when compared with the simulator."

As has been previously noted, human minimum separable acuity, which is approximately 1 minute of arc, is the poorest of the 4 measurable acuities. Minimum perceptible acuity as well as vernier acuity and stereo-acuity are all better; with minimum perceptible acuity being the best at approximately 0.5 seconds of arc. According to Brown (1975), Chase (1971) put forward the hypothesis that, "The reduced spatial resolution available in simulations is a significant factor in the differences in performance between an aircraft simulation and the aircraft itself."

The differences in resolution between current visual systems and human perception are probably a key factor in the differences of vertical velocity at touchdown between the actual aircraft and the simulator. Another major factor which has been previously disregarded is probably stereopsis. To this author's knowledge, no simulation research in landings has been done utilizing binocular vision to its fullest potential capability.

Landings are being emphasized here because of the potential implications of the differences in vertical velocity at touchdown. It is not known what the inadequacies in simulation are that cause this difference. This ignorance causes us to be unaware of what effects the lack could have on low-level flight other than landings. The lack of stereo cues may be a significant factor in all forms of low level flight simulation. See 7.1.1 and 15.7.

7.2.6 Color Perception and Simulation

Without question, the ideal CIG system would have the capability of providing accurate and realistic color. Brown (1975) points out that "Observers are quite tolerant of rather large deviations in actual color, and subjective standards of acceptability are probably quite adequate." Lewandowski (1979) found that, although during an actual sunset the three primary colors decrease at different rates, he could decrease them at the same rate without eliciting a negative response from observers. In fact, the difference was not detected.

Although Thomas and Jones (1977) say that "Chromatic color has been proven necessary in flight simulation through numerous experiments," they do not cite any such experiments, and indeed the present authors did not find any definitive data to prove that color was absolutely essential.

"There is no question as to pilot preference with respect to the dimension of color; pilots almost unanimously prefer color to black-and-white presentations in simulations of the visual world" (Chase, 1971, via Brown, 1975). "Qualitative tests of advantages afforded by color have shown small, but positive results" (Chase, 1970, 1971, via Brown, 1975). Brown goes on to say "Color would appear to be important in those circumstances where important information is encoded in color variations and, second, for its value in enhancing the pilot acceptance of a simulation device."

It appears that color is helpful and at least eliminates ambiguity in certain instances. Because simulation cannot currently provide real-world visual cues, cues which a pilot might normally use and choose for his own purposes are not necessarily available in a CIG-generated scene. When color is provided, it can give additional cues which may be used in lieu of the preferred cues when they are missing.

7.2.6.1 What color does in simulation. In one subjective evaluation of simulators (Rivers, 1977), the following has been written: "The evaluation pilots found color to be significantly beneficial for identifying objects and for providing added realism. In cases where resolution problems were encountered, color was critical in target acquisition and recognition. By making the visual scene appear more normal, color aided in providing effective depth perception cues." Rivers goes on to say, "For monochrome displays, similarity in outline of two objects caused confusion in identification. For example, similarity in outline made a gravel pit and lake indistinguishable from one another, until within very close range."

Identification of known objects (e.g., a lake versus a gravel pit, a taxiway versus a runway, etc.) can be facilitated by color.

Color and flicker, as well as relative motion, allow pilots to differentiate other air traffic from city lights (Kraft, 1979).

Moving, dark objects shift toward the blue; a moving bright object shifts toward the red. The color of the object may not be important, but the sky color may be very important, because when a dark object on a light background is shifted toward the blue, it tends to blend into the background (Kraft, 1979).

7.2.6.2 What color does not do in simulation. Color may not add much to the perception of motion in depth, although it may help in the identification of objects and thereby facilitate their utilization in the determination of relative distance. The key to the perception of motion in depth appears to be the precise timing of changes in the visual motion patterns involved as they relate to pilot control inputs (Brown, 1975).

An object smaller than 11 minutes of arc is almost colorless (Kraft, 1979). Target detection of very small objects should not, therefore, be influenced by color.

7.2.6.3 The mission task implications of color.

(a) Air-to-Ground

Color may enhance the apparent contrast between objects and thereby facilitate the acquisition of targets in the air-to-ground mission task (Thomas and Jones, 1977) if those targets are larger than 11 minutes of arc when detected. Rivers (1977) found that "color proved an important factor for normal object recognition and identification in air-to-surface training devices."

Another subjective study (Greening, 1977) states that 58% of the pilots queried in Southeast Asia felt that color contrast was no help or only slight help in detecting targets, while 42% of the pilots queried felt that color contrast was of moderate or extreme utility. While 42% is less than half, it remains nonetheless a significant number. Of the cues which were listed, only motion and size were considered to be more significant in utility than color contrast.

(b) Landing

Staples (1978) states that Chase found significant differences in altitude error and time away from the glide path during a landing approach when he first used red approach and blue taxiway lights and then changed to blue approach and red taxiway lights. When red and blue lights are equidistant, the red light always appears nearer. This effect is more pronounced with stereoscopic viewing (binocular) than with monocular viewing. In this case, as Staples points out, a deficiency in the display system becomes an asset. Whether or not the absence of color in a monochrome system affects landing performance remains unclear but these findings do raise the question. What is clear is that color, when it is used, does affect performance.

One other point that Staples makes has unknown consequences. The foveal vision response time to the color of blue is about 18% faster than red. With response times ranging around 300 milliseconds, these differences could be significant and could affect tight closed-loop control tasks.

(c) Terrain Following

Contrast and color "play an important role in ranging, particularly in low-level flight over contoured terrain. The separation of ridges and the assessment of distance between successive ridges is almost entirely deduced from their relative contrast and color" (Staples, 1978). Consequently, in the terrain-following task, color may prove to be a significant factor in the avoidance of obstacles.

7.2.6.4 Color contrast. Although contrast is a function of both color and black-and-white scenes, it is most often thought of in relationship to black-and-white scenes alone. However, as previously stated, contrasts in color can be the key to the differentiating of objects. Contrast can make an image appear sharper than it actually is and can enhance what might be otherwise inadequate.

7.2.7 Texture as a Perceptual Cue

In simulation, as in the real world, homogeneous surfaces do not give cues to depth perception adequate to determine altitude accurately. Flight over, or amphibious aircraft landings on, undisturbed water are extremely difficult. Sand and snow, as well as ice, offer similar problems if they lack convolutions. One researcher reports that bush pilots may add cues to a visual scene, which is lacking them, by throwing items such as red blankets out of the aircraft. The pilot then uses those blankets as cues to perform the approach and flare during a landing (Reynolds, 1978). For the purpose of CIG, texture may be considered to be any pattern which is added to an otherwise homogeneous surface and does not impact system capacity by adding edges. See 5.2(r) and 7.2.10.

7.2.7.1 Why texture? A CIG scene may or may not provide adequate cues to depth perception for the judgment of altitude to be successfully performed. If it does so, it must provide those cues through the utilization of edge capacity or texture. Utilizing edge capacity for this purpose limits overall scene complexity. The edge capacity of the system may not prove adequate for the task of providing both scene complexity, e.g., buildings, roads, bridges, rivers, lakes, mountains, etc., as well as cues to depth perception for judging altitude in low-level flight. It has become obvious that defining only the main features of a scene by edges and filling in the blanks with texture is a more efficient approach to the cue sufficiency problem than increasing the edge capacity utilizing current technological approaches (Harvey, 1978). Only a technological approach differing from current approaches, and offering a system capacity of 100,000 to 300,000 edges, or more, might reasonably be expected to utilize edge capacity in lieu of texture. This high edge capacity approach could not be utilized without automated data base building.

From the previous paragraphs one must conclude that using system edge capacity in lieu of texture is not cost effective and cannot be justified with current systems because of two factors:

(a) Using edges to fill in the blanks subtracts them from the available edge capacity needed to portray non-textural scene elements.

(b) Using edges to fill in the blanks requires excessive programming time and effort during data base building with non-automated systems.

"Texture plays a very important role in the perception of motion and distance. The function of texture is to supply neither detailed information nor information about details, but to give very important visual cues about motion, speed, direction, altitude, distance, and the like." (Cohen, February, 1979.)

Bunker and Ingalls (1978) suggest that texture be considered as a "level-of-detail." They point out that when an observer looks out over a field of grass that observer does not see individual blades of grass from a distance but only the effect of their combination, which then creates a surface which is not grass (individual blades) but is a conjugate of grass, which they call "grassy." Upon approach, the observer would find the "grassy" surface turning into individual grass blades. At this point, the texture would then belong to the individual grass blades. This example is given only to illustrate a point and should not be taken literally. The level of effort necessary to accomplish this feat cannot be justified by the necessity for providing the requisite cues. Individual blades of grass are beyond the capacity of any conceivable, near-term CIG system. They would also be beyond the capacity of the observer to utilize in any meaningful way.

As Bunker and Ingalls point out, the application of texture appears to be most appropriate to natural terrain rather than cultural (man-made) features. Texture has only minimal value when perceived from a distance (Crawford and Topmiller, 1977) but can be crucial "when the viewpoint comes in close proximity to the surface of the terrain" (Bunker and Ingalls, 1978).

Lewandowski (1979) has conducted some ad hoc research on the amount of perspective information a low-flying helicopter pilot (in a simulator) had to be given to successfully accomplish low-level flight over gently rolling terrain. Specifically, Lewandowski drew "checkerboards" over the terrain to provide geometric perspective. This checkerboard approach can be considered a form of texture.

Lewandowski varied the physical length of the edges of the "squares" in the "checkerboard." Pilots who flew over the terrain were flying at simulated altitudes of 10 to 100 feet, and at speeds of 0 to 70 knots. Lewandowski found that the optimum edge length was 130 feet. If the "square" was much bigger, it was "no cue." If it was much smaller (i.e., 50 feet on a side), it gave "too much information" and made the pilot ill whenever he yawed because of the terrible busyness of the scene. The optimum size of the squares increased with velocity beyond 70 knots. See Figure 13.

The 130-foot squares were of the optimum size and provided adequate cues to maintain height above the terrain only when "tree stumps" were added to the scene. Without these additions, pilots could not tell whether they were approaching a 130-foot square at 30 knots or a 260-foot square at 60 knots. The "tree stumps" took the form of truncated pyramids which were defined as being 3 feet in height. These three-dimensional "tree stumps" served a dual purpose. They provided rate information to the pilot as well as giving him a known size reference, so that he would have a sense of scale when viewing the terrain made up of "squares."

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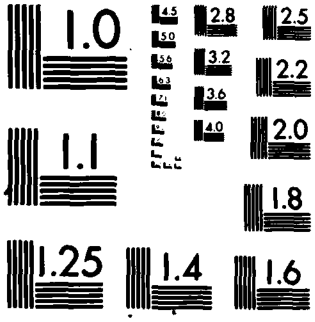

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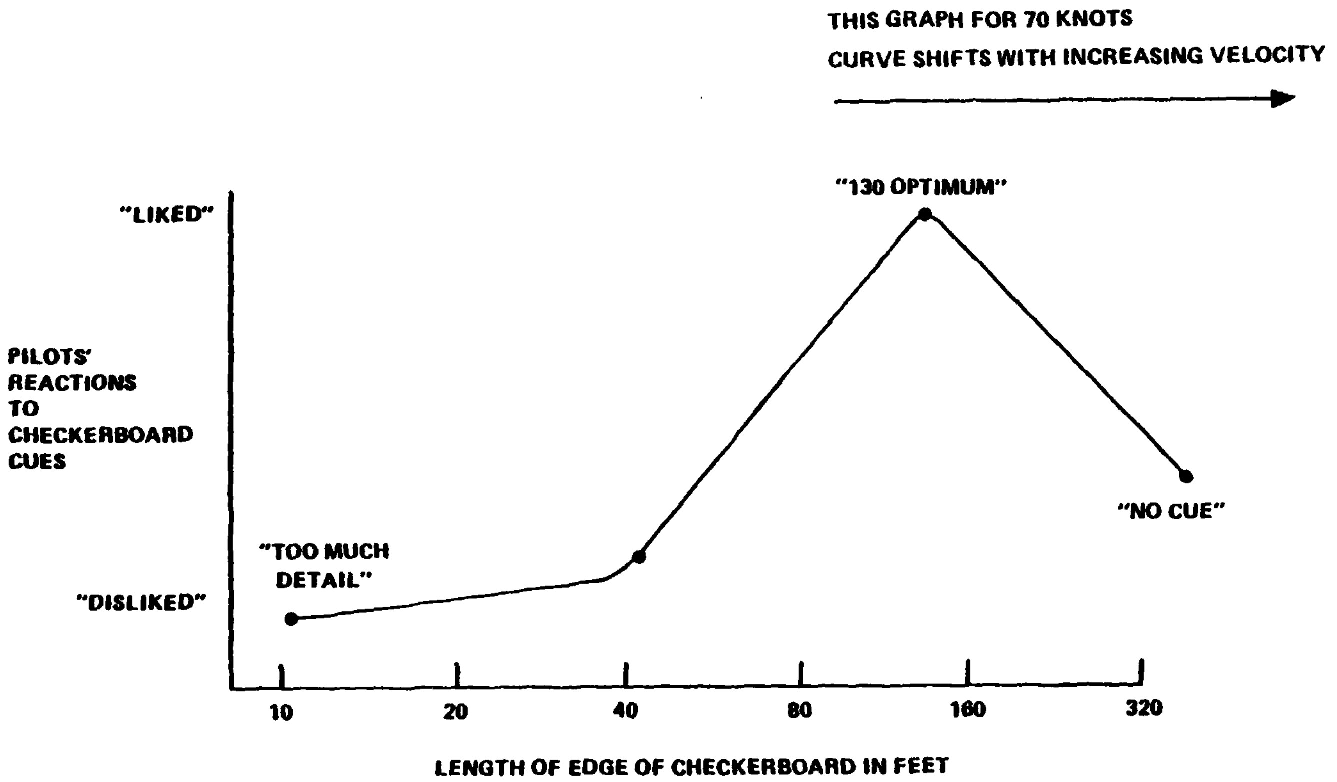


Figure 13. Lewandowski's Checkerboard with Tree Stumps

7.2.7.2 Types of texture. Texture may be two-dimensional (2-D) or three-dimensional (3-D). (2-D texture is texture which does not protrude from the surface it is applied to, 3-D texture does). Texture may vary with time (e.g., white caps on an ocean, a field of wheat in the wind, etc.) or remain unchanging. Texture may be a pseudorandom tesselation of patchwork fields or a geometric pattern laid down on the terrain. Pseudorandom noise, which would create blobs whose perspective and size changed correctly with changes in position and relative distance, has been suggested, but no viable approach for the generation of such a pattern is available (Bunker and Ingalls, 1978). In an earlier paper, Bunker and Ferris (1977) point out that an attempt to generate contours was unsuccessful as no viable algorithm could be found to generate the gradient for the contour at the intersection of the edges. In contrast, the map texture experiments that were executed worked out well, with a geometric, textural pattern being successfully generated.

At the SAAC, a checkerboard scene of brown and green is used to give altitude and altitude-rate cues. Initially, this pattern was made up of squares which were 1 mile on a side. Air-to-air combat could not be successfully practiced below 4,000 feet with squares of this size. When the squares were reduced in size to 1/2 by 1/2 mile, pilots were able to control the simulator to altitudes below 1,000 feet by visual reference alone (Stark, 1976).

Experiments at ASPT demonstrated that performance improved with increases in geometric texture which was applied to the runway.

At Technology Service Corporation (Reynolds, et al., 1978; Stenger, 1979), experiments have been done with the concept of a texture tile. A texture tile is derived from a photograph of the real-world texture which is to be simulated. This process creates a continuous tile boundary and eliminates the macro-patterns within the tile. The tile can then be laid down on a surface much like kitchen tile is laid down on a floor. The patterns created appear relatively random and do not permit the differentiation of an individual tile. This technique has been only partially successful to date for reasons covered in 17.2.10.

Altitude and altitude-rate cues will require three-dimensional texture or objects when in close proximity to the terrain for scaling purposes. Additionally, the ability of three-dimensional textural objects to occlude one another could prove to be a very powerful cue.

7.2.8 Motion Cues

While motion is not a visual cue producer, it has an undeniable effect on the interpretation of visual cues.

Stark (1976) points out that both pressure and vestibular (inner ear) cues are required "to provide a reasonably complete portrayal of cockpit motion, in addition to visual cues." He states that R.J. Shirley, in a thesis done in 1967 at M.I.T., titled "Motion Cues in Man Vehicle Control," found that the "visual system generally lags the vestibular." Stark states that at the SAAC it has been found that the absence of platform motion induced vertigo. In addition, control was somewhat more erratic. Motion and g-seat cues appeared to quicken some responses such as tracking tasks.

Brown (1975) also states that visual motion "in the absence of physical motion can be quite disturbing." The cause is a disparity in the level of stimulation to one sensory system in comparison to the other sensory systems. More importantly though, the responses to the stimulation may not be the same as that which would occur under natural circumstances.

Apparently, even simple physical vibration unassociated with actual motion or controlled maneuvers has been used successfully to increase subjective realism, Brown (1975). There is some question in the present author's mind as to whether or not this would, in fact, improve performance, but it obviously can affect subjective judgments.

Miller and Riley (1976) found that the use of a motion base extended the range of acceptable transport delays in the visual system.

Thomas and Jones (1977) state that three reports (Navtoland, 1977; Simulation Study for V/STOL, 1975; Visual Simulation and Image Interpretation, 1969) have determined that motion is required for V/STOL hover and hover transition tasks. They also state that one report has shown fixed-wing angle of attack with air-speed experiments require motion (Simulation for Aerospace Research, 1964).

Negative aspects of motion bases do exist. The technique of "washout," through which motion which started abruptly is gradually terminated and a return to the neutral or resting state of the platform is established, seems to work fairly well; however, "The correct representation of all the linear and angular components of acceleration for a given motion path can only be achieved by exact duplication of that motion path" (Brown, 1975). Parrish (1978) reported problems at Langley with an unacceptable roll axis presentation. Rivers (1977), in his "Simulator Comparative Evaluation," reports that "The consensus was that current platform and beam motion systems evaluated do not provide effective cues for enhanced realism for the performance of A/A or A/S tasks. . ." They appear to enhance realism only in the area of transition maneuvers.

In dome systems, motion may displace the pilot's head far enough from the center of the dome to induce distortions in linear perspective (Thomas and Jones, 1977).

Studies done at ASPT have shown that platform motion does not improve simulator training capability. What this means to the present authors in terms of R&D simulation is uncertain. There is some question as to the correctness of the cues given by the motion system at ASPT (Rivers, 1977).

The psychologists at ASPT seem to feel that a blanket statement that motion is not important is short-sighted. They point out that force cues probably affect responses to the unexpected more than anything else. For the experienced pilot, a compelling visual scene is adequate to create the illusion of actual flight. However, if there were to be some disturbance (e.g., a change in wind velocity or direction, etc.), the pilot will not get the kinds of cues that are necessary for him to compensate from the visual scene alone (Buckland et al., 1979).

G-seat, g-suit and buffet system requirements must be considered. Stark (1976) states that the SAAC system has shown pilot performance to be less accurate without g-seat cues. Apparently, longitudinal acceleration can be judged better with it. A loop performed without g-seat cues was difficult because of incorrect motion base cues; the g-seat cues corrected this problem. Sustained g-maneuvers could be better sensed with the g-seat. Additionally, "Pilots flying the simulator with motion but without the g-seat were unable to develop techniques for controlling the simulator to 1/4 g without looking at the accelerometer. With the seat operating, they were able to control the simulator to 1/4 g and to avoid 0 and negative g with essentially no practice, even though the cues associated with the weight of the feet on the rudder pedals were not available."

Rivers (1977) concluded that "Both evaluation teams agreed that an effective visual system, enhanced by optimized g-suit, g-seat, and buffet systems, would provide adequate cues for the performance of A/A and A/S tasks. . ."

SECTION 8

PERCEPTUAL ILLUSIONS

8.1 ILLUSIONS AND FLIGHT

The majority of the information dealing with illusions and flight is excerpted from the article by the same title (1979). Of all the illusions which can occur in actual flight, the most hazardous are those which affect the pilot's judgment during a low-level flight. For example:

Weapons delivery and recovery can be extremely dangerous when traversing featureless terrain, such as calm water or a desert area, at very high speeds.

During the approach to a landing, visual illusions may occur due to a number of causes. In Table 19 one or any combination of features may cause such an illusion.

Table 19. A Partial List of Factors Inducing Illusion in Flight

Sloping approach terrain
Sloping runways
Runway width
Rain on wind screen
Featureless approach terrain
Runway lighting intensity
Shallow fog
Rain showers.

8.1.1 Sloping Runways or Terrain

Sloping runways or terrain may cause a pilot to misjudge his apparent height above the ground or glideslope. The standard ILS glideslope of 3° creates an angle of 177° with the runway when the runway was level. Experienced pilots used both of these angles to determine the proper glideslope. Anything other than a level approach terrain or runway will create an illusion.

8.1.2 Runway Width

Runway width can change the apparent geometric perspective of the runway. "Increasing or decreasing the distance between the lines (runway edges). . . can create the illusion of shortening or lengthening them." Example: A wider-than-normal runway will appear to be shorter than normal. In turn, the runway will make the apparent altitude less than normal to the pilot-observer.

8.1.3 Rain

Rain, by diffusing the flow of lights and causing them to appear less intense will make them seem further away. "On the other hand, only a little scattering due to water on the wind screen can cause runway lights to bloom and double their apparent size . . . Even though an aircraft is correctly aligned on the approach pad, it can appear to the pilot to be above or below the correct glideslope or left or right of the runway centerline, depending upon the slope of the wind screen or other circumstances. The apparent error might be as much as 200 feet at a distance of 1 mile from the runway threshold."

Rain Showers or a heavy rainstorm "moving towards an aircraft can cause a shortening of the pilot's visual segment - that distance along the surface visual to the pilot over the nose of the aircraft. This can produce the illusion that the horizon is moving lower and, as a result, is often misinterpreted as an aircraft pitch change in the nose-up direction."

8.1.4 Featureless Approach Terrain

Featureless approach terrain can make an accurate descent very difficult. "Visual descents over calm seas, desert or snow, or over unlit terrain, at night, can be hazardous even in good visibility. The absence of external vertical references makes judgment of height difficult, and the pilot has the illusion of being at a greater height than is actually the case. . . ." Lack of contrast between the runway surface and surrounding terrain, caused by snow on the ground, may also cause problems, as will descent into the sun or restricted forward visibility.

8.1.5 Runway Lighting Intensity

Runway lighting intensity can be the cause of a visual illusion because brighter lights appear closer to the observer.

8.1.6 Shallow Fog

Shallow fog, which just blankets the runway lights and permits them to be viewed while above the fog level but obscures the runway lights when it is descended into, may cause visual illusions. "This is likely to cause an illusion that the aircraft has pitched nose up, which may induce a pilot to make a corrective movement in the opposite direction."

8.1.7 Horizons Formed by Cloud Layers

Horizons formed by cloud layers occur when a pilot flies between two cloud layers. As the visibility may be excellent under these conditions, the tendency is for the pilot to use the two cloud layers as a visual reference for leveling the wings. A problem arises due to the fact that the cloud layers often are not parallel with the earth's surface.

8.1.8 Autokinesis

Autokinesis is an illusion which occurs when one small source of light is viewed against a uniformly dark background. The illusion manifests itself as motion on the part of the small source of light. The pilot may have a tendency to attempt to correct the apparent motion of the aircraft in reference to the light.

8.1.9 High Altitude

High altitude may cause a problem which is not an illusion and has been previously mentioned. This problem occurs because there is little or nothing in the distance to focus on and instead of focusing at infinity the eye goes to its resting state, which is only a few feet away. The only sure way to cause it to focus at infinity is to look at objects further than 20 feet away, such as the wing-tip of the aircraft if it is visible, or the ground or clouds or vapor trails, etc. This must be done every three or four seconds during a search pattern. See the section on accommodation for a further discussion.

"Other high-altitude flying problems include the fact that the horizon is depressed with respect to the true horizontal. . ." The pilot may drop a wing too low in an attempt to level the wings, or he may drop the nose below the actual horizon in an attempt to level it.

8.1.10 High-Speed Flight

High-speed flight actually causes a phenomenon to occur which people in the early twentieth century thought would occur with the automobile. It was thought that man would not be able to control the automobile at speeds greater than that of a horse, because man was not adapted to such speeds. "As the speed of flight increases, it is no longer valid to think in terms of an instantaneous visual picture. The elapsed time between initial perception of an external object and its recognition becomes significant, and, in the case of collision courses, additional time will be required to alter the aircraft's line of flight. The problem becomes more serious at high altitude where it is difficult to judge distance, relative speed and size of an object when it is seen against an empty visual field."

8.1.11 Other Considerations

In earlier sections other illusions, such as the "moon illusion," have been mentioned. These illusions may or may not be associated with illusions in flight.

Not all the illusions discussed are currently reproducible in CIG simulation, nor would they necessarily be required in an R&D environment. They may be of interest in training simulation or crash investigation. More significantly, these illusions may be associated with illusions accidentally and unintentionally created by CIG systems.

8.2 ILLUSIONS IN SIMULATION AND PERCEPTUAL DISTORTIONS

People spend most of their lives looking at broad vistas, full of detail. Then, when they must look at a narrow and simplified scene, the change can induce some powerful perceptual distortions which are relevant to CIG displays.

8.2.1 Tunnel Effects

When one looks at a scene through a simple cardboard tube containing no magnifying lens, the scene seems to be magnified. A similar effect arises when a pilot looks at a display which suhtends a relatively narrow field of view. For example, a 48-degree horizontal field-of-view was used by Lewandowski (1979). He found that when an object was geometrically 100 yards away from the viewer it was psychologically only 30 to 75 yards away. See Table 20. When Lewandowski compressed the x-axis of his display by a factor of two (i.e., he squeezed things together, side-to-side), the resulting display, which was geometrically distorted, was psychologically accurate. The 100-yard distance was now judged as being from 90 to 100 yards. Similarly, he found that observers judged the 45-degree field of view as actually being between 75 degrees and 120 degrees.

Table 20. Lewandowski's Averages

Physical Situation	Physical Estimate
45° Field of View	75° to 120° Field of View
100-yard Distance	30 to 75 Yards
100-yard Distance Compressed 2 x Laterally	90 to 110 Yards

It may be that this effect is caused simply by texture on the surface of the cone which is used to restrict the field-of-view. It appears that the further out the texture goes the further out the eye accommodates. The further out the accommodation point the bigger (closer) the object appears (Roscoe et. al, 1980). The shielding around Lewandowski's display could be conductive to a distant accommodation point; and, therefore, to a greater magnification. See "Moon Illusion" 7.1.5.

8.2.2 Filled Space

Another well-known phenomenon (applied here to a simple line) is that length or area is psychologically affected by the extent to which it is "filled." A bisected line will appear shorter than a non-bisected line of the same physical length. But if there are many "cross-ties" on the line, it will appear even longer than the non-bisected line. One of the present authors observed this effect on a CIG display which had reticles superimposed. A target object happened to line up across the reticles. The object suddenly seemed larger, and therefore closer, because of the filled-space illusion.

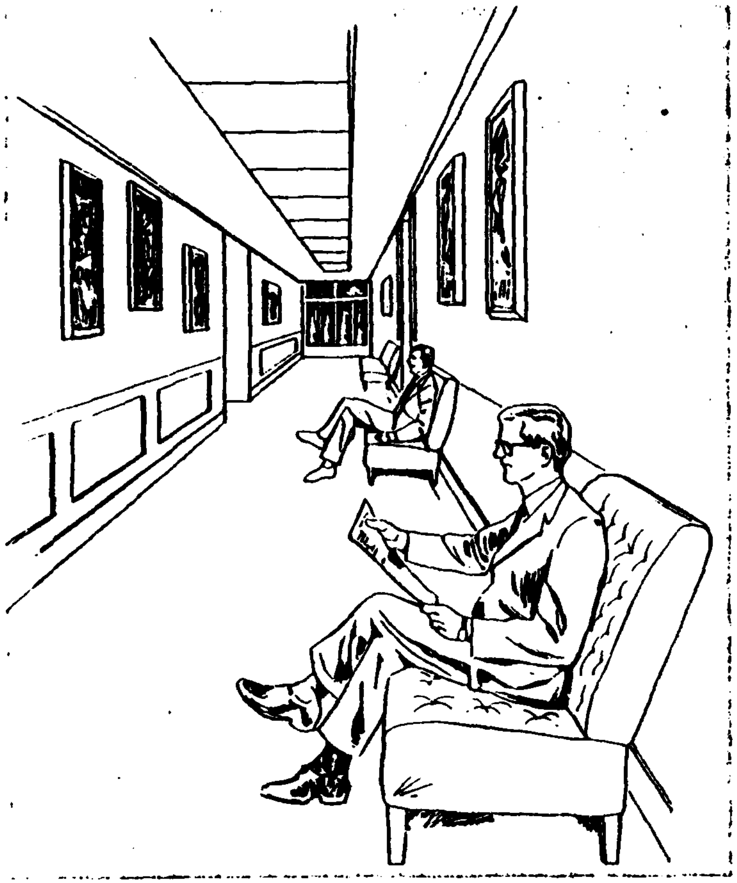


Figure 14(a). Perspective Cues Enchancing Constancy

Figure 14(b). Illustration of Reduced Constancy

(Reproduced from Rock, 1975)

8.2.3 Failure of Constancy

In daily life, our knowledge of relative sizes influences our perception in a way which is called "constancy," and when other cues (notably convergence of the eyes) are absent, constancy may fail. Since a CIG display is indeed a picture, it also may cause failures of constancy. An illustration of constancy is provided by Figure 14, adapted from Rock (1975). The smaller man is physically the same size in both pictures. In Figure 14(a), however, perspective cues enhance constancy, and the man seems larger than he does in Figure 14(b).

8.2.4 Other Effects

A complicated version of the Poggendorff effect has been observed in CIG systems. The effect is illustrated in Figure 15. The top dashed line is actually an extension of the diagonal, solid line, but the bottom dashed line seems to be.

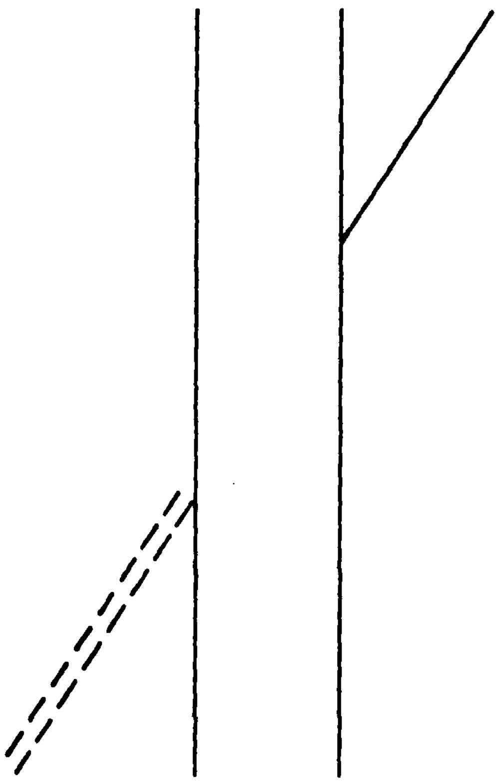


Figure 15. The Poggendorff Effect

Certain other effects may be generated in CIG displays. One is the Orbison effect, shown in Figure 16. The smaller circle is actually round, and not lumpy as it may appear.

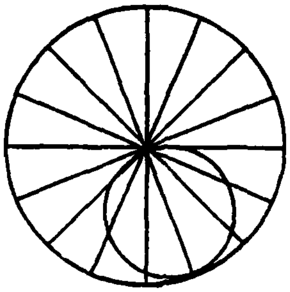


Figure 16. The Orbison Effect

A similar phenomenon is the Eherenstein effect, illustrated in Figure 17. The rectangle in the center is rectangular, and its sides are not really bowed in.

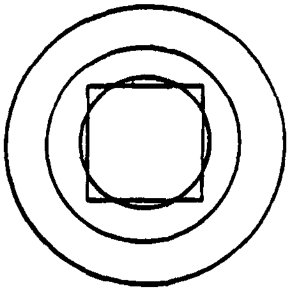


Figure 17. The Eherenstein Effect

The Oppel illusion shown in Figure 18 is very powerful. It has been found in chickens and monkeys as well as people. The vertical line is actually the same length as the horizontal line.

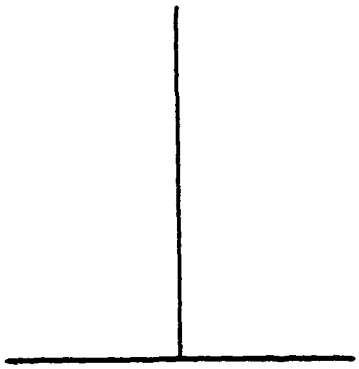


Figure 18. The Oppel Illusion

A similar powerful effect is the Sander illusion, illustrated in Figure 19. The dashed lines are of equal length, although one seems longer than the other.

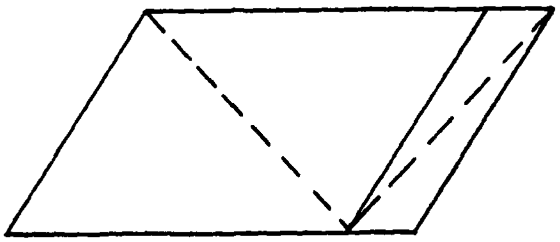


Figure 19. The Sander Illusion

Other illusions, caused by or associated with the CIG systems, occur because of the high emphasis placed on those limited cues which are available in an austere CIG scene lacking real-world redundancy. Additionally, perceptual cues which are misimplemented in CIG systems will cause illusions (e.g., lack of atmospheric perspective [haze], causing distant objects to appear closer than they are in actuality and inducing the perception of incorrect roll rates, etc).

8.2.5 Disparity in Cues

Nausea, while definitely no illusion, may be induced by a disparity in cues from various sources. For example, a compelling visual scene without corresponding motion or g-suit/g-seat cues is a potential cause.

8.2.6 Illusions with "No Cause"

CIG scenes may induce illusions even when they meet all commonly recognized perceptual characteristics. Lewandowski found that objects tended to appear to float under certain circumstances. Table 21 shows these circumstances and what can be done to correct the situation.

Table 21. Lewandowski's Determinants of "Floating"

Object	What holds it down	What lets it float
"Tree"	Trunk	More detail
"Tree"	Shadow	More detail
"Stump"	Angled edges	Vertical edges
Tank on road	Perspective of road	More detail
Tank off road	Shadow	No shadow

8.2.7 Timing and Perceptual Distortions

It has been shown that perceptual distortions are greatest when a person sees the scene for only about 100 to 200 milliseconds (Piaget, 1958). Since this time of exposure is in the range of viewing times which a pilot may experience the need for avoiding such perceptual distortions becomes especially acute.

8.2.8 Illusions in Landing Simulation

Kraft et al. (1977, 1979) found that, in the display of CIG night landing scenes, far-end lights on a runway appeared larger than near-end lights. In an attempt to correct this discrepancy, attenuation of the distant lights was utilized. This "fix" was only partially successful. However, without it, if the observer viewed a runway surface in combination with the runway lights, the runway was perceived as being level and the lights went uphill.

Prior to attenuating the lights, experiments were done with three categories of information being presented: Category I was Lights Only; Category II was Surface Only; Category III was Lights and Surface. With lights only, the estimation by the experimental subjects that they were too high was significant; with lights and surface, this estimation came down somewhat; with surface only, they were right on their estimated glide slope. Experiments were done with still photographs; when the experimental subjects flew the approach on an actual CIG scene, they flew under the visual glide slope as though they were compensating for what they had seen in the static imagery.

The pilots flew to correct for the apparent but erroneous cues provided by the runway lighting. Significantly, this response changed, dependent upon how far out the surface of the runway was acquired. If the pilot acquired the surface one mile out, a proper approach would be made regardless of whether the lights were attenuated with distance or not. However,if the surface was not available until the threshold was crossed over, the test subjects displayed a 15-foot disparity in distance for an altitude, nominally, of 45 feet.

8.2.9 Illusions from Sound Cues

Sound can affect how the pilot perceives what he sees. It is interesting to note that cues other than visual cues may be overlooked. This was the case when overlooking the fact that high-density air at low altitude sounds differed from low-density air at high altitude as it crosses over the canopy. Pilots flying at low altitude without the cue made gross errors in setting up specific air speeds in one evaluation (Stark, 1976). When the differential air flow cues were added to the oral cue system "velocity control by 'visual' reference became quite accurate."

Rivers (1977) found that realism was improved with the addition of effective sound cues such as missile launch and gun firing.

SECTION 9

AFWAL/FIGD MISSION TASKS

The AFWAL/FIGD must perform ten mission tasks. They are as follows:

(a) Air-to-Air (A/A)

(b) Air-to-Ground (A/G) (Air-to-Surface [A/S])

(c) Terrain Following (TF)

(d) Cruise

(e) Takeoff and Landing

(f) Refueling

(g) Station Keeping

(h) Formation Flying

(i) Sensor Simulation

(j) Other

Tables 22 through 31 define the visual characteristics of each of these mission tasks.

Table 32 breaks mission tasks down by percentage of utilization according to the simulators which perform the tasks.

Table 33 is a summation of Table 32.

The source for Tables 22 through 33 was the AFWAL/FIGD.

Table 34 is a synopsis of the major mission task requirements.

Table 22. Air-To-Air Mission Task

WORD DESCRIPTION:

THIS TASK INVOLVES HIGH PERFORMANCE, NEAR GROUND ENCOUNTERS WITH OTHER AIRCRAFT. ENEMY AND POSSIBLY FRIENDLY AIRCRAFT MAY BE INVOLVED (1 OR MORE). MISSIONS MAY INVOLVE THE PRESENCE OF A WINGMAN. DETECTION AND IDENTIFICATION OF TARGET OBJECTS AT DISTANCE AND THROUGHOUT A WIDE FIELD-OF-VIEW IS REQUIRED. DEPICTION OF FRIENDLY AND/OR ENEMY ORDNANCE USAGE AND IMPACT REGISTRATION IS AN IMPORTANT FEATURE. ENVIRONMENTAL CONDITIONS COULD INCLUDE TIME OF DAY (LIGHTING) AND LIMITED OR RESTRICTED VISIBILITY. FLY TO AND THROUGH CLOUD MANEUVERS MAY BE INVOLVED. USE OF A HUD DEVICE MAY BE DICTATED. PURSUIT AND ENEMY ENGAGEMENT WOULD GENERALLY BE CONTAINED WITHIN A RELATIVELY SMALL GEOGRAPHIC AREA OWING TO THE NATURE OF THE MISSION.

VELOCITY $\leq .9$ MACH (CLOSING VELOCITY MACH ≤ 2)
UNLIMITED ORIENTATION
ROLL (300°/S), PITCH (150°/S), YAW (150°/S)
WITHOUT DETECTABLE BLURRING, PHASE LAG OR STEPPING

5000 FT AND BELOW (AS LOW AS 50 FT)
NEED FOR ACCURATE VELOCITY, ATTITUDE, AND ALTITUDE CUES NEAR GROUND
ADEQUATE DETAIL IN TERRAIN SCENE
ABILITY TO ALTER AND TAILOR TO SUIT MISSION (EASE OF DATA BASE MANIPULATION)

DIFFERING AIRCRAFT POSSIBLE (BELIEVABLE REPRESENTATION)
DISTINGUISHABLE BY TYPE/CONFIGURATION/ETC. (CARGO: C-141 OR C-5; FIGHTER: MIG OR F-4)
UP TO 3 INDEPENDENTLY MOVING (RELATIVE TO SUBJECT) ENEMY AIRCRAFT AND ONE WINGMAN VISIBLE TO PILOT AT ANYTIME EACH PERHAPS EXECUTING ITS OWN HIGH PERFORMANCE MANEUVERS
AIRCRAFT COULD BE DISTANT (VISUAL THRESHOLD) OR PROXIMATE (50 FT) - AIRCRAFT CAMOUFLAGE

REINFORCES NEED FOR ±90° HORIZONTAL FIELD OF VIEW
REINFORCES NEED FOR DEPICTION OF PROXIMATE AIRCRAFT
REINFORCES NEED FOR DEPICTION OF PARTICULAR AIRCRAFT FOR DESIGNATION AND IDENTIFICATION
INDEPENDENT OPERATION AT DISTANCE POSSIBLE

DETECTION AT REAL WORLD DISTANCES (UP TO 25000 FT) RANGE - (IMPLIES CERTAIN RESOLUTION)
IDENTIFICATION - 3600 FT RANGE
(RECOGNITION - 5200 FT)

±90° SIDE VISION (MINIMUM)
+90° UPWARD VISION (MINIMUM)
-30° DOWNWARD VISION (MINIMUM)

ABILITY TO DEPICT BOTH INCOMING AND OUTGOING MISSILE FLIGHT INCLUDING REGISTRATION OF IMPACT - WOULD INCLUDE "CONTRAILS"
ABILITY TO DEPICT OTHER ORDNANCE EXHANGE BOTH INCOMING AND OUTGOING - BULLETS (INCENDIARY)
ACCURATE POSITIONING IN SPACE AND TIME OF TARGET AIRCRAFT TO ASSURE ACCURATE ORDNANCE DELIVERY SCORING
±10 FT IN POSITION   WHICHEVER IS MORE
±2 MILLIRADIANS   RESTRICTIVE

SUN ANGLE
SUN IMAGE - EFFECT OF SUN ON TARGET VISIBILITY AND TACTICS
DAY, DUSK/DAWN, NIGHT LIGHTING

"OVERCLOUD" FLIGHT
PATCH CLOUD
DEFINABLE LIMITED VISIBILITY, SVR (SLANT VISUAL RANGE), ETC.
HAZE

CREATE REALISTIC CLOUDS THAT CAN BE APPROACHED AND FLOWN THROUGH. NOT JUST HORIZON EFFECT.

100 x 100 NAUTICAL MILE GAMING AREA
POSSIBLY TERRAIN FEATURES COULD BE PART OF COMBAT STRATEGY (MOUNTAINS, ETC.)

Table 23. Air-To-Ground Mission Task

WORD DESCRIPTION:

THIS TASK INVOLVES HIGH PERFORMANCE, LOW ALTITUDE MANEUVERS THAT ENTAIL INTERACTION WITH THE GROUND. DELIVERY OF VARIOUS ORDNANCE (GUNS, BOMBS, MISSILES) AGAINST ONE OR MORE FIXED OR MOVING TARGETS IS THE PRINCIPAL OBJECTIVE. DETECTION AND IDENTIFICATION OF TARGET OBJECTS (AND FRIENDLIES), AT DISTANCE AND WITHIN THE NORMAL FIELD-OF-VIEW OF A TYPICAL CLOSE SUPPORT AIRCRAFT IS REQUIRED. MANEUVERS WOULD INCLUDE HIGH SPEED, HIGH OR LOW DIVE ANGLE APPROACH, AND COULD INCLUDE "ROLL IN" MANEUVERS TYPICAL OF ORDNANCE WORK. MOST SUCH MANEUVERS WOULD OCCUR AT LOW ALTITUDE, AND COULD INVOLVE HIGH RATES. THE POSSIBILITY OF THE PRESENCE OF A WINGMAN EXISTS, WHERE HE MUST BE VISIBLE THROUGHOUT THE USUAL VIEWING VOLUME. DEPICTION OF FRIENDLY AND/OR ENEMY ORDNANCE USAGE AND IMPACT REGISTRATION IS NECESSARY. THE TERRAIN GEOGRAPHICAL ENVELOPE FOR SUCH MISSIONS IS GENERALLY NOT LARGE, HOWEVER, THE TERRAIN IN THE ENGAGEMENT AREA COULD CONSIST OF ANY OF MANY VARIED TOPOGRAPHICAL COMPOSITIONS (MOUNTAINS, PLAIN, CITY, ETC.). THE TARGET OBJECT(S) AND "FRIENDLIES" COULD ALSO BE OF MANY TYPES. ENVIRONMENTAL CONDITIONS COULD INCLUDE TIME OF DAY AND DEFINABLE, LIMITED OR RESTRICTED VISIBILITY.

VELOCITY ≤.9 MACH
ROLL (200°/S), PITCH (120°/S), YAW (120°/S), ORIENTATION
UNLIMITED θ ±90°
WITHOUT DETECTABLE BLUR, PHASE LAG OR STEPPING

5,000 FT AND BELOW (TO 50 FT)
NEED FOR SUFFICIENT VELOCITY, ATTITUDE, AND
ALTITUDE CUES NEAR GROUND
ADEQUATE DETAIL OF TERRAIN

IMMEDIATE IMPACT REGISTRATION OF ORDNANCE NECESSARY
ABILITY TO DEPICT BOTH INCOMING (TRACERS, SAMS ETC.) AND
OUTGOING (MISSILE, TRACER, BOMB, ETC.) ORDNANCE, INCLUDING
IMPACT REGISTRATION IS NECESSARY. INCOMING SAM MUST SEE TRIAL.
ABILITY TO PERFORM ACCURATE DELIVERY FOR
PURPOSES OF SCORING ANALYSIS. THIS IMPLIES
ACCURATE POSITIONING OF TARGETS IN SPACE
AND TIME
±10 FT IN POSITION WHICHEVER IS
±2 MILLIRADIANS MORE STRINGENT

DEFINABLE TARGETS (VARIABLE-USER CONSTRUCTED)
UP TO 3 SIMULTANEOUS INDEPENDENTLY MOVING TARGETS
ON GROUND AND ONE AIRBORNE WINGMAN AND HIS ARMAMENT.
DETAIL SUFFICIENT FOR DIFFERENTIATION AND
RECOGNITION

DETECT AT 25,000 FT
RECOGNIZE AT 5,200 FT
IDENTIFY AT 3,600 FT
IMPLIES DETAIL OF OBJECTS

±90° SIDE MINIMUM
+30° VERTICAL
-30° VERTICAL

-60° DIVE, OR -5° STRAFE
VELOCITY ≤.9 MACH

REINFORCE ±90° HORIZONTAL VIEWING REQUIREMENT AND -30° VERTICAL

SIDE VISION REQUIREMENT REINFORCED
PROXIMATE, DETAILED AIRCRAFT REQUIRED
DISTANT INDEPENDENT OPERATION

SEE ABOVE

100 x 100 NAUTICAL MILE AREA

ABILITY TO TAILOR TERRAIN TO MISSION NEEDS BOTH
IN TERMS OVERALL TERRAIN FEATURES (MOUNTAINS,
VALLEYS, ETC.) AND CULTURAL AND TARGET DETAIL
ARCHITECTURE OF TERRAIN MAY BE PART OF MISSION -
FLIGHT THROUGH MOUNTAINS

≈80% DAY, 15% DUSK/DAWN, 5% NIGHT WITH LIGHTS, HORIZON, ETC.
SUN SHADING, SUN IMAGE

OVERCLOUD FLIGHT WITH PENETRATION TO DELIVERY
PATCHY CLOUD
DEFINABLE LIMITED VISIBILITY (SLANT VISUAL RANGE - SVR)
HAZE

Table 24. Terrain Following Mission Task

WORD DESCRIPTION:

THIS TASK INVOLVES LOW AND VERY LOW ALTITUDE, RELATIVELY HIGH PERFORMANCE FLIGHT OVER EXTENDED DISTANCES. CRITICAL AND PRECISE EXECUTION OF FLIGHT MANEUVERS IS NECESSARY DUE TO THE PROXIMITY OF THE GROUND. VARYING TERRAIN REQUIREMENTS WOULD EXIST DEPENDING ON MISSION SPECIFICS (MOUNTAIN, PLAIN, RIVER, CITIES, ETC.), WITH SPECIFIC LANDMARKS PERHAPS BEING REQUIRED. ENVIRONMENTAL CONDITIONS WOULD INCLUDE TIME OF DAY, AND DEFINABLE, LIMITED OR RESTRICTED VISIBILITY.

LOW AND VERY LOW ALTITUDE	50 FT TO 1000 FT ABOVE GROUND FOLLOWING LOCAL SHAPE OF TERRAIN NEED FOR PROPER VELOCITY, ATTITUDE AND ALTITUDE CUES NEED FOR GOOD TERRAIN DETAIL
HIGH PERFORMANCE	VELOCITY ≤ .9 MACH ROLL (200°/S), PITCH (150°/S), YAW (150°/S) NO BLUR, PHASE LAG OR STEPPING IN SCENE
EXTENDED DISTANCES	① FLIGHT EITHER ALONG PREDETERMINED COURSE SPECIFIED CORRIDOR 30 x 500 NAUTICAL MILES WITH EXPECTED (PREDETERMINED) TERRAIN INCLUDING LANDMARKS. NOT NECESSARILY STRAIGHT LINE PATH. ② NON-SPECIFIC FLIGHT OVER EXPECTED TERRAIN ③ NON-SPECIFIC FLIGHT OVER GENERALIZED TERRAIN ② AND ③ WOULD REQUIRE 500 x 500 NAUTICAL MILE AREA
CRITICAL AND PRECISE EXECUTION OF FLIGHT MANEUVERS	SEE ABOVE - NEED FOR VELO, ATT. AND ALT. CUES RANGE CLOSING CUES "PROXIMITY TO" CUES FIELD OF VIEW ±90° SIDE, ±30° VERTICAL
VARYING TERRAIN REQUIREMENTS	ABILITY TO ALTER/DEFINE TERRAIN TO SUIT MISSION NEED ABILITY TO MODEL SPECIFIC AREA ACTUALLY EXISTING, E.G., GERMANY, EDWARDS AFB
WITH SPECIFIC LANDMARKS	ABILITY TO MODEL SPECIFIC TERRAIN AND/OR IMPLANT SPECIFIC LANDMARKS QUALITY OF TERRAIN MUST ALLOW RECOGNITION OF SUCH FEATURES
TIME OF DAY	DAY, DUSK/DAWN, NIGHT - WITH HORIZON LIGHTING SUN SHADING
DEFINABLE, LIMITED OR RESTRICTED VISIBILITY	DEFINABLE LIMITED VISIBILITY (SLANT VISUAL RANGE - SVR) HAZE

Table 25. Cruise Mission Task

WORD DESCRIPTION:

THIS TASK INVOLVES EXTENDED FLIGHT OVER TERRAIN AT MEDIUM TO HIGH ALTITUDE. NORMALLY, HIGH PERFORMANCE MANEUVERS ARE NOT PART OF THE MISSION PROFILE (THOUGH HIGH SPEED MAY BE INVOLVED. IT IS NOT UNUSUAL TO TRAVERSE EXTENSIVE TERRAIN RANGES ON THIS TYPE OF MISSION, ESPECIALLY IF RELATIVELY HIGH CRUISE SPEEDS ARE INVOLVED. USE OF TERRAIN FEATURES, BY WAY OF SPECIFIC LANDMARKS, MAY BE PART OF THE CRUISE MISSION, HOWEVER, CRUISE MISSIONS ARE USUALLY CONCERNED WITH SOME AIRCRAFT RELATED OBJECTIVE (NAVIGATION, CREW TRAINING, ETC.) AND NOT OUT THE WINDOW DETAILS. ENVIRONMENTAL CONDITIONS WOULD INCLUDE TIME OF DAY AND DEFINABLE LIMITED OR RESTRICTED VISIBILITY AS WELL AS CLOUD PHENOMENON (FLY THROUGH).

EXTENDED FLIGHT OVER TERRAIN	MAY BE FLIGHT WITH DEFINED CORRIDOR OR ALONG PRESCRIBED, PREDEFINED PATH MAY BE "FREE FLIGHT" - UNSPECIFIED COURSE
MEDIUM TO HIGH ALTITUDE	1,000 TO 60,000 FT
HIGH PERFORMANCE MANEUVERS ARE NOT PART OF THE MISSION	.5 MACH ≤ VELOCITY ≤ 3 MACH ROLL (100°/S), PITCH (50°/S), YAW (50°/S)
EXTENSIVE TERRAIN RANGES	CORRIDOR 500 x 30 NM* GAMING AREA OF 500 x 500 NM* (FOR UNRESTRICTED MANEUVERING)
TERRAIN FEATURES	CONFIGURABLE TERRAIN SUFFICIENT CUES FOR USE OF TERRAIN FEATURES IN MISSION IF DESIRED (E.G., NEARNESS TO/HEIGHT ABOVE MOUNTAIN, RANGE TO LANDMARK)
SPECIFIC LANDMARKS	ABILITY TO CREATE AND PLACE SPECIFIC LANDMARKS RECOGNIZABLE - SUFFICIENT DETAIL
TIME OF DAY	DAY, DUSK/DAWN, NIGHT SUN ANGLE
LIMITED OR RESTRICTED VISIBILITY	ABOVE CLOUD HAZE PATCHY CLOUD DEFINABLE LIMITED VISIBILITY
CLOUD PHENOMENON	REALISTIC CLOUD WHICH CAN BE APPROACHED AND FLOWN THROUGH

*NM - NAUTICAL MILES

Table 26. Takeoff and Landing Mission Task

WORD DESCRIPTION:

THIS TASK INVOLVES ACCURATE APPROACH, TOUCHDOWN, TAXI, TAKEOFF, AND DEPARTURE MANEUVERS OF AN AIRCRAFT RELATIVE TO AN AIRFIELD/RUNWAY COMPLEX WHICH MAY INCLUDE A NEED FOR THE AIRCRAFT TO COME TO A FULL STOP. GO AROUND CAPABILITY IS ALSO A NECESSARY MISSION TASK REQUIREMENT. MANEUVERS INVOLVED WILL GENERALLY BE LOW PERFORMANCE AND LOW SPEED IN NATURE BUT WILL REQUIRE CRITICAL AND PRECISE EXECUTION. THE GEOGRAPHICAL AREA WILL CONSIST OF THE APPROACH AND DEPARTURE CORRIDORS TO THE RUNWAYS (VARIOUS HEADINGS) AND ADEQUATE LATERAL AREA TO PERFORM THE GO AROUND MANEUVERS. ALTITUDES WILL BE RELATIVELY LOW, WITH GLIDESLOPE AND APPROACH DISTANCES DETERMINING MAXIMUM LATITUDE NEEDS. THE AIRFIELD COMPLEX WILL TYPICALLY CONSIST OF SEVERAL RUNWAYS AT VARIOUS HEADINGS. TAXIWAYS, AIRFIELD BUILDINGS, ETC., MUST BE PRESENT. RUNWAY LIGHTING MUST BE COMPLETE AND CONTROLLABLE, AND MUST INCLUDE STROBE, APPROACH, REIL, RUNWAY, VASI, AND TAXIWAY LIGHTS. DIFFERING RUNWAY, AIRFIELD COMPLEX, AND SURROUNDING TERRITORIES CONFIGURATIONS MIGHT BE NEEDED FOR EACH MISSION. ENVIRONMENTAL CONDITIONS WOULD INCLUDE TIME OF DAY, AND WELL-DEFINED, CONTROLLABLE LIMITED VISIBILITY.

CONVENTIONAL 3°-4° GLIDESLOPE AND STOL 6°-8°
  GLIDESLOPE APPROACHES.
VARIOUS AIRCRAFT COULD BE INVOLVED
  F-16, A-10, B52, STOL, ETC.
ON GROUND TAXI - EYE HEIGHT AS LOW AS 9 FT
BOTH TAKEOFF AND LANDING IMPLY THAT AIRFIELD
  COMPLEX IS "CENTRALLY LOCATED"

ABILITY TO COME TO FULL STOP AT GROUND HEIGHT

ALSO TURN INTO FINAL APPROACH
LOCATING AIRFIELD
GO AROUND, TURN IN, AND AIRFIELD LOCATION
  REQUIRE SIDE VISION CAPABILITY ±90°

VELOCITY LESS THAN 200 KNOT
ROLL (100°/S), PITCH (50°/S), YAW (50°/S)

POSITION IN THREE SPACE RELATIVE TO RUNWAY MUST
  BE ACCURATE
ALL NECESSARY CUES MUST BE PRESENT FOR VELOCITY
  ATTITUDE AND ALTITUDE
RUNWAY MARKINGS, RUNWAY SKID MARKS, ETC.
REINFORCES REQUIREMENT FOR ±90° HORIZONTAL
  VISION (PERIPHERAL CUES)

A CORRIDOR MUST BE 30 NAUTICAL MILES IN LENGTH -
  EITHER APPROACH OR TAKEOFF
LATERAL DISTANCE IS ±15 NAUTICAL MILES
ABOVE IS REQUIRED FOR EACH RUNWAY

ALTITUDE 10,000 FT TO GROUND LEVEL FOR LONG APPROACH
FINAL APPROACH 5,000 FT TO GROUND

RUNWAYS OF VARYING HEADING AND OF VARYING LENGTH
  (STOL FOR EXAMPLE) EACH WITH APPROACH CORRIDOR

LIGHTING INTENSITY MUST BE CONTROLLABLE AND
  CORRELATE WITH REAL WORLD
LIGHTING MUST BE CONFIGURABLE (SEE BELOW)
LIGHTING MUST BE DIRECTIONAL (AS NORMALLY)

AIRFIELD AND TERRAIN SURROUNDING MUST BE TAILORABLE
  TO SATISFY MISSION
    A) DIFFERENT RUNWAY HEADINGS INTERRELATIONSHIPS
    B) DEFINED TERRAIN/AIRFIELD CONFIGURATIONS
       WHICH MAY INCLUDE SPECIFIC LANDMARKS, ETC.
    C) COMPLEX ITSELF MUST TAILORABLE

SUN SHADING
DAY, DUSK/DAWN, NIGHT (CITY, AIRFIELD LIGHTING)

PENETRATION
ABOVE CLOUD
HAZE
PATCHY CLOUD
DEFINABLE LIMITED VISIBILITY (CONTROLLABLE)

Table 27. Aerial Refueling Mission Task

WORD DESCRIPTION:

THIS TASK INVOLVES LOW AND MEDIUM PERFORMANCE MANEUVERS RELATIVE TO THE TANKER AIRCRAFT. PRECISE AND ACCURATE POSITIONING OF THE SUBJECT AIRCRAFT RELATIVE TO THE TANKER (WHICH MAY BE UNDERGOING INDEPENDENT RELATIVE MOTION) IS REQUIRED. THIS MISSION INHERENTLY INVOLVES INTERACTION WITH THE TANKER AIRCRAFT'S BOOM, WHICH ITSELF WILL BE MOVING. VARYING TANKER AIRCRAFT MAY BE NECESSARY. THE MANEUVER COULD INCLUDE THE ACQUISITION PHASE WHERE THE TANKER AIRCRAFT IS SOUGHT OUT AND APPROACHED. THE MISSION REQUIRES BOTH A GOOD LOOK-UP CAPABILITY (TANKER ACQUISITION), AND VIEW (SIGHTING OF BOOM). ENVIRONMENTAL CONDITIONS COULD INCLUDE TIME OF DAY. THE GEOGRAPHICAL BOUNDARIES FOR SUCH A MISSION AREA FUNCTION OF MISSION DURATION (SUCCESS OF "CONNECT" AND TIME TRANSFER), WITH DETAILED TERRAIN INFORMATION USUALLY BEING OF SECONDARY IMPORTANCE.

*NM = NAUTICAL MILE

VELOCITY ≤.75 MACH
ALTITUDE 10,000 - 30,000 FT
ROLL (100°/S), PITCH (50°/S), YAW (50°/S)

NECESSARY CUES FOR PROXIMATE INTERACTION
ACCURATE DEPICTION OF TANKER AND BOOM IN THREE
DIMENSIONAL SPACE AND TIME
NO STEPPING OF TANKER/BOOM

TANKER MAY BE PERFORMING OWN MANEUVERS (MOVING OBJECT)
(EITHER CANNED OR UNDER PILOT CONTROL)
TANKER CAN BE SEEN FROM ALL ANGLES

BOOM DYNAMICS POSSIBLE (MOVING OBJECT)
INTERACTION WITH BOOM UP TO AND INCLUDING
COUPLING MUST BE POSSIBLE
PROXIMITY OF INTERACTION WITH BOOM REQUIRES
GOOD SPATIAL CUES

ABILITY TO CREATE AND/OR TAILOR AIRCRAFT TO
MEET MISSION NEEDS. KC-135, KC-10, ETC.
EACH WITH SUFFICIENT DETAIL FOR PROPER
RECOGNITION AND IDENTIFICATION

VIEWING VOLUME (SEE BELOW)
RESOLUTION
- DETECTION 25000 FT
- RECOGNITION 5200 FT
- IDENTIFICATION 3600 FT
RELATES TO TANKER ABILITY TO PERFORM INDEPENDENT
MANEUVERS

+90° LOOK UP
-30° LOOK DOWN

±60° SIDE

DAY, DAWN/DUSK, NIGHT
SUN ANGLE
AIRCRAFT LIGHTING

200 x 50 NM* CORRIDOR, 200 x 200 NM* IF HEADING UNSPECIFIED

ADEQUATE TERRAIN CUES TO ALTITUDE, VELOCITY
HORIZON OR FLIGHT ABOVE CLOUD COVER

Table 28. Station Keeping Mission Task

FORWARD AIR CONTROLLER, DROPPING OF PARATROOPER

WORD DESCRIPTION:

THE TASK INVOLVES LOW PERFORMANCE, LOW AND MEDIUM ALTITUDE FLIGHT OVER A RELATIVELY SMALL GEOGRAPHICAL AREA. PURPOSES FOR SUCH MISSIONS INCLUDE CARGO/TROOP DROPS, OBSERVATION, NAVIGATION SUPPORT, MAIN RECOVERY, ETC. ATTENTION FOR SUCH MISSIONS GENERALLY CENTERS AROUND SOME PARTICULAR GEOGRAPHICAL FEATURE OR LOCATION, WHICH REQUIRES A WIDE FIELD-OF-VIEW TO MAINTAIN VISUAL CONTACT. THE NATURE OF THESE INTEREST AREAS COULD VARY FROM MISSION TO MISSION AS WELL AS THE SURROUNDING ENVIRONS. ENVIRONMENTAL CONDITIONS COULD INCLUDE TIME OF DAY AND DEFINABLE LIMITED OR RESTRICTED VISIBILITY.

VELOCITY ≤.5 MACH
ROLL (200°/S), PITCH (50°/S), YAW (50°/S)

ALTITUDE LESS THAN 10,000 FT

30 x 30 NAUTICAL MILES

ABILITY TO CONFIGURE TERRAIN TO SUPPLY GENERAL AND SPECIFIC (LANDMARK) MISSION REQUIREMENTS

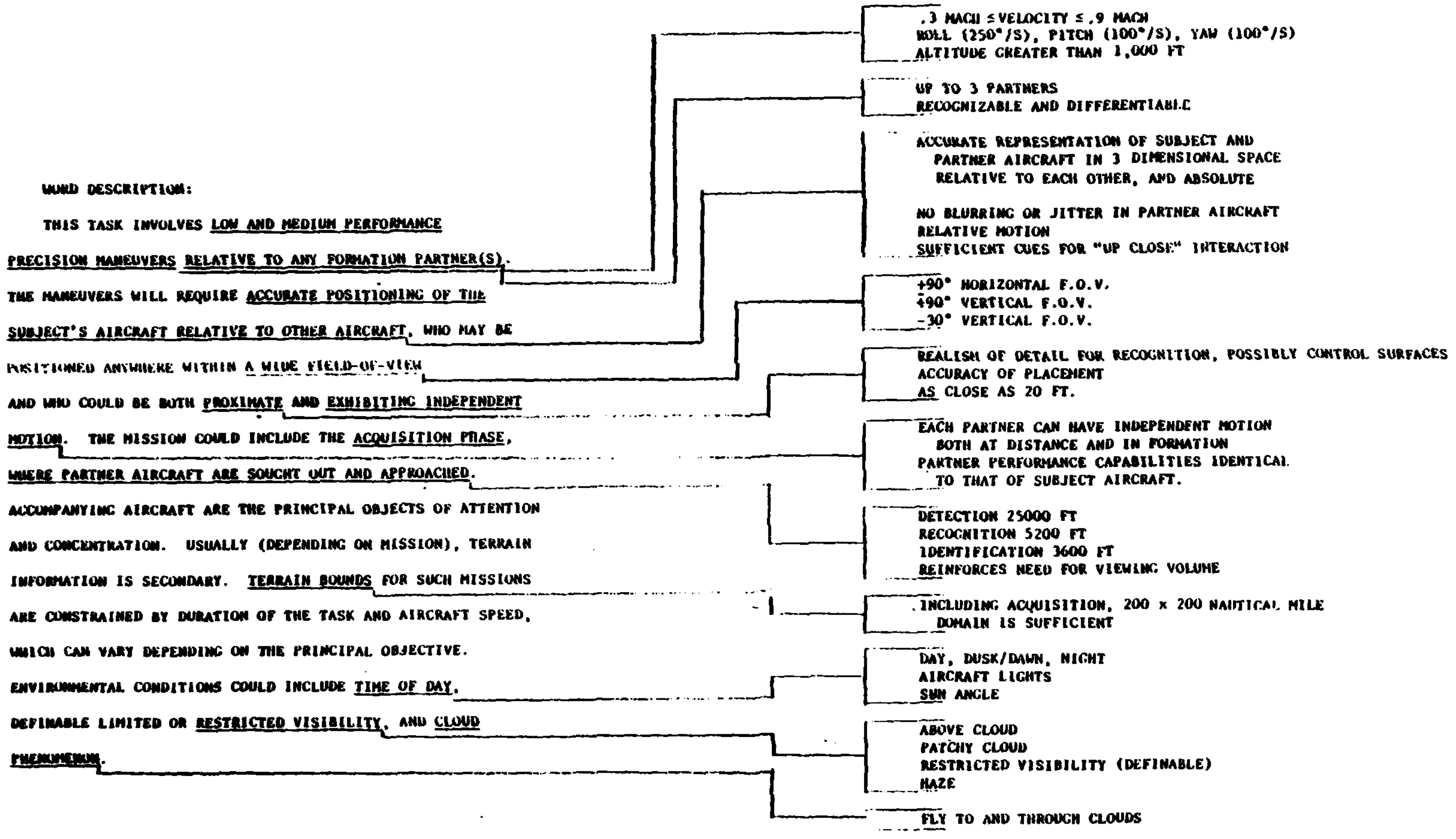
±90° HORIZONTAL (MINIMUM)
±30° VERTICAL

TAILORABLE, FLEXIBLE DESIGN CAPABILITY TO ALTER OR TOTALLY RECONSTRUCT SCENE IN GENERAL OR REGARDING SPECIFIC FEATURES TO SUIT MISSION

DAY, DUSK/DAWN, NIGHT
GROUND LIGHTING REFLECTING TIME OF DAY
SUN ANGLE

HAZE
DEFINABLE, CONTROLLABLE LIMITED VISIBILITY
OVER CLOUD FLIGHT

Table 29. Formation Flying Mission Task



WORD DESCRIPTION:

THIS TASK INVOLVES LOW AND MEDIUM PERFORMANCE PRECISION MANEUVERS RELATIVE TO ANY FORMATION PARTNER(S). THE MANEUVERS WILL REQUIRE ACCURATE POSITIONING OF THE SUBJECT'S AIRCRAFT RELATIVE TO OTHER AIRCRAFT, WHO MAY BE POSITIONED ANYWHERE WITHIN A WIDE FIELD-OF-VIEW AND WHO COULD BE BOTH PROXIMATE AND EXHIBITING INDEPENDENT MOTION. THE MISSION COULD INCLUDE THE ACQUISITION PHASE, WHERE PARTNER AIRCRAFT ARE SOUGHT OUT AND APPROACHED. ACCOMPANYING AIRCRAFT ARE THE PRINCIPAL OBJECTS OF ATTENTION AND CONCENTRATION. USUALLY (DEPENDING ON MISSION), TERRAIN INFORMATION IS SECONDARY. TERRAIN BOUNDS FOR SUCH MISSIONS ARE CONSTRAINED BY DURATION OF THE TASK AND AIRCRAFT SPEED, WHICH CAN VARY DEPENDING ON THE PRINCIPAL OBJECTIVE. ENVIRONMENTAL CONDITIONS COULD INCLUDE TIME OF DAY, DEFINABLE LIMITED OR RESTRICTED VISIBILITY, AND CLOUD PHENOMENON.

.3 MACH ≤ VELOCITY ≤ .9 MACH
ROLL (250°/S), PITCH (100°/S), YAW (100°/S)
ALTITUDE GREATER THAN 1,000 FT

UP TO 3 PARTNERS
RECOGNIZABLE AND DIFFERENTIABLE

ACCURATE REPRESENTATION OF SUBJECT AND PARTNER AIRCRAFT IN 3 DIMENSIONAL SPACE RELATIVE TO EACH OTHER, AND ABSOLUTE

NO BLURRING OR JITTER IN PARTNER AIRCRAFT RELATIVE MOTION
SUFFICIENT CUES FOR "UP CLOSE" INTERACTION

+90° HORIZONTAL F.O.V.
+90° VERTICAL F.O.V.
-30° VERTICAL F.O.V.

REALISM OF DETAIL FOR RECOGNITION, POSSIBLY CONTROL SURFACES
ACCURACY OF PLACEMENT
AS CLOSE AS 20 FT.

EACH PARTNER CAN HAVE INDEPENDENT MOTION BOTH AT DISTANCE AND IN FORMATION
PARTNER PERFORMANCE CAPABILITIES IDENTICAL TO THAT OF SUBJECT AIRCRAFT.

DETECTION 25000 FT
RECOGNITION 5200 FT
IDENTIFICATION 3600 FT
REINFORCES NEED FOR VIEWING VOLUME

INCLUDING ACQUISITION, 200 x 200 NAUTICAL MILE DOMAIN IS SUFFICIENT

DAY, DUSK/DAWN, NIGHT
AIRCRAFT LIGHTS
SUN ANGLE

ABOVE CLOUD
PATCHY CLOUD
RESTRICTED VISIBILITY (DEFINABLE)
HAZE

FLY TO AND THROUGH CLOUDS

Table 30. Sensor Related Studies Mission Task

WORD DESCRIPTION:

THIS TASK INVOLVES THE USE OF SEVERAL SENSOR SYSTEMS IN "SAMPLING" THE OUTSIDE ENVIRONMENT. THESE SYSTEMS INCLUDE FORWARD LOOKING INFRARED (FLIR), LOW LIGHT LEVEL T.V. (LLLTV), AND DOWNWARD LOOKING AND FORWARD LOOKING RADARS. THESE SYSTEMS ARE DISPLAY ORIENTED, CONVERTING THE OUTSIDE ENVIRONMENT INTO AN ELECTRONIC IMAGE. THESE MISSIONS OFTEN ARE COUPLED WITH "OUT-THE-WINDOW" OPERATION IN AN AUGMENTING ROLE. APPLICATION FOR THE SENSOR DATA VARIES ACCORDING TO TYPE, AND INCLUDES, FOR EXAMPLE, TOPOGRAPHICAL AND CULTURAL INFORMATION GATHERING, AND THREAT IDENTIFICATION WITHIN THE OPERATIONAL CAPABILITIES OF EACH PARTICULAR DEVICE. IT SHOULD BE NOTED THAT THESE TYPES OF TECHNOLOGY, (AND PARTICULAR SYSTEMS WITHIN EACH TYPE) WILL HAVE VARYING PERFORMANCE CAPABILITIES AND CONSTRAINTS IN TERMS OF RESOLUTION, RANGE, AND DISCRIMINATION ABILITY.

DISPLAY ORIENTED	FOR FORWARD LOOKING, FIELD OF VIEW WOULD BE NARROW TO MEDIUM DEPENDING ON SENSOR (5° TO 60°) DOWNWARD LOOKING (RADAR) IS NORMALLY 360° CIRCULAR FORMAT ACTUAL DISPLAYS ARE BOTH CALLIGRAPHIC AND RASTER FORMAT DEPENDING ON SENSOR SIMULATED SENSOR DISPLAY NEED ONLY RESEMBLE ACTUAL DISPLAY
CONVERTING THE OUTSIDE ENVIRONMENT INTO AN ELECTRONIC IMAGE	IMAGE MUST STRONGLY RESEMBLE ACTUAL SENSOR IMAGE IN TERMS OF IMAGE PRODUCED, BOTH QUALITATIVELY AND QUANTITATIVELY "REAL TIME" PROCESSING AND PRESENTATION
MISSIONS OFTEN ARE COUPLED WITH "OUT-THE-WINDOW" OPERATION	SENSOR DISPLAY IMAGE MUST CORRESPOND WITH "OUT THE WINDOW" VIEW IN 3 DIMENSIONAL SPACE AND TIME
TOPOGRAPHICAL AND CULTURAL INFORMATION GATHERING	TERRAIN MUST BE ABLE TO BE MODELED BOTH IN GENERAL AND WITH REGARD TO SPECIFIC FEATURES (LANDMARKS) ACTUAL (REAL WORLD) TOPOGRAPHY MAY BE INVOLVED (MUST BE ABLE TO MODEL PARTICULAR DEFINED AREA)
THREAT IDENTIFICATION	MOVING OBJECTS (UP TO 5) DESIGNATION/IDENTIFICATION CAPABILITY ON PAR WITH ACTUAL DEVICE
VARYING PERFORMANCE CAPABILITIES AND CONSTRAINTS	THE SENSOR ITSELF IS NOT AS IMPORTANT AS HOW IT IS USED IN PERFORMING A MISSION TASK PARTICULAR SENSOR PACKAGES ARE NOT GOING TO BE MODELED, BUT SENSOR TYPES MUST BE SIMULATED WITHIN PERFORMANCE WHICH CAN ADEQUATELY APPROXIMATE THE REAL WORLD CAPABILITIES FOR SATISFYING MISSION

Table 31. Other Mission Tasks

WORD DESCRIPTION:

OTHER MISSION TASKS WHICH MIGHT BE PERFORMED WOULD PROBABLY NOT BE HIGHLY VISUALLY ORIENTED (IF THEY WERE, THEY WOULD BE COVERED BY THE PRECEDING DESCRIPTIONS). SUCH MISSIONS MIGHT INCLUDE PILOT WORKLOAD STUDIES, NAVIGATION STUDIES, DISPLAY EVALUATIONS, AND OTHER CREW OF AIRCRAFT SPECIFIC ANALYSES. THE IMPACT OF THEIR VISUAL REQUIREMENTS WOULD BE MINIMAL, AND, IN ANY CASE, ADEQUATELY SATISFIED BY THE PERFORMANCE PROPERTIES PROVIDED IN SATISTYING THE FORMERLY SPECIFIED MISSION TASK NEEDS.

Table 32. Percentage Utilization by Mission Task and Simulator

Simulator		Mission									
		Air to Air	Air to Ground	Terrain Following	Cruise	Takeoff and Landing	Refueling	Station Keeping	Formation Flying	Sensor Simulation	Other
Multicrew	As presently configured	╳	╳	2%	35%	25%	3%	20%	╳	10%	5%
	As this generic aircraft type should address	╳	╳	10%	30%	22%	3%	15%	╳	15%	5%
Fighter/ Bomber	As presently configured	15%	25%	5%	15%	12%	3%	10%	0%	10%	5%
	As this generic aircraft type should address	20%	25%	10%	10%	5%	3%	4%	3%	15%	5%
Lamars	As presently configured	50%	15%	0%	15%	5%	0%	0%	0%	0%	15%
	As this generic aircraft type should address	30%	25%	5%	5%	5%	3%	3%	4%	15%	5%
Total Systems Integration Simulator (TSIS)		37%	20%	5%	5%	5%	3%	2%	3%	15%	5%

*Projected

Table 33. Summation of Mission Tasks by Percentage*
(For All 4 Simulators in Combination)

1.	Air-to-Air	-	21.75%
2.	Air-to-Ground	-	17.5 %
3.	Terrain Following	-	7.5 %
4.	Cruise	-	12.5 %
5.	Takeoff/Landing	-	9.25%
6.	Refueling	-	3.0 %
7.	Station Keeping	-	6.0 %
8.	Formation Flying	-	2.5 %
9.	Sensor	-	15.0 %
10.	Other	-	5.0 %
		TOTAL	100.0 %

* A complete mission could be a composite of one or more of the individual mission tasks. Missions could be combined either sequentially or in parallel (e.g. Air-to-Air [A/A] and Sensor). Caution must be exercised in utilizing this table.

Table 34. Mission Task Requirements

	A/A	A/G	TERRAIN FOLLOWING	CRUISE	TAKEOFF & LANDING	AERIAL REFUELING	STATION KEEPING	FORMATION FLYING	SENSOR
Velocity (MACH)	≤ .9	≤ .9	≤ .9	.5 to 3	< 200 kts	< .75	< .5	.3 to .9	
ROLL (°/SEC)	300	200	200	100	100	100	200	250	
PITCH (°/SEC)	150	120	150	50	50	50	50	100	
YAW (°/SEC)	150	120	150	50	50	50	50	100	
CLOSURE (MACH)	≤ 2	--	--	--	--	--	--	--	
MAX. ALT. ABOVE TERRAIN (ft)	5,000	5,000	1,000	60,000	10,000	30,000	10,000		
MIN. ALT. ABOVE TERRAIN (ft)	50	50	50	1,000	9	10,000		1,000	
HORIZONTAL FOV (Degrees)	± 90	± 90	± 90		± 90	± 60	± 90	± 90	± 2.5 to ± 30
VERTICAL FOV (Degrees)	+ 90 - 30	± 30	± 30			+ 90 - 30	± 30	+ 90 - 30	360° cone axis normal to the earth
GAMING AREA Nautical Miles (NM)	100 x 100	100 x 100	500 x 500	500 x 500	--	200 x 200	30 x 30	200 x 200	
CORRIDOR (NM)	--	--	30 x 500	30 x 500	30 x 60	50 x 200			
MOVING MODELS	4 AC, x-missiles	1 AC, 3 targets, x-missiles				1 AC, 1 boom, 1 probe		3 AC	
Detection range (ft)	25,000	25,000				25,000		25,000	
Recognition (ft)	5,200	5,200				5,200		5,200	
Identification (ft)	3,600	3,600				3,600		3,600	

SECTION 10

CIG SYSTEM TYPES: A COMPARISON OF DAY/NIGHT CALLIGRAPHIC CIG SYSTEMS TO RASTER SCAN CIG SYSTEMS

According to Cohen (February, 1979), ". . . For night scenes, which are composed mainly of light points, and a limited number of surfaces with a small amount of information, calligraphic systems prove to be advantageous. However, for more information-rich scenes, such as day scenes, raster systems have better capabilities." Because most of the AFWAL/FIGD mission tasks are day oriented and require high scene content, calligraphic systems were not deemed applicable to this study.

Schumacker and Rougelot (1977) point out that calligraphic systems provide red and green including a yellow-white. These colors are well suited to night/dusk applications but do not represent daylight illumination levels or color realistically. Calligraphic displays are free of color fringing and convergence problems normally associated with raster systems. White brightness of beam penetration CRTs is a factor of three or four below that obtainable from full color raster CRTs. Increasing this brightness is not practical because of persistence characteristics which result in image smearing. Display drawing speed is the principal limiting factor in calligraphic systems. Although they display images as they are computed and thereby save significantly on system complexity and cost (one rack including the General Purpose (GP) computer versus ten typical for a daylight CIG system) their drawing time increases with scene complexity, thereby limiting scene content.

Raster scan CIG systems cannot provide the resolution possible with beam penetration calligraphic systems. "In all cases the resolution is substantially lower than that obtainable from penetration CRTs because of physical structures within the device, spot sizes, or the inability to support faster scan rates." Both the positional resolution and the size of the spot itself are better in the calligraphic CIG system. "Spot motion with no discernible discrete steps can be achieved. The spot size for typical scene lights can approach 1/2000 of a display width. This translates to less than 1.5 arc minutes in typical visual system use." Generally light points in a raster CIG system are spread out over several pixels so that discrete motion between pixels is not apparent. This technique improves the apparent motion smoothness. ". . . we would have to decrease the raster size by about a factor of four to match the performance of the calligraphic display" (Schumacker and Rougelot, 1977).

Certain scene anomalies common to raster scan CIG systems do not appear in calligraphic systems. These anomalies are those associated with spatial aliasing as well as the temporal aliasing associated with interlace effect and field tracking. Please see Section 17.2.1.

SECTION 11

CIG DATA BASES

11.1 MANUAL INTERACTIVE DATA BASE BUILDING

With the exception of the E&S, CT5 CIG system which utilizes foreground and background modes, thereby allowing modeling to be done at the same time as simulation is taking place, all current CIG systems utilize either the front end, general purpose CPU or a separate, dedicated system for CIG data base building. If the front end, general purpose CPU is utilized, the special purpose hardware of this CIG system remains idle.

The front end computer interfaces with an X-Y coordinate Data Tablet/Digitizer input. The operator enters the X-Y coordinates of the vertex points (on the object) being modeled. To do this the operator positions a stylus or cursor at each vertex one at a time. This process and the one which precedes it (documenting and drawing the model) is very time consuming.

It is not until the preliminary model's data has been created that the special purpose hardware is used to view the results.

At the NASA Engineering Laboratory, the E&S PICTURE SYSTEM, a stand-alone, dedicated system, is used for data base building. At VTRS, a camera station was originally intended to serve as an aid in manual interactive data base building. Its use was not highly successful, and they are going over to a MOVIE BYU system. At NTEC, Jack Booker has developed a high-level language for CIG data base creation. GE personnel at ASPT are currently developing a dedicated data base building system.

E&S considers a standard air field model, with terrain features using the maximum capacity of the system, to be nominally a four-person week effort. At ASPT, the average data base is considered to be a six-month effort for two people - minimum. Building a generic scene takes much less time than building a real-world scene in which cultural and natural objects must be replicated and placed at specific points. Each level-of-detail (LOD) must be developed individually. NASA considers four face boundaries per person-hour to be a reasonable figure when generating a data base. This time includes data gathering, digitizing and checkout. At NASA, the typical airport scene requires one to two months of uninterrupted effort or three to four months with interruptions. Link considers 6.25 edges per hour to be a reasonable figure for data base building.

The authors have heard figures ranging from 2¢ to $20 an edge for data base building under contract. It is difficult to pin the figure down. Data base costs for a research and development simulator can better be understood, however, if one considers the fact that at ASPT approximately 50 data bases have been created, and ASPT personnel consider the average data base to require one person-year of effort. Operator proficiency is a significant aspect of these requirements. The times stated are for experienced modelers who may have had as much as one to six months of training. They are individuals who must combine two normally divergent skills, that of an artist/draftsperson and that of a mathematician.

Current techniques for digitizing data are simply not appropriate to building large data bases. A terrain following example will illustrate the point:

(a) With a square gaming area bounded by 500 nautical miles sides, the total area would be 250,000 square nautical miles. Within this gaming area a 30 by 500 nautical mile terrain following corridor would encompass an area of 15,000 square nautical miles, leaving 235,000 square nautical miles where low-level detail could suffice.

(b) If we choose to concentrate our available edge capacity for an altitude of 200 feet or less, the horizon would appear at approximately 15 nautical miles slant range and nothing beyond that point need be depicted.

(c) A 180° FOV and a 15 nautical mile slant range would encompass approximately 350 square nautical miles. Dividing the usable system capacity by this area will give us the edge count per square mile for the high-detail corridor. Table 35 illustrates the futility of using current, partially automated data base building technology. Some form of automated or iterative process is required to fully utilize system capacity when building a large gaming area. This also holds true in an environment where new or numerous data bases are required.

Table 35. Futility of Manual Data Base Building

Total System Capacity	Usable System Capacity (80% of Total)	Edges/ Sq. NM	Total Edges in 15,000 Sq. Mi. Corridor	Total Edges Outside Corridor	Total Edges in Data Base	Person-Hours (5 Edg/ Hr)	Person-Years (1920 Hrs/Yr
8,000	6,400	18	270,000	235,000	505,000	101,000	52.6
30,000	24,000	69	1,035,000	235,000	1,270,000	254,000	132.3
100,000	80,000	229	3,435,000	235,000	3,670,000	734,000	382.3

If acceptable, some form of automated iterative data base building could be appropriate. This technique would allow for the modeling, in high detail, of a small area which could then be repeated over and over again.

Another approach would allow for the building of generic scenes automatically by specifying simple parameters. Using this technique, a city could be built by simply specifying its perimeter dimensions, street widths and lengths, as well as alley widths and lengths. The program would fill in the blanks with randomly generated buildings, having a height and density appropriate to a city of the size specified.

Yet another approach is the use of the Defense Mapping Agency Aerospace Center Digital Data Base. This data base is currently being converted to a CIG data base on the B-52 flight simulator. Future studies will enhance its applicability and transport ability. The major current weakness of this approach is its inability to depict recognizable cultural and terrain features.

When a CIG approach that does not use separation planes and does not restrict the utility of an automated data base conversion is utilized, it has been demonstrated that an area as large as 1/3 of the State of Washington can be digitized in one day (Cyrus, 1979).

11.2 AUTOMATED DATA BASE BUILDING

One look at the magnitude of the manual, interactive data base building task should be enough to convince anyone that there must be a better way. During the latter half of the 1970s, one of the better ways that has evolved is the use of the Defense Mapping Agency Aerospace Center Digital Data Base (DMAAC DDB). This data base, originally used for Digital Radar Land Mass Simulation (DRLMS), has been applied to CIG data base building to a limited extent. Future systems will have to utilize it extensively if gaming area sizes, system capacities and level-of-detail requirements continue to increase as they most certainly will. Any automated data base building technique should include automatic generation of low levels-of-detail from the most detailed scene. The advantages of the use of a single data base such as the DMAAC DDB is two-fold.

(a) It allows for automation of the data base building task.

(b) It eliminates the confusion and inaccuracies caused by the use of numerous sources of data to build current CIG data bases.

Hoog (1978) points out that CIG data bases are currently produced from four different sources of information:

(a) Airfield Civil Engineering Drawings

(b) Aerial Photographs

(c) Ground Photographs

(d) Large-scale, Local Area Maps.

If you combine these with the sources of data for Digital Radar Land Mass Simulation, the problem becomes apparent:

(a) DMAAC DDB

(b) Intelligence Data Locating Radar Threats

(c) Flight information publications (FLIPs) for locating navigation aids.

DMACC DDB consists of two files:

(a) Terrain Elevation

The terrain elevation file is a matrix of elevation values available at three different resolution levels, i.e., three arc-second spacing, one arc-second spacing, and half arc-second spacing. "This equates to approximately 300 feet, 100 feet, and 50 feet spacing, respectively, at the equator" (Hoog and Stengel, 1977). The three arc-second longitudinal spacing ". . . increases to six seconds at 50° latitude, nine seconds at 70°, twelve seconds at 75° and eighteen seconds at 80°, in an attempt to maintain an approximately square matrix. Data is stored in 1° x 1° squares" (Hoog, 1978).

(b) Planometry

"The planometry file describes the content of the earth's surface. This file contains two basic levels of information, i.e., resolution levels, compilation levels, etc., based on the size and separation of objects. The file describes objects as areal, linear, or point features, depending on their shape and size. Each feature is also described by its predominant surface material, height above terrain, its identification and characteristics depending on its type. . . . Level I data (the coarsest level) is provided over the entire area. Level II data (a higher resolution level) is provided only when identified as being required for higher level of detail by a user. This concept was adopted since Level II data is about 15 times as costly to produce as Level I (the factôr actually varies, depending on the specific area being produced, i.e., urban vs. rural)." (Hoog, 1978.)

Hoog points out the following reasons for choosing the DMAAC DDB:

(a) "The extensive geographic coverage."

(b) "A worldwide reference datum."

(c) "Expandable to include additional resolution levels."

(d) "Adaptable for use with other data sources for enhancement of localized areas."

(e) "Reduces the quantity of data sources required to model specified geographical areas."

The use of the DMAAC DDB may never be totally automated satisfactorily, although it represents a tremendous improvement over manual interactive data base building. Not only may manual intervention be required to filter the raw data, but augmentation or enhancement of the product of the automated conversion is required in order that specific natural and cultural artifacts may be accurately rendered, e.g., Niagara Falls, Mount Rushmore, the Golden Gate Bridge, New York City, etc. For the purpose of enhancement or augmentation, some form of automated generic object creation or manipulation is required. LINK, for example, is working on an automated cultural object generator, in which the operator specifies the width of the streets and the width of the alleys and the size of the city blocks and the maximum size of a building in each block. Alleys are differentiated from streets in that buildings facing alleys may protrude into them. Given the preceding information, the program will randomly place buildings of varying height, up to the maximum specified, within the city blocks, with street size of the width specified, and alleys of the width specified. This approach may work well where a generic cultural scene is appropriate. It will not work, however, where specific objects must be recognizable.

To speed up the process of generating recognizable objects, a library of primitives and models must be built and maintained. The manipulation of the primitives to change their shape and size and orientation, must be automated. The next section (11.3) describes one such approach.

11.3 AUTOMATED DATA BASE BUILDING CONCEPT

To allow for manual intervention and manipulation of data bases which have been automatically generated, a technique which provides a library of primitive shapes and models is required, as well as the ability to manipulate these primitive shapes and models in any manner desired. What is being proposed here does not yet exist but should be considered almost essential if extensive data base building is foreseen.

The following discussion specifies the type of data base design capabilities that would be required to allow the user to keep up with the ever-expanding edge count capacities. Table 36 shows the basic steps used when generating a visual data base. It covers the very basic primitive generation to the actual review and update of the final visual data base and is meant to augment the imperfect results of the use of the DMAAC DDB.

11.3.1 Build Primitives

The primitive will provide the basic building blocks for the construction of visual models. See Figure 20. These primitives are equivalent to the nuts and bolts that are present in aircraft, cars, trucks, etc. They will be used in the construction of the visual models by pushing, pulling, scaling up/down, truncating, adding to and combining to create the final finished model.

Primitives will be constructed in such a way that they will have universal use. This attribute will reduce the amount of primitives and will reduce the number that the modeler must be familiar with. This will not preclude the inclusion of all the essential primitives necessary for the construction of models that realistically resemble the modeled object. Care must be taken in the number of edges used to develop these primitives because of their common and multiple use in the construction of various models.

Once the primitive has been created, it must be labelled and cataloged to allow for easy access. This catalog should be multi-indexed to allow the modeler to search for a form by either its shape or name.

Table 36. CIG Data Base Creation Phases

Phase 1: Build Primitives (See Figure 20)

1. Analyze visuals to be modeled
2. Define the primitives that are the basic parts of many objects
3. Define shape (i.e., vectors from one apex to the next)
4. Attributes (basic color)
5. Identify (label, i.e., cube, pyramidate)
6. Store in catalog
7. List updated primitive catalog

Phase 2: Build Models (See Figure 21)

1. Analyze model
2. Break into identifiable primitives
3. Build rough model using primitives
4. Customize rough model to produce final model
5. Add attributes (color, movement, components)
6. Add priority view scheme
7. Store in catalog
8. List updated model

Phase 3: Formulate Environment (See Figure 22)

1. Analyze area to be monitored
2. Input DMAAC data for area
3. Define models to be used
4. Define background features
5. Apply background texture where required
6. Position models
7. Fashion to provide best scene

Phase 4: Compile Environment (See Figure 23)

1. Process updated environment through compiler
2. Review errors
3. Make any corrections required
4. Process corrected environment
5. Catalog and save final correct compiled version

Phase 5: Review and Update (See Figure 24)

1. Input geographical area to be viewed
2. Determine models to be viewed
3. Review models and background to determine their correctness
4. Make minor adjustments to scene for improved dynamic presentation
5. Review updates
6. Save in data base without recompiling

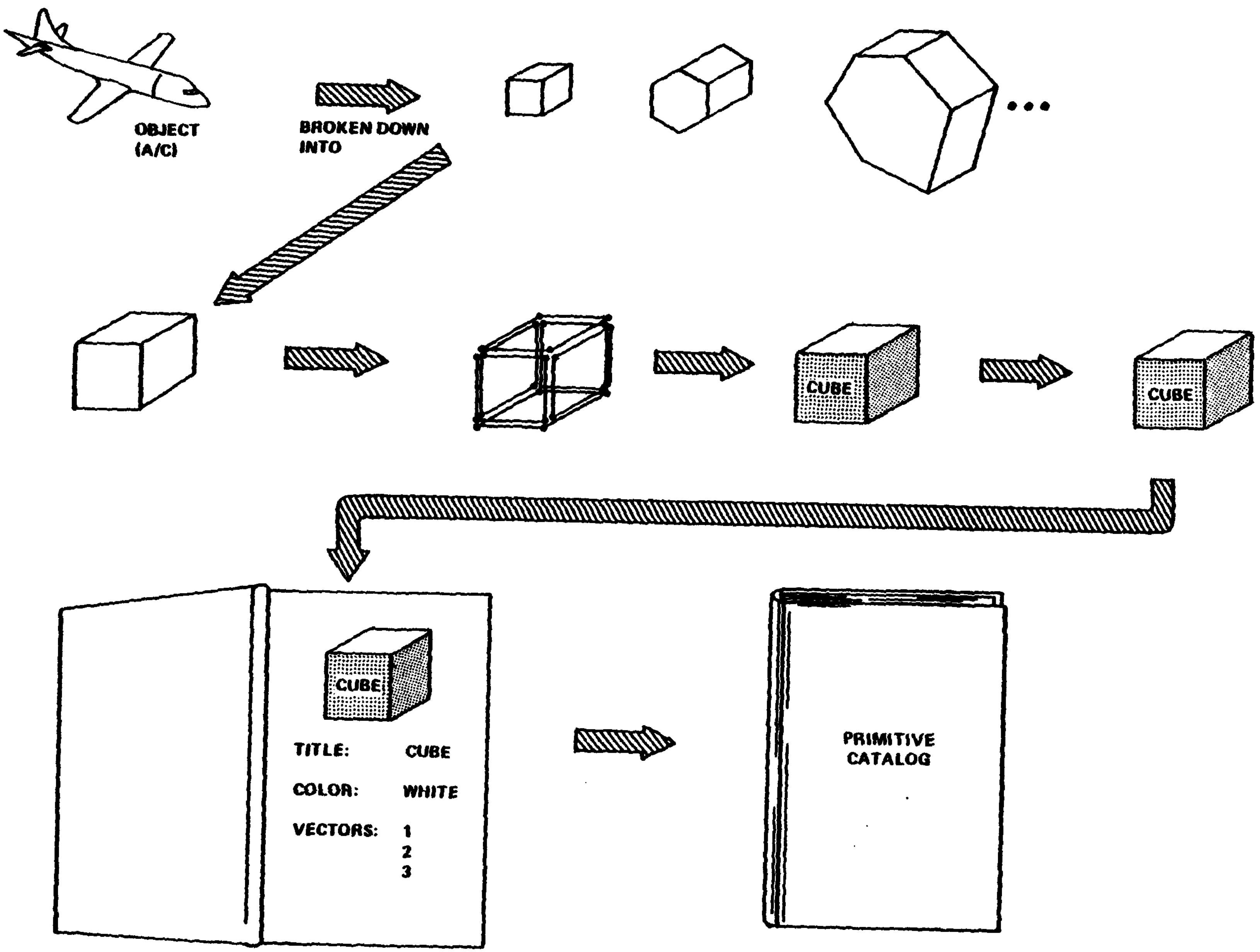


Figure 20. Phase 1: Build Primitives

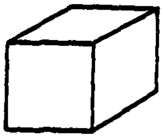
A primitive library must accept other data base primitives and reorganize them into the current systems configuration. A lot of time and effort is required in the analysis and development of the primitives and this feature will allow for the use of currently available primitives.

A hard copy catalog should be available to allow the model maker the ability to, in an off-line mode, evaluate which primitive he might want to use before he gets on the system. A user training syllabus catalog should be developed that would break various common models into the corresponding primitive structures. The models selected should use the greatest number of varied primitives. These models would be broken out in a fashion similar to a parts catalog with each primitive identified and a cross-reference to where it could be found.

The primitive library must be available in all phases of scene creation to allow the user to make use of these common forms for either model creation, environment construction or review and update.

The primitive must be able to be accessed by the number of edges to enable the user to determine the most appropriate primitive to use by edge efficiency criteria.

The following is a sample of how a primitive might be labelled:



Name: Box

Generic type: Cube

Edges: 12

Resembles: Box, ice cube, sugar cube,.....

Link next higher (edge count): (Generic type)

Detail primitive: 13 Hedron heptahedron

Link next lower (edge count): (Generic type)

Detail primitive: Pentahedron

11.3.2 Build Models

Models made up of primitives will be used to construct the total scene. Figure 21 depicts the information flow during the construction of a model. This will allow the user to create larger scenes using predefined objects. This will speed in the construction of the scene and allow the user to save time in using already constructed objects. This means that the person constructing the scene does not have to be an expert in the construction of a particular model.

Models will also be cataloged by many different keys to allow the user easy access to the information. This data will be stored in a hard copy catalog for use in preparing for the scene construction in an off-line mode.

11.3.3 Formulate Environment

Phases 1 and 2 are basic to almost all current CIG applications. The next 3 phases are usually unique for each application. The modeler in this case could or would be the end user. The following discussion will present the information flow followed in the final construction of a visual data base.

Phase 3, Figure 22 is the scene creation or formulate environment phase. The modeler draws information from maps, aerial photos, model photos, and personal experience. He now consults with the primitive catalog, model catalog, and textures to construct a CIG scene. The modeler will now introduce the information into the CIG data base manager who will use the input commands in conjunction with prior information (DMAAC DATA, PREVIOUS CIG DATA, and Current CIG data) to form a CIG data base source stream.

11.3.4 Compile Environment

The next phase (phase 4), Figure 23, is accomplished in a similar fashion to a compiler. It takes the visual source data and converts it into a binary format that can be used by the real-time image generator. It also validates source inputs and notifies the user of any input errors. Once all errors have been corrected, the new visual data is stored and ready for use by the real-time image generator.

11.3.5 Review and Update

The final phase is the review and updating of the CIG data base in real time. See Figure 24. This is a very important phase. It is used to do the final tuning of the visual scene. Because we have to deal with a non-realistic portrayal of the real world, some of the scenes and models just do not look correct when they interact with each other. During this phase it is important to be able to view, in real time, the scenes as they progress, make adjustments to the scene, and then review the corrected scene immediately. All modifications made during the review stage will be made part of the real-time visual data base. After the review stage, the data base is ready for a real-time flight.

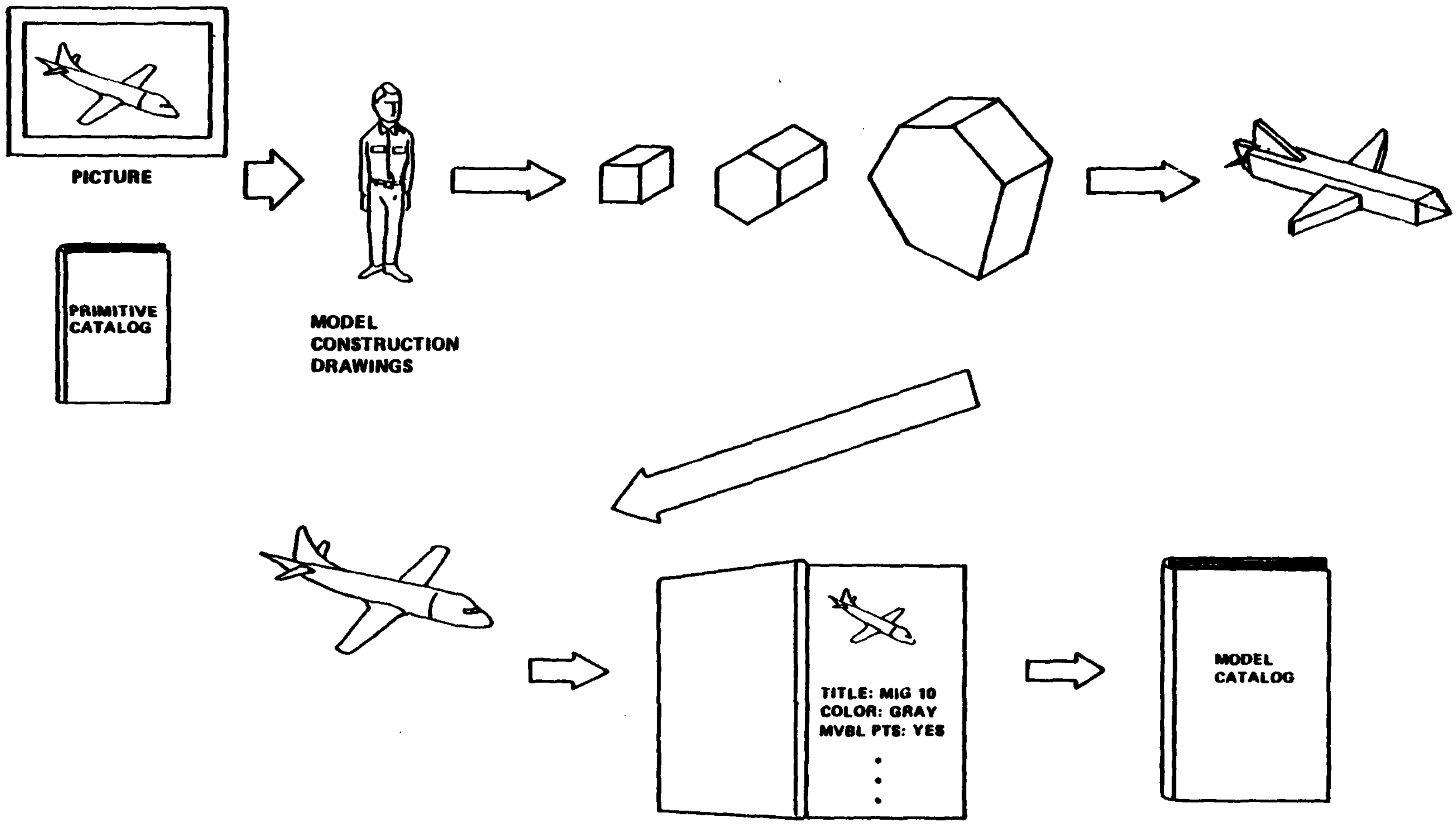


Figure 21. Phase 2: Build Models

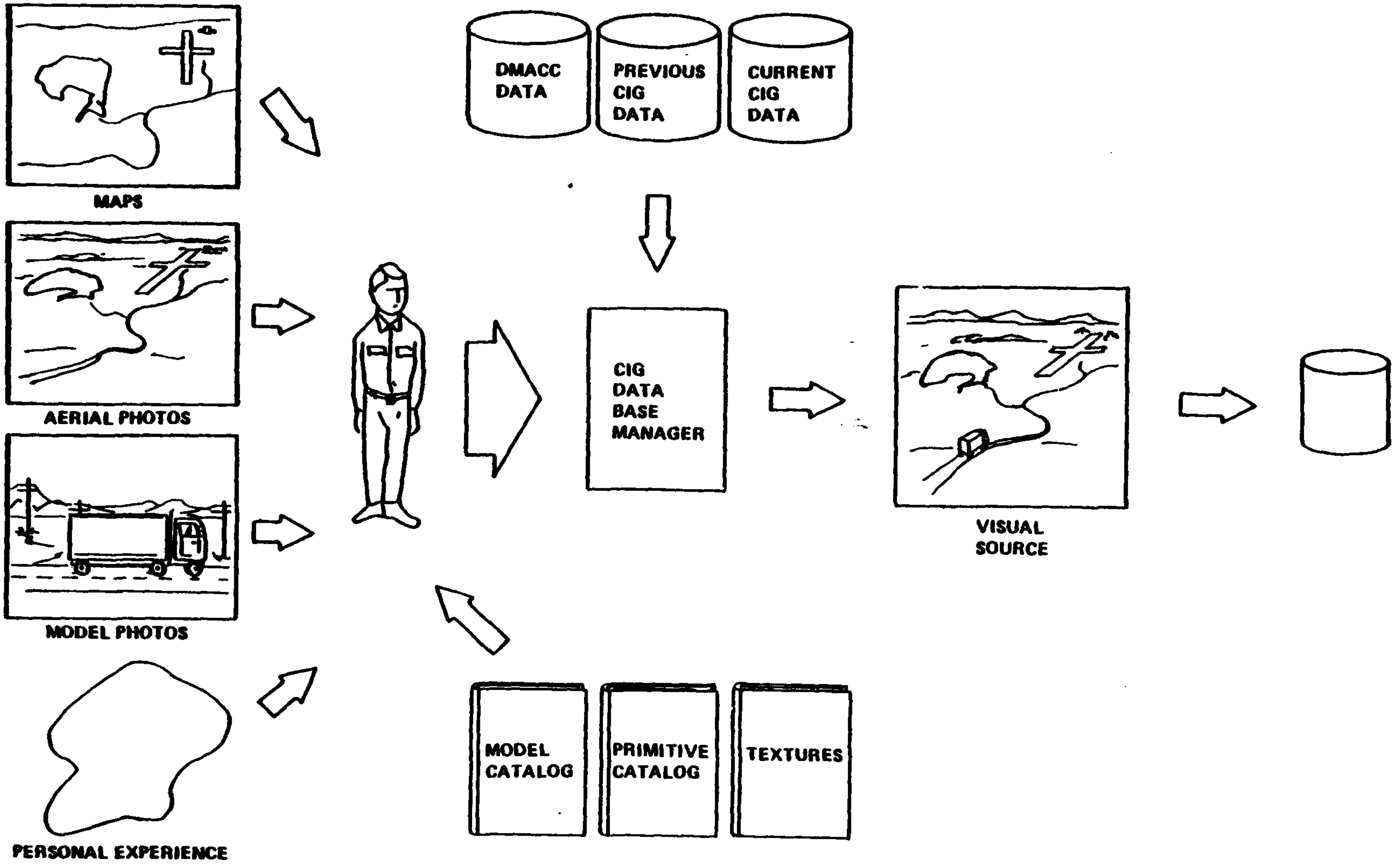
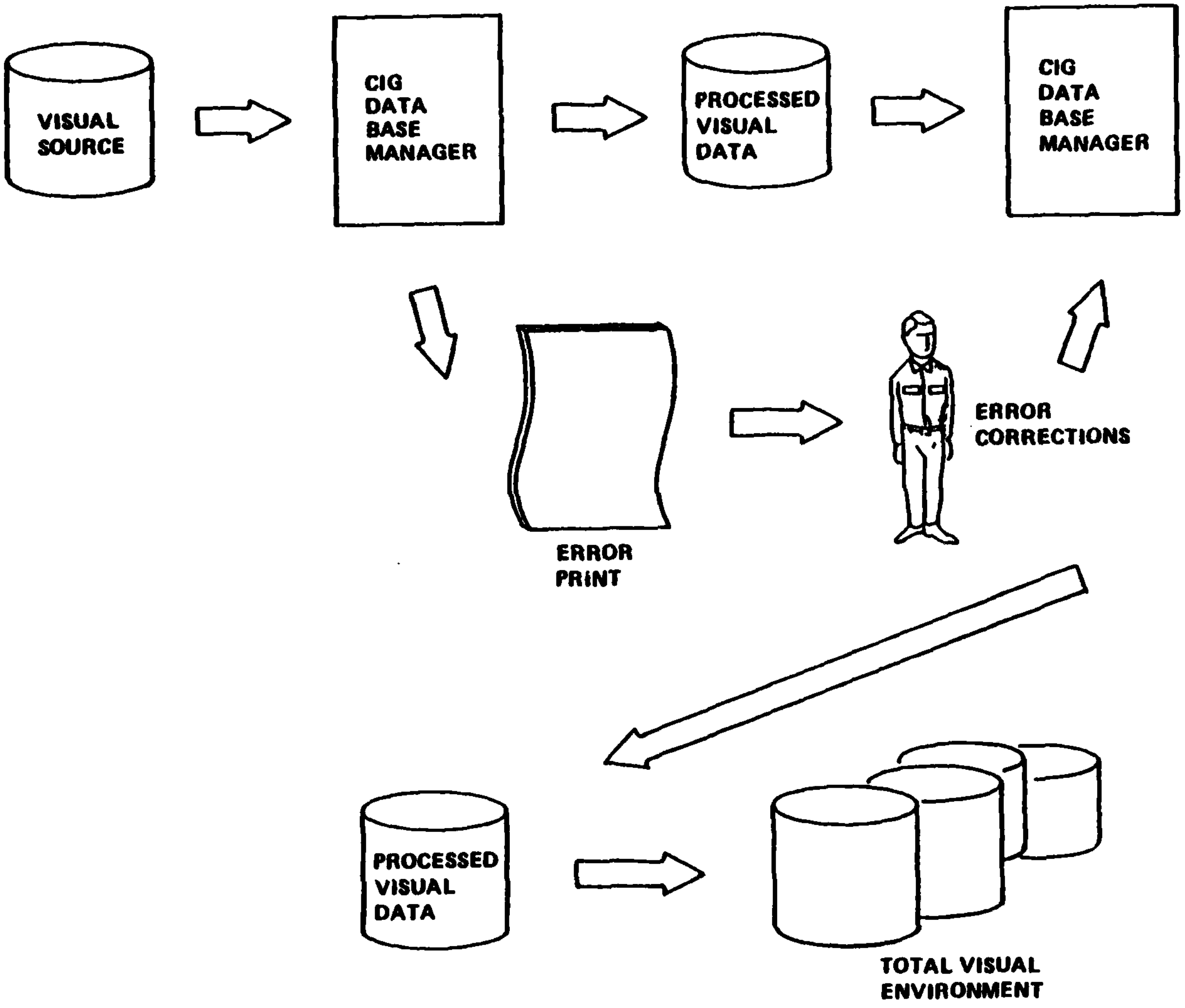


Figure 22. Phase 3: Formulate Environment



DATA BASE CREATION

Figure 23. Phase 4: Compile Environment

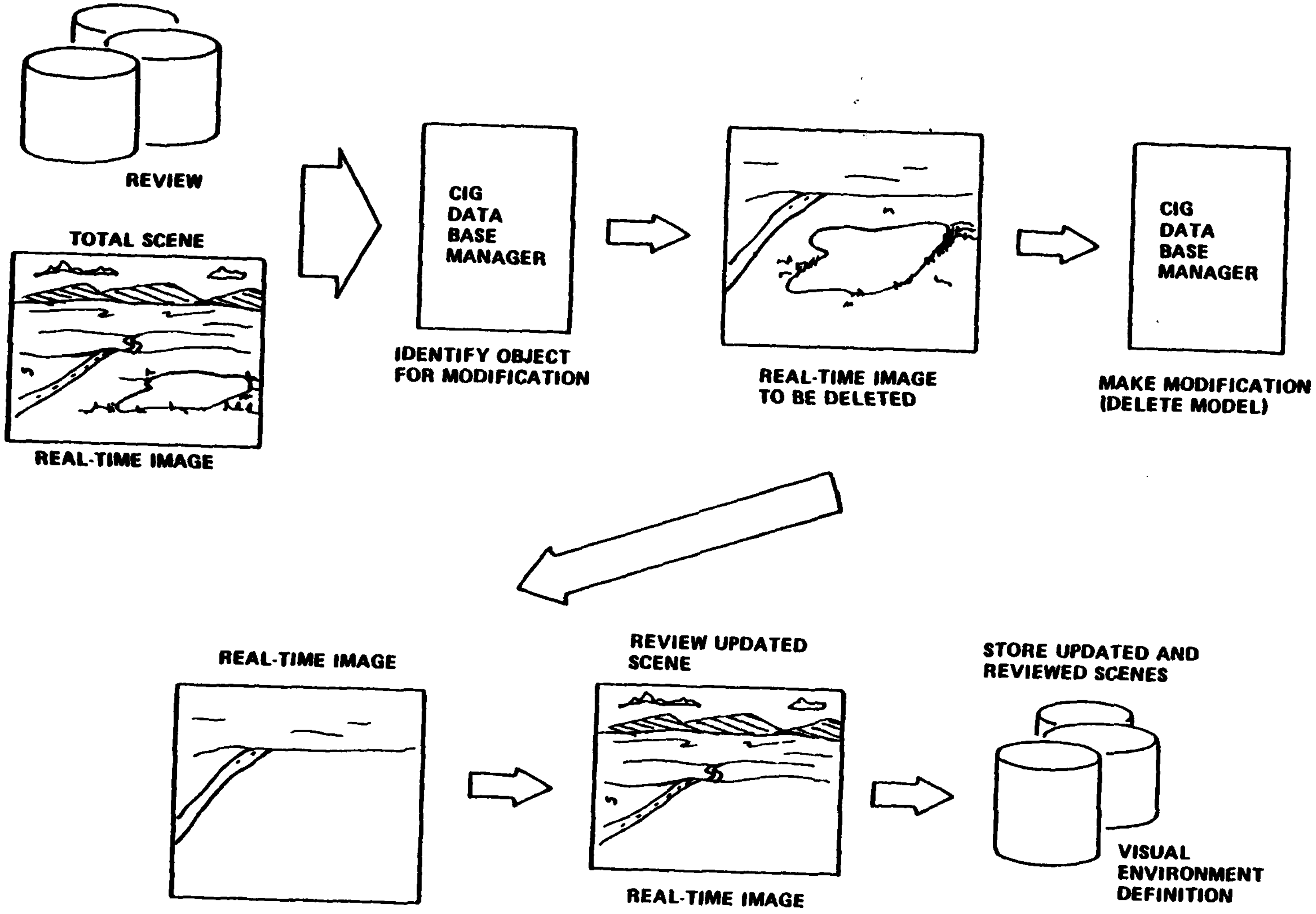


Figure 24. Phase 5: Review and Update

If this sort of CIG data base manager can be perfected, automating all possible areas, making the system user-oriented, and easy to use, the time and costs of building CIG data bases in the future should remain reasonable.

11.4 DATA BASE INTERCHANGEABILITY

The commonality and transportability of data bases leaves much to be desired. There are four aspects of interchangeability to be concerned with. The first three relate to interchange of data bases between CIG systems from the same manufacturer. The fourth aspect relates to interchange of data bases between manufacturers.

11.4.1 Lateral Compatibility

Lateral compatibility deals with the interchange of data bases between systems having identical capacities. If the CIG systems are totally identical, there is no question of interchangeability. Data bases prepared on one should run on another. If, however, the systems have identical capacities but dissimilar features (e.g., color vs. monochrome, horizontal scanning vs. vertical scanning, etc.), the data bases may be interchangeable but will not be optimized for the new system. The implication is that all the features may not be utilizable or though utilizable, various degrees of overload may occur.

11.4.2 Upwards Compatibility

Upwards compatibility works well when additional capacity and new features, not directly related to the data base, are the only changes to the system. This is the case at Boeing where their GE-built Compu-Scene 1000 data base may be run on their new Compu-Scene 2000 system. The old data base does not, however, fully utilize the new system capacity. If the new CIG system utilizes an approach different from the old, as is the case with the E&S CT-4 to CT-5 evolution, the data bases will not be interchangeable.

11.4.3 Downwards Compatibility

Data bases built for, and fully utilizing, systems having a greater on-line, active, or displayable data base capacity may not be used on systems having lower capacity without incurring overload. Some sort of automated hierarchy must be developed in order that systems of lower capacity may determine which edges/polygons can be eliminated.

11.4.4 Transfer

Transfer between manufacturers is not currrently possible. Cohen (Summer, 1979) has suggested the concept of a meta-language, which could create an interim data base which could then be converted for use on a specific system. Some success has been experienced in the computer graphics field, with the implementation of a common graphics system proposed by the ACM/SIGGRAPH (Reed, 1978). Revisions to this approach, first published in 1977 by the Graphics Standards Planning Committee of the ACM, have been published in Computer Graphics, a quarterly report of SIGGRAPH-ACM, Vol. 13, No. 3, August, 1979. Beck and Hoog (1979) presented the automatic conversion of the DMAAC DDB to a

CIG data base as an approach which held the potential within it of producing transportable data bases. Only the future will provide an answer as to their success or failure.

11.5 SENSOR SIMULATION DATA BASES

Data bases utilized for sensor simulation are similar to but different from CIG data bases. The similarities are in the areas of:

(a) Perspective

(b) Priority

(c) Raster Artifacts.

The differences are in the area of:

(a) Detail

(b) Data Base Encoding Scheme.

Infrared (IR) data base encoding includes:

(a) Temperature

(b) Time of day.

Low light level television (LLLTV) data base encoding includes:

(a) Absence of sun

(b) Addition of active light sources.

IR and LLLTV data base similarities include:

(a) Characteristics change with time of day

(b) Characteristics change with atmospheric conditions

(c) Characteristics change with season.

Infrared and low light level television data bases differ in that infrared has a temperature gradient per surface problem.

The preceding paragraphs on sensor simulation were synopsized from Basinger and Ingle (1977).

CIG sensor simulation hardware and data bases may be separated from CIG visual simulation hardware and data bases. If so, the data bases must share a common source in order that accuracy may be maintained and simulations track. One single data base for both sensor and visual CIG is not out of the question if the special attributes which make them unique can be appended to each modeled area or object. Sensor simulation is not currently implemented this way.

SECTION 12

CIG SOFTWARE

12.1 SOFTWARE COMMONALITY

The software used in the CIG systems normally appears in the front end computational section. It is also used in the generation and maintenance of CIG Data Base bases. The commonality of software is generally measured by the similarity of the computer languages used in its construction. The extent or the proportion of higher and lower level machine dependent code has not been made available to the authors. Therefore it is hard to make comparisons with existing systems.

Some manufacturers share the use of the high-level FORTRAN language. Therefore, for those programs written in FORTRAN the move from one manufacturer's CIG system to another would be relatively easy. How easy depends on the target CPU. If the target CPU is the same or a newer bigger machine of the same make, the move should be trivial because most of today's CPUs are upward compatible. If the move is in the reverse, there may be more problems. If the target CPU was manufactured by a different company, the move will be dependent upon the machine involved.

The proportion of assembly code which is machine unique will dictate an absolute as far as moving costs from one manufacturer to another. The code that was done in assembly would have to be converted to the new CPU's assembly language. Most logic coded in assembly is done to enhance the efficiency of the code and minimize the time required to execute it. Therefore, each system would have to be analyzed to determine, first, what the specific goals for the current assembly code are, second, what features are available in the target's system, and third and finally, how these goals can be reached in the target system. Since the major problem in CIG presentation is the speed, most systems are processing time optimized. The system software is generally not thought of as portable as it pertains to moving from one manufacturer to the other.

Other constraints on commonality to consider are the memory requirements, CPU execution time, and available general purpose routines when moving between systems.

Most CIG systems use the general purpose CPU for the visual data base management. Therefore, if a move is to be made, the new features (i.e., operating system) must be able to accomplish the tasks required in the time required. There may also be constraints in the new data storage media which must be anticipated to ensure that the large amounts of data can be accommodated.

Overall, it appears that the current and near term systems are not easily transportable from CPU to CPU and if the front end CPU was to be changed, the

CIG software originators must be consulted to ascertain the total impact of the move.

The generation of general-purpose computer graphics software packages is moving towards the creation of a graphics standard. These packages are used to provide a means to easily generate graphic patterns and take advantage of common graphics construction routines. They could be used in the CIG visual data base generation and in some of the rotation and clipping routines of the real-time application.

There is currently an effort to make a standard graphics language. This would allow for commonly used graphic routines to be used in many applications. Computer Graphics, Volume 13, No. 3 (August 1979) describes the constructs and the current status of the effort. It was pleasing to note that they have expanded their effort to include the raster scan technology in their standardization. But, at this time, the CIG application may present a highly specialized graphics application that cannot fit into the standard world.

Some facilities such as ASPT and VTRS have either successfully partitioned their software or are planning to partition their software and distribute it among multiple processors.

Currently Booker at NTEC is working on a high level CIG language.

12.2 LANGUAGES

High level languages allow the user to construct a program in a language that is more familiar to him without the need to know and understand the particular computer instruction set he is using. It also has the capability to be directly usable on more than one machine. There are some unique features encountered when transferring but for the most part, the programs written in one high-level language may be compiled on the new machine and they will work with that system.

There are many languages available for the task (i.e., Ada, ALGOL, BASIC, FORTRAN PASCAL, PL/I). For this discussion we will only concern ourselves with two. One is the most frequently used and the other is probably the most effective language for the real time simulator application.

12.2.1 FORTRAN

The FORTRAN language has been around forever and is usually taught to all people about to go into the computer world. Therefore, it is well known and familiar to a large segment of the users. Not only do most people know how to use the language but almost all computer manufacturers include the FORTRAN language in all their products. There are many subroutines for the solutions of all types of problems located in FORTRAN libraries. In addition, the simulation problem is basically a scientific application of the computer and FORTRAN was basically written to help scientists program solutions to their problems.

Probably for the above reasons, current Air Force and Navy specifications require the maximum use of FORTRAN wherever possible (Sigmund, 1977). This requirement has a tendency to perpetuate the use of FORTRAN because all new simulators for the Air Force and the Navy will be programmed in FORTRAN.

It is interesting to note that none of the above pluses for the use of the FORTRAN language called it the optimal language for the real-time software application. In fact, according to Newman and Sproull (1973), "FORTRAN offers no program structure facilities of any worth: its subroutines and functions are non-recursive, and impose strange conventions regarding parameter-passing; the If statement is clumsy and lacks an Else clause." Sigmund (1977) compares an optimized FORTRAN against the assembly code of the same function and arrives at around a 16-17% average increase in memory and time required for the same function.

Therefore if you evaluate FORTRAN solely on its ability to solve the real time software problem, it does not rate well.

12.2.2 PASCAL

There is a new language, currently becoming available, which appears to be the best (ignoring availability, previous use and use by existing manufacturers). It is called PASCAL, named after a philosopher and mathematician. The advantages of this language are:

(a) It is machine independent (i.e., it is transportable with no changes as opposed to FORTRAN which might require modification)

(b) It has very good subroutine capabilities

(c) It is fast in its execution

(d) It is easier to learn than FORTRAN

(e) It is a more powerful language for defining data structures

(f) It has structured constructs.

PASCAL is gaining approval and use throughout the computer world and hopefully will be available on all types of machines, micro to maxi, in the near future.

To be fair to FORTRAN, it must be pointed out that newer versions of FORTRAN are implementing new constructs that remedy some of its faults. Also using structured preprocessors, it can provide much of the required structured programming capability used in today's software development. The decision as to which language to use is based on many variables and they all must be considered when choosing.

12.3 SOFTWARE EASE OF USE

The ease of using the software of a CIG system is related to how much has been coded in a high-level language. CIG systems usually contain both high-level and assembly codes in them; therefore the greater the use of the higher level language, the easier it will be to use and understand.

Assembly language requires the user to understand a great deal more about the workings of the specific computer as well as requiring more time to write. Each instruction must be written individually as opposed to the high-level language where one statement may cause five or more instructions to be generated.

Some higher level languages are easier for a programmer to learn and use than others and the same goes for assembly language. There are many areas that affect the ease of use:

(a) The documentation that describes how to use the language

(b) The constructs of the language

(c) The supporting software that compiles and activates the output.

When acquiring a new CPU, system software analysis should be done to ensure that the following areas have been well analyzed to ensure that the system will do what is expected. Once areas such as efficient code, ease of use, and ease of learning have been considered, a recommendation can be made as to the impact one set of system software has in relation to the others offered.

With the ever-declining costs of memory, the major costs in a system are the initial software development and the follow-on software maintenance. The days of the clever programmer who used all kinds of cute tricks to make a program fit into the space available have passed. It is now more cost effective to make the program as simple and straightforward as possible. This eases the problems encountered during both the integration phase and maintenance, thus reducing the actual overall costs.

The software must be well-designed and the logic must be structured so that it is apparent to any follow-on programmer what was going on. Programmers normally have a fear of making their software understandable, assumably because it may expose their own questions on how the program should work. This is also true in documentation of the various systems. People tend to cloak their designs in large complicated verbiage and the user is left still wondering what he has and how it works.

There is a design and programming technique out at the present which addresses this problem. It is called structured design and top down programming. The structured design eliminates complex loops and non-standard transfers. This makes for easier understanding of what the program is doing and where it is going. The top down design is a concept where the uppermost functions of a system are defined first. Then each function is subdivided into its component parts. This subdivision is continued until the subfunction is trivial. In the production phase the upper level functions are coded first. Wherever a subfunction is to be used a stub is inserted until that program is complete and can be used. This allows the program to be continually tested and working from day one. The subfunctions are added one at a time as they are complete. Therefore, they are tested against a working tested system. Any new problems that are encountered should be the result of the added subfunction. When the final sub-subfunction is added and tested, the entire system has been tested. This avoids the normal integration phase where many subfunctions are thrown together and tested. Problems encountered using the normal approach are not as easily traceable to the subfunction that is the villain, and human nature states that "it is the other guy's problem until it's shown to be mine."

Using structured design and programming techniques will produce a product that will be easier to maintain and will probably function better from the beginning. The programs will be easier to understand when maintenance or improvements are required.

SECTION 13

CIG HARDWARE BLOCK DIAGRAMS

13.1 GENERAL ELECTRIC (GE)

The block diagram of the GE Compu-Scene system (Figure 25) is depicted in greater detail and appears first in this section because more information has been published about the GE approach. For an in-depth discussion of their approach the reader is urged to see the article by R. R. Raike (1976) on this subject.

13.2 SINGER-LINK

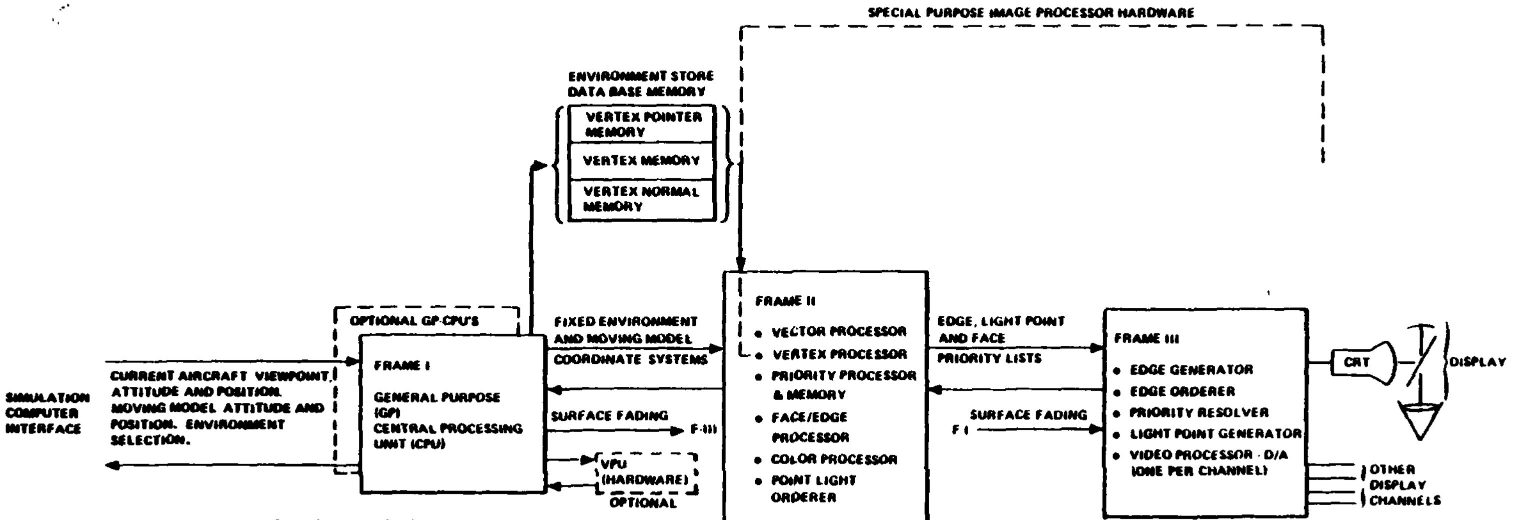
The block diagram of the Link Digital Image Generation (DIG) system (Figure 26) comes from discussions with the Link.

13.3 EVANS AND SUTHERLAND (E&S)

The block diagram of the E&S CIG system (Figure 27) is of the CT5, which is currently under development. This diagram comes from discussions with E&S.

13.4 ADVANCED TECHNOLOGY SYSTEMS (ATS)

No block diagram of the current ATS approach has been published in this section. The interested reader is directed to an early article by Dr. R. Swallow (1978).



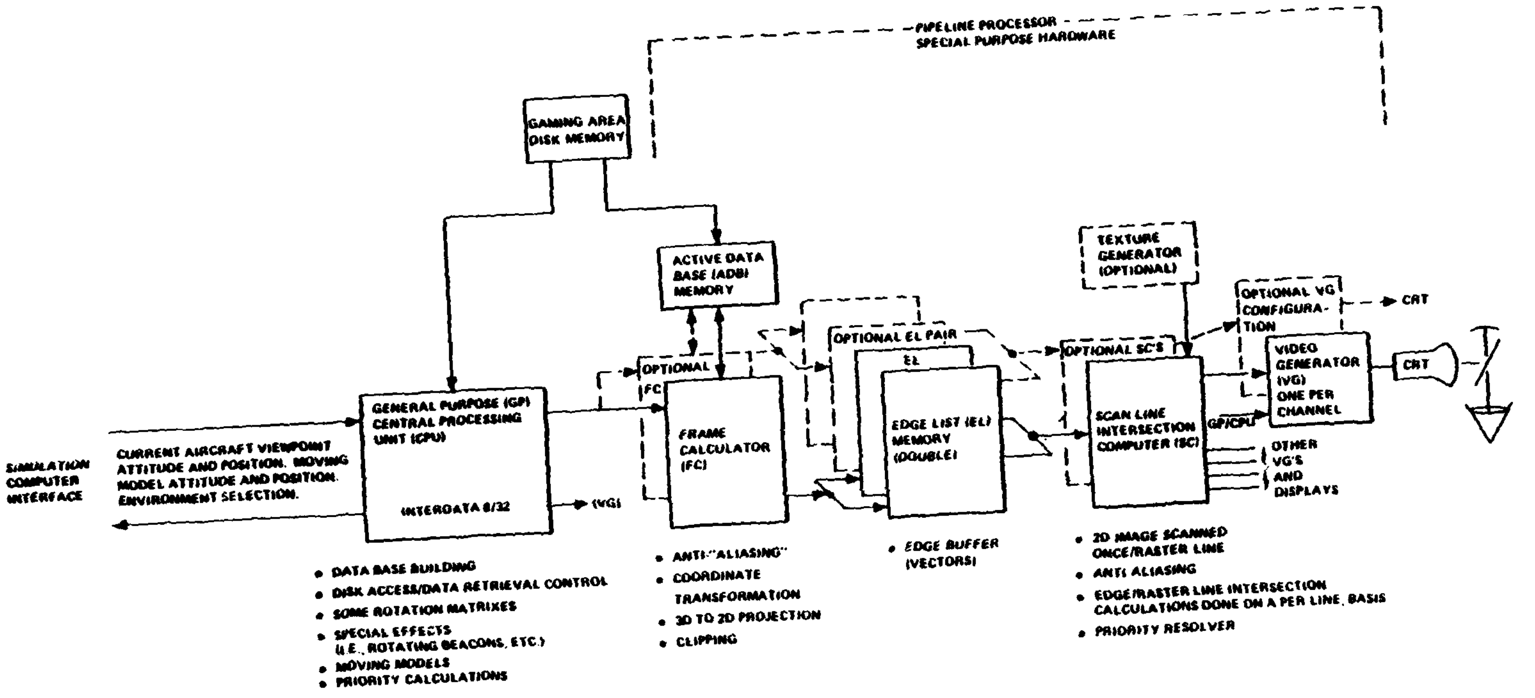
- DATA BASE BUILDING
- EXTRAPOLATE SIMULATOR DATA TO CIG
- UPDATE ACTIVE DATA BASE
- COMPUTE FIXED WINDOW DIMENSIONS
- COMPUTE SIN/COS OF ROTATION ANGLES
- COMPUTE DIRECTION COSINE MATRICES
- SCALE AND FORMAT DATA FOR VECTOR PROCESSOR UNIT (VPU)
- COMPUTE COORDINATE SYSTEM PRIORITY LIST
- ADJUST BLINKING LIGHTS (ON/OFF STATUS)
- ROTATE VECTORS INTO MOVING MODEL COORDINATES
- VPU ROTATES WINDOWS INTO MOVING MODEL COORDINATES
- SCALE AND FORMAT DATA FROM VECTOR PROCESSOR UNIT (FRAME 2)
- COMPUTE FADING (VISIBILITY) DATA CONSTANTS
- CONTROL INTERFACE OPERATIONS
- MAINTENANCE

- VECTOR CALCULATIONS · COMPUTE VECTORS FROM VIEWPOINT TO EACH MODEL, OBJECT AND FACE VERTEX
- LOD SELECTION AND CHANNEL ASSIGNMENT
- FACE CHANNEL ASSIGNMENT
- 3D TO 2D TRANSFORMATION OF VECTORS ONTO DISPLAY PLANE GIVE TRUE PERSPECTIVE 2D IMAGE
- TRUNCATE EDGES AT WINDOW BOUNDRIES (CLIPPING)
- PRIORITY PROCESSOR · USES SEPARATION PLANES TO CONSTRUCT PRIORITY LIST
- EDGE WORD GENERATION
- POINT LIGHT · ORDERER

- 2D IMAGE SCANNED ONCE/RASTER LINE
- EDGE/RASTER LINE INTERSECTION CALCULATIONS DONE ON A PER LINE BASIS
- EDGE INTERSECTIONS PLACED IN PRIORITY ORDER
- EDGE PRIORITY RESOLVED (RESOLVES OCCLUSIONS OR OCCULTATION)
- EDGE SMOOTHING CALCULATIONS DONE
- POINT LIGHT/RASTER LINE INTERSECTION PRIORITY ORDERING AND RESOLUTION CALCULATIONS PERFORMED
- RED, GREEN, BLUE (RGB) CALCULATIONS MADE FOR EDGE AND LIGHT POINT INTERSECTIONS WITH RASTER LINE
- NON-COMPOSITE (MONOCHROME) (RGB) VIDEO GENERATED (2 TO 1 INTERLACED) FOR EACH CHANNEL

NOTE: EACH FRAME MAKES 30 PASSES A SECOND (33.3 MS/PASS).
THE TIME FOR FRAME III INCLUDES THE DISPLAY TIME.

Figure 25. GE Compu-Scene Top Level Block Diagram



NOTE. FC CALCULATIONS ARE DONE EITHER AT THE <u>FIELD RATE</u> (16.7 MS TYPICALLY) OR <u>FRAME RATE</u> (33.3 MS TYPICALLY)

Figure 26. Link DIG Top Level Block Diagram

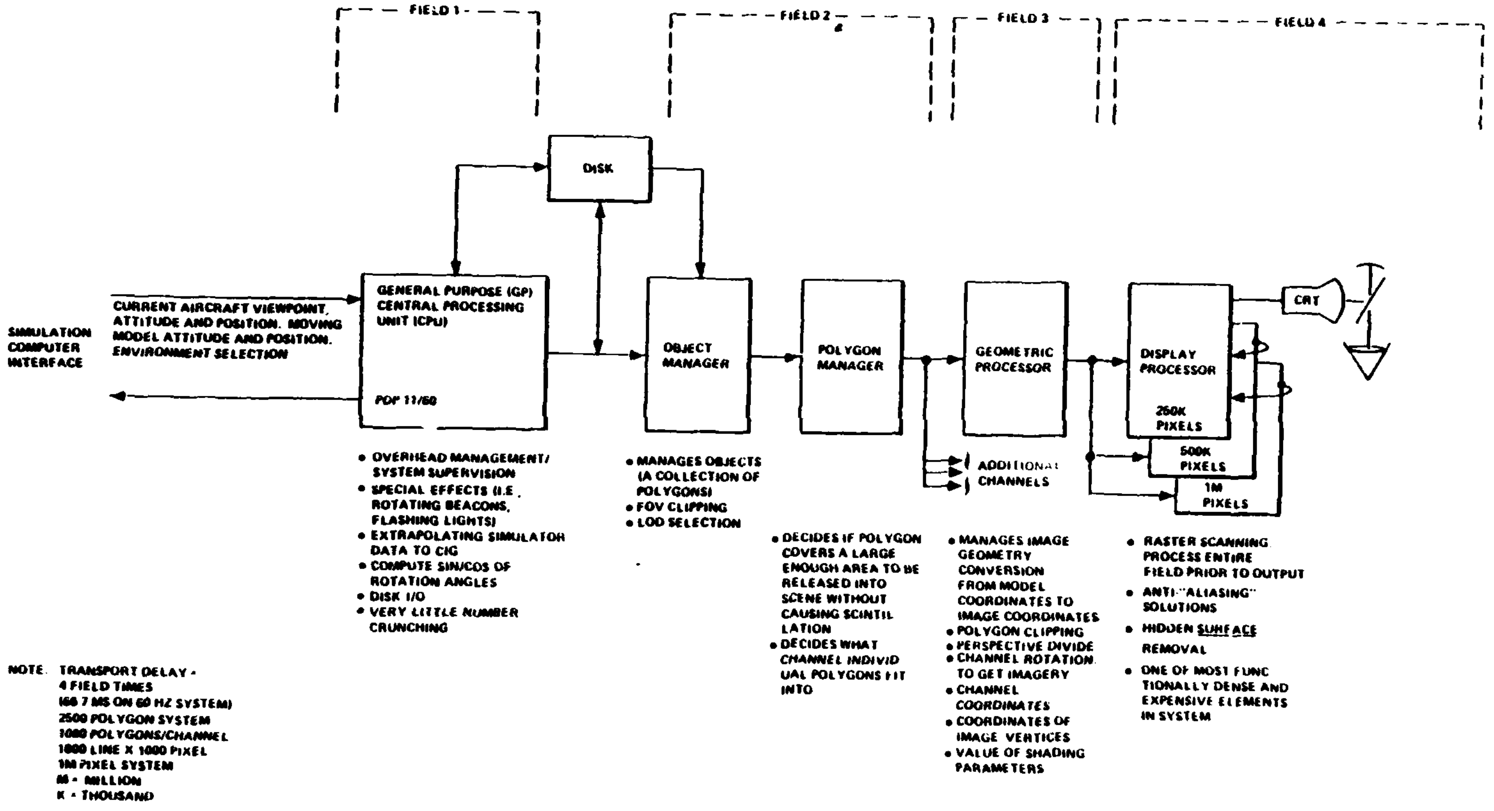


Figure 27. E&S CT5 Top Level Block Diagram

SECTION 14

DISPLAY HARDWARE

14.1 DISPLAY CONSIDERATIONS

No attempt will be made to specify a type of display, as this approach could prove counter-productive to satisfying mission task requirements in that it disallows innovation on the part of the bidding contractors. While pushing the state-of-the-art in CIG systems may not be a wise choice (see 18.2), display systems, because of their current weaknesses (see 15.1, 15.3, 15.6 15.7 and 15.8), may require pushing simply to meet mission task requirements.

Current systems use numerous forms of insetting and combinations of approaches to satisfy resolution and other requirements. What follows is a discussion of those concerns which delimit display systems.

14.1.1 Bandwidth and Resolution

The method used to generate visual information via television (TV) video is beyond the scope of this report. However, certain fundamental concepts cannot be ignored. What follows is a general review of these concepts. Conventional TV will be used as an example for this discussion. See Figure 28.

Bandwidth

Bandwidth can most simply be defined as the minimum frequency required to support the transmission of data through the display. The figures given here are for an ideal monochromatic system. They do not take in to account signal-to-noise ratios and other factors which can degrade the ideal.

We will define an active (displayable) raster line as a series of individually controllable picture elements (pixels).

Figure 29 illustrates the following discussion.

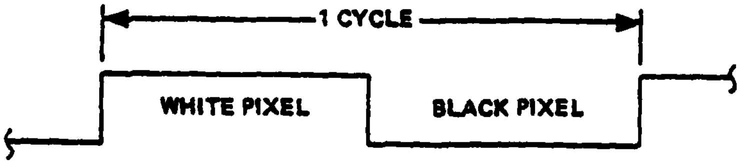
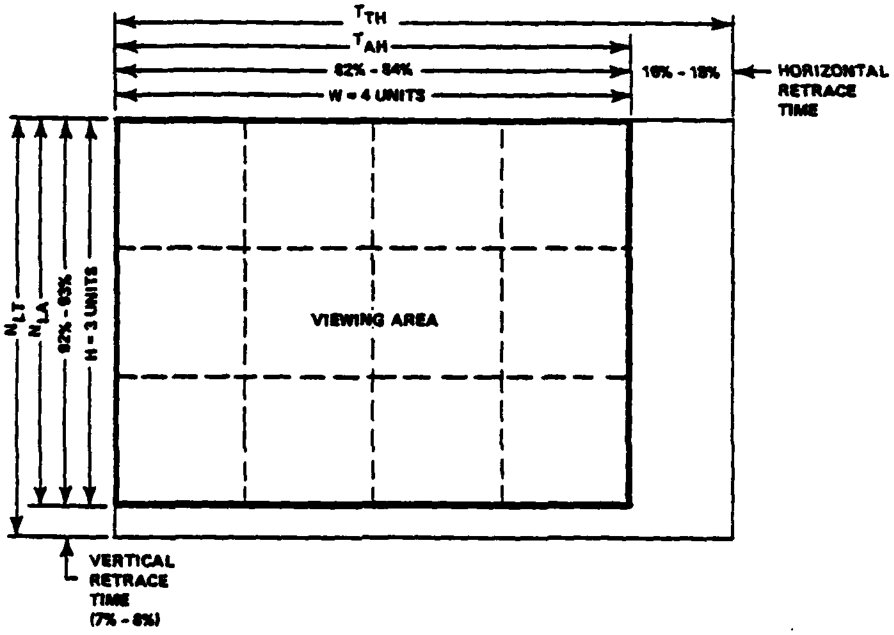


Figure 29. Two Pixels = One Cycle

If 800 pixels per active raster line are specified we can determine the required band width as follows:

> 800 pixels made up of 400 white and black <u>pairs</u> can be represented by an electrical signal containing 400 cycles.



		EXAMPLE
V_{FI}	- VERTICAL FIELD REFRESH RATE	[60 Hz]
V_{FR}	- VERTICAL FRAME REFRESH RATE = $\frac{V_F}{2}$	[30 Hz]
N_{LT}	- TOTAL NUMBER OF RASTER LINES PER FRAME	[525]
N_{LA}	- NUMBER OF ACTIVE (DISPLAYABLE) RASTER LINES = 92% - 93% N_{LT}	[483 - 490]
N_{LS}	- TOTAL NUMBER OF LINES PER SECOND = $V_{FR} \cdot N_{LT}$	[30 · 525 = 15,750 Hz]
T_{TH}	- TOTAL HORIZONTAL TIME INTERVAL = $\frac{1}{N_{LS}}$	[63.5μ sec]
T_{AH}	- ACTIVE HORIZONTAL TIME INTERVAL = 82% - 84% T_{TH}.	[52 - 53.3μ sec]
H	- PICTURE HEIGHT	
W	- PICTURE WIDTH	
K	- KELL FACTOR = .7	
R_V	- VERTICAL RESOLUTION = $K \cdot N_{LA}$	[.7 · 490 = 343]
R_H	- HORIZONTAL RESOLUTION (IN TV LINES PER PICTURE HEIGHT)	[600]
A_R	- ASPECT RATIO = DISPLAYABLE W:H	[4:3]
A_C	- ASPECT RATIO COMPENSATION MULTIPLIER = $\frac{H}{W}$	[$\frac{3}{4}$]
N_P	- NUMBER OF DISPLAYED PIXELS = $R_H \cdot A_R$	[600 · $\frac{4}{3}$ = 800]
N_C	- NUMBER OF DISPLAYED CYCLES (BLACK TO WHITE = 1) = $\frac{N_P}{2}$	[400]

Figure 28. Television Display Format

The period of 1 cycle = t

$$t = \frac{\text{Active Horizontal Time Interval}}{\text{Number of Displayed Cycles}}$$

$$\therefore t = \frac{T_{AH}}{N_C}$$

The Bandwidth (BW) = $f \geq \frac{1}{t}$

$$\therefore BW \geqq \frac{N_C}{T_{AH}} = \frac{\frac{N_P}{2}}{.83\ (T_{TH})} = \frac{\frac{N_P}{2}}{.83\ \left(\frac{1}{N_{LS}}\right)}$$

$$BW \geqq \frac{\frac{N_P}{2}}{.83\left(\frac{1}{V_{FR} \cdot N_{LT}}\right)} = \frac{(N_P)(V_{FR})(N_{LT})}{(2)(.83)}$$

$$\boxed{BW \geqq .6\ (N_P)(V_{FR})(N_{LT})}$$

It is important to note again that this equation is for the ideal monochrome system and defines the minimum frequency required in order for the system not to be band width limited. An example of the solution to the equation follows:

N_P = Number of Displayed Pixels = 800

V_{FR} = Vertical <u>Frame</u> Refresh Rate = 30Hz

N_{LT} = Total Number of Raster Lines/Frame = 525

$$BW \geqq .6(N_P)(V_{FR})(N_{LT})$$

$$\geqq (.6)(800)(30)(525)$$

$$\geqq 7.56\ \text{MHz}$$

Vertical Resolution

Vertical Resolution is defined by Horizontal Test Lines. The standard TV system with 525 Total Raster Lines Per frame actually displays approximately 486 active lines. This is because of the vertical retrace time requirement. In the ideal situation if a test pattern of 486 alternating white and black lines (243 ea.) were to be displayed, each line would fall on a raster line and all lines would be visible.

However, if the test pattern is displaced 1/2 of a line width up or down, the center of every pixel would be on the junction of the white and black lines. No pixel would be white or black, they would all be the average of the white and black lines - Gray. Consequently the entire field would be depicted as gray.

Admittedly the example given is worst case, however the effect does occur whenever the center of the pixel is offset from the center of the line. To compensate for this a constant has been devised called the Kell factor. It is a rather flexible number but is generally given as .7. To use the Kell factor, simply multiply it times the number of active TV lines to get the Vertical Resolution:

$$\boxed{R_V = K\,(N_{LA})}$$

$$= .7(486) = 340 \text{ TV lines}$$

Horizontal Resolution

Unfortunately, Horizontal Resolution is not as straight forward as Vertical Resolution. Horizontal Resolution is defined by Vertical Test Lines just as Vertical Resolution was defined by Horizontal Test Lines. If we are speaking of pixels per horizontal raster line things remain simple enough, however if we use lines to define Horizontal resolution a term called "TV lines per picture height" creeps in. This term uses the "H" dimension of the display (see Figure 28) and theoretically places this dimension along the horizontal raster. The Horizontal Resolution, then, is the number of vertical lines which will pass through the portion of the horizontal raster which is H-long.

If the number of pixels per line is known, the horizontal resolution may be derived. To do so multiply the pixel count by the inverse of the Aspect Ratio:

$$\boxed{R_H = N_P \cdot \frac{1}{A_R}}$$

$$= N_P \cdot A_C$$

$$= 800 \;.\; 3/4 = 600 \text{ "TV lines per picture height"}$$

Of course it is possible to go the other way as well. If the system has 600 "TV lines per picture height" resolution, we can find the number of pixels by:

$$\boxed{N_P = R_H \cdot A_R}$$

$$= 600 \cdot 4/3 = 800$$

For additional information on the "How" of TV resolution, refer to:

(a) Hansen, L.G., 1969

(b) Schade, O.H., 1953

(c) Schade, O.H., 1967

(d) Kell, R.D., et.el, 1940

(e) Farrell, R.J. and Booth, J.M., 1975

14.1.2 Color

Color - see 7.2.6 and 15.5

14.1.3 Contrast

Contrast in a display is an important factor. See 7.1.2.

One study determined that a 20 to 1 ratio should be a design goal for a wide field-of-view visual display (Thomas and Jones, 1977) but did not define contrast. The implied contrast may be the second form of the C_M equation given in Figure 30. This form is often encountered.

Contrast may be defined in numerous ways. There are four definitions which are of particular interest to us. See Figure 30 for a partial list. See Farrell and Booth (1975) for a full discussion.

14.1.4 Depth-of-Field

Depth-of-field is a consideration in image generation systems using optical pickups. This is not a factor in CIG systems, however, as all of the image is presented in sharp focus.

14.1.5 Distortion

Distortion must be a major consideration in any display approach, as its presence will lead to erroneous judgments of geometric perspective and position. See 7.1.5.3 and 15.1.2.

14.1.6 Exit Pupil

Exit pupil diameter is of concern as it defines the required head position of the observer and the number of observers possible. "The exit pupil diameter

$$C_m = \left|\frac{L_t - L_b}{L_t + L_b}\right| = \frac{L_1 - L_2}{L_1 + L_2} = \frac{(L_1 - L_2)/2}{L_0}$$

$$C_r = \frac{1 + C_m}{1 - C_m}$$

$$C_d = \frac{2C_m}{1 + C_m}$$

$$C_1 = \frac{2C_m}{1 - C_m}$$

where: C_m = The contrast as modulation

C_r = The contrast ratio

C_d = The contrast for dark targets ($L_t < L_b$)

C_1 = The contrast for light targets ($L_t > L_b$)

L_t = Target Luminance

L_b = Background Luminance

L_1 = Maximum Luminance

L_2 = Minimum Luminance

L_0 = Average Luminance = $(L_1 + L_2)/2$

Figure 30. Contrast Equations

is defined as that opening (real or virtual) which represents the common base of all the cones of light emerging from the system. Another way to define the exit pupil is the image of the aperture stop of the system, as formed by the optics. The larger the exit pupil, the greater the lateral head movement that is possible while still being able to see the full field-of-view. For a side cockpit configuration, an especially large exit pupil diameter is required (up to as much as 48 inches) if both the pilot and the co- pilot are to see the same visual display" (Thomas and Jones, 1977). See 15.8 for accommodating multiple observers.

14.1.7 Eye Relief

Eye relief is defined as the distance between the pilot's eyes and the closest optical element.

14.1.8 Field of View (FOV)

Field-of-view requirements are determined by the mission task. Yeend and Carico (1978) reported a technique they developed for determining flight simulator field-of-view requirements. An amber cellophane (AMBERLITH) with openings cut in it to represent individual channels of a proposed visual system was placed in the canopy and windscreen of the aircraft which was to be simulated. The test pilot wore blue lenses which allowed him to view through the cutouts but blocked all light passing through the AMBERLITH. In effect, the holes in the AMBERLITH represented the channels of the proposed display. A safety observer accompanied the pilot and wore no glasses. A subjective evaluation was made by the test pilot of his ability to perform specific mission tasks. It was recommended that pilots familiar with specific individual missions be included in the evaluation. While the present authors do not feel that a subjective evaluation of this nature is adequate, it may be considered as a first step. Objective evaluations of pilot performance with control response being the key factor could give a much more accurate evaluation of the required field of view. Even this approach must be tempered with the realization that real-world visual cues cannot be matched in a simulator. Translating experiments done in an actual aircraft to the simulator can be dangerous when so much greater emphasis is placed on the available cues in the simulator. It may be that some method of reducing the test pilot's visual acuity during the test could improve on this weakness.

Rivers (1977) found that, "Normal techniques and procedures could be employed only in simulators that duplicated the field-of-view of the aircraft."

In multi-channel systems, current standards for individual channels are determined by the aspect ratio of the Cathode Ray Tube (CRT) utilized. The aspect ratio is the ratio of the two sides of the display (4:3). Individual channels in a multi-channel system may have either a 30° x 40° field-of-view or a 36° x 48° field-of-view. Additionally there are some round CRTs in use with a 1:1 aspect ratio.

Mission implications of the field-of-view are numerous. At ASPT, it was found that students could get by satisfactorily with a 70° x 90° field-of-view in range delivery experiments (Buckland et al., 1979). This was a conventional range with a single large target on the ground versus a tactical range in which could be found numerous objects such as tanks and other forms of targets. Cohen (February, 1979) states that Rivers (1977) found that "one-window display systems allow only the straight-ahead tasks to be performed. Some discomfort was experienced because of the lack of peripheral visual cues, and great attention was paid to the instruments. Three-window displays did not give an increased capability over single-window displays. They did, however, allow for targets to be tracked more easily, and their major benefit appeared to be more normal performance of straight-ahead tasks." Brown (1975) reports that "...Studies show that a remarkable degree of reduction in field-of-view is possible without gross impairment of a pilot's control capability. It has been shown that limiting of the horizontal field to 22 degrees or somewhat less, even down to 15 degrees, may be accompanied by little measurable degradation in performance." These conclusions are probably only relevant to tasks which are straight ahead in nature and probably do not pertain to any tasks requiring changes in orientation. Additionally, these tasks may have been done in actual aircraft, not in a simulator where there is already a severe limitation on the number of cues available to the pilot.

Staples (1978) reports that a wide field-of-view is not required to land an aircraft. Landings were performed in two actual aircraft - one with a field-of-view of 22.9 degrees, the other with a field-of-view of 171.9 degrees. The landings were performed at night in poor visibility. The visual system on a simulator for the aircraft with the wider field-of-view had a field-of-view of 85.9 degrees. In each case, the sink rate was lower in the actual aircraft than that of the simulated aircraft. "There is no detectable difference between the aircraft, which, in spite of the poor visibility, both show a factor of 2 improvement in mean touchdown rate and over 3 in standard deviation of bank angle, compared with the simulator."

Staples does say that a wide field-of-view can be justified in other mission tasks such as helicopter hover, helicopter landing, helicopter low-level flight, helicopter nap-of-the-earth, fixed-wing circling approach to a landing, fixed-wing slow approaches in strong crosswinds, assessment of helmet-mounted sites, formation flying, etc. He points out that "peripheral vision is particularly acute in detecting velocity changes." To reiterate: field-of-view requirements are determined by the mission task. To the authors knowledge no existing studies define them.

14.1.9 Area-of-Interest (AOI)

See 5.2(f), 14.3.3 and 14.4.

14.1.10 Flicker

Flicker in the periphery can be perceived by some individual at a frame rate as high as 25 to 30 Hz. Increasing luminance increases the flicker threshold and could increase the required frame rate to 50 or 60 Hz (Staples, 1978, and Tyler, 1978, respectively). See also Section 15.6.

14.1.11 Smoking

Smoking should be curtailed as the smoke tends to build up on optical surfaces, reducing performance.

14.1.12 Windscreen and Canopy

Windscreen and canopy can degrade the visual information reaching the pilot. These components function as an optical element in the visual system, and any nonuniformity acts to the detriment of that system. A 1% difference in the apparent physical size of an object reaching one eye in comparison to the other eye can make the visual scene unendurable to the viewer for long periods of time. Even the very best material available will transmit only about 90% of the light reaching it (Kraft et al. 1978, 1979).

At a minimum, and dependent upon the field of view utilized, at least the windscreen should be omitted from any simulation. Opaque structures which act as part of the windscreen and canopy assembly must remain, however, as they provide the occulting and potential parallax information.

14.2 LIGHT INTENSITY AND PERCEPTION

Without light, there is no transmission of visual information to the human visual/perceptual system, but what amount of light is necessary to carry useful information from a display system? Light may be measured by two different techniques:

(a) Radiometry

Radiometry is the measurement of light made with a sensor having equal response to all wavelengths. For the purpose of this report, it will not be further described or considered.

(b) Photometry

Photometry is the measurement of light made with a sensor having a spectral response similar to the average human eye. The peak of the human eye's sensitivity to light comes at 550 nanometers, which is in the yellow-green area of the spectrum.

Luminous flux, luminous intensity, illuminance and luminance are four factors in the measurement of light. A full description and definition of these terms follows but most important are:

(a) Luminous Flux

Luminous flux, which is considered to be the total light output of a source and is measured in lumens.

(b) Luminance

Luminance which is the amount of light reflected from or emitted by a surface and is measured in foot lamberts.

The following is excerpted from Ganz.

14.2.1 Luminous Intensity

"The basic unit of photometry is the candela (C). This is the unit of luminous intensity adopted by the Commission Internationale de l'Eclairage (CIE). Until 1948 the candle was represented by groups of carbon filament lamps. The new candle, called candela to distinguish it from the old unit, is defined as 1/60 of the luminous intensity of 1 cm^2 of a black-body radiator at the freezing temperature of platinum (which is 1755° C). Candlepower (cp) is luminous intensity expressed in candelas."

14.2.2 Luminous Flux

"Luminous flux (F) refers to the rate of flow of light as a function of time. The lumen (lm) is the unit of luminous flux. A source of 1 candela emits 1 lumen of light through 1 steradian. The steradian is a unit solid angle best defined by a point source of light placed at the center of a sphere with radius of 1 meter. The cone which originates at the center and intersects the sphere so as to cut an area of 1 meter square is the steradian. There are 4 steradians in the entire sphere. Hence, a 1-candela source emits a total of 4 lumens.

14.2.3 Illuminance

"Illuminance (E) is the density of luminous flux falling on a surface. Density equals the total flux divided by the area of the surface. The lux (lx) is the unit of illuminance when the square meter is taken as the unit of area. One meter away from a 1-candela light source, a surface receives an illuminance of 1 lux per square meter. When, instead of the square meter, the unit of area is the square foot, then the footcandle is the unit of illuminance. If a square centimeter is used as the unit of area, then the phot is the unit of illuminance. This proliferation of units is quite confusing. It is helpful to note that the units are all interchangeable; one simply multiples by a constant to transform one into the other. For example, according to Table 3[7], if a surface receives 1 lux of illuminance this is equivalent to saying it receives 0.0929 footcandles. An illuminance of 2 lux is equivalent to 2 X 0.0929, or 0.1858 footcandles."

"A source of 1 candela of luminous intensity always emits the same luminous flux, 1 lumen per steradian. Imagine the 1-steradian cone of light emerging from the center of a sphere. Now let the sphere expand until its radius is 2 meters instead of 1. The steradian now intersects an area on the sphere of $(2)^2$ meters^2 or 4 meters^2. Thus the illuminance is now 1 lumen (the flux in the steradian) per 4 meters^2, or 1/4 lux. If the sphere expands to a radius of 3 meters, then the steradian will intersect an area on the sphere of 9 meters^2. Hence the illuminance will have dropped to one lumen per 9 meters^2, or 1/9 lux. It should be intuitively clear that (a) when a constant amount of light (of lumens) is spread over a larger area, that area is less highly illuminated and (b) the area of a disc that intersects a cone is inversely proportional to the square of the distance from the point from which the cone emerges. In other words, the inverse-square law applies to illuminance:

$$E = kcp/d^2,$$

Table 37. Relative Magnitudes of Units of Luminance and Illuminance

Units	Candle/cm^2 (stilb)	Lambert	MilliLambert	Candle/in^2	FootLambert
Candle/cm^2 (stilb)	1	3.142	3142	6.452	2918
Lambert	0.3183	1	1000	2.054	929
MilliLambert	0.000318	0.001	1	0.00205	0.929
Candle/in^2	0.1550	0.487	487	1	452
FootLambert	0.000342	0.001076	1.076	0.00221	1

Relative Magnitudes of Units of Illuminance

Units	Lux	Phot	Milliphot	Footcandle
Lux	1	0.0001	0.1	0.0929
Phot	10,000	1	1000	929
Milliphot	10	0.001	1	0.929
Footcandle	10.76	0.001076	1.076	1

(From Teele, 1965, according to Ganz)

where E is the amount of illuminance on a surface, cp is the candlepower of the source, D is the distance between the source and the surface, and k is a constant. For example, imagine you are in a room with dark walls and a single light bulb illuminating your reading surface. If you bring the bulb five times closer to the reading material, it will be illuminated twenty-five times more.

"In addition to a standard light source of 1 candela and the inverse-square law, photometry is based on judgments of equal brightness by human subjects. Suppose, for example, we want to measure the amount of illuminance falling on a test surface. We illuminate another surface similar in color to the first one with our standard source of 1 candela (a 1/60 cm^2 surface of platinum at its freezing temperature). Say the human subject views the two surfaces and reports that the one illuminated by the platinum sphere looks brighter. We then move the platinum source farther and farther away until the two surfaces look equally bright when the platinum source is 3 meters away; then by the inverse-square law we know that the platinum source is now illuminating the surface with 1/9 lux, and at the same time we also conclude that the unknown test illuminance must be 1/9 lux.

"As the reader may imagine, one does not use platinum heated to its freezing point for field measurements of illuminance. Using the platinum source, one first determines the candlepower of an incandescent bulb when some given amount of electric current goes through it (once more matching brightness and using the inverse-square law), and then uses the incandescent bulb in the field.

14.2.4 Luminance

"This photometric measure is closely related to brightness. Luminance refers not to the light falling on a surface, but to the source itself, indicating how much candlepower the source has per unit of its surface. Thus, a very large 1-candela source does not have as much luminance as a very small 1-candela source. Normally, the large source looks dim and the small source looks bright, even though they have the same candlepower. Units of luminance are candles per unit area of the source (the areal density of luminous intensity). A stilb (sb) is a unit of luminance of 1 C/cm^2. (Note that luminance refers to the output of the source relative to the area of the source; the distance between the source and the subject is irrelevant.) There are numerous units of luminance and Table 37 shows that they are interchangeable."

Human perception spans a very wide range of luminance. See Figure 31 for an example. This figure has been adapted both from Van Cott and Kinkade (1972), as well as from Farrell and Booth (1975).

Thomas and Jones (1977) give as an example some typical values of illuminance: sunlight = 100,000 $lumens/m^2$ (9,300 foot lamberts reflected from a perfect diffusing surface). The minimum recommended for close work is 100 $lumens/m^2$ (9.3 foot lamberts, reflected from a perfect diffusing surface). It may be noted that the preceding values correspond closely to the values given in Figure 31.

Screen luminance versus lumens must be considered for system-utilizing screens (dome or flat). The following simplified equation may be used to determine the screen luminance in foot lamberts:

$$\boxed{B = \frac{L}{A} \times G}$$

where B is luminance in foot lamberts, A is screen area in square feet, L is lumin output of the projector and G is screen gain.

Brown (1975) states that "Information processing by the visual system depends upon the spatial distribution of relative luminance information and not upon absolute levels. Once the minimum necessary luminance level has been achieved for efficient extraction of visual information from a display, there is little advantage in further increases in luminance." The exception to this rule, he points out, is the effect which a brilliant light source (glare) might have in hampering the pilot's ability to perform the required tasks. (See 5.2 [ab]). This light source could be the sun, bright searchlights, or the detonation of a nuclear weapon. Andrews (1979) states that "The human visual system is highly sensitive to sharp, well-defined changes in contrast but is very poor in judging absolute brightness." From these statements and the above figure, it becomes apparent that the luminance-level <u>goal</u> for a display system should be approximately 10 foot-lamberts. This figure is high in relation to the state-of-the-art and may not be obtainable in the near term. If it were available it could produce flicker under certain circumstances.

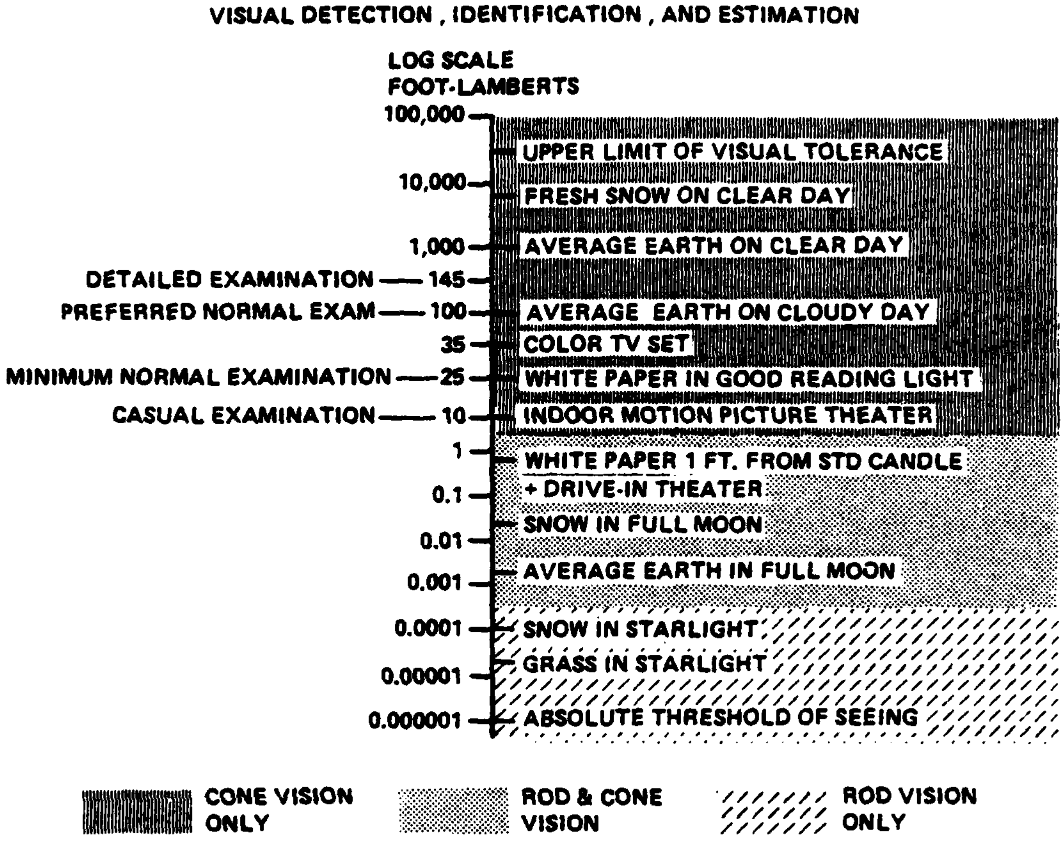


Figure 31. Examples of Various Levels of Luminance (Composite of Van Cott and Kinkade (1972) and Farrell and Booth (1975))

14.3 TYPES OF DISPLAYS

What follows is a synopsis of the Thomas and Jones (1977) study on wide field-of-view visual display systems. Statements in quotations but lacking an author notation are from this report. Additional information on virtual image displays may be obtained from Spooner (1975) as well as LaRussa and Gill (1978).

14.3.1 Real Image Displays

Real image displays are displays which present an image on a surface for viewing by the observer. They may be either direct view CRTs or projection systems.

14.3.1.1 Direct view CRTs. Direct view CRTs are perhaps the simplest method of presenting visual information via a television display. Their limitations are rather severe, as close viewing is required, forcing the eyes to focus unnaturally, and head motion causes gross parallax errors to occur. These errors occur because the viewer expects a change in head position to give a corresponding change in the visible surfaces of the close objects which are displayed. No such change in visible surfaces can take place with direct view CRTs at close distances.

14.3.1.2 Projection systems. Projection systems may utilize one or more flat screens or a spherical screen. Flat screens, unless they utilize rear projection, are subject to keystoning. Additionally, the copilot may see an object such as the runway as much as 24 degrees to the left of its actual position (Spooner, 1975). "Since the image is real and only 6 to 10 feet, the eyes are not focussed at infinity, and a true simulation of eye focussing is not obtained." "The advantage of the projection screen display method is that it is simple in theory, simple to implement, low in cost and a real image is produced without optical distortions." The flat screen technique is among the earliest ever used, and either rear or front projection is possible.

In spherical dome systems, television projection or laser projection can be utilized to place the image on the screen.

With the exception of the laser approach, spherical dome systems suffer from an overall low level of resolution, as well as luminance. To improve the resolution, some form of target insetting is often used.

The scanned laser approach may, in time, provide resolution to 5 minuts of arc but currently 8 or 9 minutes of arc is a more realistic expectation over the entire FOV. While a current Redifon system uses a model board as the image source, the display technique could lend itself to a CIG source. .They are currently working on color. Singer-Librascope is reported to be working on a laser display utilizing individual channels to create a multichannel display. NTEC has set aside its 360° non-programmed laser display system.

Both Redifon and Singer have demonstrated this type of hardware with more advanced demonstrations being probable over the next 1 to 1.5 years.

14.3.2 Virtual Image – Infinity Optics Systems

A virtual image of an object is an image which can be seen but is not formed on a surface. The image appears to occupy a point in space. The light rays which make up the image appear the emanate from this point in space. A good demonstration of the concept occurs whenever a person sees his or her own image in a mirror. The image appears to be the same distance behind the mirror that the viewer is in front of the mirror. In this example the image was formed by reflective optic(s) but virtual images can also be formed by refractive optics.

The process of forming a virtual image is important in visual flight simulation because most of the visual information being presented is at or near infinity in the real world. If the simulation presents the image too close to the viewer, the viewer may get conflicting depth cues. It is possible through the use of reflective or refractive optics to form a virtual image, of the visual scene, at infinity.

Infinity optics systems offer the potential for lower cost, higher brightness, and higher resolution than most projection techniques. Infinity optics systems can be configured in numerous different ways, such as refractive displays and at least four types of reflective displays: non-pupil-forming, single-mirror displays; pupil-forming, dual-mirror displays; in-line reflective pupil-forming and non-pupil-forming displays; and off-axis reflective displays.

14.3.2.1 Refractive displays. "Refractive displays are defined as those display techniques using refractive lens elements only. By placing the object at the focal point of the lens system, the image, as seen by the observer, appears to be at infinity; the lens simply collimates the light. This simple approach eliminates one of the disadvantages of the wide screen displays in that the image on the screen now appears virtual and at infinity. The collimating lens elements, however, are usually quite large (48 inches), heavy, and are difficult to manufacture." Additionally, chromatic aberration is a problem and reduces resolution as well as user acceptance (Heinzman and Shumway, 1976). "An interesting alternative would be a plastic fresnel lens, which is a flat, thin piece of plastic on which are molded zones. They extend from center to the outer margin. Each groove is a miniature refracting facet capable of bending light. The lens ability to pass light is greatly increased over that of a conventional lens of the same focal length. Therefore, a large-diameter, light-weight lens with a short focal length is possible."

14.3.2.2 Non-pupil forming, single-mirror displays. "The single-mirror, non-pupil-forming reflective system consists of an input screen, a beam splitter and a spherical mirror with a viewing position located at the center of curvature of the mirror. . . . In a non-pupil-forming display, the object placed at the focal point of the infinity lens system is a real image, such as a diffusive screen or a CRT face plate. The actual viewing position is located slightly toward the spherical mirror to allow lateral head movement and still see the full field-of-view. The eye relief dimension is 24 to 36 inches. The compact construction and potential light weight makes the approach very attractive. Perhaps the main advantage of the reflective system or the refractive display technique is that there are no color aberrations generated. The overall light transmission is good, but the beam splitter reduces the image brightness 80%.

"The most limiting characteristic of the single-mirror, beam splitter, non-pupil-forming display is in the restricted field-of-view and, in particular, the vertical field-of-view. This requires that for a wide field-of-view visual system several units are required to cover the field-of-view. The eye relief of this type is also limited."

14.3.2.3 Pupil-forming, dual-mirror displays. The drawback of the single-mirror system is the intrusion of the input screen into the optical path, limiting the maximum obtainable vertical field-of-view. Instead of using a real image as the input, a virtual image could be used. In this way, no screen would protrude into the field-of-view, thus allowing a wider potential vertical field-of-view. A pupil-forming display places a virtual image input at the focal point of the infinity lens system. One method of producing the virtual image is to use a projection mirror. " . . . The technique is termed a concentric system since the centers of curvature of the two mirrors and input screen coincide. The inclined beam splitter . . . reduces the eye relief distance significantly. Eye relief distances of 18 to 24 inches, however, are easily obtained. In the pupil-forming system, the viewing position is best placed within the area defining the exit pupil such that the full field of view is visible. Since a reflective mirror is used as the lens element, no chromatic aberration will be generated. Only spherical aberrations appear as the major problem and can be minimized by using large-radius mirrors. The concentric mirror's system has several disadvantages. Special input screens must be used which have a small radius of curvature but large field-angle coverage. If a CRT is used as the input screen, a special CRT would have to be constructed to minimize collimation errors. The display system is physically larger than the single-mirror reflective or multiple-lens refractive systems, which may make it more difficult to attach to a motion platform. Another drawback in the dual-mirror system is that two beam splitters are necessary to implement the display properly. This means that only 4% light transmission can be achieved. Again, greater requirements are placed on the input video device, since a much brighter display is required."

14.3.2.4 In-line reflective, pupil-forming and non-pupil-forming displays. "In order to correct one of the problems of earlier reflective displays - that of large size - the Farrand Optical Company, Valhalla, New York, developed a reflective infinity display optics, termed the pancake window. The goal of the new display technique was to provide an infinity display system that would be compact and lightweight without sacrificing field-of-view and image quality" "The input image can be a diffuse screen input for a non-pupil-forming display or a virtual image for a pupil-forming display. The image passes through the spherical beam splitter and is reflected off the flat beam splitter and back to the surface of the spherical beam splitter, where it is collimated and reflected toward the observer. To prevent the incorrect image from being observed, the image is polarized" "The action of the flat beam splitter is to locate the input image of the focal surface of the spherical beam splitter. This allows a much larger eye-relief distance and a more compact structure.

"Although at first glance, the pancake window appears to be an ideal optical display, there are several noticeable disadvantages.

"The most undesirable characteristic is the 1.2% light transmission. A second drawback is that there are unwanted ghost images generated.

"The polarizers and quarter wave plates are not 100% effective in blocking out the unwanted images. The redeeming feature of the unwanted images is that they are not focussed at infinity, and in a dynamic training situation these images will not be noticed by the pilot."

Additionally, a color capable version of this display is still under development.

14.3.2.5 Off-axis, reflective displays. "Redifon Flight Simulation, Ltd., has taken a different approach to obtain a virtual image display system. The main lens element is still a reflective mirror, but instead of having the image placed on the same axis as the observer, the image is placed off-axis. This off-axis display is known as Duoview. The prime advantage of this technique is that no beam splitters are necessary, thus increasing the eye relief distance and the light transmission. One of the prime uses of the off-axis system has been in the side-by-side seating arrangement. Since the input is a diffuse screen, the system is non-pupil forming. Due to the large size screen necessary, a video projector and rear projector screen are used. Folding mirrors are used to minimize the physical distance between the screen and projector while maintaining the correct optical path length. The mirrors also correct for image distortion created by the off-axis mirror lens. There is no color distortion created by the display since reflective optics are used. The only drawback of the Redifon Duoview is that the field-of-view is limited to only 60 degrees." The current authors feel that an additional drawback is the restricted resolution of this system, which is 8 to 10 minutes of arc (compared to 2.7 minutes of arc at Boeing Aerospace [GE]), as well as the difficulty in cleaning the mirror surfaces.

14.3.3 Virtual Image — Helmet-Mounted Displays

Helmet-mounted displays may be considered to be a second form of virtual image display system. Several groups have been doing work with this type of display system: The Naval Air Development Center, Warminster, PA (Thomas and Jones, 1977); The 6570 Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio (Kocian, 1977); the Farrand Optical Company, Incorporated; ASPT; and VTRS.

A helmet-mounted display may be used alone or in combination with any other type of display system. It can provide a narrow, instantaneous field of view, which is capable of being repositioned, through eye-position sensing, to give a wide field of view. This approach may provide monocular or binocular information and is attractive because of its potential cost savings as well as simplicity. Its potential disadvantages are that there may be a disparity in brightness, problems with display registration and eye dominance to consider (Kocian, 1977). Additionally, unless some universal helmet type is developed, the time for fitting may be extensive, running to 1/2 hour or more. ASPT is considering utilizing an inflatable bladder which is internal to the helmet and will make it universal, thereby providing a 5-minute fitting time.

14.4 AREA-OF-INTEREST CONSIDERATIONS

Edge conservation may be accomplished through the realization that the eye is a variable acuity device. Acuity of the human visual system decreases with increasing angular distance from the optical axis with the foveal area having the greatest resolution. Dial (1976) has suggested a variable acuity, remote viewing system, which takes advantage of the fact that "The human visual capability can be represented by about 130,000 resolution elements, provided that these elements are sized non-linearly according to the eye acuity function. . . ."

The required density of displayed information is inversely proportional to the size of the area-of-interest, while the cost of a CIG system is directly proportional to its edge capacity. A potential for savings exists if an area-of-interest approach is utilized (Monroe and Richeson, 1977).

The area-of-interest approach may be implemented in a real image display system or a virtual image display system. A helmet-mounted display could be used in conjunction with this approach or alone or the area-of-interest could be implemented in the displays themselves without utilizing a helmet-mounted display.

It should be noted that both helmet-mounted displays and area-of-interest presentations require either head-position sensing or both head-position sensing and eye-position sensing. By their very nature, they infer the use of a helmet.

The area-of-interest approach does have its weaknesses. Booker (1979) at NTEC pointed out that in order to develop an area-of-interest image you have to develop a highly detailed image over the entire environment, then present the specific area which is being viewed. This approach does not improve the data base building problem; in fact, it exaggerates it. Neither Booker nor Chambers had confidence in the area-of-interest approach. At ASPT, pilots found that it was "extremely difficult to maintain their orientation without a horizon throughout the display" (Monroe and Richeson, 1977) when using the area-of-interest. The limited field-of-view experiments done at ASPT demonstrated that a horizon line added outside the cone kept the pilot from becoming disoriented when performing certain maneuvers.

Since a helmet-mounted display may not provide this feature, helmet-mounted displays used alone, may prove to be an unacceptable display technique. The problem manifested itself most obviously when the pilot's head motion caused the area-of-interest to slew around the cockpit. This problem may not exist for a straight-ahead task, such as an approach to a landing (Cyrus, 1979).

14.5 RASTER-SCAN IMAGING EFFECTS ON PERFORMANCE

Biberman (1973) gives a partial list of parameters affecting performance in raster-scan systems. See Table 38.

Table 38. A Partial List of Raster-Scan Imaging System Parameters Affecting Observer Performance (Adapted from Biberman, 1973)

Mean luminance	Aspect ratio
Size [and shape]	Raster direction
Viewing distance	Contrast enhancement
Number of active raster lines	Video bandwidth
Contrast	Detector irradiance level
Scene movement	Target and background characteristics
Gamma	Terrain masking
Signal-to-noise level	

He credits Johnson (1958) with determining the number of TV lines required for various levels of object discrimination. Johnson defines four levels of object discrimination:

(a) Detection. An object is present.

(b) Orientation. The object is approximately symmetric or asymmetric, and its orientation may be discerned.

(c) Recognition. The class to which the object belongs may be discerned (e.g., house, truck, man, etc.).

(d) Identification. The target can be described to the limit of the observer's knowledge (e.g., motel, pickup truck, policeman, etc.).

Biberman points out that Johnson's information has been misused and, in some cases, systems have been underdesigned by a factor of 4 or more. The two major factors causing this error are:

(a) The confusion between the definition of "TV lines" and "line pairs"

(b) The minimum dimension of the object is the determining factor, not the maximum.

"Line pairs" are significant in TV raster displays because 2 lines are required to show 1 cycle of information; that is, 2 lines are required to show a transition between an object and its surround. No definition of an object's edge is possible with a single raster line.

The minimum dimension must be used in lieu of any other object dimension as it is the critical factor in object discrimination.

Two factors of critical importance in meeting Johnson's criteria are:

(a) The "signal-to-noise" ratio

(b) The image contrast

Without a sufficient signal-to-noise ratio or image contrast, the following tables become invalid. Johnson's criteria for the resolution required per minimum object dimension versus discrimination level is given in Table 39. It must be noted in this table that the resolution given is in TV lines - not line pairs. The next table, Table 40 gives the resolution necessary to discriminate typical ground targets.

Table 40 gives the number of lines required in "line pairs." The averages are rounded off from the previous table. The minimum dimension of a truck, tank, or car would be its height; the minimum dimension of a soldier, standing, would be his width; and the minimum dimension of 105 Howitzer would be its slant height from the bottom of its wheels to the top of its shield.

Table 39. Johnson's Criteria for the Resolution Required Per Minimum Object Dimension (Adapted from Biberman, 1973)

Discrimination level	Resolution per minimum object dimension, TV lines
Detection	2 +1.0 -0.5
Orientation	2.8 +0.8 -0.4
Recognition	8.0 +1.6 -0.4
Identification	12.8 +3.2 -2.8

Table 40. Required Resolution for Detection, Orientation, Recognition, and Identification (Adapted from Biberman, 1973)

Target Resolution Per Minimum Dimension in Line Pairs

Broadside View	Detection	Orientation	Recognition	Identification
Truck	0.40	1.25	4.5	8.0
M-48 Tank	0.75	1.20	3.5	7.0
Stalin Tank	0.75	1.20	3.3	6.0
Centurion Tank	0.75	1.20	3.5	6.0
Half-Track	1.00	1.50	4.0	5.0
Jeep	1.20	1.50	4.5	5.5
Command Car	1.20	1.50	4.3	5.5
Soldier (Standing)	1.50	1.80	3.8	8.0
105 Howitzer	1.00	1.50	4.8	6.0
Average	1.0±0.25	1.4±0.35	4.0±0.8	6.4±1.5

The use of Johnson's criteria requires that a calculation be made of the visual angle subtended by the target object at the desired slant range. The visual angle in degrees of arc may be defined as:

$$\boxed{\text{Visual Angle} = \text{arctangent} \ \frac{\text{Minimum target dimension}}{\text{Slant range to target}}}$$

For example, with a target whose minimum dimension is 10 feet, having a desired detection range of 25,000 feet, the visual angles = arc tangent $\frac{10}{25,000}$ = .0229° of arc or 1.375 minutes of arc. The system capable of providing this resolution would require one "line pair" (two TV lines), according to Johnson's criteria, per 1.375 minutes of arc for detection at 25,000 ft.

No examples are given by Johnson or Biberman for airborne targets. It may be that the same requirements apply. Rivers (1977) reports that the Differential Maneuvering Simulator (DMS) pilots were able to acquire and effectively determine the aspect as well as range and range rate for targets the size of an F-4 aircraft at slant ranges up to 18,000 feet. Gordon et al. (1975) claims that slant ranges of 300 to 45,000 feet are available from the DMS, but he does not give the field of view or active TV line count for the target projector utilized; consequently, no line-pair figure per arc minute can be determined.

The resolution of a display system may also be defined by the number of arc seconds per line pair of the display:

$$\boxed{\text{Resolution} = \frac{120 \times \text{FOV}}{N_{LA}}}$$

where the resolution is in arc minutes per line pair, the field-of-view is in degrees and N_{LA} is the number of active TV lines in the system.

Example:

N_{LT} = Total number of raster lines per frame = 1024

N_{LA} = 92% - 93% of $N_{LT} \approx .947$

Vertical FOV = 30°

$$\text{Vertical Resolution} = \frac{120 \times 30}{947} = 3.8 \text{ arc min/line pair}$$

It can be seen by looking at this equation that the number of line pairs in this definition is related to angular measurement. Conventional resolution concepts relate the number of individual lines (rather than line pairs) to millimeters (rather than angular measurement).

One last note should be made though not totally appropriate to this section on displays: Johnson's findings are for the ideal case, anything which decreases the contrast of the object to its surround (noise, camouflage, etc.) will impact his figures, as will the similarity of the object's dimensions to objects in its surround. The amount of impact cannot be quantified as it varies with the source.

14.6 MEASUREMENT OF IMAGE QUALITY

It has been demonstrated that there is a relatively low correlation between intentional degradation of resolution and performance (Task et al., 1978). Task suggests that resolution not be used as a general indicator of image quality, and that, in any case, its use be exercised with caution.

Modulation Transfer Function (MTF) evaluation is a more worthwhile tool to use. The Modulation Transfer Function is equal to the Output Modulation divided by the Input Modulation. If the peak-to-peak (PP) amplitude of an Input signal is said to be 1 unit and the PP amplitude of the Output is the same; dividing Output by Input equals 1 or 100% MTF. If the output is .5 of the Input the MTF equals 50%.

The log Band Limited Modulation Transfer Function Area (log BLMTFA) has been found to give the highest correlation between the measured image quality and performance (Task et al., 1978).

Biberman (1973) as well as Ewart and Harshbarger (1975) discuss the setup for measuring MTF.

Melrose (1976) describes the modulation transfer function in the following manner: "If a TV system is required to reproduce a gross, black-to-white transition, consisting of resolution bar patterns, the video signal wave form would take virtually no time to move up from minimum black reference level to maximum white response level. A complete square wave replica of the bar pattern results. As the bar pattern intervals are reduced (to higher resolution spatial frequencies), and given the TV system's timing constraints, the move-up time reaches its practical limit, at or before the given interval is transversed. This results in just reaching (peaking) the maximum white level (100 percent contrast/modulation) or partially reaching that level (percentage modulation). Partial or percentage modulation, then, is suitable as a valuable tool in measuring resolution [image quality]."

For further discussion of MTF also see:

(a) Johnson, C.B.

(b) Farrell, R.J. and Booth, J.M., 1975

SECTION 15

DISPLAY WEAKNESSES

This section contains a discussion of weaknesses which may generally be attributed to the display technology rather than CIG technology.

15.1 RESOLUTION

Over a wide instantaneous field-of-view display resolution cannot match human perceptual characteristics nor will it be able to in the near future. Kraft (1979) has graphically portrayed the relationship between display resolution, defined as visual angle in minutes of arc to human vision and visual efficiency in percent. See Figure 32. This type of comparison relates only to one form of human visual acuity, minimum separable acuity. Minimum separable acuity is the least sensitive of the four acuities, which also include vernier, stereo and minimum perceptible acuity. Each of the last 3 is much more sensitive than minimum separable acuity with minimum perceptible acuity being better than .6 seconds of arc. See Section 7.1.1.

There is no definitive information showing the correspondence between the magnitude of this weakness and the degradation in performance on the part of the pilot; however, Kraft (1979) asks how we could expect a pilot who is "legally blind" to perform a visually oriented task. Legal blindness is defined as 20/200 vision, which corresponds to 10 minutes of arc resolution. This figure is poorer than some current CIG systems are capable of but is used to illustrate a point.

15.2 DISTORTION

Distortion correction (see 7.1.5.3 and 14.1.5), particularly in a dome system may, by necessity, be quite extensive. AT VTRS, a doubling of the CIG edge capacity has been required to accommodate the truncation of edges which occur during distortion correction calculations. Uncorrected distortions may affect geometric perspective and may change the perception of the position in space.

Mays and Holmes (1978) in their paper titled, "A Three-Channel, High-Resolution-T.V. Image-Generation System" describe a geometric distortion correction system. Although this system is meant to correct the distortions created principally by a wide-angle, optical probe and associated electro-optical components, in a camera/model system this approach could possibly be applicable to correcting other sources of geometric distortions, such as dome systems.

15.3 LUMINANCE

Luminance in display systems is not as high as it should be to support human acuity. It is true that beyond a certain point increases in the level of

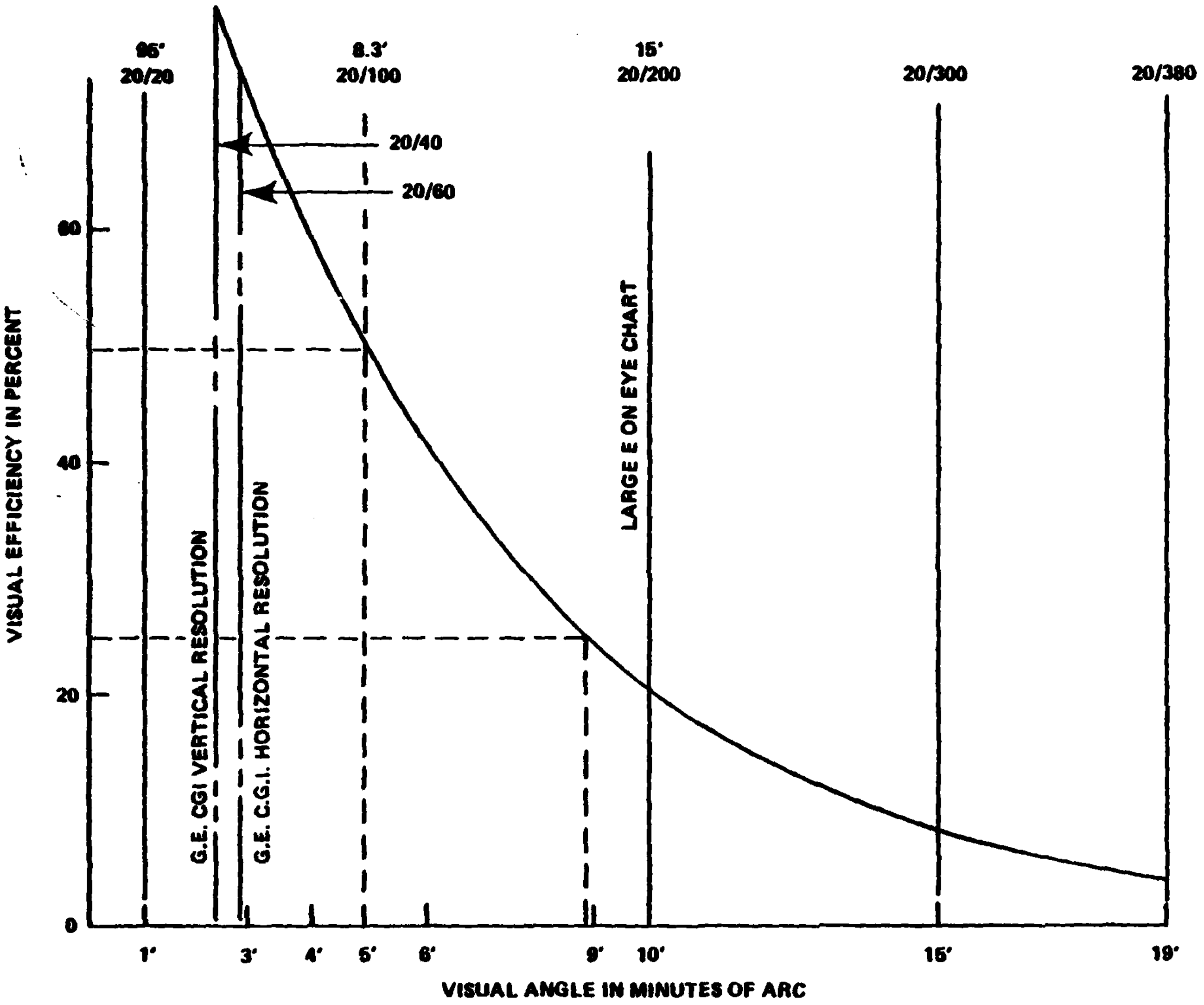


Figure 32. The Relationship Among Simulator Resolution, Visual Efficiency, and Visual Acuity (Kraft, 1979)

light do not significantly affect perception and that the human being is relatively insensitive to the absolute level of light. However, levels below 10 foot-lamberts begin to impact perceptual characteristics significantly (Van Cott and Kinkade, 1972; Farrell and Booth, 1975).

15.4 TONAL RANGE

Tonal range in display systems does not match the real world. Contrast, being a function of the tonal range, is affected. Contrast is a very significant factor in perception; relative contrast determines detectability.

15.5 COLOR

In CIG, no additional feature comes without some consequence to system performance or cost. Color is certainly no exception. At Boeing, during experiments on the legibility of alphanumeric characters presented by CIG systems, it was found that the convergence of the three-gun system was critical to the legibility of the characters being presented. Even the slightest deterioration in convergence worked to the detriment of legibility (resolution). Without near-perfect convergence, the display would not meet its stated specifications.

At NASA, it has been found that the overall color balance varies between one tube and another. In systems where mismatched tubes are juxtaposed, the difference in color is very obvious. No conclusions have been reached as to what possible detrimental effects these differences may have.

In addition to color convergence, fringing and separation problems exist in three-gun raster CRT-based systems. Without perfect convergence, performance will suffer. Holmes and Mays (1978) describe a technique for correcting color aberrations for three-gun CRT systems in their paper titled, "A 25-inch, Precision Color Display for Simulator Visual Systems." This technique may be of interest.

The use of color may cause a lower level of luminance to be available from the system. Color increases cost.

15.6 FLICKER

Flicker is a problem which may be disturbing to some observers. The flicker threshold varies with the individual, as well as with the level of luminance, refresh rate, and phosphor-persistence. It is generally visible in the periphery and becomes more apparent in wide field-of-view displays. Increasing the level of luminance of the display requires an increase in the update rate to keep flicker below the perceptible level.

15.7 STEREO

Stereo displays are possible but, to the author's knowledge, have not been implemented in flight simulation. See also 7.1.1(a) and 7.2.5.5.

Two-to-one, interlaced video information lends itself very well to right-eye/left-eye stereo presentation. One approach, developed at the Naval Ocean Systems Center, San Diego, CA 92152, utilized this fact by presenting alternating fields of information to each eye and using glasses which alternately shut off, then allow to pass, light from the visual system. The even field contains information for one eye and the odd field contains information for the other eye. In order to utilize this approach with a CIG system, the CIG system would be required to do calculations for two different eye points, i.e., the right eye, then the left eye. CIG has the accuracy to do this. Light transmission through the glasses is very poor and is the one weakness of this system.

Another approach for presenting stereo information, which might be applicable to simulation, has been developed by Bolt, Beranek and Newman, Inc. (bbn) of Cambridge, MA 02138. This technique utilizes a vibrating mirror to displace a CRT image of an object along the Z (depth) axis. The part of the object being displayed at any one instant in time is dependent upon the position of that part along the Z axis. The net effect is a whole object (the sum of its parts) receding in space. This type of display might lend itself admirably to some CIG algorithms because of the manner in which it uses Z axis information.

Spooner (1975) has made a rather uniquely circular argument against the necessity for a stereo display. His assertion is that, because a display cannot provide the resolution necessary to match real-world stereopsis, a stereo display is unnecessary. He points out that with an acutance of 10 seconds of arc and an eye spacing of 2.5 inches stereopsis should function to over 4,000 feet. Since, in this example, the TV display system can provide only approximately 10 minutes of arc, it is 60 times less sharp than needed for the threshold of detection of retinal disparity. The net effect would be a functional stereopsis at a distance no greater than 75 feet in the simulator. Carrying his reasoning further, however, a display system which could provide one minute of arc resolution could also provide stereopsis to a distance of 750 feet. The possible necessity for stereoscopic presentation should not be dismissed simply because it is currently impractical to conceive of an adequate method for implementation.

15.8 ACCOMMODATING MULTIPLE OBSERVERS

Accommodating multiple observers is not easily accomplished by current display systems.

Approaches such as Duoview, which may provide an exit pupil large enough, do not generally provide higher resolution images (10 minutes of arc).

Non-collimated visual systems, such as dome systems, are inappropriate for multiple observers, as they displace those observers from the center of the dome and cause distortions in geometric perspective to occur. One potential solution to this displacement is a very high-gain dome surface, which would provide different images for each observer, while inhibiting the image intended for one observer being viewed by another. The major disadvantage of this approach is that it would require distortion correction calculations for each observer.

Helmet-mounted displays offer promise in resolving the problem of multiple observers.

15.9 UNCONTROLLED VARIABLES

Uncontrolled variables can cause unexplained changes in performance on the part of the pilot. See also 17.1.1. The determination of which variables cause which effects is essential.

As previously stated (see 7.2.5.3[i] and 8.2.8) Kraft, et al. (1977-1979) found that how well a pilot maintains the visual glide slope is entirely dependent upon the range at which the runway surface is acquired in respect to the runway lights. The availability of a runway surface is totally dependent on how the maintenance personnel set the relationship of the day scene to the night scene. If left unattended it would become a random variable in the flight simulation.

15.10 ALPHANUMERIC LEGIBILITY

Alphanumeric characters may appear on the runway or other surfaces in a CIG scene. When interaction takes place between the motion of characters and the raster structure, misinterpretations can occur. An experiment was done using those letters and numbers which are most often confused with others (Kraft, 1979). During the experiments, nobody got the letter M correct; it was always seen as a letter H. The cause was the rate of motion of the letter M and the period of time during which the crossbar was written. It really did turn out looking like an H.

On a color system, legibility is most affected by the degree of convergence of the three color guns. If the three guns are not converged almost perfectly, the legibility will drop off.

15.11 TARGET PROJECTOR POSITIONAL ACCURACY

Positional accuracy and repeatability in display systems utilizing target projectors can be a problem. MAGICAM, Inc., a subsidiary of Paramount Pictures Corporation in Los Angeles has developed a synchro/servo system which may alleviate the problem but could require direct access to simulation data.

15.12 MULTIPLE CHANNEL REGISTRATION

Multiple channel registration can be a problem. Raster shaping of the display is required and not all displays support raster shaping.

SECTION 16

CIG STRENGTHS

General CIG strength becomes apparent when it is compared at the system level with camera/model systems. It has been demonstrated that in sorties, which included landings, night only as well as day/night, CIG systems feeding a closed circuit television (CCTV) display system demonstrated a greater increase in flying skills than did a camera/model CCTV display system (Thorpe, et al., 1978). Additionally, although Thorpe concluded that "Neither the day nor night (CIG) system was more effective than the other," in at least one instance (the check ride evaluations, Table 41), the day/night CIG system did appear to out-perform the night-only CIG system.

Table 41. Final CCTV Check Ride Evaluations

Evaluation	Day	Night	TV
Highly Qualified	9	5	4
Qualified	1	5	6

The individual strengths of CIG systems can best be illustrated when a comparison is made with the specific weaknesses of camera/model systems. What follows is a comparison of this type:

(a) Depth-of-Field

Depth-of-field is a problem with camera/model systems, which simply does not exist in CIG.

(b) Resolution

Camera/model system resolution and clarity is a problem which may not be resolvable. Boeing felt that the best theoretically possible from a camera/model system was 8-1/2 arc-minutes of resolution. From actual experience, they found it to be as bad as 19 arc-minutes. The GE Compu-scene at Boeing has vertical resolution of 2.7 arc-minutes per pixel (5.4 arc minutes per line pair), and this is definitely not the limit possible from a CIG system. Current goals for non-inset raster systems* range between 1 and 2 arc-minutes. Insetting has demonstrated a much greater potential.

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* Inset raster systems have a high resolution target or area-of-interest inserted into a low resolution background.

Rivers (1977) found that "Of the A/S [Air to Surface] systems evaluated, only CIG systems afforded the clarity and resolution necessary to recognize and identify objects at normal slant ranges."

(c) Unlimited Attitude and Position

Camera/model systems may have restricted roll and pitch, while CIG systems are unlimited in attitude or position.

(d) Unrestrictive Gaming Area

The limited gaming area available from a camera/model system can cause a pilot to expend an inordinate amount of time staying within the gaiming area (Rivers, 1977). A CIG system has no such problem with gaming areas, potentially extending to 500 to 500 nautical miles or more.

(e) Easily Modified

Fixed models are not easily modified or replaced. CIG systems have the potential for doing this easily but at some cost.

(f) No Mechanical Lags or Overshoots

Mechanical lags, overshoots, and positional resolution problems which restrict accuracy and repeatability in camera/model systems do not exist in CIG systems. The response of a CIG system to changes in attitude is inertia free.

Positional and computational accuracy as well as repeatability are the strong points of CIG. Boeing measured the positional accuracy of their GE system. The result startled them. They found that the accuracy at the display was .12% and repeatable. E&S has no calculation accuracy figures for perspective relative error (which is the error from one pixel to another). Rather they use the concept of step resolution. This concept takes into consideration angular and positional representations at very low viewpoint or eye height. Of concern is the appearance of runway stripes when sitting on the runway in a fighter-type aircraft. Slow taxi and turns may cause what appears to be discrete jumps in the position of the runway markings such as the runway center line. With the accuracy that E&S uses at low eye height taxiing, the runway stripe does not index discretely under slow rates of angular and positional change (Doenges, 1979). Link has a worst case of calculation inaccuracy of ± 1/4 pixel in the x and y linear dimensions (1 part in 4000, because there are, generally speaking, 1000 pixels per line).

If there is one problem with positional accuracy, it is on the part of the display when depicting light points which may be spread out over several pixels so that motion from one pixel to another does not appear to occur in discrete jumps. Subscan line averaging of light points could alleviate this problem, however. Please see Section 17.2.12.

(g) Special Effects

Special effects are either difficult or impossible to do with camera/model systems. Effects such as moving targets, missile threats, bomb bursts, strafing, day, dusk, night, sun image, weather effects, etc., are possible with CIG.

(h) No Probe Crash

Probe crash simply does not exist in a CIG system.

(i) Multiple Levels-of-Detail

Closure (decreasing slant range) on a camera/model system does not provide additional detail, as would be expected, past a certain point. As an approach is made, it is true that more detail becomes visible, but only to the point where there is additional detail to become visible. Leaves on a tree will not become visible unless they are there, neither will the pattern of wheat in a field unless it is there.

(J) Distortion Correction

Distortion at the periphery exists in camera/model systems, and the result is a potential for geometric perspective distortion. Geometric perspective is, perhaps, the most invariable cue in the real world and can be accurately provided by a CIG system, although it may not be displayed accurately by the display portion of the system.

(k) Wide Field-of-View

A wide field of view, multi-channel approach is possible but perhaps impractical in a camera/model system. CIG lends itself well to this approach (until the FOV becomes so wide that Rθ calculations must replace tan θ calculations and impact system capacity by doing so).

(l) Reliability and Availability

Maintenance time, person-loading, and down time are higher with a camera/model system than a CIG system (NASA). Simply stated, reliability and availability are higher with a CIG system.

(m) Synthetic or Augmented Effects

Synthetic effects not found in the real world are not easily supportable by a camera/model system. Effects such as aim points, hit marks, and highways in the sky can be implemented in CIG systems.

(n) Different Mission Tasks — Same Hardware

Additional hardware is required to support different missions such as formation flying and air-to-air combat in camera/model systems.

No additional hardware is required to incorporate different mission tasks in a CIG system as long as the CIG system has the capability in the first place.

(o) Space Efficient

Space requirements for a camera/model system or systems can be quite extensive. While CIG systems are not small (some approach 20 bays), they do occupy significantly less space than some large camera/model systems using terrain model boards.

SECTION 17

CIG WEAKNESSES

The list of CIG weaknesses is extensive, and after reading it one may think, "Wy bother? There must be a better way." In truth, there is not.

With the exception of laser image generation, other image generation techniques (e.g., camera/model systems, film systems, etc.) are not improving in quality or providing new capabilities at a rate as fast as CIG; nor do they have the potential for improvement which CIG promises.

17.1 GENERAL SYSTEM WEAKNESSES

Weaknesses within the total visual system, which includes both image generation and image display may cause a number of undesirable side effects. For example:

17.1.1 Incidental Learning May Occur

Incidental learning is the acquisition of a skill without the operator's knowledge. See also 15.9. Although it is true that in an R&D environment, training is not the purpose of simulation, it is also true that learning does occur. If this learning is not related to responses to known cues, the implications of those responses become ambiguous.

Incidental learning occurred at Boeing when pilots made an approach to a landing using the CIG system. If the pilots were on the centerline, the runway edges appeared to crawl at an identical rate. If the pilot departed the flight path to the left of the centerline, the left runway edge appeared to move away, while the right runway edge appeared to move toward the pilot. The inverse was true if the pilot departed the flight path to the right of the centerline. The implication of this occurrence is that the pilots were probably able to get lined up with the centerline of the runway further out than they could in the real world, using this non-standard cue subconsciously. This type of effect falls into a group of raster CIG problems call anomalies. Anomalies are discussed later in this section.

17.1.2 Missing Motivation

Where motivation is lacking, it will not be enhanced by a visual scene which is a caricature of the real world. This should not be a problem, however, in an R&D environment.

17.1.3 Erroneous Cues

Some cues simply cannot be presented correctly. Extremely small scene elements such as edges of objects at a great distance, if they are portrayed at all, cannot be portrayed any smaller than one pixel in width. In effect, they will look larger than they should and may induce an illusion in the area of distance judgment.

17.1.4 High Initial Cost

High initial cost is a major drawback of any state-of-the-art, high-capacity, raster-scan CIG system. Several reasons contribute to the high cost:

(a) High complex, special-purpose hardware must be designed, built, and checked out to perform the CIG task.

(b) Most systems delivered are some form of prototype. The technology is changing so rapidly that each new system usually has new capabilities when compared to its predecessor. The implication is that there are technical and economic risks which are taken by the manufacturer and passed on as an increase in cost.

(c) A major portion of the systems is composed of CIG specific hardware. Therefore, there is not a broad market for the equipment developed, and costs cannot be amortized. "Modified" off-the-shelf hardware or "lab systems" are the closest one can come to a standard product when successive CIG systems are analyzed.

In the following sections an attempt has been made to divide the problems into the categories which either created them or are responsible for controlling them.

17.2 IMAGE GENERATION ASSOCIATED WEAKNESSES

The following is a list of significant image generation weaknesses. They are of importance not because they can be eliminated but because of their impact on system performance. How well these weaknesses are dealt with can be used for evaluation of proposed approaches.

17.2.1 Scene Anomalies

A good portion of what follows is a synopsis of a technical paper written by Szabo (1978). It should be referred to for a detailed discussion of CIG anomalies and illustrations.

Computer image generation causes a number of scene anomalies often referred to as aliasing. These anomalies occur because of the very nature of computer image generation and display, which requires that the scene elements represent an instantaneous point in space and time. The consequence of this requirement is that there are two types of anomalies or artifacts produced: spatial, dealing with space or position, and temporal, dealing with time.

Generally, the higher the contrast, the greater the scene anomaly problem becomes, regardless of type.

Conventional raster scan television images display an image which is the average of time and distance quantities over the period just preceding the display. In its simplest form, CIG does not do time or distance averaging.

17.2.1.1 Spatial anomalies. Spatial anomalies are the result of the interaction between the edge of the object and the raster structure of the display. It exhibits itself in a number of different effects such as:

(a) Stair-Stepping

Stair-stepping is the most noticeable of all the anomaly problems. It occurs when a diagonal line, such as the horizon line, changes position in successive fields or frames, as the horizon would do when the aircraft was rolling. If the raster lines run horizontally and the aircraft is horizontal, the horizon will be on one raster line. As the roll starts, the horizon line would cross an increasing number of raster lines and appear to be a series of steps increasing in number with the increasing number of raster lines crossed.

(b) Crawling

Crawling occurs when an object which crosses several raster lines moves horizontally. If the object is irregularly shaped or rectangular and at a slight angle from the horizontal, its leading and trailing edges will pass the center of pixels on different lines at different times. Consequently, the pixel no longer represents the object, even if the object still crosses through a part of the pixel. To be represented by a pixel an object must impinge on the pixel's center in the simplest CIG systems. When it does not, the object will appear to increase and decrease in volumetric size.

(c) Scintillation

Scintillation occurs when a very small object passes through the center of the pixel and is represented by that pixel. Movement away from the center of the pixel into another pixel's domain causes the object to be unrepresented by either pixel until the object passes through the center of the second pixel. The net effect is that the object appears and disappears as it moves.

Scintillation may also occur in the display of texture, although here it has been considered to be a temporal aliasing problem (Stenger et al., 1979).

(d) Line Break-up

Line break-up occurs when a diagonal line passes through a number of pixels and does not impinge on some of the centers of some of the pixels. The line would be represented by all the pixels through which it passed and hits the center. It would not be represented at all by the pixels whose centers were missed. Rather than appearing as a straight line, it would appear as a dashed or intermittent line.

(e) Mock Bands and Incidental Learning

Mock bands occur when there is a differential in contrast, at the junction between two surfaces, greater than 2.5 % (Kraft, 1979). The edge on the lighter side is perceived as being lighter than it is in actuality, while the edge on the darker side is perceived as being darker than it is in actuality. The net effect is that of a band falling between the two surfaces. Mock bands can appear during an approach to a landing. Under this circumstance, they show up as an edge moving down the runway at a velocity matching that of the aircraft and maintaining a constant distance from the aircraft. Mock bands which appear during an approach to a landing probably give false velocity cues, as they provide the observer with a visual reference, moving at his own speed down the surface of the runway.

(f) Moire Effects

Moire effects occur both in broadcast television and CIG-generated images. They are the product of the interaction of two patterns upon each other. The patterns are those of the visual information being presented and the raster structure itself. Some success has been reported in correcting moire effects (Stenger et al., 1979).

Correction of spatial anomalies is possible through several different techniques. These techniques have the effect of producing an image which may look less sharp than the uncorrected version but eliminates or subdues the anomalies. A form of filtering is used at the edge to reduce the high spatial frequency changes which occur there.

Crow (1977) suggested an approach for controlling anomalies which seems to work well (Stenger et al., 1979). Another approach using sub-pixel elements to average the pixel value also works well. Objects which are smaller than one pixel may be totally eliminated from the display in order to eliminate scintillation.

17.2.1.2 Temporal anomalies. Temporal anomalies are the second form of anomaly presented by raster-scan display systems. Unlike spatial aliasing, some forms of temporal aliasing are characteristic of broadcast television as well as CIG displays. In general terms, they are not as disturbing as spatial anomalies, but, on the other hand, they are less well understood. What is presented here is only a small part of a very complex issue.

Types of temporal effects which are of interest are:

(a) Interlace Effect or Field Tracking

The interlace effect occurs when the eye tracks an object moving vertically up or down on the screen. This effect is most apparent when large, evenly illuminated surfaces move up or down the distance of one scan width per field time.

As the eye tracks the object any particular point on the object appears at the same point on the retina in each successive field. Because of the tracking, areas on the retina directly above this point or below the point do not receive any light stimulus from alternating scan lines, and consequently a dark gap is perceived between scan lines where the alternate scan line should have been seen.

The interlace effect could be eliminated if a non-interlaced display were feasible. Unfortunately, it may not be, due to cost and the current state-of-the-art. Schumacker and Rougelot (1977) report significant improvements in the interlace effect or field tracking problem by changes made in the image-processing algorithms without going to a non-interlaced display scan.

(b) Frame Rate Update Effect or Double-imaging

The frame rate update effect or double-imaging is also caused by the eye tracking an object. In this case, however, the object being tracked is moving in a horizontal direction. The problem will only manifest itself if alternating fields are not updated. That is to say that if the CIG scene is recalculated at the frame rate rather than at the field rate this problem will exist. As is the case with the interlace effect, the act of the eye tracking the object causes the object to be positioned on the retina at a fixed location, as the eye moves. If the object continues to move at a fixed rate, and frame rate updating is occurring, successive fields will contain the same information. That is, field 1 and field 2 would display the object in the same position; then the next field 1 and field 2 would portray the object displaced in position by the distance which it would have traveled in the time between the first field 1 and the second field 1. The eye, consequently, is tracking the object from frame to frame, but every second field displays the object in the same position as the first field, and, as the eye moves, the object appears twice on the retina. It was thought that this effect could be corrected by field rate updating but recent evidence casts doubt on this solution and points to a non-interlaced display as the only solution (Ingalls, 1980).

(c) Stroboscopic Effect

The stroboscopic effects may be observed when an object moves in a repetitive manner or multiple objects of a similar nature follow each other sequentially. Due to the apparent snapshot effect of CIG, these objects may be displayed in the same location as similar objects previously appeared. If the objects appear in the same location, there will be no apparent motion. If the objects appear in an area close to where the earlier objects appeared, the motion will tend to be perceived as being in a forward or reverse direction, dependent upon where the subsequent objects appear. This effect manifests itself when objects like rotor blades, runway centerline stripes, or rows of lights are presented, and the rate of displacement positions them in near-identical locations with earlier objects of a similar type.

If blurring could be implemented in a CIG system, the stroboscopic effect might be eliminated.

Correction of Temporal Anomalies could be very complex and consequently costly. Temporal anomalies are less well understood than spatial anomalies and are correspondingly more difficult to correct.

17.2.2 Inadequate Overload Management

17.2.2.1 Edge crossings per system scan line restrictions. Edge crossings per system scan line restrictions are perhaps the most underrated factor having major impact on the full utilization of system capacity.

Only one manufacturer (E&S) has no such restriction, and even then there is a restriction on the number of polygons per field.

It is important to note that, as stated, the edge crossings per scan line restriction pertains to the entire system and is a total of each of the individual channels. Individual channels may have specific restrictions of their own. To avoid overload the ideal target figure for permitted edge crossings per system scan line should be 20% or more of the displayable system capacity (ASPT); however, a more practical figure might be 10%. See 5.2(c).

Even simple scenes can cause edge crossing overload when low level flight is encountered. In most CIG systems flying straight and level causes the horizon line to be represented by a single raster. Every object in the scene gets jammed up on this single raster/horizon line. Result: simple scene yet overload nonetheless.

The most obvious solution, a vertical raster system, only postpones the problem. As soon as a steep or vertical bank is executed by the pilot, the entire scene may be eradicated by the CIG.

Rolled raster systems are systems in which the rasters remain parallel to the horizon regardless of attitude. If edge crossing overload occurs in this type of system, it will do so regardless of the attitude as long as the horizon is within the FOV.

There is no good way to determine how many edge crossings a scene will generate when its data base is being built. It simply requires a cut and try empirical design approach.

In some systems it is possible that the total displayable edge capacity may never be utilizable. An inadequate number of allowable edge crossings per system scan line would be the culprit.

17.2.2.2 Position change induced overload. When closure on an object occurs, it grows in apparent size. In a multi-channel system, this growth may cause the object to expand from a single channel into a larger number of channels. When the object or objects pass through adjacent channel boundaries "pseudo-edges" may be created to truncate the object or objects at the boundary (E&S is the exception to this approach). The resultant "pseudo-edges" created may cause the system capacity to be exceeded. In one example, 25 edges became more than 100 (Rife, 1977). See Figure 33 for an example of 4 edges becoming 7.

17.2.2.3 Attitude change induced overload. Attitude change-induced overload may occur when the system is near overload and a very rapid change in attitude is initiated. The new attitude brings into sight objects which were previously outside the FOV. Consequently, the edge count skyrockets over the maximum. See Figure 34 for an example of this phenomenon.

17.1.2.4 Results of position or attitude change-induced overloads. Results of position or attitude change-induced overloads can be the loss of the display on all channels following the channel which induced the overload conditions for channel 5, the remainder of channel 5 could be blank as could channels 6 and 7 in a 7-channel system.

Overloads induced by changes in position or attitude may cause objects or parts of objects to be removed from the scene. Objects may pop into view well after the edge of the field of view has exposed their intended position to scrutiny.

Another potential effect of overload is double framing. Double framing may occur when a change in attitude causes an overload of the processing capability of the CIG system. The appearance of double framing is a scene which jumps from point to point.

Edge-crossing induced overload may cause streaks to appear in place of the information on the overloaded raster line, or the raster line may be replaced by the preceding raster line.

17.2.2.5 Compensation for overload. Compensation for overload may be accomplished in numerous ways. Using part of the system capacity as a buffer will forestall the onset of overload. By monitoring their own loading, CIG systems may gracefully implement overload management techniques such as fading to a lower level of detail.

A flexible sync standard, for the display, may be implemented to allow a small amount of additional time for the completion of calculations to occur. There are 2 potential side effect of this technique:

(a) The flicker threshold may become noticeable.

(b) Transport delay avoidance through synchronous updates of attitude and position as well as their rates become impractical unless the CIG system is in control of the transfers.

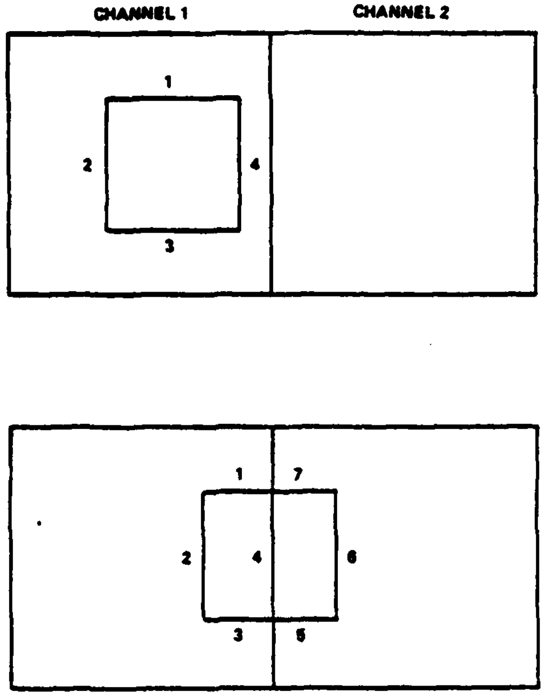

Figure 33. When Do Four Edges Equal Seven?

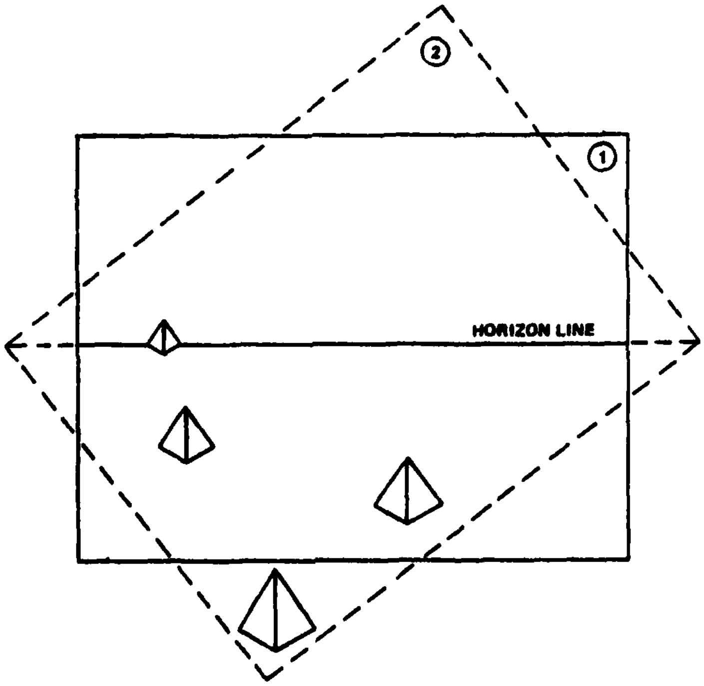

Figure 34. How to Exceed System Capacity

17.2.2.6 Level of detail switching compensation for overload. Level of detail switching may successfully be used as an overload management technique, but unless it is done correctly its effects can be very disturbing to the viewer.

As has been previously stated, the processing of visual information take approximately 250 milliseconds (Leshowitz et al., 1974). If a different stimulus is presented during that period of time, there is a large loss in retention of the original information. This may explain why abrupt changes in level of detail are very disturbing to some viewers.

A form of prioritizing must be used which allows scene elements of lesser importance to be removed first. The change in level of detail may not be accomplished through fading if the overload occurs very rapidly.

At ASPT the overload algorithm deletes models in priority order determined in 2 ways (Rife, 1977):

(a) Model importance

(b) Channel prioritization

The channel prioritization could be linked to an Area-Of-Interest technique and become more effective.

17.2.3 Data Base Building Weaknesses

Current data base building techniques are almost totally inadequate for an R&D facility. Research and devopment requires that data bases be custom tailored, as well as easily and quickly built. Current techniques are too time-consuming and expensive to allow this to be done cost efficiently. The consequence is that CIG software becomes hardware, remaining unchanged or only slightly modified long past the requirement for totally new software data basis.

The automation of the data base building process is mandatory. It must include the capability to convert DMAAC data to a CIG data base, as well as the creation and utilization of libraries of standard primitives. See Sections 11.2 and 11.3 for a more detailed discussion.

17.2.4 Separation Planes and Automated Data Base Building

A separation plane is a flat two-dimensional surface which is passed through a fixed or moving model (e.g., building or aircraft, etc.) to aid in resolving the priority of occluding surfaces within the model. By using separation planes, parts of the model are grouped into "clusters" and priority calcultions may be done on the "clusters" rather than on a surface by surface basis. Schumacker (et al) devised this approach in 1969 and it is still being used to this day.

If one object is inside the concave part of a second object (see Figure 35[a]), a separation plane cannot be passed between them. The second object

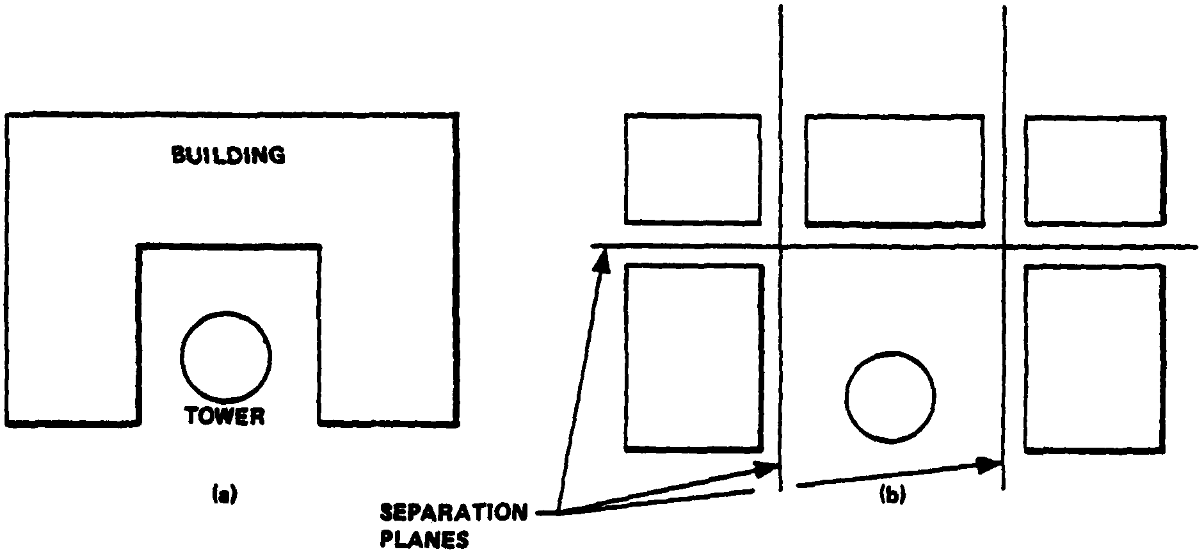

Figure 35. Separation Plane Implementation

must be broken down into smaller "clusters" to accommodate the separation plane. See Figure 35(b). The gap is imaginary but may become real in some systems, when depicting moving models, due to a faulty algorithm implementation.

Current approaches which utilize separation planes to determine occultation priorities do not lend themselves well to the automated conversion of DMAAC data to CIG data bases. It is most difficult to create an algorithm which will handle all cases of separation plane creation during conversion. A current movement away from separation planes may alleviate this problem.

17.2.5 Data Base Non-interchangeability

The commonality and transportability of data bases leaves much to be desired. See Section 11.4 for a full discussion of this CIG weakness.

17.2.6 Transport Delay

Transport delay can affect the performance of certain tracking tasks (e.g., formation flying, aerial refueling, etc.).

Transport delay can be defined as the time that elapses between the receipt of flight data from the host simulation computer until the completion of the display of the last raster line associated with that aircraft attitude information.

There are three different ways of looking at transport delay:

(a) Transport delay may be considered strictly as a function of the CIG system. Attempts to reduce this form of transport delay significantly below 100 milliseconds per frame, which is the current norm, would be counterproductive since it would come at the expense of either computational power or additional system hardware and cost.

A CIG system which is updating the display system at the field rate (60 Hz) has a transport delay which is either 50 ms (GE and Link) or 66.6 ms (E&S). The latter uses the additional 16.6 ms (1 field time) for scan line conversion, thereby eliminating any edge crossing per system scan line restriction.

This form of transport delay should not be considered as the key factor in the transport delay problem because the simulation program should provide for it.

(b) Variance from actual aircraft delay characteristics must be a significant consideration. It is possible for the display system to depict motion earlier or later than what would be expected in the actual aircraft.

(c) Disparity in cues and cue conflicts between various elements of the simulation system such as the visual system, platform motion system, g-suit system, g-seat system, and cockpit instrument must be compensated for.

Transport delay times and their effects have been discussed by a number of researchers. See Ricard et al. (1976) for additional information. Quiejo and Riley (1975) found that transport delays of 47 milliseconds could affect pilot performance in certain highly demanding tasks. In this experiment the primary task was that of tracking a target aircraft in a simulator. There was a side task meant to increase the pilot's workload to a level where any degradation in the visual presentation that affected his response could be measured. The target aircraft went through the sinusoidal oscillation in altitude varying ±100 feet within a 30-second period. Generally, it was found that transport delays of up to 141 milliseconds could be tolerated "without affecting the subject's performance or operating procedure." When the target oscillation period was decreased to 15 seconds, even a 47 millisecond delay was too long. The acceptable level of visual-scene time delays decreased with increases in task complexity and target rate or degradation of vehicle handling qualities. It is interesting to note that transport delays of 172 milliseconds were readily apparent to the subject while transport delays of 141 milliseconds were not. Indications are that, while subject performance may suffer and operating procedures may differ, subject awareness of these changes does not necessarily occur. The implication is, of course, that <u>subjective judgments of image accuracy or visual adequacy must be suspect</u>.

Kraft (1979) states that less than 2% of the population will <u>see</u> any visual lag if you keep the transport delay time under 100 milliseconds. He also quotes the Jerry Westheimer doctoral dissertation as indicating that transport delays of 147 milliseconds will probably incur pilot induced oscillation.

Cyrus (1979) states the opinion that ± 125 milliseconds from the delay of the actual aircraft will not be noticed by the pilot.

Other researchers (Cooper et al., 1975) have found that, while a 100 millisecond transport delay of visual presentation does not affect learning performance, it did cause them to perform their piloting skills differently. Both aileron control displacement and aileron control force varied significantly from the norm. There were no statistically significant differences found in the other four control parameters. It should be noted that the 100 millisecond figure given by Cooper is a delay in addition to the transport delay of the CIG system which itself varied between 12.5 and 25 milliseconds. The pilots actually perceived a delay of 112 milliseconds to 125 milliseconds.

Gum and Albery (1976) confirm that transport delays have their greatest effect on the control of aircraft roll position. They go on to say that "compensating for the majority of the CIG system transport delay turned out to be essential for proper simulation of formation flight." This compensation did not appear to affect other tasks such as approach and landing maneuvers as these tasks don't require precise judgments of linear distances and high frequency control input.

Ricard (et al., 1978) states that in formation flying, frequency of stick input were previously found to be as high as 3 Hz (Cyrus, 1976). Roll angle, pitch angle, and z-axis should be of particular concern because ". . .only the responses along these axes contained enough high frequency energy to create problems of "flutter" in the visual display" (Cyrus, 1976). Miller and Riley (1976) confirm that as the task difficulty increases, the acceptable time delays decrease (according to Ricard et al., 1978).

Motion helps offset the effects of transport delay by roughly doubling the acceptable delay (Miller and Riley, 1976).

Cue coincidence is of major importance and cue conflict between visual, motion, g-seat, g-suit and aircraft instruments can be very detrimental. Research seems to conflict in how best to compensate for this type of disparity. Bunker (August, 1978) while discussing training effectiveness versus simulation realism used as an example the installation of the NASA Differential Maneuvering Simulator (DMS) at Langley AFB, Virginia. Conceptually "Maximum realism is desirable – absolute realism requires zero delay – so all delays in the system were reduced to their practical minimum. This subjective effect of flying the system was highly unrealistic and unsatisfactory. They then determined which element in the system had the maximum irreducible delay and they increased all the system delays to match it. The result was a satisfactory system." This technique cannot be used, however, if it exceeds the delay which could normally be accounted for by the lag in response time of aircraft dynamics, which was shown in a later attempt to do the same thing. Gum and Albery (1976) say, "The cues could be brought more nearly into alignment by removing the CIG system transport delay compensation. However, pilots preferred to have the visual system delay minimized as much as possible, especially for formation flying." It should be noted that the motion delays in this system (ASPT) probably exceeded those of the actual aircraft.

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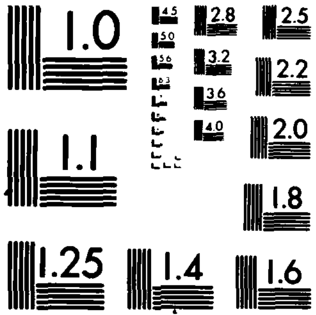

MICROCOPY RESOLUTION TEST CHART
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Attempts at compensation for transport delay have been made. Look ahead, through the use of predictor equations, has been used and works well for linear slew. However, system step response deteriorates. At ASPT increasing the host simulation computer's calculation of latitude/longitude information from 7.5 iterations to 15, and thereby doubling the transfer rate to the CIG system, had a dramatic effect on the pilot's ability to fly in formation (Gum and Albery, 1976). Prior to this "fix," pilot-induced oscillation (PIO) was normally the end results of closure on the lead aircraft during attempts at formation flying. Two studies (Ricard et al., 1976 and 1978) use filtering of aircraft response characteristics to compensate transport delay. Filtering in the range of 3/4 to 1 Hz was found to be most effective for the T-37 aircraft used in the simulation of formation flight.

Transport delay circumvention is to be preferred over any form of compensation. While compensation may allow improvement in apparent control of the aircraft, it cannot guarantee that pilot response in control force, control displacement and control frequency will match that of the actual aircraft under all circumstances. While compensation effectively removes noise from the system it also reduced resolution. High performance aircraft typically show a 200-300 millisecond delay between pilot control deflection and onset of aircraft response (Blatt, 1979). If flight control information was acquired by the CIG system directly from the flight controls and the CIG system had the equations of flight for the particular simulation, the transport delay characteristics of the CIG system could be utilized as part of the flight equation calculations. Totally bypassing the host simulation CPU in this manner could eliminate the hardware and software delays which are a normal part of every flight simulation system.

The flight equation iteration rates should be identical to the field update rate of the CIG system and synchronous with it; 50/60 Hz would then be considered the minimum iteration rate. In order that a disparity does not develop between the visual information and all other information developed by the host simulation CPU, position and rate information calculated for the CIG scene in this manner should be sent back to the host simulation CPU for its use.

An alternative to this approach is to do the equations of flight in the host simulator at an iteration rate identical to that required by the CIG system and synchronize the CIG system to the host CPU data transfers. The equations of flight would have to include the normal transport delay time of the CIG system (50 ms for GE and Link, 66.6 ms nominal for E&S per field).

This approach may solve the transport delay problem for the aircraft simulation visual presentation. It does not, however, approach the problem of moving targets. Airborne targets moving at high rates of speed and changing altitude rapidly will suffer from the same transport delay phenomenon if their flight information reaches the CIG system in a conventional manner. It is suggested that host CPUs calculate moving model equations with the fixed transport delay of the CIG system being a consideration. Again, transfer of information between the host simulation CPU and the CIG system should be synchronous with the CIG system calculation and presentation.

17.2.7 Field-Rate Updating or Non-Interlaced Display Impact

Field-rate updating, which may or may not eliminate a form of CIG scene anomaly (see 17.2.1.2[b]0, can cut the system capacity in half.

A non-interlaced display, which could correct two CIG scene anomalies (see 17.2.1.2[a] and [b]), may be beyond the state-of-the-art of current CIG technolgoy. It would double the required bandwidth and cut CIG system capacity.

17.2.8 Yaw Rate Restrictions

Restrictions in yaw rate may occur in some systems when the active data base does not contain adequate data to sustain high rates of change. Current Link systems display this phenomenon.

17.2.9 Moving Model Restrictions

Moving models, because they utilize separation planes (which disallow actual distance information) and a dynamic coordinate system cannot be fully preprocessed in order to determine their occlusion priorities off-line in the way that terrain and fixed cultural objects can be. If the software is used to generate the moving models, as is done in the E&S, SP1, and SP2 calligraphic systems, the systems could be hard-pressed to do the calculations for one mocing model if there were more than 1 channel involved. Approaches such as those taken with the E&S CT5 raster system utilize hardware to do the dynamic coordinate system calculations and forestall the time overrun which can occur with software calculations. For example, the GE system at VTRS which initially utilized a single PDP-11 general purpose computer as its front end, became too loaded down to depict all six of its moving models at the field rate. If six moving models are to be utilized, three must be updated at the frame rate. To correct the problem, the program will be partitioned and a second PDP-11/55 will be added to run in parallel with the first.

17.2.10 Texture Inadequacy

Texture currently is inadequate in its support of Terrain Following (above 50 ft.) and Nap-of-the-Earth (below 50 ft.) simulation.. In its two- and three-dimensional versions, texture is probably a very important cue in low-level flight. However, texture is only now becoming available in a rudimentary (geometric perspective) form. Advances are promised, but none are currently fully available. See 5.2(r) and 7.2.7.

As long as texture remains low in contrast, the scene anomalies which it creates will only be marginally visible. High-contrast texture can create scene anomalies which are difficult to correct and require sophisticated anti-aliasing techniques. Boundaries between levels of detail can become obvious and appear as a horizontal line, parallel to the horizon, on the terrain. This boundary remains at a constant slant range as the terrain passes below the aircraft. In one study, this juncture between levels of detail caused bands of scintillating textured material (Reynolds et al., 1978). Successful anti-aliasing techniques originated by Crow (1977) were utilized at Technology

Service Corporation (Stenger et al., 1979). They found, however, that the texture tile approach was only partially successful for three other reasons:

(a) In the process of generating the texture tile, only one original photograph is used. This original is the basis for different levels of detail (e.g., an entire forest, a group of trees, a single tree, etc.). These three different texture tiles would have worked more efficiently had they each originated from their own unique photographic source. In addition, the close-range texture tile should have permitted the perception of three-dimensional texture.

(b) In the process of creating the texture tile, manipulation was necessary to provide invisible boundaries when the source tile was juxtaposed next to itself and to eliminate macro-patterns within the tile. The result, when the tile was laid over a large area, was a homogeneous, bland appearance. The problem could be eliminated and an improvement in the overall image quality could be realized by one of two methods:

    (1) "Superimposing a different macro-pattern over large areas; or

    (2) shading to simulate either the effect of different growing rates, grass colors, etc. or the natural rolling terrain."

(c) During the dive-bombing portion of this study, a problem with the texture scintillating became apparent. The reason is unknown, but it appears to be a temporal aliasing problem, which must be corrected through further study.

17.2.11 Low Fidelity Realism

Unrealistic "cartoonish" visual presentations are the hallmark of CIG. In and of itself, this factor is not necessarily a weakness. Only when cues are inadequate to support a control strategy identical to that of the real world does this factor become a weakness.

Lack of image content and detail can make flying a CIG scene unrealistically easy when items such as turning point, initial point, and targets are too easily recognizable (Cohen, February, 1979), or unrealistically difficult in successfully maintaining low level flight.

The CIG world is a "flat world." There is no curvature to terrain which is depicted as being flat, nor do long runways have anything but a flat appearance. The net effect of this fact on mission tasks such as air-to-air combat, air-to-ground weapons delivery, terrain following and landings is unknown (Kraft, 1979).

Complex shapes are not easily or efficiently reproducible. They must be simplified but cannot be simplified to a point where their presentation may lead to questions about their orientation when no such questions would arise in the real world.

17.2.12 Pixel/Light Point Size Limit

Light points cannot be depicted by less than one full pixel. Because of anti-aliasing techniques, light points are often spread out to cover more than one pixel and may indeed cover as many as a three by three matrix of pixels. Even a one-pixel light point (e.g., 2.47 by 2.87 minutes of arc at Boeing) is not small enough to present what the eye would be expected to perceive when viewing a light point at a great distance. (See 5.2 [p] and 7.1.1.[d].) The net effect causes the light point to be perceived as being closer in distance.

During an approach to a landing, if no compensation is made for light point size, pilots will fly lower than they would in the real-world situation (Kraft et al., 1977). To compensate for this deficiency, Kraft successfully used a technique which reduced the luminance of the light points in a manner proportional to their distance. (See 5.2 [p] and 7.1.1 [d].)

A second aspect of light point resolution — the first being spot size — is positional resolution. Positional resolution, while highly accurate in CIG-based visual systems, can nevertheless be no better than the size of a pixel.

SECTION 18

CIG SYSTEM ACQUISITION

18.1 SPECIFYING A CIG SYSTEM — WHAT AND HOW TO SPECIFY

"Each system has, in effect, a simple message: 'Tell me what you need, and I'll see if I have it.' Unwary users receive another message as well: 'If you don't tell me what you need, I'll give you what I have'. . . .But digital systems also have another message: 'If you don't tell me exactly what you want, you won't recognize what I give you'" (Stark, 1977). Stark points up the pitfalls rather succinctly. What to specify is of paramount importance.

Orlansky and String (1977) say: "Emphasis should be given to the development of specifications for the visual and perceptual characteristics of such displays to complement the emphasis now being given to the development of improved means of visual simulation."

Cohen (1979) calls for a perceptually oriented rather than engineeringly oriented specification. He says, "Ideally, the training organization should specify the perceptual requirements for certain training, and simulators and CIG systems should be specified accordingly." These features may include range for target detection, recognition, identification, numbers and types, as well as aircraft operating parameters and minimum operational height above terrain. "Separately, the engineering features to support the required perceptual requirements should be understood and specified (if possible and implementable)."

The current authors feel that not only should engineering specifications be separated but that they should be minimal in nature, only specifying engineering features whose absence would severely restrict the ability of the system to provide the specified perceptual information. Items of this nature such as the permissible number or percentage of edge crossings per system scan line, the percentage of buffered system capacity, as well as expansion characteristics, etc., are appropriate. If it can be avoided, attempts to characterize the hardware approach should not be made as this restricts the innovation with which different manufacturers may solve the same perceptual problem.

As an aid to answering the question, "What to specify?", further studies are required in the perceptual area. Without a full understanding and definition of the perceptual requirements, the CIG user will buy more than he wants and get less than he needs. Please refer to Section 6 on Realism and Section 7 on Perception and Cues as well as Section 8 on Illusions for further discussions in this area.

"Not only must overly ambitious goals be reduced to realistic state-of-the-art requirements, but proposed system elements in components must function together in such a way as to assure program success. "We must first try to establish realistic goals. We cannot ignore cost and state-of-the-art constraints. Assuming goals can be established as requirements, and that someone will arrive at a complete solution, is unrealistic and may be disastrous" (Heintzman and Shumway, 1976). Establishing these goals requires that existing devices, which are similar in nature to the proposed device, be evaluated — thus the importance of this study. The decisions must be based on known system performance, and comparable applications must be taken into account. Lastly, a Draft Procurement Package should be sent to the prospective vendors to avoid unrealistic specifications.

Renderings of the visual scenes could be prepared as part of the perceptual characteristics specification. Stark (et al., 1977) recommended this technique for data base design, but the concept could and should be extended to the perceptual specification.

The specification must include a documented method, whereby the system may be evaluated.

18.2 OFF-THE-SHELF VERSUS PUSHING THE STATE-OF-THE-ART

Many factors go into the decision to specify an off-the-shelf CIG system versus pushing the state-of-the-art. Off-the-shelf system applicability, in addition to the cost, plays an important role in this decision.

18.2.1 Off-the-Shelf Systems

The off-the-shelf CIG system currently offers many desirable attributes, as well as some drawbacks.

(a) Advantages of Off-the-Shelf

(1) The system will be thoroughly tested and have known attributes that can be verified, it represents a low risk.

(2) Users may be questioned on their evaluation of the system and specific features.

(3) Because it already exists, the development costs should be minimal.

(4) The system should be operational in a short time since the main integration is complete.

(5) The amount of maintenance and maintenance personnel required may be calculated using existing figures on that system's current performance.

(6) At least one visual data base will already exist.

(7) Comparison can be made between different manufacturers' CIG systems, and subtle details may be discerned and evaluated.

(b) Disadvantages of Off-the-Shelf

(1) The systems will be at least 1 to 2 years old. This means that all the innovations which have been developed since the implementation may not be available.

(2) The design of the system may have been targeted for another type of application which is not applicable to the one the user desires. Converting these areas to the user's needs may further degrade the system capabilities.

(3) A certain amount of money may have to be spent to modify the CIG system to its new application.

18.2.2 Pushing the State-of-the-Art

Some important factors should be considered in the cost of pushing the state of-the-art.

(a) Advantages of Pushing

(1) The system procured would contain the latest CIG innovations that are available at the time of delivery, as well as those which have been developed specifically for this application.

(2) The new innovations may allow the user to more successfully perform the required R&D task.

(3) The new technology may improve the maintainability and reliability.

(b) Disadvantages of Pushing

(1) From the inspections of existing CIG systems in the field, it was determined that after delivery it took 1 to 1.5 years to complete the installation. This included working out the design bugs and attaining reasonable system reliability.

(2) There has been a tendency to specify systems that are well past the ability of the manufacturer to produce, and, consequently the end product has not satisfied the users.

(3) There are pitfalls in specifying a CIG system. The numbers game can and will be used for and against the user in such a way that the system meets the numbers specified, but because of other related variables that were not specified, the system may not do what the user had intended.

(4) Specifying a new system will dictate a protracted production lead time (average - 24 months) to allow for new developments.

18.2.3 Past History of Pushing

Two users, Boeing and NASA, who have previously pushed the state-of-the-art in CIG, are no longer doing so. Their most recent purchases have been off-the-shelf systems. Their stated reasons for following this new course are lower risk, cost, and check-out time. Their previous reasons for pushing the state-of-the-art were the inability of current CIG systems to perform the required tasks.

In a situation where it is practical and cost effective to build prototypes and have a flyoff between two or more CIG system manufacturers, this may be an appropriate approach to take. Specifically, if there are to be follow-on production units, this lowers the risk of pushing state-of-the-art to attain a specific goal. However, in the case where only one system is to be produced, pushing the state-of-the-art may not be justifiable. The only exception may be in the area of display technology, which is so far behind image generation that it may be essential to take a new and unique approach in order to reach any reasonable goal. (See Section 15).

It appears that in the past, as well as currently, military users have attempted to drive the design of CIG systems into areas that were not yet attainable. They thereby suffered the consequences of having newly implemented functions that did not perform to expectations and in the process wasted development funds in the attempt to reach unattainable goals.

18.3 TEST AND EVALUATION

18.3.1 Testing

The Naval Training Equipment Center Document IH-251 (Harris, 1977) "Acceptance Testing of Flying Qualities and Performance, Cockpit Motion, and Visual Display System Simulation for Flight Simulators" is quite exceptional. This Navy document, developed at the Computer Laboratory, NTEC, provides test configurations for visual systems as well as test procedures. It makes recommendations which are either not covered in other military standards or are covered but should be changed. Of particular interest in this document are:

(a) Figure 1, "Visual Systems Test Configuration"

(b) Table 3, "MIL-T-9212 (USAF) Training Device Tests"

(c) Table 7, "Project 2235 (USAF) Technical Testing Program"

(d) Table 8, "Recommended Visual Display Testing"

(e) Table 11, "Recommended Areas of Visual Display System Testing"

(f) Table 15, "Comparison of and Recommendations for Visual Display Simulation Tolerances"

(g) Appendix C, "Recommendation for Specification for Fundamental Test Requirements for Evaluating Visual Display Systems, as Used with Aircraft Weapons System Trainers and Operational Flight Trainers"

This document may be considered a baseline document for test and evaluation.

18.3.2 Supportability Demonstration

Puckett (1978) suggests the concept of a "supportability demonstration." Although he is more concerned with logistics involved in pre-production prototypes of flight simulators or flight simulators which are going into operational environments, this concept can be applied to one-of-a-kind R&D simulators. He points out that the acquisition of flight simulators requires six major activities to occur almost simultaneously:

(a) Spares and support equipment delivery.

(b) Operational testing and evaluation of the simulator.

(c) Technical publication preparation and verification.

(d) Maintenance and operator technician training.

(e) Depot-level repair center build-up.

(f) Follow-on provisioning actions.

18.3.2.1 Parameters for the evaluation of the supportability demonstration. There should be measurable and contractually enforceable parameters such as:

(a) Mean time between maintenance actions.

(b) Maintenance man-hours per operating hour.

(c) Operational availability

(d) [Successful performance of mission tasks.]

(e) [Absence of unwanted characteristics, e.g., inappropriate LOD management, ineffective overload management, etc.]

These parameters may be evaluated over a one-year demonstration and evaluation period.

Pilot performance on the delivered system in the simulation of an existing aircraft, is one criteria which could be utilized for evaluation.

18.3.2.2 Procurement phases. According to Puckett, the procurement steps go through three phases:

(a) Phase I: Definition of the appropriate design parameters.

(b) Phase II: All actions by the contractor and procuring agency between Phase I and Phase III occur during this phase. Included are in-plant qualification testing using normal physical configuration audits, normal system acceptance test procedures and a short-term, high-risk reliability test. "The short-term reliability test serves as an integrated and final check-out of hardware and software, assuring the procuring agency that the flight simulator has a reasonable chance of meeting the more rigorous requirements of the supportability demo.

(c) Phase III: The supportability demo. The supportability demo includes, at its midpoint, an evaluation of the technical publications to be provided with the simulator. This evaluation is to be completed by the user personnel who were trained in the manufacturer's school.

A final set of technical publications should be provided which reflect the actual as-built configuration. Of greatest significance is the idea that the acceptance test should extend over a period of time and not be confined to one specific demonstration or series of demonstrations.

The acceptance testing could be aided by an outside third party knowledgeable in CIG concerns. The testing firm should be responsible for the delivery to the AFWAL/FIGD of a fully functional and working system if this approach is taken.

As has been pointed out earlier, some software problems may not be apparent immediately, and some software-induced problems may be correctable only in hardware. Knowing that this is true implies two things:

(a) A fully operational data base for each mission task must be delivered at the time of system delivery.

(b) An extended period of time must be allowed for the evaluation of the performance of these data bases.

A supportability demonstration or extended acceptance period allows time for an evaluation of the system to uncover any uncontrolled variables (15.9) or incidental learning (17.1.1). By doing so AFWAL/FIGD may avoid the pitfall of misinterpreting the research results which have been affected by them.

During the course of this study it became apparent that after a new CIG system was delivered it took approximately 1 to 1.5 years to make the system function reliably. The personnel requirements for the time between the initial delivery and the functioning system were handled in two ways:

(a) The vendor was hired to resolve the engineering problems after acceptance with a large cadre of vendor support personnel; or

(b) The facility personnel became CIG experts on the system and provided the same services.

Both of these solutions would be an expense to the AFWAL/FIGD. If the support is to be provided by the vendor, there would probably be a cost advantage realized by negotiating the support in parallel with the CIG production contract hence the recommendation of a supportability demonstration.

SECTION 19

CIG SYSTEM INTEGRATION

19.1 HARDWARE AND SOFTWARE INTEGRATION CONSIDERATIONS

19.1.1 AFWAL/FIGD Current Displays

The current 625-line 50 Hz video system is inadequate to meet the resolution requirements for future simulation. Its replacement will be necessary and should not be considered a restriction on any new CIG system acquired.

19.1.2 Transport Delay Circumvention

Direct interfacing with the flight controls is suggested with a portion of the CIG system performing the calculations for the equations of flight. These calculations should be synchronous with the CIG presentation and at the same iteration rate. The flight control information coming from the flight deck should be analog in nature and conversion to digital should occur only as part of the flight equation calculations and not prior to them.

The CIG system should return the results of the equations of flight calculations to the host simulation computer so that a disparity does not occur. If this recommended technique is utilized, the host simulation CPU must provide the flight characteristics of the aircraft being simulated to the CIG system.

If the preceding approach is not taken, and the host simulation CPU provides the flight information to the CIG system as is conventionally done, an attempt should be made to make the transfers synchronous with the CIG system calculation and if possible these transfers should be made at the iteration rate of the CIG system. Failing this, the highest possible iteration rate should be maintained. Predictor equations and filtration may also be required for some mission tasks under these circumstances. Other possible solutions are discussed in 17.2.6.

19.1.3 Host Simulation Computer to CIG System Interface

19.1.3.1 Aircraft parameters. Aircraft position, attitude and heading data must be provided if 19.1.2 is not implemented.

19.1.3.2 Direct memory access (DMA). The interface may be required to provide for DMA to the CIG system.

19.1.3.3 Moving model information. The interface must provide moving model type and status (e.g. position, attitude, heading, hit, etc.) to the CIG system.

19.1.3.4 Armament and target status. The interface must provide armament (e.g., weapons firing, SAM missile launch, etc.) and target (i.e. hit and location of miss) status to the CIG system.

19.1.3.5 Environmental conditions. The interface must provide information on environmental conditions (e.g., visibility range, weather, etc.) to the CIG system.

19.1.3.6 Instructor actions. The interface must send information pertaining to instructor actions taken at the host simulation instructors station (e.g. program freeze, program reset, program start, Latitude/Longitude change, airport selection, etc.).

19.1.4 CIG System to Host Simulation Computer Interface

19.1.4.1 Simultaneous simulations. If the CIG system is shared, and must support simultaneous simulations, questions concerning the destination of data returning to the separate host simulation computers will arise and must be resolved.

19.1.4.2 Terrain elevation. The host simulation data base does not contain ground contours. This information resides in the CIG data base and the CIG system must provide it to the host simulation computer. Terrain elevation data permits scoring pilot performance in terrain following or nap of the earth flight. Also, the simulation system may update model positions accurately and keep surface riding models in contact with the surface.

19.1.4.3 Collision information. Contact between aircraft or aircraft to ground contact can be be detected by CIG systems. This information must be returned to the host simulation computer.

19.1.4.4 CIG system loading. The interface should return CIG status (e.g., % of edge crossings, % of edge capacity, etc.) to the host simulation computer. Evaluation of the impact of CIG overload management on pilot performance may be ascertained by using this data.

19.2 COMPATIBILITY OF NEW CIG WITH EXISTING AFWAL/FIGD SYSTEM COMPONENTS.

CIG systems are designed to attain the fastest computational speeds possible. Speed dictates special-purpose hardware with the exception of the GP CPU front end; it is highly unlikely that any of the CIG system hardware, or software, will be directly interchangeable with existing AFWAL/FIGD equipment.

The acquisition of SEL GP CPU by the AFWAL/FIGD does offer the potential for interchangeability with some next generation CIG systems (i.e., B-52).

SECTION 20

CIG SYSTEM UTILIZATION

20.1 ON-LINE SIMULATION, EVALUATION AND ANALYSIS

On-line simulation, evaluation and analysis requires a CIG experimenter's or research station.

A CIG experimenter's or research station serves two functions, the first in the on-line mode, the second in the off-line mode which is discussed in Section 20.2. This separate stand-alone station would minimize interference with and from other simulation activities.

In the on-line mode, the CIG experimenter's or research station should support the following functions (partly from Rivers, 1977):

20.1.1 Repeater Display(s)

Repeater display(s) showing in real time, the entire visual scene being presented by the CIG system (channels switch selectable if a single display is utilized).

20.1.2 Plan View Display

Provide a display of the plan view of the in flight aircraft in relation to its foe(s) or target(s).

20.1.3 Control of Variables

Provide for the control of all variables which are normally under the control of the host simulation CPU.

20.1.4 Flight Recording, Replay and Restart Control

Provide control of flight parameter recording, instantaneous replay and restart capabilities.

20.1.5 Display and Record CIG System Parameters

Display and recording of the CIG system operating parameters (such as system loading, edge crossing loading, and the visual characteristics which were selected, etc.) so that their impact on research may be ascertained and evaluated.

20.1.6 Display Critical Aircraft Instrumentation

Display critical aircraft parameter readouts and instrumentation.

20.1.7 Display Weapons Release

Display weapons release parameters.

20.1.8 Display Weapons Scoring

Display weapons scoring information.

20.1.9 Control of Host Simulation

Provide control of key host simulation functions such as aircraft malfunction insertion.

20.2 INDEPENDENT OPERATION

Independent operation is the second function of the CIG experimenter's or CIG research station. Here, not only must all the features available during online simulation be available, but additional features such as joy stick and throttle as well as control of weapons selection and release may be desirable. Canned demonstrations and diagnostic testing programs could be run in the same manner as the on-line mode replay allows with the exception that the CIG system must store and supply the required flight parameters initially. No existing system offers all the features mentioned in this section or Section 19 at their operator's station.

20.3 SIMULTANEOUS SIMULATIONS

Theoretically, current systems are capable of supporting two simultaneous simulations (each of which requires a separate eye point). This approach, however, requires both a sharing of displayable edge capacity and multiple data bases on-line when different missions are being run. Unless one mission had a minimal impact on edge capacity requirements, the simultaneous simulation environment may be too restrictive for the AFWAL/FIGD. In general, the AFWAL/FIGD mission tasks would stress any current CIG system to its absolute limits and beyond. See 5.2(g).

SECTION 21

CIG SYSTEM MAINTENANCE

21.1 HARDWARE AND SOFTWARE DEBUGGING AND MAINTENANCE PROCEDURES

The CIG systems of today are large complex systems in their own right. Some consist of 17 or more racks of electronic equipment. The sheer size of the systems makes problems inevitable. A major portion of these systems are constructed in special-purpose hardware to increase computational speed. For this reason it is essential that the CIG system be designed and produced incorporating the most sophisticated debugging and maintenance tools available.

The design and production phase is the time when Built-In Test Equipment (BITE) and Fault Isolation Tests (FIT) should be incorporated. BITE and FIT tests can be very expensive but they can, in the long run, pay for themselves through:

(a) Fewer and lower levels of maintenance personnel required.

(b) Quick diagnosis of system problems to yield greater system utilization and improved Life Cycle Costs (LCC).

These factors must be weighed against Initial Cost when purchasing a system.

During the course of the study it was apparent from the CIG systems visited that more extensive BITE and FIT led to higher reliability, fewer and lower levels of maintenance personnel, and more usable simulator time. Manufacturers differ as to the current depth of BITE and FIT supplied with their systems.

In addition to the ability to test the system, there may be real-time systems monitoring. The monitoring could consist of diagnostic messages that notify the user of impending or immediate problems. These messages could be broken down into three types depending upon the severity of the problem.

(a) Error Message Type 1

This message would be the least severe. It would be used to notify the user that some internal problem had arisen that will not reduce the total simulator capability. No immediate action would be required at this point, but the user should be aware of the limited capability.

(b) Error Message Type 2

This message would be of moderate severity. Its purpose would be to notify the user that some action will be required in the near future or the system will deteriorate to a level of non-use. If the proper steps are taken, the system should be functioning again where it left off.

(c) Error Message Type 3

This is the most severe message. It would be used to notify the user that the system has crashed and give the cause, if possible. There would be no options here other than starting over again after the problem has been fixed.

The real-time system monitoring may be used in conjunction with periodic preventative maintenance to keep the system operating at peak performance. It should be noted that, to the authors knowledge, no current systems have this feature. It may not be cost effective to implement such a system in which case morning readiness tests must take its place. Most failures will be immediately visually apparent to the observer without it.

Debugging Procedures. If the system does fail, tools should be available to isolate and fix the problem area.

The specification should state what level of troubleshooting must be supported (i.e., board level, component level etc.).

21.1.1 Software Debugging and Maintenance Tools

It is important to note that not only does software require debugging but it also may require maintenance just as hardware can. The reason for this necessity is that, in the case of CIG software, data patterns vary in accordance with the eyepoint of the viewer. Although a specific CIG package may be completely debugged and appear operational, it is possible for unique and untested viewer eyepoints to cause problems at a much later date.

The following software debugging tools should be available as a minimum:

(a) The ability to trace the communications between and within modules.

(b) The ability to halt the system upon the execution of a specified instruction. There should be more than one breakpoint or trap available, with ten or more not being excessive. The instruction stopped at and the appropriate registers should be available.

(c) The ability to dump any part of the system memory.

(d) The ability to inspect and modify words in memory.

(e) The ability to record specified areas of memory upon the execution of prespecified instructions.

The information provided by these software debugging tools should be available in real time via a CRT or in hard copy format on a high-speed printer.

21.1.2 Hardware Availability, Debugging and Maintenance Tools

21.1.2.1 Availability Concept. Reliability may be directly linked to the concept of availability. Availability is determined by two factors:

(a) Mean Time Between Failures (MTBF); and

(b) Mean Time To Repair (MTTR).

Availability is defined by the following equation: $A = \frac{MTBF}{MTBF + MTTR}$

21.1.2.2 MTBF and factors affecting it. The following are factors which affect MTBF:

(a) Preventive maintenance

Preventive maintenance, though of limited applicability to digital systems, is required in the video-generation portion of CIG systems where analog signals are to be found. In addition, clocks as well as air filtration require periodic preventive maintenance.

One important aspect of preventive maintenance is the control of variables which may affect image quality. For example, Kraft (et al., 1977) found ". . . the visibility of the runway texture must be set and controlled in day-to-day operations. It appears from these data that the best approximation of the glide slope will occur when the detail just becomes visible 2,500 feet before the aircraft reaches the visual touchdown marks on the runway." It is important to both recognize and control variables within a CIG system. ". . . This variable can be controlled by the day-to-day maintenance procedures with this method of setting the apparent contrast and texture brightness and its operation."

Global diagnostics and morning readiness tests may be considered a part of the preventive maintenance procedures. They are also included below in Section c.3, (MTTR/BITE and FIT).

(b) Hardware Complexity

Hardware complexity is considered to be to the key to MTBF figures. CIG systems use integrated circuits (ICs). Several different families are utilized with Schottky – TTL integrated circuits currently predominating. In addition, ECL, CMOS, and MOS technologies are utilized. Current CIG systems include one or more general-purpose CPUs as well as special-purpose hardware. The Link special-purpose hardware ranges in complexity from 20- 50,000 ICs, occupying six bays (Link F-111 and NASA SMS). The Boeing CIG system special-purpose hardware occupies eight cabinets and totaled approximately 96,000 ICs (GE Compu-Scene), while the VTRS system special-purpose hardware occupies nine cabinets, comprising 1,200 boards for black and white versus 1,550 for color (GE). The ASPT system occupies 17 cabinets of special-purpose hardware, containing 188,000 ICs. This system could probably be built today in 14 cabinets, containing 100-120,000 ICs (GE). The C-130 system, which is a 5-channel, 6-display system, occupies 20 cabinets of special-purpose hardware and contains 144,000 ICs (GE). These figures are estimates and are given simply to allow the reader to grasp the complexity of current CIG hardware.

(c) Miscellaneous Factors Affecting MTBF

Power distribution and grounding as well as cooling, connector types and even smoke can affect MTBF.

Power distribution and system grounding is perhaps the most critical and difficult implementation problem in packaging of a CIG system. With 3-500 amps at 5 volts per cabinet being a typical cabinet requirement, power distribution system design must be excellent. This has not always been the case in CIG systems. Tin-plated back planes and aluminum bus bars have created problems. Gold or silver-plated copper bus bars are not an unheard solution.

Cooling can be critical, and, to a certain point, the lower the temperature the higher the reliability of the system.

Connectors and card guides are another important factor in system reliability.

Even smoke from cigarettes can be detrimental to CIG system performance. Not only does it clog filters and affect disk operations, it tends to build up in the optical portions of the display system and affects resolution, brightness, and contrast.

21.1.2.3 MTTR and factors affecting it. Mean time to repair is the elapsed time between the start of diagnostic troubleshooting and the isolation and replacement of the failing subsystem or board. It does not include the time necessary to troubleshoot down to the component level, nor do the diagnostic aids provided by the average CIG systems allow for this. Numerous factors affect the MTTR:

(a) Documentation

Documentation is inversely proportional to MTTR. The greater the amount of documentation available and the easier its use, the shorter the MTTR. Current documentation runs the gamut from non-existent through cookbook. Somewhere in between falls engineering documentation, which is often the best that is available. Engineering documentation is sufficient for the engineer who designed the system but generally inadequate for a technician to utilize.

(b) Training

Training is essential, both for those who are users of the system and those who are to maintain the system. The manufacturers offer training courses of both types.

(c) BITE and FIT

BITE and FIT equipment is as essential as documentation for hardware and software maintenance. Considering the hardware complexity, it cannot be eliminated or even relegated to a low level of importance in any CIG system. In addition to the diagnostic software, BITE equipment successively wraps test data back around to the front end, general- purpose CPU. These tests treat the CIG system as a pipeline, with patterns being generated by the CIG GP CPU and sent out, first to the closest hardware in line from the CPU and progressively further and further out as each successive test proves out the hardware in the pipeline.

Morning readiness or global diagnostics are provided for in CIG systems. These tests give a cursory evaluation of the system and take 15 minutes to 1/2 hour to run. Exhaustive diagnostics can take 5-1/2 hours to run. BITE may be provided down to the card level.

(d) Card Testers

Card testers may be available for some systems but may be very expensive ($450,000) and may not test all the cards in the system.

At least one user, after specifying that the diagnostics should allow troubleshooting to the board level, found that the diagnostics were inadequate for the task and did not allow troubleshooting to the board level (Boeing).

(e) Sparing

Sparing. In order to keep the MTTR at a minimum, it is essential that a full complement of spares be kept on hand. There is no alternative to their immediate availability. Due to the complex nature of the CIG system, it is impractical to attempt to troubleshoot to a lower level during scheduled operation. Maintenance time must be allotted for this form of troubleshooting, and sparing down to the component level must be provided to facilitate it. Repair turnaround time can be excessively long when not done in-house, but for some parts of the CIG system this is the only alternative.

21.2 MAINTENANCE: EXPERIENCES AND APPROACHES

The NASA Engineering Lab, utilizing a CT3 (E&S), has experienced 13 failures in 31 months of operation, five days a week, 24 hours a day. This gives an availability of over 99% and approximately 1,200 hours MTBF. Although no data were available on MTTR, the new CT5 system has a targeted MTBF of 200 hours.

E&S states that 100 to 200 hours MTBF is not unreasonable for a modest-size system (Doenges, 1979).

At ASPT (GE) the CIG system is currently averaging 95%.

NASA originally used a camera model system. With that system and a very large maintenance staff, the best availability NASA was ever able to attain was 75%; the norm was lower. Currently, with the SMS, the system availability is averaging over 80%, with the CIG system being much higher than that.

21.2.1 Person Loading

At the NASA Engineering Lab, one person is responsible for the maintenance of the entire CT3 CIG system.

At VTRS, one local engineer and one GE rep are all that are required to maintain the CIG system.

At the NASA SMS, where operations go on 7 days a week, 24 hours a day, four men are required for the CIG hardware alone. Two additional men are utilized for display and two additional men for software maintenance. A total of 32 people make up the maintenance and engineering staff on the simulator. These people are responsible not only for ongoing maintenance of the equipment but for the implementation of any hardware or software changes which may be required. All the software engineering is done by this group and some of the hardware engineering. Because NASA's situation is fluid in its requirements, they have a large number of personnel on board continuously to allow for the changes. These personnel keep track of mission and spacecraft changes very closely in their simulation. Because AFWAL/FIGD's operational requirements are so similar to the NASA/SMS environment, with the exception of the schedule, similar personnel requirements will exist.

21.2.2 Maintenance Contracts

Maintenance contracts have been utilized at ASPT, VTRS, and NASA. These symbiotic relationships appear to work well.

Ranc and Kusner (1978) stated a number of pros and cons for contractor maintenance of training devices:

21.2.2.1 Pro. Arguments in favor of maintenance contracts:

(a) Personnel costs are lower.

(b) An employee during training is non-productive.

(c) A trained employee who returns prior to equipment delivery loses technical proficiency.

(d) Operators are often trained in maintenance as well as operation, which is a waste.

(e) The contractor is liable for providing fully trained personnel.

(f) The contractor attempts to maximize personnel efficiency.

(g) The contractor can supply experienced personnel.

(h) Maintenance staff administration is eliminated.

(i) The contractor's reputation is at stake on the maintenance of his own equipment.

(j) Lower acquisition costs may be incurred because documentation need not be as extensive.

21.2.2.2 Con. Disadvantages are as follows:

(a) The Government may find itself in an untenable position, if for any reason they choose to discontinue contract maintenance and have to provide their own personnel with training and documentation to maintain the equipment or find another contractor.

(b) The contractor may gain so much experience that he effectively becomes a sole source for maintenance of the equipment and no other contractor may be interested in taking over that maintenance.

(c) There may be potential difficulty in integrating the contractor into the military environment.

(d) It is essential that the contract maintenance has defined performance standards or measurements.

21.2.2.3 Disagreement. We disagree with only two points made by Ranc and Kusner.

(a) The Government needs to train personnel in maintenance so that those personnel can evaluate the effectiveness of maintenance procedures and adequacy of documentation.

(b) We do not feel that savings should be attempted by the reduction of documentation, as this reduction may prove detrimental at a later date when the documentation is required and unavailable for maintenance.

21.2.2.4 Recommendations. As previously stated (18.3.2.2) the AFWAL/FIGD should contract for an extended supportability demonstration period of at least 1 to 1.5 years. Following this period should be a 1 year period of contractor maintenance. Only after this contractor maintenance period should AFWAL/FIGD even consider in house maintenance.

Thorough, automatic maintenance and test procedures using BITE and FIT minimally to the card level are recommended. This cost may seem high at the front end, but for an installation that uses CIG as a tool to accomplish its primary task of R&D it seems the better choice than a low availability figure.

SECTION 22

CIG SYSTEM UPGRADING

22.1 ADD-ON FEATURES

The expansion of a system by the addition of features which were omitted at the time of purchase is possible. It is practical and less costly only if it was planned for from the beginning. At VTRS, for instance, both color and distortion correction were considered to be key features, which would eventually be added to the CIG system. With this in mind, interfacing as well as the physical cabinetry and logic racks in which these additions would be resident, was a part of the original system. Other candidates for feature expansion could be additional channels and expanded on-line data base capacity.

22.2 RETROFITTING NEW TECHNOLOGY INTO AN EXISTING CIG SYSTEM

The ease of retrofitting the CIG system is heavily dependent upon what change is proposed, as well as on the age of the system. Systems, although "off-the-shelf," usually incorporate features unique to the particular application. Therefore, a feature new to a more advanced system may not be installable in an older system at all.

As time passes, technological changes occur not only in CIG approaches but in the basic hardware used to implement those approaches. Logic families, for example, which were in heavy use 7 or 8 years ago, are no longer even available.

In some cases it appears to be possible to retrofit new technology, in others it is not. The ASPT is currently being or already has been retrofitted with additional system capacity, additional moving models, and circular features. This approach is very expensive when possible and cannot be considered unless it is less costly than buying a new system.

SECTION 23

FUTURE TRENDS

23.1 GREATER EFFICIENCY

Future systems will make more efficient use of the system capacity which is available. They may do this in a number of manners.

23.1.1 Texture

Texture may replace edges where detail is not required but cues are. It may be used to fill in the blanks.

23.1.2 Utilizing Human Perception Through AOI/LOD Management

It may be possible to take greater advantage of human perceptual characteristics. Future techniques (i.e., AOI/FOV implementation) may allow for the current excess edge/polygon usage, which occurs out of the foveal area to be restricted.

23.1.3 Level-of-Detail Management

Level-of-detail management with blended transitions will continue to improve the manner in which edge capacity is utilized.

Level-of-detail management could become more sophisticated. During terrain following, as velocity increases, the slant visual range of the objects being observed also increases. This is to say that the observer will continue to look further out from the aircraft as the aircraft velocity increases. A method may be found to allow for changes in the level of detail in relationship to velocity and altitude (Szabo, 1979).

In addition, as velocity increases, the amount of time available for perception decreases, allowing the level of detail required and consequently edge-count to decrease as well (Szabo, 1979).

23.1.4 Automated Data Base Building

Automated data base building is becoming of greater concern as gaming area sizes, as well as system capacities, increase. See 11.2 and 11.3.

Beck and Hoog (1979) have put forward the concept of a hardware/software "discriminator" which would act as a filter between the online data base and the CIG system accessing that data. The discriminator would:

- (a) "Continuously monitor processor load in active data base (ADB)."
- (b) "Restrict data transfer from mass storage to ADB, based on preset criteria:"
    - (1) "Simulator characteristics"
    - (2) "Mission phase"
    - (3) "Mission specific"
- (c) "Maintain constant optimal load in image generator."

The payoffs for this approach would be as follows:

- (1) "Optimal loading of image generator."
- (2) "Nominal image generator capacity."
- (3) "On-site data base use flexibility."
- (4) "Avoid multiple versions of visual DDB."
- (5) "Reduce transformation requirements."

There are also the following potential payoffs:

- (a) "Single, generic data base."
- (b) "One transformation program."

The Defense Mapping Agency Aerospace Center Digital Data Base (DMAAC DDB) was also a topic of discussion for Beck and Hoog (1979). They proposed an approach for DDB conversion to CIG data bases. The intent of this program is:

- (a) "New DMA DDB development."
- (b) "Maximize transformation."
- (c) "Determine degree of enhancement required."
- (d) "Demonstrate concept of transportability of CIG data bases."

The use of the DMAAC DDB for automated CIG data base building will not provide an adequate CIG data base without human intervention. This intervention must come in the form of enhancement to the CIG data base, which is automatically derived from the DMAAC DDB. This enhancement could come from synthetic feature generation, as well as a library of generic features and the more conventional techniques utilized to generate non-generic scenes currently.

23.1.5 Transportability

Transportability of CIG data bases was also considered by Beck and Hoog (1979) with two factors being mentioned:

- (a) "Established, deliverable, transportable CIG data base."
  - (1) "Standardized format."
  - (2) "Allowance for growth."
  - (3) "Simplified conversion for any CIG system use."
- (b) "Established library of CIG data bases."
  - (1) "Available for all users."
  - (2) "Criteria for acceptance."
  - (3) "Can be modified if necessary."

The amount of concern shown by both Beck and Hoog for this area of future CIG development can only point up its importance to future systems.

23.2 INCREASED EDGE CAPACITY

Higher system edge capacity is inevitable. Current manufacturers have implied that edge capacity will more than likely double or triple over the next 2 to 3 years. While these figures may apply only to a frame rate updated CIG system, and could decrease by 50% in field rate update CIG system, they do point out the trend.

Current approaches do have intrinsic limits to growth within them. Figure 36 which was provided by Boeing (Cyrus, 1979), illustrates the fact that most hidden-surface algorithms increase the number of computations made proportionately to the edge/polygon count of the system. The one exception shown in this figure is a new approach taken by the Computer Graphics Research Group at Ohio State University (Csuri et al., 1979). This figure is not meant to imply that there is a direct monetary cost relationship between the algorithms and the number of calculations required as scene complexity increases. Indeed, this is not the case as some of the algorithms' hardware implementation is much simpler than others. The Computer Graphics Research Group approach is currently non-real time. This approach may never be implemented in real-time hardware, and then again it may. Its implied potential is 100,000-300,000 edges.

Figure 37 is a replot of data from Cohen (Feb, 1979). The implication is staggering, but the additional capacity may well be useless unless a much more efficient method of data base building is utilized.

23.3 MORE CIG FEATURES

CIG features and special effects will continue to be added to CIG systems. Refer to Section 25, Table 52 for features which are not currently available but will become available over the next five years.

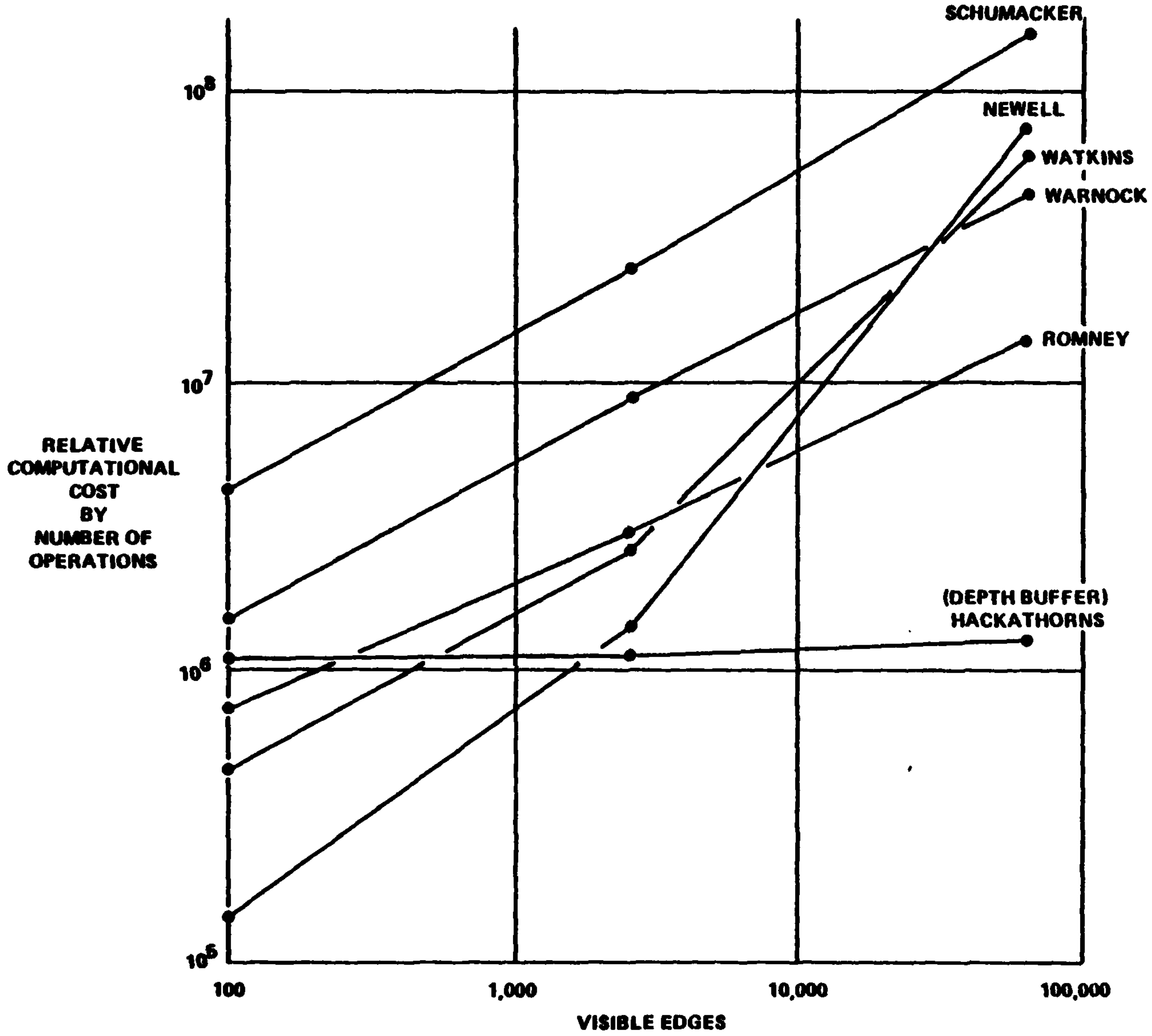

Figure 36. Competitive CIG Algorithms (Cyrus, 1979)

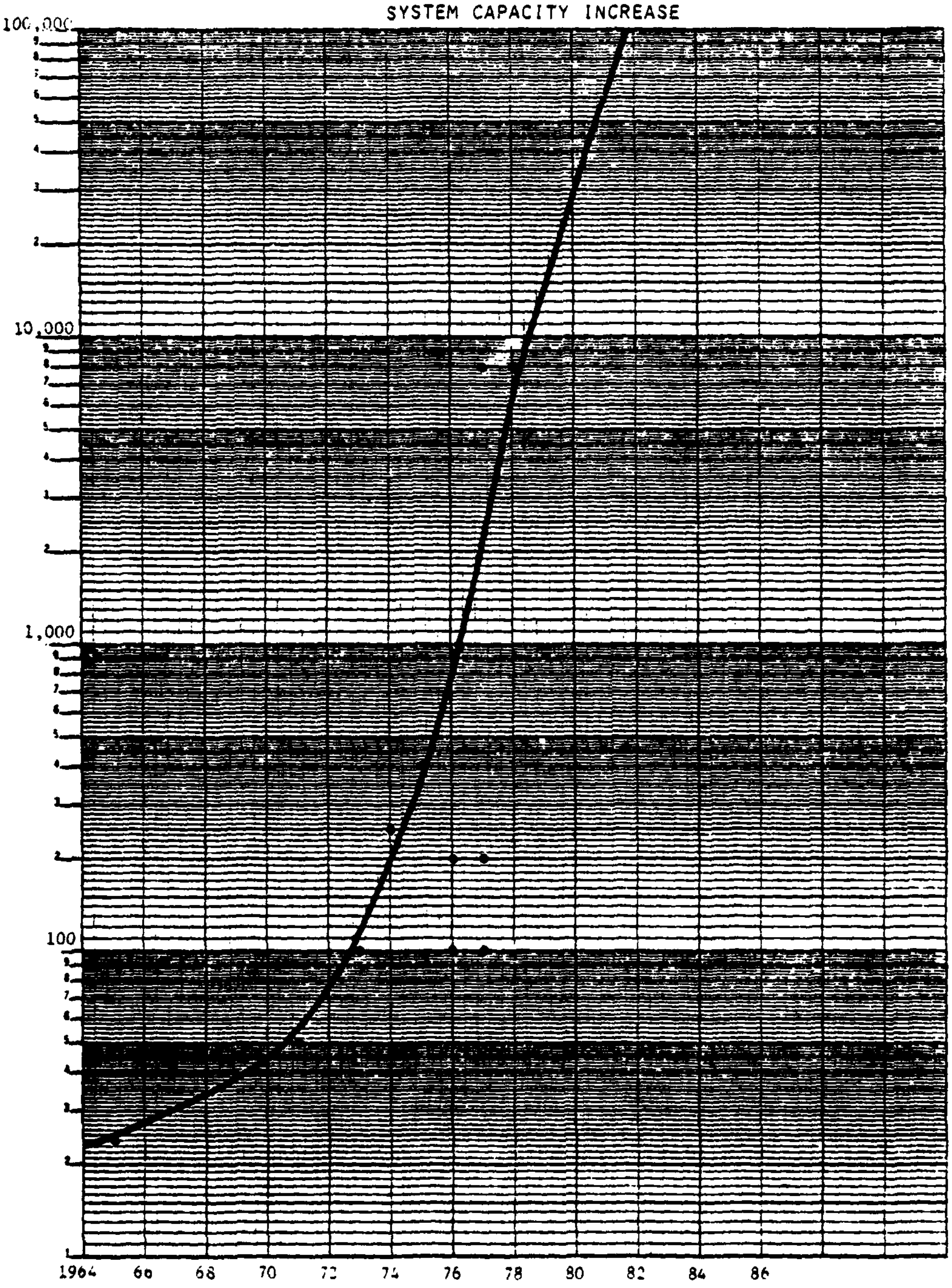

Figure 37. Future System Capacity (Reploted from Cohen, Feb, 1979)

23.4 IMAGE QUALITY

Image quality and anti-aliasing features continue to make up a larger portion of CIG hardware/software in relation to the traditonal functions of translation, rotation, clipping and hidden surface removal. As additional features are added, those features require that heavier emphasis be placed on image quality and anti-aliasing features (e.g., color and texture).

23.5 NEW CIG APPROACHES

Development of a CIG system from inception to a working hardware implementation appears to take approximately three years. This three-year cycle time would probably be a good rule of thumb to be aware of when considering future approaches. In addition to those future manufacturers mentioned previously in this report (i.e., ATS, Gould, Grumman, and Marconi), there are other individuals and groups working on future CIG approaches (e.g., the Defense Engineering Division of Chrysler Corporation, D. Cohen at USC Information Sciences Institute, Boeing collaboration with Computer Grpahics Research Group, etc.).

The Boeing collaboration approach is of interest because of its high potential for a greater than one order of magnitude increase in system capacity, as well as automated data base building potential.

Cohen's approach is of interest because of its simplicity of implementation and the fact that E&S, GE and Link are interested in it.

Other work continues to be done in computer graphics at universities across the nation. The future impact of this research cannot be predicted.

It seems unlikely that the current CIG manufacturers will push for a major breakthrough in CIG technology. Their past performance implies an orderly evolution from earlier work, rather than a revolution.

SECTION 24

PRICING INFORMATION

24.1 SPECIFIC COST FIGURES

During the course of this study, it was not possible to obtain specific pricing information on individual CIG features due to the competitive nature of the manufacturers who bid at a system level. They find it impractical to cost out each potential feature.

To say that the manufacturers are reluctant to divulge pricing information is to be guilty of a profound understatement.

The table reproduced below (see Table 42) was graciously provided by Paul Hulin and Len Suminski of Computer Sciences Corporation, System Sciences Division, Orlando, FL 32803. It is excerpted from their soon to be complete Computer Generated Image (CGI) Current Technology Assessment and Cost/Performance Model Feasibility Study. (This study is being performed for PM TRADE).

24.2 BALL PARK FIGURES

It is possible to give ballpark figures for two types of systems.

(a) A training system with an 8,000 edge capacity and no displays would cost in the neighborhood of $3 million ± 15%.

(b) A research and development simulator, such as can be found at ASPT, would probably cost $6-1/2 million ± 15%, with the addition of a visual system bringing the cost up to $10 million, ± 15%.

24.3 COLOR COST

The cost impact of adding color to a CIG system is minimal. The impact in the display area is more significant, however.

(a) E&S, image generation, color costs are approximately 3% on a per-channel basis.

(b) GE color accounts for 6 to 10% of the image generation hardware cost. The higher figure is incurred when no provisions are made at the time the system is specified for adding color at a later date.

(c) Link color costs are approximately 1% of the image generation hardware costs.

Table 42. GE Cost Figures (Hulin and Suminski, 1980)

DATA ELEMENTS	COMPU-SCENE I	COMPU-SCENE II	
MODEL/YEAR	1976 - PRESENT	1979 - PRESENT	
DATA BASE (ON-LINE) EDGES & LIGHTS	10,000	40,000	
DISPLAYED EDGES/LIGHTS	2,000/2,000	8,000/8,000	
DISPLAY RESOLUTION (ARC-MIN)	4	2.2	
EDGE CROSSINGS PER RASTER LINE	256	600	*Attempt to maintain a 10:1 ratio edges tp EC/RL
SCAN RATE	525	875	
CONTRAST RATIO	20:1	25:1	
BRIGHTNESS (FT-LAM)	>6	>6	
FOV PER DISPLAY*	40 x 30	43 x 32	*Instantaneous FOV
DAY/DUSK/NIGHT	Yes	Yes	
COLOR RANGE (Levels/Colors)	256.64^3	1024/256^3	
FACE SHADING (Sun Shading)	No	Yes	
TEXTURED WATER	Yes (Point Lights)	Yes (Patterns)	
MOVING OBJECTS	2	8	
DELIVERY LEAD TIME	18 MONTHS	30 MONTHS	
COST RANGE	\$2.0M — \$4.0M	\$3.0M — \$6.0M	
FACES (SURFACES)	1000	4000	*Attempt to maintain roughly 2:1 ratio edges to faces

(d) Obviously the addition of color to a CIG system is not without cost or added complexity. At AWAVS, the GE monochrome system currently installed utilizes 1,200 boards. An additional 350 boards will be added to implement the color feature. This means that in a color system almost 23% of the special-purpose system hardware is devoted to color generation. There is, of course, some decrease in reliability, accordingly.

24.4 REALISM AND COST EFFECTIVENESS

Increases in two forms of CIG fidelity cause increasing relative cost. Pictorial realism is the most obvious. However, increasing dynamic or interactive fidelity (accuracy of response of the visual scene to control inputs on the part of the pilot) also causes an increase in relative cost. When these two forms of fidelity are increased concurrently, relative cost skyrockets (Bunker, 1978). Heintzman and Shumway (1976), when talking about camera/model image generation systems, gave us some advice which is very appropriate to CIG systems as well. They said, "Indiscriminate modeling may be pleasing to the eye and just the thing for museum display, but worthless for simulation. Remember — simulate, don't duplicate." Excess fidelity is like altitude above you and runway behind you; it's useless and can be extremely costly.

24.5 DATA BASE COSTS

The preceding costs did not necessarily, include the costs of developing, require CIG Data Bases in the quality or size necessary to meet AFWAL/FIGD requirements. See 11.1.

SECTION 25

GENERAL CONCLUSIONS

25.1 PERFORMANCE VERSUS REQUIREMENTS

The results of this study are not black and white, not a choice of this system over that, not a recommendation to buy now versus waiting for the next generation of CIG. The purpose was, hopefully, to have educated the reader to CIG technology as it exists today and to suggest what might be available in the future.

The system required by the AFWAL/FIGD is, in some cases, available today; in others, tomorrow (1980-1985); and, in still others, the distant future. The question still remains as to need. The technology in the computer industry is moving very rapidly, which may cause some of the obstacles to disappear with the development of new and cheaper hardware. See 23.1 - 23.5 Future Trends.

Today's CIG systems can accomplish a good part of the AFWAL/FIGD mission task requirements if scaled down goals (e.g. fewer moving models, higher level flight profiles, etc.) are set. These scaled down goals can be defined by looking at what is currently being accomplished at other research and development facilities such as ASPT and VTRS as well as utilizing the current CIG capabilities discussed in this report.

If scaled down goals are considered to be inadequate, the future holds significant promise for meeting a less restrictive set within a reasonable time frame.

25.1.1 Cues: The Big Question

Because so little definitive information is available on what cues are required to perform what specific mission tasks, cues remain the big question mark. Additional work must be done. ASPT and VTRS, as well as other researchers, will provide additional information in the future. See Appendix C for current research. Without this information, specifying a CIG system can only be a "best guess," and utilization must, by necessity, be dictated by what can be done.

If AFWAL/FIGD wishes to participate in this research it is now clear that a systematic procedure (which may be time consuming) can be used to specify the kinds of cues which a CIG system must generate for the pilot. (See 7.2.2).

First, the designer must remember that there is no reason to overload the pilot with information. Five or ten bits of new information per second is all a person can normally handle.

Second, intuitive and more objective procedures may be used to identify those aspects of any particular scene which carry the most valuable information to the pilot. In particular, a line or feature which is clearly changing tends to carry most of its information around the point of change. After identifying the features which are most likely to carry the information, scenes drawn from them should be evaluated experimentally.

Third, in the artificial world of CIG displays, scenes which are geometrically correct may be psychologically wrong. Some of the conditions causing these perceptual distortions are well known, and the displays should be examined to guard against misleading illusions.

Fourth, those items which are obviously of great importance (such as two-dimensional and three-dimensional texture in low level flight), should be incorporated.

25.1.2 CIG's Ability to Meet Mission Task Requirements

Some of the mission task requirements are easily met by current CIG capabilities. Others are not easily met and, in some cases, not even possible. Please refer to sections dealing with display hardware, system accuracy, cues, realism, and CIG strengths and weaknesses for a full discussion. What follows is an integration of those sections.

2.5.1.2.1 Air-to-air combat simulation. The air-to-air combat simulation task can be partially satisfied by current CIG technology. However, to a certain extent, CIG cannot yet exceed a camera/model and target projector system for this type of simulation. Although CIG does allow for any number of different types of aircraft to be portrayed, it does not yet offer the detailing available from a model aircraft. The detail which is available does appear to be adequate.

CIG simulation of 2 highly detailed aircraft with terrain which would allow flight to below 1,000 feet, are currently feasible. The depiction of 4 aircraft at an altitude of 50 feet with missiles in flight is not, however.

Because of restrictions in display technology, detection at 25,000 feet has not been demonstrated.

2.5.1.2.2 Air-to-ground weapons delivery simulation. Air-to-ground weapons delivery can best be looked at in two different manners, simple targets (within the state of the art) and realist targets (beyond the current state of the art).

(a) Simple Target Simulation.

If a simple target is to be represented on the terrain, CIG can do an admirable job of air-to-ground weapons delivery. In this arena, CIG capabilities exceed those of any other simulation technique.

Under these circumstances, CIG's capability has been described as "spectacular," as well as ". . .more effective, sorti for sorti, than the airplane" in a training situation (Cyrus and Fogarty, 1978).

Booker (1979) described dive-bombing training with a limited edge capacity (500 edges) system at Kingsville as being "very effective"; in fact, this was one of the few tasks at which the Navy feels it was effective.

According to Monroe (1976), ". . . Project 2235's major conclusion is that computer image generation is the most viable approach to air-to-surface, full-mission visual simulation."

Rivers (1977) found that "Of the A/S (Air to Surface) systems evaluated, only CIG systems afforded the clarity and resolution necessary to recognize and identify objects at normal slant ranges." He further went on to say that air-to-surface special effects, such as weapons impact indications and moving targets, were best demonstrated by ASPT, a CIG-based visual system.

(b) Realistic Target Simulation

If the air-to-ground weapons delivery task involves the detection of a target such as a tank, which is camouflaged and hidden within a surround of similarly dimensioned objects which are of similar color, or if the tank is hidden in a hedgerow or trees, CIG cannot even come close to depicting the scene. Available scene complexity as well as target dimensions which correspond to the surround, is the cause of the problem. Adequate detail simply cannot be generated over a wide enough area.

Greening (1977) lists three factors, only indirectly associated with the target, that affect target acquisition. They are:

(1) "The clutter and pattern of the terrain and its natural and man-made features"

(2) "The atmosphere and its effects on contrast"

(3) "Masking and obscuration by terrain and (for small targets) foliage."

He also states that the image should meet six requirements to properly represent the effects of terrain on target detection:

(1) "Meaningful, unique, large-scale features, relatable to maps"

(2) "Terrain and foliage masking, including partial obscuration"

(3) "Road networks; rail lines, streams in natural relationships"

(4) "Confusing objects of a variety of kinds, sizes, densities"

(5) "Indicators (such as dust plumes, mud holes, glint, motion)"

(6) "Contrast reduction related to range and sun angle" (glare)

He stipulates that these characteristics must be represented only when they are significant to performance, and if that performance is of concern to the particular simulation involved. Only 2 of the 6 preceding considerations (1 and 6) are within the reach of current CIG technology. This inadequacy makes target recognition unrealistically easy.

25.1.2.3 Terrain following simulation. Maintaining controlled flight at minimal height above terrain is only just becoming possible with current future CIG systems being able to demonstrate this capability. There is no indication, however, that simply being able to avoid contact with the terrain implies pilot control action identical to the real world. In fact, it seems to be highly unlikely. Texture is probably essential. Without texture, the level of detail required in the data base for terrain following, over anything other than the simplest of terrains, requires a large system capacity and automated data-base building. Future systems will support terrain following; no current system does, however.

Terrain following requires a heavy effort in data base building because of the necessary surface detail and surface area covered. Of all the missions tasks terrain following places the heaviest emphasis on the requirement for automated data base buiding capabilities.

25.1.2.4 Cruise simulation. Cruise simulation is well within the capabilities of current CIG systems.

25.1.2.5 Take off and landing simulation. Take off and landing simulation is currently within the capabilities of CIG systems. Both CIG systems and camera/model systems, however, are incapable of providing a simulation which allows the pilot to establish a vertical velocity at touch-down equivalent to that found in the actual aircraft.

25.1.2.6 Aerial refueling simulation. Aerial refueling simulation can be performed by existing CIG systems. As is the case with air-to-air combat, camera/model systems are equal to or more effective than CIG systems in this area.

The CIG depiction of the aerial refueling task may have two other problems to deal with. Transport delay may cause pilot-induced oscillations (PIO)and lack of a stereo presentation of the boom may omit crucial cues.

25.1.2.7 Station keeping simulation. Station keeping simulation is currently within the capabilities of CIG.

25.1.2.8 Formation flying simulation. Formation flying simulation with 2, and possibly 3, aircraft being depicted is conceivable, if terrain were minimal, with current technology. Some rather significant problems exist in the area of transport delay induced PIO, as well as cue disparities between simulation subsystems such as visual/motion base. Please see Section 17.2.6 on Transport Delay.

25.1.2.9 Sensor simulation. Sensor simulation is not currently a function of CIG systems. Future systems, such as B-52, utilizing CIG for the visual image generation also use CIG technology for sensor simulation. The image generation for sensor simulation takes place in separate hardware which is a sub-set of the visual CIG system. Commonality occurs only at the source level of the generation of the two respective data bases.

25.2 NON-CIG ALTERNATIVE APPROACHES

The image for image generation may be derived from three possible sources:

(a) Photographic sources have been utilized and have demonstrated varying degrees of success. Both motion picture films and holograms fall into this category.

(b) Models of various types have been used very successfully as sources for visual information. Closed Circuit Television (CCTV) camera/model systems, laser pickups, as well as an optically coupled, fish-eye probe (Yager, 1975) have been conceived of and/or utilized.

(c) Computer Image Generation from a pre-programmed, visual data base.

Of the three approaches, only models and pre-programmed data bases for CIG generation hold any current promise for the future. If flexibility and potential growth of future technology are considered, only CIG remains a viable alternative for all of the mission tasks. Although CCTV camera/model systems have in the past been used for air-to-air combat simulation, as well as take-off and landing, aerial refueling, and formation flying, these uses can currently be rivaled by, and will in the future be exceeded by, CIG. The laser-scanned model board system shows promise in the area of nap-of-the-earth (NOE) (below 50 ft.) flight which is beyond the state-of-the-art of current CIG systems. If terrain following (above 50 ft.) is considered, however, CIG is showing good progress.

This study disclosed no other approach with greater future potential for image generation. As stated earlier (Section 17 Introduction) for full mission simulation there simply is not any other choice.

25.3 AFWAL/FIGD MISSION TASK VERSUS CIG IMPLEMENTATION

Tables 43 through 51 (at the end of the section) break the mission task's requirements down into related visual requirements and CIG implementations. In addition there is information within the CIG Implementation column relating to specific CIG features. This special information (i.e., [I 1-4]) refers back to the Roman numeral and associated digits in Table 7.

The CIG implementation column in these tables contains conclusions drawn from the study results. This column does not list a "hard requirement" but rather a recommended ultimate goal.

25.4 THREE POTENTIAL CIG SYSTEM CONFIGURATIONS

When establishing the configuration for the AFWAL/FIGD CIG system, many different requirements and constraints were considered. Previous sections in this report have specified and explained in detail their impact. At this point, the idea is to define the system required in a summary fashion.

The main problem in this study has been to acquire factual information on the next generation of CIG systems (systems which are currently being developed). The only complete information was that which came from systems that have been in use for a minimum of 1 to 2 years. All sites visited and personnel queried were using existing systems as opposed to the next generation of CIG systems. These existing systems do not have the capabilities of the next generation.

Table 52 contains conclusions drawn by the authors of this study from the results of the study. They should be used only as a guide to CIG configurations. Their use should be in conjunction with information provided for the generic system configuration specified by in the Tables 43 through 51. Refer to Sections 5, 6, 7 and 18 for additional information. The system configurations to be found in the following tables provide the features that would comprise three system configurations:

(a) Minimal System Configuration – Available features on systems specified in 1980.

(b) Optimal System Configuration – Available features on systems specified in 1982 – 1983.

(c) Fully-developed System Configuration – Available features on systems specified in 1985 – 1987.

The minimal system configuration is the only system of the three which is available today (1980). Its cost is that of the 8,000 edge system previously priced (see Section 24). The two future systems should cost approximately the same in 1980 dollars when they become feasible. This is true because even though more complex they will be less expensive to manufacture, because of new approaches and technology. (e.g. video disk memories, distributed processing, very large scale integration [VLSI] integrated circuits [ICs], custom ICs, sub-nanosecond emitter coupled logic [ECL], etc.). See Table 52.

Table 43. Air-To-Air

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. High performance.	A. Velocity ≤ .9 Mach, Closing velocity ≤ 2 Mach.	A. Active data base updating scheme at rate sufficient to inhibit overrunning data base.
	B. Unlimited orientation (roll, pitch, yaw) P (300°/S), Q (150°/S), R (150°/S).	B. • Detail for entire sphere stored in active data base. • To eliminate frame rate effect (horizontally moving object doubling) field rate updating is required. • To eliminate interlace effect (field tracking vertically moving object causes one field to seem to disappear) requires non-interlaced frame.
	C. Without detectable blurring, phase lag or stepping.	C. • Non-interlaced frame. • 60 cycle update rate. • Transport delay under* 60 milliseconds. • [I 1-4]
		*This is a target figure and should not be viewed as inviolable. No absolute figure has been determined by research. See section 17.2.6. on transport delay.

Table 43. Air-To-Air (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
2. Near ground encounters with other aircraft.	A. 5000 ft. and below (as low as 50 ft.) B. Need for accurate velocity attitude, and altitude cues near ground.	A,B • High level of detail - large quantity of edges. • Detailed texture capabilities 2D and 3D. • [I 1,2, IV 1,3,4, V 2-6, VI 1]
	C. Adequate detail in terrain scene.	C. • Vary the scene level of detail by the slant range to the object, object priority, size and channel. • Area of interest display - vary contrast and visibility with slant range. • [I 2, II 1,2, V 1-6]
	D. Ability to alter and tailor to suit mission (ease of data base manipulation).	D. • Flexibility in altering the CIG data base. • Automated Data Base Building.

Table 43. Air-To-Air (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
3. Enemy and possibly friendly aircraft may be involved (1 or more).	A. Differing aircraft possible (believable representation).	A. • High level of detail in aircraft model • [I 1,2, V 3,6,7,8, VI 1-4]
	B. Distinguishable by type/configuration (cargo: C-141, C-5 versus Fighter F-4 or MIG)	B. Numerous aircraft models in data base.
	C. Up to 3 independently moving enemy (relative to subject). D. Aircraft wingman visible to pilot at anytime each perhaps executing its own high performance maneuvers.	C,D • Four independently moving aircraft require 4 to 32 independently moving models (dependent on control surfaces including speed brakes) • [VI 3]
	E. Aircraft could be distant (visual threshold) or proximate (50 ft.) - (aircraft camouflage).	E. • Display system with high resolution target capacity. • [I 2]

Table 43. Air-To-Air (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
4. Missions may involve the presence of a wingman.	A. Reinforces need for ± 90 horizontal field of view.	A. Wide FOV requires large number of visible edges and non-restricting edge crossings per system scan line or AOI display as an alternative.
	B. Reinforces need for depiction of proximate aircraft.	B. • Large edge count • Multiple levels of detail with fade from one to the other as wingman comes closer and detail increases. • If wingman control surfaces move 8 or more (1 fuselage, 2 ailerons, 2 dive breaks, 2 elevators, 1[a] rudder(s) moving models are involved to create wingman, otherwise only 1. • [I 1,2, IV 1-3,6-9, VI 1-3]
	C. Reinforces need for depiction of particular aircraft for designation and identification.	C. • Numerous AC models in data base.
	D. Independent operation at distance possible.	D. • High resolution • [I 2]

Table 43. Air-To-Air (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
5. Detection and identification of target objects at distance.	A. Detect at 25,000 ft.	A. • Detection at 25,000 ft. implies display resolution between 1 and 2 minutes of arc. No camouflage.* • [II 2]
	B. Recognize at 5,200 ft.	B. Recognition at 5,200 ft. implies adequate detail to tell generic type. No camouflage.
	C. Identify at 3,600 ft.	C. Identification at 3,600 ft. implies adequate detail to differentiate types with genre. No camouflage.
	D. Implies details and resolution of objects.	D. [I 2] *Camouflage decreases the maximum potential range for detection, recognition and identification. See 7.1.2, 14.5 and 25.1.2.2(b).

Table 43. Air-To-Air (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
6. Throughout a large field of view is required.	A. ± 90° side vision (minimum). B. + 90° upward vision (minimum). C. - 30° downward vision (minimum). Note: Measure from centerline of visual display system.	A,B,C imply one of four display approaches: first 3 require very large displayable edge counts: • Multiple channels - requires CIG system to handle multiple channels and either not increase edge count when edges cross boundaries between channels* or have enough buffered capacity to handle up to 4 times the number of edges displayed when the same scene at a greater distance appears on one channel. [I 2, II 2] *See 17.2.2.2. • Multiple channel inset target dodecahedron - same requirements plus additional channel capacity and ability to key out background area covered by inset. [I 2, II 2] • Background/target projector dome system - one or more background channels, one target projector per wingman and target. Requires geometric correction for display. Background could be AOI. [I 2] • Helmet mounted display - requires implementation of AOI sensing (head slaved only). Minimizes edge count due to limited instantaneous FOV.+ [I 2] +See 5.2(f) and 14.1.8.

Table 43. Air-To-Air (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
7. Ordnance usage and impact registration.	A. Ability to depict both incoming and outgoing missile flight including registration of impact - would include "contrails".	A,B • Real time data base building to create contrails and possibly bomb burst. • [VI 3-8]
	B. Ability to depict other ordnance exchange both incoming and outgoing-bullets (incendiary).	
	C. Accurate positioning in space and time of target aircraft to assure accurate ordnance delivery scoring. ±10 ft. in position or ±2 milliradians (whichever is more restrictive).	C. Accuracy of computation: • X,Y,Z position ±10 ft. beyond 10,000 ft. • X,Y,Z position ±2 milliradians (±6' 53") within 10,000 ft. slant range
8. Time of day (lighting).	A. Sun angle.	A,B [III 1,4, V 3,6,8,9,10,11,12]
	B. Sun image (effect of sun and target visibility and tactics.	
	C. Day, dusk/dawn, night lighting.	C. • Day [III 1,4, V 3,6,8,9,10,11,12] • Dusk/dawn [III 1,5, IV 4] • Night lighting [III 2,3,6, IV 3,4]

Table 43. Air-To-Air (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
9. Limited or restricted visibility.	A. "Overcloud" flight	A. • Cloud layer with specifiable top and bottom. Top illumination relative to sun position, gray bottom illumination relative to thickness and sun angle. Internal illumination relative to layer depth and sun angle algorithms to detect flight internal to a cloud and inhibit crash detection. [III 4, IV 7, 8,9,10, V 1,2,3,5,7,10]
	B. Patchy cloud	B. • Scattered and broken clouds. Clouds as individual objects. Extensive edge requirements. [I 1,2, II 1,2, IV 5,6,8,9,10, V 1,2,3,5,7,10]
	C. Definable limited visibility, SVR (Slant Visible Range) with fog or haze.	C. • Definable range fading with objects losing saturation and fading to blue if in color. • Edges beyond visible range should not count as part of displayable edge count. • [I 2, III 4, IV 1,2,3]

Table 43. Air-To-Air (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
10. Fly to and through cloud maneuvers.	A. Create realistic clouds that can be approached and flown through. Not just horizon effect.	A. • High edge capacity to model three dimensional clouds as individual objects. • Algorithms to detect flight internal to a cloud and inhibit crash detection.
11. Relatively small geographic area.	A. 100 x 100 nautical mile gaming area.	A. On line data base large enough to contain 100 x 100 nautical mile gaming area.
	B. Possibly terrain features could be part of combat strategy (mountains, etc.).	B. [V 1]

Table 44. Air-To-Ground

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. High performance	A. Mach $\leq .9$	A. Active data base updating scheme at rate sufficient to inhibit overrunning data base.
	B. Unlimited orientation roll, pitch, yaw P(200°/S), Q(120°/S), R(120°/S)	B. • Detail for entire sphere stored in active data base. • To eliminate frame rate effect (horizontally moving object doubling) field rate updating is required • To eliminate interlace effect (field tracking vertically moving object causes one field to seem to disappear) requires non-interlaced frame.
	C. Without detectable blurring, phase lag or stepping	C. • Non-interlaced frame. • 60 cycle update rate. • Transport delay under 60 milliseconds. • [I 1-4]

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
2. Near ground encounters	A. 5000 ft. and below (as low as 50 ft.)	A,B. • High level of detail - large quantity of edges. • Detailed texture capabilities 2D and 3D. • [I 1,2, IV 1,3,4, V 2-6, VI 1]
	B. Need for accurate velocity, attitude, and altitude cues near ground	
	C. Adequate detail in terrain scene	C. • Vary the scene level of detail by the slant range to the object, object priority, size and channel. • Area of interest display - vary contrast and visibility with slant range. • [I 2, II 1,2, V 1-6]
	D. Ability to alter and tailor to suit mission (ease of data base manipulation).	D. • Flexibility in altering the CIG data base. • Automated Data Base Building.

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
3. Delivery of various ordnances (guns, bombs, missiles).	A. Immediate impact registration of ordnance necessary for hit or miss.	A,B. • Real time data base building to create contrails and possibly bomb burst. • [VI 3-8]
	B. Ability to depict both incoming (tracer, Sams, etc.) and outgoing (missile, tracer, bomb, etc.) ordnance (incoming SAM must display trail)	
	C. Ability to perform <u>accurate</u> delivery for purpose of scoring analysis. This implies accurate positioning of targets in space and time. ± 10 ft. in position ± 2 milliradians (whichever is more stringent)	C. Accuracy of computation: • X,Y,Z position ± 10 ft. beyond 10,000 ft. • X,Y,Z position ± 2 milliradians (± 6' 53") within 10,000 ft. slant range

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
4. One or more fixed or moving targets.	A. Definable targets (variable-user constructed).	A. Interactive data base building capability to build various target models.
	B. Up to 3 simultaneous independently moving targets on ground and one air wingman and his armament.	B. • Targets - 3 <u>moving</u> objects (9 if tank with moving turret and elevatable gun) • Wingman - 1 moving object (8 moving objects if ailerons, elevators, rudder and speed brakes are shown) • Armament a) Tracers b) Missiles c) Bombs d) Impact • [VI 1-3]
	C. Detail sufficient for differentiation and recognition.	C. • Displayable edge capacity sufficient to depict wingman, 3 tanks and terrain detail. • Large edge count.

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
5. Detection and identification of target objects (and friendlies) at distance.	A. Detect at 25,000 ft.	A. • Detection at 25,000 ft. implies display resolution between 1 and 2 minutes of arc.* No camouflage. • [II 2]
	B. Recognize at 5,200 ft.	B. Recognition at 5,200 ft. implies adequate detail to tell generic type.* No camouflage.
	C. Identify at 3,600 ft.	C. Identification at 3,600 ft. implies adequate detail to differentiate types with genre.* No camouflage.
	D. A through C imply detail of objects.	D. [I 2]
		*Camouflage decreases the maximum potential range for detection, recognitiion and identification. See 17.1.2, 14.5 and 25.1.2.2(b).

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
6. Normal field of view for a close support aircraft.	A. ± 90° Side Minimum B. + 30° Vertical C. - 30° Vertical NOTE: Measure from the centerline of visual display system.	A,B,C imply one of four display approaches: first 3 require very large displayable edge counts: • Multiple channels - requires CIG system to handle multiple channels and either not increase edge count when edges cross boundaries between channels* or have enough buffered capacity to handle up to 4 times the number of edges displayed when the same scene at a greater distance appears on one channel. [I 2,II 2] *See 17.2.2.2. • Multiple channel inset target dodecahedron - same requirements plus additional channel capacity and ability to key out background area covered by inset. [I 2, II 2] • Background/target projector dome system - one or more background channels, one target projector per wingman and target. Requires geometric correction for display. Background could be AOI. [I 2] • Helmet mounted display - requires implementation of AOI sensing (head slaved only). Minimizes edge count due to limited instantaneous FOV.+ [I 2] +See 5.2(f) and 14.1.8.

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
7. High speed, high or low dive angle approach.	A. -60° dive, or -5° strafe	A. No pitch restriction on CIG
	B. $M \leq .9$	B. Active data base updating scheme at rate sufficient to inhibit overrunning data base.
8. "Roll in" maneuvers.	A. Reinforce ± 90° horizontal viewing ± 30° vertical	A. Wide FOV requires large number of visible edges and non-restricting edge crossings per system scan line or AOI display as an alternative.
9. The possibility of the presence of a wingman exists.	A. Side Vision requirement reinforced.	A. Wide FOV requires large number of visible edges and non-restricting edge crossings per system scan line or AOI display as an alternative.
	B. A proximate, detailed aircraft required.	B. • Large edge count • Multiple levels of detail with blending or fade from one to the other as wingman comes closer and detail increases. • If wingman control surfaces move 8 moving models are involved to create wingman, otherwise only 1 • [I 1,2, V 1-3,6-9, VI 1-3]
	C. Distant independent operation.	C. • High resolution • [I 2]

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
10. Friendly and/or enemy ordnance usage and impact registration is necessary.	A. Immediate impact registration of ordnance necessary for hit or miss. B. Ability to depict both incoming (tracer, Sams, etc.) and outgoing (missile, tracer, bomb, etc.) ordnance (incoming SAM must display trail)	A,B • Real time data base building to create contrails and possibly bomb burst. • [VI 3-8]
11. Geographical envelope for such missions is generally not large.	A. 100 x 100 nautical mile area.	A. • Data base to include area 100 x 100 nautical miles. • Some form of automated data base building capability if new gaming areas are to be created and interactive data base manipulation if existing data bases are to be modified.

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
12. Any of many varied topographical compositions (mountains, plain, city, etc.).	A. Ability to tailor terrain to mission needs both in terms overall terrain features (mountains, valleys, etc.) and cultural and target detail.	A. • Automated generic object building. • Complex object library. • Automated manipulation of objects from library to desired position in gaming area. • Ease and flexibility of data base creation and updating. • [I 1,2, II 1-4, V 1-12]
	B. Topography of terrain may be part of mission (flight through mountains).	B. • Three dimensional detailed objects making up terrain (increase edge count). • Proximal flight may require extremely high edge count or two and three dimensional texture. • [I 1]

Table 44. Air-To-Ground (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
13. Time of day.	A. Day (80%) with sun image and shading.	A. [III 1,4, V 3,6,8,9,10,11,12]
	B. Dusk/dawn (15%).	B. [III 1,5 IV 4]
	C. Night (5%) with lights, horizon, etc.	C. [III 2,3,6 IV 3,4]
14. Definable, limited or restricted visibility.	A. Overcloud flight with penetration to delivery, patchy cloud.	A. • Cloud layer with specifiable top and bottom. Top illumination relative to sun position, gray bottom illumination relative to thickness and sun angle. Internal illumination relative to layer depth and sun angle algorithms to detect flight internal to a cloud and inhibit crash detection. [III 4, IV 7, 8,9,10, V 1,2,3,5,7,10] • Scattered and broken clouds. Clouds as individual objects. Extensive edge requirements. [I 1,2, II 1,2, IV 5,6,8,9,10, V 1,2,3,5,7,10]
	B. Definable limited visibility (SVR - Slant Visible Range) - haze.	B. • Definable range fading with objects losing saturation and fading to blue if in color. • Edges beyond visible range should not count as part of displayable edge count. • [I 2, III 4, IV 1,2,3]

Table 45. Terrain Following

STATEMENT OF TASK REQUIREMENT	RELATEL VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. Low and very low altitude.	A. 50 ft. to 1000 ft. above ground. Following local shape of terrain.	A. • Very high edge count. • [I 1,2, V 1]
	B. Need for proper velocity, attitude and altitude cues.	B,C [I 1,2, IV 1, V 2-5]
	C. Need for terrain detail.	
2. High performance.	A. Velocity ≤ .9 Mach.	A. Active data base updating scheme at rate sufficient to inhibit overrunning data base.
	B. P (200°/S), Q (150°/S), R (150°/S)	B. • Detail for entire sphere stored in active data base. • To eliminate frame rate effect (horizontally moving object doubling) field rate updating is required. • To eliminate interlace effect (field tracking vertically moving object causes one field to seem to disappear) requires non-interlaced frame.
	C. No blur, phase lag or stepping in scene.	C. • Non-interlaced frame. • 60 cycle update rate. • Transport delay under 60 milli-seconds. • [I 1-4]

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Table 45. Terrain Following (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
3. Extended distances	A. Flight either along predetermined course specified corridor 30 x 500 nautical miles with expected (predetermined) terrain including landmarks. Not necessarily straight line path. B. Non-specific flight over expected terrain. C. Non-specific flight over generalized terrain. D. 500 x 500 nautical mile geographic area.	A-D • Very large on line data base. • Automated data base building capability to create new data bases. • Interactive data base manipulation to add and modify recognizable natural as well as cultural features. • [V 4,5]

Table 45. Terrain Following (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
4. Critical and precise execution of flight maneuvers.	A. Velocity, attitude, altitude visual cues.	A,B,C [I 1,2, IV 1, V 2-5]
	B. Range closing cues.	
	C. "Proximity to" cues.	
	D. Field of view ±90° horizontal ±30° vertical.	D. Implies one of four display approaches: first 3 require very large displayable edge counts: • Multiple channels - requires CIG system to handle multiple channels and either not increase edge count when edges cross boundaries between channels* or have enough buffered capacity to handle up to 4 times the number of edges displayed when the same scene at a greater distance appears on one channel. [I 2, II 2] *See 17.2.2.2 • Multiple channel inset target dodecahedron - same requirements plus additional channel capacity and ability to key out background area covered by inset. [I 2, II 2] • Background/target projector dome system - one or more background channels, one target projector per wingman and target. Requires geometric correction for display. Background could be AOI. [I 2] • Helmet mounted display - requires implementation of AOI sensing (head slaved only). Minimizes edge count due to limited instantaneous FOV.+ [I 2] +See 5.2(f) and 14.1.8.

Table 45. Terrain Following (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
5. Varying terrain requirements.	A. Ability to alter/define terrain to suit mission need.	A. • Interactive flexible CIG data base manager. • Totally automated for generic terrain definition or conversion of DMA data.
	B. Ability to model specific area actually existing, e.g., Germany Edwards AFB.	B. • CIG data base updates using digitizer that will accept maps, charts, blueprints, photos, etc. • CIG data base manager which facilitates rapid construction of various models.
6. Specific landmarks.	A. Ability to model specific terrain and/or implant specific landmarks.	A. • CIG data base updates using digitizer that will accept maps, charts, blueprints, photos, etc. • CIG data base manager which facilitates rapid construction of various models.
	B. Quality of terrain must allow recognition of such features.	B. Displayable edge capacity which supports detailed modeling for recognition.
7. Time of day.	A. Day, dusk/dawn, night - with horizon lighting.	A,B. • Day [III 1,4, V 3,6,8,9,10,11,12] • Dusk/Dawn [III 1,5, IV 4] • Night [III 2,3,6, IV 3,4]
	B. Sun shading	

Table 45. Terrain Following (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
8. Definable, limited or restricted visibility.	A. Definable limited visibility (SVR) Haze.	A. • Definable range fading with objects losing saturation and fading to blue if in color. • Edges beyond visible range should not count as part of displayable edge count. • [I 2, III 4, IV 1,2,3]

Table 46. Cruise

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. Extended flight over terrain.	A. May be flight with defined corridor or along prescribed, predefined path. B. May be "free flight" - unspecified course.	A,B • Large medium definition on line data base. • Automated data base building capability to create new data bases. • Interactive data base manipulation to add and modify recognizable natural and cultural features.
2. Medium to high altitude.	A. 1,000 to 60,000 ft.	A. • General surface information providing orientation and rate cues. • Texture may not be required. • [V 1,2, (V 3,4 possible)]
3. High performance maneuvers are not part of the mission.	A. .5 Mach ≤ velocity ≤3 Mach.	A. Active data base updating scheme must transfer mass data at a rate high enough to inhibit overrunning data base.
	B. P (100°/S), Q (50°/S), R (50°/S).	B. • Detail for entire sphere stored in active data base • [II 1-4]

Table 46. Cruise (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
4. Extensive terrain ranges.	A. Corridor: 30 x 50 nautical miles. B. Gaming area 500 x 500 nautical miles for unrestricted.	A,B • Large on line data base. • Automated data base building capability to create new data bases. • Interactive data base manipulation to add and modify recognizable natural and cultural features.
5. Use of terrain features.	A. Configurable terrain.	A. • Interactive flexible CIG data base manager. • Totally automated for generic terrain definition or conversion of DMA data. • This requirement is similar to but much less stringent than Terrain Following 5A.
	B. Sufficient cues for use of terrain features in mission if desired (e.g., nearness to/height above mountain, range to landmark, etc.)	B. [V 1,2 (V 3,4 possible)]

Table 46. Cruise (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
6. Specific landmarks.	A. Create and place specific landmarks. B. Sufficient detail for recognition.	A,B • CIG data base updates using digitizer that will accept maps, charts, blueprints, photos, etc. • CIG data base manager which facilitates rapid construction of various models. • Displayable edge capacity which supports detailed modeling for recognition.
7. Time of day.	A. Day, dusk/dawn, night. B. Sun angle.	A,B • Day [III 1,4, V 3,6,8,9,10,11,12] • Dusk/dawn [III 1,5, IV 4] • Night [III 2,3,6, IV 3,4]

Table 46. Cruise (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
8. Limited or restricted visibility.	A. Above cloud. B. Patchy cloud.	A,B • Cloud layer with specifiable top and bottom. Top illumination relative to sun position, gray bottom illumination relative to thickness and sun angle. Internal illumination relative to layer depth and sun angle algorithms to detect flight internal to a cloud and inhibit crash detection. [III 4, IV 7, 8,9,10, V 1,2,3,5,7,10] • Scattered and broken clouds. Clouds as individual objects. Extensive edge requirements. [I 1,2, II 1,2, IV 5,6,8,9,10, V 1,2,3,5,7,10]
	C. Definable limited visibility (haze).	C. • Definable range fading with objects losing saturation and fading to blue if in color. • [I 2, III 4, IV 1,2,3]

Table 46. Cruise (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
9. Cloud phenomenon (fly through).	A. Realistic cloud which can be approached and flown through.	A. • Cloud layer with specifiable top and bottom. Top illumination relative to sun position, gray bottom illumination relative to thickness and sun angle. Internal illumination relative to layer depth and sun angle altorithms to detect flight internal to a cloud and inhibit crash detection. [III 4, IV 7, 8,9,10, V 1,2,3,5,7,10] • Scattered and broken clouds. Clouds as individual objects. Extensive edge requirements. [I 1,2, II 1,2, IV 5,6,8,9,10, V 1,2,3,5,7,10]

Table 47. Takeoff and Landing

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. Accurate approach, touchdown, taxi, takeoff, and departure maneuvers.	A. Conventional 3° - 4° glide slope and STOL 6° - 8° glide slope approaches. B. Various aircraft could be involved F-16, A-10, B-52, STOL, etc. C. On ground taxi - eye height as low as 9 ft. D. Both takeoff and landing imply that airfield complex is "centrally located".	A-D • Attitude and position rates-of-change extrapolation technique must accomodate different types of models. • Large displayable edge capacity is required to present cues for approach. • No discrete jumps during slow taxi or turn (See 16(f).
2. Full stop.	A. Ability to come to a full stop.	A. Accurate repeatability is required so that no apparent motion occurs when aircraft has stopped.

Table 47. Takeoff and Landing (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
3. Go around capability.	A. Also turn into final approach. B. Locating airfield. C. Go around, turn in, and airfield location require side vision capability ± 90°.	A-C Wide FOV • Multiple channels - requires CIG system to handle multiple channels and either not increase edge count when edges cross boundaries between channels or have enough buffered capacity to handle up to 4 times the number of edges displayed when the same scene, at a greater distance, appears on one channel. [I 2, II 2] • Helmet mounted display - requires implementation of AOI sensing (head slaved only) Minimizes edge count.
4. Maneuvers will generally be low performance and low speed in nature.	A. Velocity less than 200 kts. B. P (100°/S), Q (50°/S), R (50°/S).	A,B • Detail for entire sphere stored in active data base. • [II 1-4]

Table 47. Takeoff and Landing (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
5. Maneuvers will require critical and precise execution.	A. Position in three space relative to runway must be accurate. B. All necessary cues must be present for velocity attitude and altitude, such as runway markings, runway skid marks, etc.	A. High correlation between simulation and CIG data bases. B. • Large displayable edge count to allow for detailed modeling. • Recognizable objects such as fuel truck and other aircraft on the ground may be required. • [I 1,2, II 1-4, IV 1, V 1-5] C. • Large displayable edge count for wide FOV. • May be reduced somewhat by implementing AOI presentation.
6. The geographical area will consist of the approach and departure corridors to the runways (various headings) and adequate lateral area to perform the go around maneuvers.	A. A corridor must be 30 nautical miles in length - either approach or takeoff. B. Lateral distance is ± 15 nautical miles for <u>each</u> airport runway.	A,B • 30 x 60 nautical mile corridor with runways located at the center of the longitudinal axis. • Requires medium size on line data base. • Automatic data base building capability to create new takeoff and approach corridors as well as interactive semi-automatic data base manager, capable of adding detail to new data bases and redefining existing data bases.

Table 47. Takeoff and Landing (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
7. Altitudes will be relatively low.	A. Altitude 10,000 ft. to ground level for long approach. B. Final approach 5,000 ft. to ground.	A,B • Large displayable edge count to allow for detailed modeling. • Recognizable objects such as fuel truck and other aircraft on the ground may be required. • [I 1,2, II 1-4, IV 1, V 1-5]
8. Several runways at various headings.	A. Runways of varying heading and of varying length (STOL for example) each with approach corridor.	A. For each runway: • 30 x 60 nautical mile corridor with runways located at the center of the longitudinal axis. • Requires medium size on line data base. • Automatic data base building capability to create new takeoff and approach corridors as well as interactive semi-automatic data base manager, capable of adding detail to new data bases and redefining existing data bases.
9. Runway lighting must be complete.	A. Lighting intensity must be controllable and correlate with real world. B. Lighting must be configurable. C. Lighting must be directional (as normally).	A,B,C [II 3, IV 1,3, VII 1-8]

Table 47. Takeoff and Landing (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
10. Differing runway, airfield complex, and surrounding territories configuration might be needed for each mission.	A. Airfield and terrain surrounding must be tailorable to satisfy mission: 1. Runways: total number and heading easily changed. 2. Defined terrain/airfield configurations which may include specific landmarks, etc. 3. Complex itself must be tailorable.	A. · Interactive semi-automatic data base manager capable of adding detail to new data base. · Large collection of stored objects.
11. Time of day.	A. Sun shading. B. Day, dusk/dawn, night (city, airfield lighting).	A,B [III 1-6, IV 3,4, V 3,6,11,12]

Table 47. Takeoff and Landing (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
12. Well-defined, controllable limited visibility.	A. Penetration. B. Above cloud. C. Haze. D. Patchy cloud. E. Definable limited visibility	A-E • Cloud layer with specifiable top and bottom. Top illumination relative to sun position, gray bottom illumination relative to thickness and sun angle. Internal illumination relative to layer depth and sun angle algorithms to detect flight internal to a cloud and inhibit crash detection. [III 4, IV 7, 8,9,10, V 1,2,3,5,7,10] • Scattered and broken clouds. Clouds as individual objects. Extensive edge requirements. [I 1,2, II 1,2, IV 5,6,8,9,10, V 1,2,3,5,7,10] • Definable range fading with objects losing saturation and fading to blue if in color. [I 2, III 4, IV 1,2,3]

Table 48. Aerial Refueling

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. Low and medium performance.	A. Velocity ≤ .75 Mach.	A. Data base access must be of magnitude large enough to support Mach .75 flight.
	B. Altitude 10,000 ft. - 30,000 ft.	B. General surface information providing orientation and rate cues.
	C. P (100°/S), Q (50°/S), R (50°/S)*. *These rates are probably low and should match Formation Flying.	C. • Detail for entire sphere stored in active data base. • Non-interlaced scan. • 60 Hz update rate • Very short, total transport delay or extrapolation and filtering of flight dynamics data from simulation computer. • [II 1-4]
2. Precise and accurate positioning	A. Necessary cues for approximate interaction.	A,B,C • High detail (high edge count). • Linked multiple moving models. Operating on same axis makeup boom. • Short transport delay • Extrapolation as well as filtering of flight dynamics data from simulation computer. • [I 1,2, II 3,4, IV 1,3, V 1,2,3, 6,7,11, VI 1,3]
	B. Accurate depiction of tanker and boom in three dimensional space and time.	
	C. No stepping of tanker/boom.	

Table 48. Aerial Refueling (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
3. Independent relative motion.	A. Tanker may be performing own maneuvers (moving objects) - (either canned or under pilot control). B. Tanker can be seen from all angles.	A,B • High detail (high edge count). • Linked multiple moving models such as boom and tanker control surfaces. • Short transport delay. • Extrapolation as well as filtering of flight dynamics data from simulation computer. • [I 1,2, II 3,4, IV 1,3, V 1,2,3, 6,7,11, VI 1,3]
4. Interaction with the tanker aircraft's boom, which itself will be moving.	A. Boom dynamics possible (moving object). B. Interaction with boom up to and including coupling must be possible. C. Proximity of interaction with boom requires good spatial cues.	A,B,C [I 1,2, II 3,4, V 1,2,3,6,7,11, VI 1,3]
5. Varying tanker aircraft.	A. Ability to create and/or tailor aircraft to meet mission needs, KC-135, KC-10A, etc. B. Each with sufficient detail for proper recognition and identification.	A,B High level of detail in aircraft model. • [I 1,2, V 3,6,7,8, VI 1-4]

Table 48. Aerial Refueling (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
6. Acquisition phase.	A. Viewing volume. Relates to tanker ability to perform independent maneuvers.	A. Implies one of four display approaches: first 3 require very large displayable edge counts: • Multiple channels - requires CIG system to handle multiple channels and either not increase edge count when edges cross boundaries between channels or have enough buffered capacity to handle up to 4 times the number of edges displayed when the same scene at greater distance appears on one channel. [I 2, II 2] • Multiple channel inset target dodecahedron - same requirements plus additional channel capacity and ability to key out background area covered by inset. [I 2, II 2] • Background/target projector dome system - one or more background channels, one target projector per wingman and target. Requires geometric correction for display. Background could be AOI. [I 2] • Helmet mounted display - requires implementation of AOI sensing (head slaved only). Minimizes edge count due to limited instantaneous FOV. [I 2]

Table 48. Aerial Refueling (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
6. Acquisition phase (con't).	B. Resolution - Detection 25,000 ft. - Recognition 5,200 ft. - Identification 3,600 ft.	B. • Detection at 25,000 ft. implies display resolution between 1 and 2 minutes of arc.* No camouflage. • [II 2] • Recognition at 5,200 ft. implies adequate detail to tell generic type. No camouflage • Identification at 3,600 ft. implies adequate detail to differentiate types with genre. No camouflage. *Camouflage decreases the maximum potential range for detection, recognition, and identification. See 7.1.2, 14.5 and 25.1.2.2(b).

Table 48. Aerial Refueling (Continued.

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
7. Good look-up capability.	A. + 90° look up. B. - 30° look down.	A,B imply one of four display approaches: first 3 require very large displayable edge counts: . Multiple channels - requires CIG system to handle multiple channels and either not increase edge count when edges cross boundaries between channels* or have enough buffered capacity to handle up to 4 times the number of edges displayed when the same scene at a greater distance appears on one channel. [I 2, II 2] *See 17.2.2.2. • Multiple channel inset target dodecahedron - same requirements plus additional channel capacity and ability to key out background area covered by inset. [I 2, II 2] • Background/target projector dome system - one or more background channels, one target projector per wingman and target. Requires geometric correction for display. Background could be AOI. [I 2] • Helmet mounted display - requires implementation of AOI sensing (head slaved only.) Minimizes edge count due to limited instantaneous FOV.[+] [I 2] [+] See 5.2(f) and 14.1.8.

Table 48. Aerial Refueling (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
8. Time of day.	A. Day, dawn/dusk, night. B. Sun angle.	A,B [III 1-6, IV 3,4]
	C. Aircraft lighting.	C. • Unique data base for night tanker aircraft model smooth shaded to emulate night lighting effects. • [II 3, V 2, IV 3, VII 1]
9. Geographic boundaries.	A. 200 x 50 nautical mile corridor, 200 x 200 nautical mile if unspecified.	A. • Large on line data base. • Automated data base building capability to create new data bases. • Interactive data base manipulation to add and modify recognizable natural and cultural features.
10. Detailed terrain information usually of secondary importance.	A. Adequate terrain cues or above cloud cover flight to altitude, velocity, horizon.	A [V 1,2 (V 3,4 possible)]

Table 49. Station Keeping

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. Low performance.	A. Velocity ≤ .5 Mach. B. P (200°/S), Q (50°/S), R (50°/S).	A,B • Detail for entire sphere stored in active data base. • [II 1-4]
2. Low and medium altitude.	A. Altitude less than 10,000 ft.	A. • High level of detail - large quantity of edges. • Detailed texture capabilities 2D and 3D • [I 1,2, IV 1,3,4, V 2-6, VI 1]
3. Relatively small geographical area.	A. 30 x 30 nautical miles.	A. Small on line data base.
4. Particular geographical feature or location.	A. Ability to configure terrain to supply general and specific (landmark) mission requirements.	A. • CIG data base updates using digitizer that will accept maps, charts, blueprints, photos, etc. • CIG data base manager which facilitates rapid construction of various models. • Displayable edge capacity which supports detailed modeling for recognition.

Table 49. Station Keeping (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
5. Field of view which allows maintenance of visual contact.	A. ± 90° horizontal (minimum). B. ± 30° vertical.	A,B imply one of four display approaches: first 3 require very large displayable edge counts: • Multiple channels - requires CIG system to handle multiple channels and either not increase edge count when edges cross boundaries between channels* or have enough buffered capacity to handle up to 4 times the number of edges displayed when the same scene at a greater distance appears on one channel. [I 2, II 2] *See 17.2.2.2. • Multiple channel inset target dodecahedron - same requirements plus additional channel capacity and ability to key out background area covered by inset. [I 2, II 2] • Background/target projector dome system - one or more background channels, one target projector per wingman and target. Requires geometric correction for display. Background could be AOI. (I 2] • Helmet mounted display - requires implementation of AOI sensing (head slaved only). Minimizes edge count due to limited instantaneous FOV.+ [I 2] +See 5.2(f) and 14.1.8.

Table 49. Station Keeping (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
6. Interest areas can vary.	A. Tailorable, flexible design capability to alter. B. Totally reconstruct scene in general or regarding specified features to suit mission.	A,B • Automated data base building capability to create new data bases. • Interactive data base manipulation to add and modify recognizable natural as well as cultural features. • [V 4,5]
7. Time of day.	A. Day, dusk/dawn, night. B. Ground lighting reflecting T.O.D. (time of day). C. Sun angle.	A,B,C • Day [III 1,4, V 3,6,8,9,10,11,12] • Dusk/dawn [III 1,5, IV 4] • Night lighting [III 2,3,6, IV 3,4]

Table 49. Station Keeping (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
8. Limited or restricted visibility.	A. Haze. B. Definable, controllable limited visibility. C. Over cloud flight.	A,B,C • Cloud layer with specifiable top and bottom. Top illumination relative to sun position, gray bottom illumination relative to thickness and sun angle. Internal illumination relative to layer depth and sun angle algorithms to detect flight internal to a cloud and inhibit crash detection. [III 4, IV 7, 8,9,10, V 1,2,3,5,7,10] • Scattered and broken clouds. Clouds as individual objects. Extensive edge requirements. [I 1,2, II 1,2, IV 5,6,8,9,10, V 1,2,3,5,7,10] • Definable range fading with objects losing saturation and fading to blue if in color. • [I 2, III 4, IV 1,2,3]

Table 50. Formation Flying

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. Low and medium performance precision maneuvers.	A. $.3$ Mach $\leq$ Velocity $\leq .9$ Mach.	A. Active data base updating scheme at rate sufficient to inhibit overrunning data base.
	B. P (250°/S), Q (100°/S); R (100°/S)	B. • Detail for entire sphere stored in active data base. • Non-interlaced scan. • 60 cycle rate. • Very short, total transport delay or extrapolation and filtering of flight dynamics data from simulation computer. • [II 1-4]
	C. Altitude greater than 1,000 ft.	C. • General surface information providing orientation and rate cues. • Texture may not be required. • [V 1,2, (V 3,4 possible)]
2. Relative to any formation partner(s).	A. Up to 3 partners recognizable and differentiable.	A. • Very large displayable edge count. • [I 1,2, II 1,2, V 1,2,3,6,7, VI 1,3]

Table 50. Formation Flying (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
3. Accurate positioning of the subjects's aircraft relative to other aircraft.	A. Accurate representation of subject and partner aircraft in 3 space relative to each other, and absolute. B. No blurring or jitter in partner aircraft. C. Relative motion. D. Sufficient cues for "up close" interaction.	A-D. • Accurate absolute position of moving models. • Non-interlaced scan. • 60 Hz update rate. • Very large displayable edge count. • [I 1,2, II 1,2,3,4, V 1,2,3,6,7]

Table 50. Formation Flying (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
4. A wide field of view.	A. ± 90° horizontal F.O.V. B. + 90° vertical F.O.V. C. - 30° vertical F.O.V.	A-C imply one of four display approaches: first 3 require very large displayable edge counts: • Multiple channels - requires CIG system to handle multiple channels and either not increase edge count when edges cross boundaries between channels* or have enough buffered capacity to handle up to 4 times the number of edges displayed when the same scene at a greater distance appears on one channel. [I 2, II 2] *See 17.2.2.2. • Multiple channel inset target dodecahedron - same requirements plus additional channel capacity and ability to key out background area covered by inset. [I 2, II 2] • Background/target projector dome system - one or more background channels, one target projector per wingman and target. Requires geometric correction for display. Background could be AOI. [I 2] • Helmet mounted display - requires implementation of AOI sensing (head slaved only). Minimizes edge count due to limited instantaneous FOV.+ [I 2] +See 5.2(f) and 14.1.8.

Table 50. Formation Flying (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
5. Other aircraft proximate.	A. Realism of detail for recognition, control surfaces. B. Accuracy of placement. C. As close as 20 ft.	A,B,C • High detail requires large displayable edge capacity. • Moving control surfaces require multiple linked moving models, (each surface is a discrete object they are all linked to move together through space). . [I 1,2, II 1-4, V 1,2,3,6,7, VI 1,3]
6. Exhibiting independent motion.	A. Each partner can have independent motion both at distance and in formation. B. Partner performance capabilities identical to that of subject aircraft.	A. [VI 3] B. Moving models capable of M .9, P(250°/S), Q(100°/S), R(100°/S) displacement with under 100 ms transport delay.

Table 50. Formation Flying (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
7. Acquisition phase, where partner aircraft are sought out and approached.	A. Detection 25,000 ft.	A. • Detection at 25,000 ft. implies display resolution between 1 and 2 minutes of arc.* No camouflage. • [II 2]
	B. Recognition 5,200 ft.	B. Recognition at 5,200 ft. implies adequate detail to tell generic type. No camouflage.
	C. Identification 3,600 ft.	C. Identification at 3,600 ft. implies adequate detail to differentiate types with genre. No camouflage.
	D. Reinforces need for viewing volume.	D. [I 2]
8. Terrain bounds.	A. Including acquisition 800 x 200 nautical miles domain is sufficient.	A. • Large on line data base. • Automated data base building capability to create new data bases. • Interactive data base manipulation to add and modify recognizable natural and cultural features. *Camouflage decreases the maximum potential range for detection, recognition and identification. See 7.1.2, 14.5 and 25.1.2.2(b).

Table 50. Formation Flying (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
9. Time of day.	A. Day, dusk/dawn, night. B. Aircraft lights. C. Sun angle.	A,B,C • Day [III 1,4, V 3,6,8,9,10,11,12] • Dusk/dawn [III 1,5, IV 4] • Night [III 2,3,6, IV 3,4]
10. Restricted visibility.	A. Above cloud. B. Patchy cloud.	A,B • Cloud layer with specifiable top and bottom. Top illumination relative to sun position, gray bottom illumination relative to thickness and sun angle. Internal illumination relative to layer depth and sun angle algorithms to detect flight internal to a cloud and inhibit crash detection. [III 4, IV 7, 8,9,10, V 1,2,3,5,7,10] • Scattered and broken clouds. Clouds as individual objects. Extensive edge requirements. [I 1,2, II 1,2, IV 5,6,8,9,10, V 1,2,3,5,7,10]
	C. Restricted visibility (definable). D. Haze.	C,D • Definable range fading with objects losing saturation and fading to blue if in color. • [I 2, III 4, IV 1,2,3]

Table 50. Formation Flying (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
11. Cloud phenomenon.	A. Fly to and through clouds.	A. • High edge capacity to model three dimensional clouds as individual objects. • Algorithms to detect flight internal to a cloud and inhibit crash detection.

Table 51. Sensor Related Studies

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
1. Display oriented	A. For forward looking, field of view would be narrow to medium depending on sensor 5° to 60°. B. Downward looking (radar) is normally 360° circular format. C. Actual displays are both calligraphic and raster format depending on sensor. D. Simulated sensor display need only resemble actual display. E. Slewable at realistic rates.	A-D • Correlate CIG data base and sensor simulation data base. • CIG data base contains sensor attributes.
2. Converting the outside environment into electronic image.	A. Image must strongly resemble actual sensor image in terms of image produced, both qualitatively and quantitatively. B. "Real time" processing and presentation.	A,B • CIG data base must contain required sensor display attributes. • Sensor and CIG displays must be presented at the same time.
3. Coupled with "out-the-window"	A. Sensor display image must correspond without the window in 3-space and time.	A. • Sensor and CIG data bases must be correlated. • Real time displays must be correlated.

Table 51. Sensor Related Studies (Continued)

STATEMENT OF TASK REQUIREMENT	RELATED VISUAL REQUIREMENT	CIG IMPLEMENTATION
4. Topographical, and cultural information gathering	A. Terrain must be able to be modeled both in general and with regard to specific features (landmarks). B. Actual (real world) topography may be involved (must be able to model particular defined area).	A,B Flexible data base manager to build sensor data base.
5. Threat identification	A. Moving objects (up to 5) B. Designation/identification capability on par with actual device.	A,B • Moving models • High detail in relationship to slant range.
6. Varying performance capabilities and constraints	A. The sensor itself is not as important as how it is used in performing a mission task. B. Particular sensor packages are not going to be modeled, but sensor types must be simulated within performance which can adequately approximate the real world capabilities for satisfying mission.	A,B • Realistic sensor modeling • Special effects to affect the sensor display.

Table 52. Potential CIG System Configurations

CIG Features	Minimal (1980) System Configuration	Optimal (1982-1983) System Configuration	Fully Developed (1985-1987) System Configuration
Occultation	X	X	X
Level of detail	3	8	8
System capacity			
Displayable d.b.*	8K D.E.†	24-32K D.E.	>100K D.E.
Active d.b.	>1.5 times displayable	6 times displayable	?
On-line d.b.	250-500K D.E./d.b.	750K-1.5M D.E./d.b.	?
Multi-channel	X	X	X
Stereo		X	X
Head/eye slaving		X	X
Multi simulations (eye points)	1-2	≥2	4
Simultaneous sensors			X
Auto d.b. building		X	X
Overload avoidance			
Edge Crossing Capacity	>3% of displayable	≥10% of displayable	≥20% of displayable
Display. d.b. buffer	5% of displayable	10%	
Overload management	Rudimentary	Extensive	Sophisticated
Anti-aliasing (spatial)	Rudimentary	Extensive	Sophisticated
Anti-aliasing (temporal)		Rudimentary	Extensive
Vertical edge smoothing	X	X	X
Horizontal edge smoothing	X	X	X
Field rate update	X	X	X
Non-restrict rates		X	X
Transport delay	<100 ms	<60 MS	Part of A/C response
Sun image		X	X
Moon image	X	X	X
Stars image	X	X	X
Day	1 level	2 levels	Variable

†D.E. = Display Edges
*d.b. = data base

Table 52. Potential CIG System Configurations (Continued)

CIG Features	Minimal (1980) System Configuration	Optimal (1982-1983) System Configuration	Fully Developed (1985-1987) System Configuration
Dusk/Dawn	1 level	1 level	Variable
Night	1 level	2 levels	Variable
Haze	X	X	X
Fog	X	X	X
Light points	6K-8K	?	?
Horizon glow	X	X	X
Scattered clouds		X	X
Broken clouds		X	X
Overcast	X	X	X
Thunderstorms		X	X
Lightning	X	X	X
Rain		X	X
2D & 3D Modeling	X	X	X
Shading (fixed)	X	X	X
Shading (sun variable)		X	X
2D texture	X	X	X
3D texture	*	X	X
Shadows			X
Circles			X
Reflections			X
Transparency			X
Translucency	X	X	X
Color		X	X
4 Seasons		X	X
Own A/C occulting FOV	X	X	X
Time variables			X
Ship wake		X	X
Collision detection	Rudimentary	Sophisticated	Sophisticated
Sun glint			X
Moving models	2	8	?

* Not yet implemented but considered a potential requirement.

Table 52. Potential CIG System Configurations (Continued)

CIG Features	Minimal (1980) System Configuration	Optimal (1982-1983) System Configuration	Fully Developed (1985-1987) System Configuration
Contrails		X	X
Tracers	X	X	X
Ordnance impact	X	X	X
Deletion after hit	X	X	X
Smoke			X
Flares			X
Grayout/Blackout	X	X	X
Glare		X	X
Gun flash			X
Lights			
Landing lights	X	X	X
Beacons	X	X	X
Runway lights	X	X	X
REIL lights	X	X	X
VASI lights	X	X	X
STROBE lights	X	X	X
Taxiway lights	X	X	X
Beacon in cloud	X	X	X
OFF line BITE & FIT	X	X	X
ON line BITE		X	X
Automated data base bldg.	*	X	X
Full function experimenters station	*	X	X
Full documentation	X	X	X
Maintenance contract	X	X	X
Test & Evaluation period	X	X	X
Data base for each mission	X	X	X

* Not yet implemented but considered a potential requirement.

SECTION 26

SPECIFIC CONCLUSIONS AND RECOMMENDATIONS

The conclusions reached in this section are specific to the AFWAL/FIGD Research and Development mission tasks. The reader is cautioned not to generalize these findings to training simulation or applications not identical to those found at AFWAL/FIGD. No quotes should be made from this section without prior reference to the associated text (see section numbers in parenthesis following conclusion). The source of the conclusions may be other than the present authors.

No specific conclusions are drawn from the first four sections of this report as they are comprised of introductory material.

26.1 CIG FEATURES

(a) Eight levels-of-detail appear to be the optimal number (5.2[a][1]).

(b) Utilizing eight levels-of-detail will double the on-line data base requirement (5.2[a][1]).

(c) Level-of-detail switching should utilize blending at transitions between levels of detail (5.2[a][2])

(d) If there is an edge crossing per system scan line limit, it should optimally be 20% of the displayable edge capacity (minimally 10%) (5.2[c]).

(e) A stereo display capability must be considered a possible requirement as it may provide missing cues (5.2[e]).

(f) Head/eye slaving should be considered as a required feature because of the potential AOI induced edge conservation available through its use (5.2[f]).

(g) The support of multiple simultaneous simulations is not recommended unless adequate scene capacity for each simulation can be guaranteed (5.2[g]).

(h) Overload avoidance should take precedence over overload management (5.2[h]).

(i) Overload management must be very sophisticated and work in parallel with level-of-detail management (5.2[i]).

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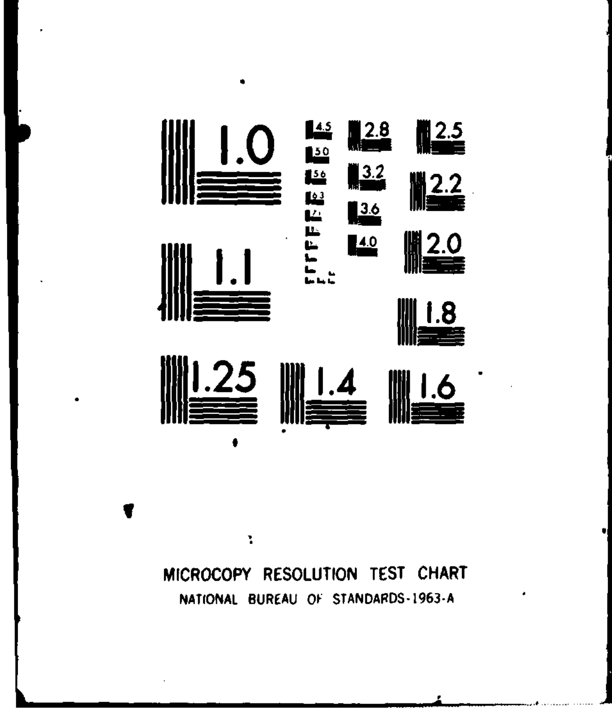

MICROCOPY RESOLUTION TEST CHART
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(j) Temporal and spatial anomalies (anti-"aliasing") require the highest level of correction available (5.2[j and k]).

(k) Field rate updating or, more desirably, non-interlaced frames are recommended; however the hardware/cost impact of their implementation may be too extensive to make either of their implementations acceptable (5.2[l]).

(l) The transport delay of the CIG system must be treated as an integral part of the overall simulation (5.2[n]).

(m) HAZE is a required CIG feature (5.2[o]).

(n) Light points must be attenuated with distance to compensate for their oversized representation (5.2[p]).

(o) In the ideal system point lights would be depicted as $\leq$ .8 minutes of arc (7.1.1[d] and 17.2.12).

(p) A 6000 displayable light point system capacity should be adequate to represent a night runway scene (5.2[p]).

(q) Both two-dimensional and three-dimensional texture should be considered essential for all mission tasks which include low-level flight within the flight envelope (5.2[r]).

(r) Shadows are not essential but could help to hold objects, which appear to float above the terrain, down (5.2[s]).

(s) Circles and elliptical features are not an essential part of CIG and may not be found to be cost effectively implementable (5.2[t]).

(t) Color should be included (or at the least the expansion into a color capability planned for) in the specified CIG system (5.2[w]).

(u) Moving models currently tax CIG system capabilities rather severely and their available numbers are limited (5.2[aa]).

26.2 REALISM

(a) Absolute realism is, and will forever remain, unattainable, through simulation (6.1).

(b) Reasonable realism is that which is within the capability of CIG to produce (6.1.1).

(c) Adequate realism varies with the mission task and flight profile; research has not yet adequately defined it for all cases, but a few examples are available (6.1.2).

(d) The gauge for adequate realism is proper pilot response (6.1.2).

(e) Subjective evaluations of what is adequate realism should not be relied upon (6.1.3).

(f) A gradual degradation of cues should not be relied upon to evaluate adequate realism (6.1.4).

(g) The pilot's performance in the simulator must match that of the actual aircraft; if this is not possible, the differences must be known and measurable (6.2).

(h) The research subject must not be allowed to adopt a control strategy different from that used in the aircraft (6.2).

(i) The danger that a modified control strategy presents in an R&D environment is that changes made in order to improve aircraft characteristics may, in actuality, be simply changes required to improve the simulator characteristics (6.2).

(j) One method for ascertaining simulator realism may be the angular-size judgment task (6.4).

(k) It is recommended that the pilot-response fidelity model be implemented to calibrate R&D simulation (6.5).

26.3 CUES

(a) No definitive study has specified all the cues necessary for all AFWAL/FIGD mission tasks (7).

(b) Cues to depth perception, almost exclusively, give relative depth information rather than absolute range (7.1.4).

(c) A CIG system probably has no need to present the pilot with more than about 5 or 10 bits of new information per second (7.2.1).

(d) Some form of area-of-interest image generation and display technique to more effectively utilize available CIG display capacity is recommended (7.2.1).

(e) Some form of graceful overload management should be implemented which does not change levels of detail more often than once every 250 milliseconds (7.2.1).

(f) Determining how to apply the limited capabilities humans have for processing data can be done through experimental, intuitive and objective as well as mathematical means (7.2.2).

(g) Highly detailed texture (more detail than .5 x .5 mile squares) is not required in simulated flight taking place one thousand or more feet above the terrain (6.1.2 and 7.2.4.1).

(h) Some cue requirements can be defined (7.2.5).

(i) When formulating what cues are required in simulation, two purposes must be kept in mind, the cues must elicit the specific, desired responses and they must avoid inducing illusions (7.2.5.4).

(j) Experienced pilots develop their own unique set of preferred cues; even after adequate research has been done it may not be accurate to predict which cues are required to perform which tasks because of this human tendency (7.2.5.4).

(k) No simulation to date, CIG or Camera/Model, provides adequate cues to allow the real world duplication of sink-rate judgments; what specifically remains missing from the simulation is a mystery and this mystery holds ramifications for low-level simulation, such as terrain following which cannot be ignored (7.2.5.5).

(l) Color may help in those mission tasks for which it can eliminate ambiguity (7.2.6).

(m) Platform motion cannot be discounted as an unnecessary cue, nor can its effect on visual perception in simulation be ignored (7.2.8).

(n) G-Suit and G-Seat offer additional cues beyond those given by platform motion alone (7.2.8).

26.4 ILLUSIONS

The potential for illusions in simulation is extensive; the types of illusions must be kept uppermost in mind when evaluating the performance of a delivered CIG system (8).

26.5 CALLIGRAPHIC CIG SYSTEMS

Calligraphic CIG systems are not appropriate to the AFWAL/FIGD mission task requirements because of their inability to depict visual scenes containing a high level of detail (10).

26.6 CIG DATA BASES

(a) Manual, interactive data base building is excessively inefficient and unacceptable if considered the primary means for building CIG data bases in a rapidly evolving R&D Simulation facility (11.1).

(b) Data base building costs can have major impact on overall system costs (11.1).

(c) Automated data base building techniques are essential to efficient operation in an R&D environment; some combination of techniques is recommended, utilizing DMAAC data augmented or enhanced by automated generic object creation, as well as a library of primitive shapes and models which can be manipulated rapidly and easily to form recognizable cultural features (11.2 and 11.3).

(d) Lower levels-of-detail should be generated automatically from the most detailed scene (11.2).

(e) Lateral, upwards and downwards compatibility of data bases as well as transfer of data bases leaves much to be desired and remains a distant goal (11.4).

(f) Sensor simulation is currently implemented in separate CIG hardware and data bases (11.5).

26.7 CIG SOFTWARE

(a) Work is currently underway to develop special purpose graphics languages to enhance software portability (12.1).

(b) Structured design and top down programming as well as programming languages other than conventional FORTRAN could do much to improve current CIG software implementations and software transportability (12.2).

26.8 DISPLAY HARDWARE

(a) Contrast is a very important factor in image quality (14.1.3).

(b) Distortion, because of its impact on geometric perspective and positional accuracy must be considered of major concern in display systems. (14.1.5).

(c) Further research is required (a technique is available) for determining the field of view necessary to support different types of aircraft and mission simulations (14.1.8).

(d) The luminance level goal for a display system should be approximately 10 foot lamberts; the level increases the critical flicker frequency however (14.2.4).

(e) The windscreeen and canopy should be deleted from any simulation; opaque structures which act as a part of the windscreen and canopy assembly must remain, however, as they provide occulting and potential parallax information (14.1.12).

(f) Johnson's criteria for detection, orientation, recognition, and identification should be used for defining target acquisition in air-to-ground mission tasks (14.5).

(g) Resolution should not be utilized as a measurement of image quality (14.6).

(h) The log Band Limited Modulation Transfer Function Area (log BLMTFA) has been found to give the highest correlation between measured image quality and performance (14.6).

26.9 DISPLAY WEAKNESSES

(a) Display technology cannot currently, nor will it in the foreseeable future, match human perceptual capabilities and no such goal is reasonable or currently attainable over a wide instantaneous field of view (15.1).

(b) No current system accommodates multiple observers without a corresponding degradation in image quality (15.8).

(c) Helmet mounted displays may offer promise in resolving the problem of accommodating multiple observers (15.8).

26.10 CIG STRENGTHS

(a) Although camera model systems do show strength in the areas of single adversary air-to-air intercept and landing simulation, for simulation involving multiple moving models or simulation tasks no other approach offers as great a current capability and future potential as CIG (16).

(b) CIG systems have demonstrated a greater increase in landing skills than did a camera/model system (16).

26.11 CIG WEAKNESSES

(a) Just as the uncontrolled variables display weakness (15.9) can cause unexplained changes in performance on the part of the pilot, incidental learning induced by CIG scene anomalies can have the same affect (17.1.1).

(b) Scene anomalies, particularly temporal anomalies, are very complex and little understood. Their total correction may be a long time in the future (17.2.1.2).

(c) Edge crossing, position change and attitude change induced overloads are all problems which are in the realm of correctability; however, the hardware implementations of these corrections may not be justifiably cost effective (17.2.2).

(d) If the edge crossings per system scan line restriction is too severe, the displayable system capacity may never be utilizable (17.2.2.1).

(e) CIG transport delay is not the cause of the transport delay problem; not using the known CIG transport delay as part of the solution to the equations of flight is the problem (17.2.6).

(f) Transport delay circumvention is possible if the real world delay between pilot control deflection and the onset of aircraft response is utilized to include the transport delay of the CIG system. In high performance aircraft, aircraft response delay is 200 to 300 milliseconds, with low performance aircraft showing a corresponding increase in aircraft response time (17.2.6).

(g) More than eight moving models do not appear to be currently practical (17.2.9).

26.12 CIG SYSTEM ACQUISITION

(a) A CIG specification must, most importantly, be perceptually oriented (18.1).

(b) Further studies are required in the perceptual areas; without a full understanding and definition of the perceptual requirements, the CIG user will buy more than he wants and get less than he needs (18.1).

(c) What is desirable to test and evaluate may be specified by AFWAL/FIGD; how to test and evaluate these desirable items may be left partially to the manufacturer (18.3.1)

(d) In the past, test procedures have been developed for the evaluation of visual system performance and these procedures may be used as a guideline for the AFWAL/FIGD specification (8.3.1).

(e) A supportability demonstration which lasts for a period of 1 to 1.5 years is strongly recommended (18.3.2).

(f) Pushing the state of the art lightly may be acceptable, pushing the state of the art hard is not recommended for AFWAL/FIGD (18.2).

26.13 CIG SYSTEM MAINTENANCE

(a) Neither built-in test equipment nor maintenance documentation should be considered as options to be deleted in order to limit total system cost (21.1).

(b) Training in operation and maintenance of the CIG system should be considered essential for at least some members of the AFWAL/FIGD. This training would allow the full evaluation and utilization of CIG system capabilities. The training, particularly in operation, should occur even if a maintenance contract is utilized following the extended acceptance period (21.1.2.2[b]).

(c) One hundred percent sparing of each unique hardware element and card type is recommended (21.1.2.3[e]).

(d) Following the extended supportability demonstration, a maintenance contract is recommended (21.2.2).

(e) Extensive automatic maintenance and test procedures using BITE and FIT (minimally to the card level) are recommended (21.2.2.4).

26.14 CIG SYSTEM UPGRADING

(a) The addition of any feature which is considered desirable, but is not included in the initial CIG acquisition, must be listed as a potential future add-on in the specification and hardware to support it addition must be included (22.1).

(b) The ability to retrofit new technology into an existing CIG system should not be taken for granted (22.2).

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APPENDIX A

BLANK CIG QUESTIONNAIRE (Blank Space Removed)

1.0 CIG DATA BASE MANAGER

1.1 TRANSPORTABILITY

1.1.2 LANGUAGE
1.1.3 HOST CPU
1.1.4 CORE SIZE
1.1.5 UNIQUE CIG REQUIREMENTS

1.2 STANDARD DATA BASE MANAGEMENT

1.2.1 COMMANDS

1.2.1.1 STATUS (REPORTS)
1.2.1.2 LOG ON/OFF (SECURITY)
1.2.1.3 HELP
1.2.1.4 SORT
1.2.1.5 PRINT
1.2.1.6 SAVE (FILES)

1.2.1.6.1 DISK
1.2.1.6.2 TAPE

1.2.1.7 SELECT (FILES)

1.2.1.7.1 DISK
1.2.1.7.2 TAPE

1.2.1.8 COPY

1.2.1.8.1 FILE TO FILE
1.2.1.8.2 DISK TO DISK
1.2.1.8.3 DISK TO TAPE/TAPE TO DISK

1.2.1.9 RENAME FILES
1.2.1.10 MERGE FILES

1.2.1.11 CREATE (FILES)

1.2.1.11.1 INITIAL LOAD
1.2.1.11.2 UPDATE
1.2.1.11.3 RETRIEVE

1.2.1.12 DELETE
1.2.1.13 LIST (CRT, PRINTER)
1.2.1.14 EDIT
1.2.1.15 UNLOAD/RELOAD
1.2.1.16 DOWN LOADING
1.2.1.17 BACK OUT CAPABILITIES/RECOVERY
1.2.1.18 COMMAND PROMPTING
1.2.1.19 ERROR DETECTION

1.2.2 FILES

1.2.2.1 FILE PROTECTION
1.2.2.2 SECURITY ACCESS

1.3 CIG SPECIFIC DATA BASE ATTRIBUTES

1.3.1 CAPACITY

1.3.1.1 TOTAL EDGE COUNT
1.3.1.2 TOTAL POINT LIGHT COUNT
1.3.1.3 TOTAL GEOGRAPHICAL AREA
1.3.1.4 MODELED DATA BASE SIZE

1.3.2 MODEL CONSTRUCTION

1.3.2.1 BASIC PRIMITIVES, (TYPES, AVAILABILITY, etc. . .)
1.3.2.2 COLORING
1.3.2.3 MOVING MODELS

1.3.2.3.1 MOVING PARTS ON MOVING MODELS
1.3.2.3.2 NUMBER OF MOVING MODELS ALLOWED

1.3.2.4 WORKING SCRATCH PAD AREA
1.3.2.5 BUILD MODELING MACRO COMMANDS
1.3.2.6 EXISTING MODEL MODIFICATION
1.3.2.7 MODEL CATALOG (PICTURES — REFERENCE NUMBERS)
1.3.2.8 MODEL BUILDING PROMPTING
1.3.2.9 DYNAMIC CHARACTERISTICS (i.e., EXPLOSION FLASH GROWING SMALL TO LARGE)
1.3.2.10 ALPHANUMERIC MODEL STATUS INFORMATION
1.3.2.11 MODELING COMMANDS

1.3.2.11.1 PRIMITIVE CREATION (ATOM CREATION)
1.3.2.11.2 PRIMITIVE SAVE
1.3.2.11.3 PRIMITIVE PRINT (CATALOG)
1.3.2.11.4 MODEL CREATION
1.3.2.11.5 MODEL SAVE
1.3.2.11.6 MODEL PRINT (CATALOG)
1.3.2.11.7 MODEL SELECTION

1.3.2.11.7.1 SELECT ON MODEL TYPE (CAR, TANK, AIRCRAFT. . .)
1.3.2.11.7.2 SELECT ON GEOGRAPHIC AREA
1.3.2.11.7.3 SELECT ON MODEL ATTRIBUTES (IR, LLLTV, MOVING. . .)

1.3.2.11.8 MODEL MANIPULATION

- 1.3.2.11.8.1 ROTATE ABOUT ANY AXIS
- 1.3.2.11.8.2 CHANGE COLORS
  - 1.3.2.11.8.2.1 NUMBER OF PRIMITIVE COLORS
  - 1.3.2.11.8.2.2 NUMBER OF INTENSITIES
  - 1.3.2.11.8.2.3 SEASONAL COLORING
  - 1.3.2.11.8.2.4 SHADES
- 1.3.2.11.8.3 ADD SEGMENTS
- 1.3.2.11.8.4 PUSH/PULL OBJECT
- 1.3.2.11.8.5 LENGTHEN/SHORTEN OBJECT
- 1.3.2.11.8.6 SCALE UP/DOWN
- 1.3.2.11.8.7 MERGE MODELS
- 1.3.2.11.8.8 DELETE SUB-MODELS FROM MODELS

1.3.2.12 MODEL ATTRIBUTES

- 1.3.2.12.1 MOVING (SPEED, HEADING, ATTITUDE. . .)
- 1.3.2.12.2 LOCATION (X,Y,Z)
- 1.3.2.12.3 RADAR
- 1.3.2.12.4 IR
- 1.3.2.12.5 LLLTV
- 1.3.2.12.6 MOVING PARTS OF MODELS (ALGORITHMS) RELATIONSHIP
- 1.3.2.12.7 LEVEL OF DETAIL

1.3.3 SPECIAL EFFECTS

- 1.3.3.1 TEXTURED BACKGROUNDS
- 1.3.3.2 LIGHT STRINGS
- 1.3.3.3 CLOUDS
- 1.3.3.4 FOG/HAZE

1.3.4 ON LINE DEBUGGING OF VISUAL DISPLAY

- 1.3.4.1 JOYSTICK, CURSOR, LIGHT PEN - IDENTIFICATION
- 1.3.4.2 FLY VISUAL SCENE
- 1.3.4.3 DISPLAY ON MONITOR - NOT THROUGH COCKPIT WINDOWS
- 1.3.4.4 UPDATE DATA BASE IN REVIEW PHASE
- 1.3.4.5 CONTROL "MOVING MODELS" DYNAMIC MOTION
- 1.3.4.6 CHANGE VIEWING ASPECT
- 1.3.4.7 TIME REQUIRED TO ENTER VISUAL MODIFICATIONS AND THEN SEE UPDATED RESULTS

1.3.5 DATA BASE VISUAL REPORTS

- 1.3.5.1 ALL MODELS
- 1.3.5.2 ALL UPDATES THIS SESSION
- 1.3.5.3 ALL MODELS BY TYPE
- 1.3.5.4 ALL MODELS BY LOCATION
- 1.3.5.5 PRIMITIVE LIBRARY
- 1.3.5.6 VISUAL CATALOG OF ALL MODELS

- 1.3.6 EXPANSION CAPABILITIES
- 1.3.7 WHAT IS RELATIONSHIP TO EXISTING DATA BASES (i.e., IS CIG DATA BASE A SUPERSET OF DMAAC DEFENSE MAPPING AGENCY AEROSPACE CENTER) OR CAN DATA BASE PROVIDE INFORMATION FOR CIG VISUAL, IR, LLLTV, IN TOTAL
- 1.3.8 RELATIONSHIP TO SIMULATION DATABASE (i.e., SAME, DIFFERENT, SUBSET)

2.0 REAL TIME CIG SYSTEM

2.1 CAPACITIES

- 2.1.1 TOTAL NUMBER OF VISIBLE EDGES
- 2.1.2 TOTAL NUMBER OF POTENTIAL EDGES AT A TIME
- 2.1.3 TOTAL NUMBER OF ELLIPTICAL FEATURES
- 2.1.4 NUMBER OF EDGES PER CHANNEL
- 2.1.5 MOVING MODELS (CARS, TANKS, AIRCRAFT)
- 2.1.6 DISPLAY CHANNELS
- 2.1.7 TOTAL NUMBER OF POINT LIGHT SOURCES
- 2.1.8 MIX OF SIMULTANEOUS POINT LIGHT SOURCES/EDGES
- 2.1.9 COLOR
    - 2.1.9.1 INTENSITIES
    - 2.1.9.2 PRIMARIES COLORS
- 2.1.10 MINIMUM RESOLUTION (i.e., 6, 3, 2, 1 MINUTES)
- 2.1.11 NUMBER OF DIRECTIONAL, PERSPECTIVE LIGHT SOURCES
- 2.1.12 NUMBER OF ELLIPTICAL FEATURES
- 2.1.13 LEVELS OF DETAIL
- 2.1.14 AVAILABLE TEXTURES
- 2.1.15 NUMBER OF POSSIBLE VIEWING ASPECTS
- 2.1.16 NUMBER AND KINDS OF SURFACE TEXTURES
- 2.1.17 ALTITUDE RANGE

2.2 CHARACTERISTICS

- 2.2.1 MODEL REPRESENTATION (POLYHEDRON/CURVED SURFACE)

- 2.2.2 SIMULATION INFORMATION REQUIREMENTS (i.e., AIRCRAFT MODEL POSITION X,Y,Z, ATTITUDE)
- 2.2.3 AREA OF INTEREST (i.e., WHAT CHANNEL IS PILOT'S VISION DIRECTED TO)
- 2.2.4 RECOGNITION DISTANCES (DETECTION, ORIENTATION, RECOGNITION, IDENTIFICATION)
- 2.2.5 ANTI-ALIASING
- 2.2.6 SHADING, CURVED SURFACES, SURFACE SMOOTHING
- 2.2.7 OVERLOAD RECOVERY
    - 2.2.7.1 VISUAL DEGRADATIONS
    - 2.2.7.2 PICTURE BLANKING
- 2.2.8 SPEED PER EDGE CALCULATION
- 2.2.9 NUMBER OF SYSTEMS DRIVEN (CIG, LLTV, IR, ETC.)
- 2.2.10 CORRELATED-VISUAL, RADAR, IR, LLLTV, MOTION CUES
- 2.2.11 SPECIAL EFFECTS

2.2.11.1 SUN

2.2.11.1.1 SUN ANGLE
2.2.11.1.2 SUN GLINT

2.2.11.2 CLOUDS
2.2.11.3 HAZE/FOG
2.2.11.4 LIGHTNING
2.2.11.5 RAIN
2.2.11.6 G-RELATED BLACKOUT
2.2.11.7 DUST FROM GROUND VEHICLES OR WEAPON NEAR MISS
2.2.11.8 WEAPON FLASH, TRACERS
2.2.11.9 WEAPON HIT
2.2.11.10 DELETION OF DESTROYED MODEL
2.2.11.11 SMOKE

2.2.11.11.1 TARGET HITS/KILLS
2.2.11.11.2 DRIFT WITH EXISTING WINDS

2.2.11.12 SAM TRAILS
2.2.11.13 LIGHTS INTENSITY VARY AS A FUNCTION OF SLANT RANGE
2.2.11.14 LANDING LIGHTS

2.2.12 MOVING MODEL

2.2.12.1 CONTROL SURFACE REALISTIC SIMULATION
2.2.12.2 AFTER BURNER, SPEED BRAKE, TURRET SIMULATION
2.2.12.3 CORRELATION TO SIMULATION DATA BASE (i.e., INTERFACE PARAMETER REQUIREMENTS AND MODEL IDENTIFICATION)

2.2.13 HIGH DETAIL
2.2.14 CRT BEAM BLANKING OF BACKGROUND
2.2.15 REAL-TIME SELECTION OF AREA OF INTEREST
2.2.16 NUMBER OF RASTER SCAN LINES SUPPORTED (i.e., 512, 1024. . .)

2.2.16.1 INTERLACED/NON-INTERLACED
2.2.16.2 UPDATE RATE

2.2.17 DYNAMIC SETTING OF INTENSITIES
2.2.18 REAL-TIME CONTROL OF FIELD OF VIEW
2.2.19 OCCULTATION
2.2.20 CIG COMPUTER

2.2.20.1 GENERAL PURPOSE
2.2.20.2 SPECIFIC APPLICATION
2.2.20.3 COMPUTATIONAL SPEED
2.2.20.4 DATA TRANSFER SPEED
2.2.20.5 CORE SIZE
2.2.20.6 CORE EXPANSION CAPABILITY
2.2.20.7 CPU TIME USE (%)
2.2.20.8 NUMBER USED
2.2.20.9 ATTRIBUTES
2.2.20.10 WORD SIZE

2.2.21 COMPUTER LANGUAGE(S)
2.2.22 CONTOURING AND CIRCLE FEATURES

2.3 DIAGNOSTIC TESTS

2.3.1 MAINTENANCE
2.3.2 PRE-TEST VERIFICATION
2.3.3 REAL-TIME DIAGNOSTICS

2.4 DISPLAY FORMAT FOR VISUAL DISPLAY (OUTPUT TO DISPLAY DEVICES)
2.5 OPERATOR CONTROL

2.5.1 VISIBILITY
2.5.2 CLOUD TOPS
2.5.3 CEILING
2.5.4 SCUD
2.5.5 FOG
2.5.6 DAY/NIGHT
2.5.7 SEASON

2.6 EXPANSION CAPABILITIES
2.7 BLOCK DIAGRAM

APPENDIX B

CIG QUESTIONNAIRE RESPONSE TABULATION

CIG DATA BASE AND FEATURES COMPARISON

The following tables may be used to compare the AFWAL/FIGD CIG requirements as they relate to various states of the CIG technology. In the tables, today's technology is represented by CURRENT systems that have been built for flight simulators and are from current manufacturers' products. The NEXT GENERATIONS are those systems that are being produced by these same manufacturers and either are being delivered currently or will be delivered within the next year. The next generation systems have greater capacities than today's but will not be fully wrung out for the next two years. The final group, the FUTURE, is made up of a representative group of manufacturers that have not as yet produced a production CIG flight simulator visual system but are now developing competitive visual systems. The group picked has varied CIG experience. Two (ATS and Marconi) have provided CIG systems for non-aircraft training simulators. The two others (Gould and Grumman) are new to the CIG world. One (Grumman) is perfecting a system that uses curved surfaces as opposed to straight lines. The other (Gould) has demonstrated and is planning to market a low-cost, low-capacity, standard CIG system for applications that do not need high detail.

The following matrix will provide the instrument for comparing the AFWAL/FIGD requirements to the following:

(a) Today's proven technology

(b) Tomorrow's technology (2 years)

(c) Possible future capabilities (4 - 7 years)

The following are discussions of the types of categories a system falls in:

(a) CURRENT: This includes major systems that have been tested and are in a stable state. Most of these systems have been in existence for more than one year.

(b) NEXT GENERATION: These systems are the ones that are in the process of being delivered or are about to be within the next twelve months.

(c) FUTURE: These systems have been proposed and some non-real time displays have been demonstrated. It must be emphasized that these systems have been neither built nor tested.

3 1 1

RESPONSES:

(a) YES: The system provides the capability specified.

(b) NO: The system does not provide the capability specified.

(c) N.S.: the AFWAL did not specify this capability.

(d) N.R. or "-" or blank: There was no response from the manufacturer on this specific item.

(e) C.P.: This response is used to indicate that the area is company private.

(f) N/A: This feature is not available.

(g) I.D: Insufficient data.

The data presented in these tables is organized and presented in a form that allows the reader to evaluate the results of the survey. The table only presents information collected. It does not make any conclusions as to whether a particular feature is good or bad. The table is merely a means of presenting information collected in an orderly manner.

The headers of the columns are the sub-question under the general header; that is on the top of the page of the table. The topics of the header were taken from the questionnaire that was sent to the CIG vendors.

The questionnaire was written in such a way that hopefully as much information as possible could be gathered from all the vendors queried. The task became somewhat difficult because each vendor has different attributes and terminology. Therefore, an analysis of basic CIG system and CIG vendors resulted in the questionnaire topics. To be fair to all vendors it was felt that all of their attributes should be listed. This produced some problems in that some topics were non-general (i.e. only affecting one vendor). As a result we received either ambiguous answers (from those vendors who do not have the feature) to no response (from those who did have the feature).

To understand the table, the reader should read down the table. 1. The header at the top of the table defines the general topic of discussion. 2. The column header provides the specific topic of discussion. 3. The rows on the left side of the table indicate the vendor and system under discussion.

One final point should be made. Only GE, LINK and MARCONI were kind enough to respond to the questionnaire. ATS, E&S, Gould and Grumman did not. Any data in their rows comes from published sources.

Table B-1 Data Base Manager Transportability

	LANGUAGE	HOST CPU	CORE SIZE	UNIQUE CIG REQUIREMENTS
CURRENT				
Evans & Sutherland				
General Electric	Fortran	SEL 32/55 Interdata 8/32	1/2 M Byte	None
Link	Fortran 6 or 7	Interdata 8/32	512 K[1] Bytes EXP to 1 M[2] Bytes	N/A
NEXT GENERATION				
Evans & Sutherland		PDP 11/60		
General Electric				
Link				
FUTURE				
ATS				
Gould				
Grumman	—	—	—	—
Marconi	Fortran IV	PDP 11 8 vax family	64 K Bytes	Interface with Picture Processor
AFWAL Specified	NA	NS	NS	NS
Generic System	High Level	None Recommended	25% Spare (A.F. req)	None

[1] K = Thousand
[2] M = Million

Table B-2 Standard Data Base Commands

	Status (Reports)[1]	Log On/Off (Security)[1]	Help[1]	Sort[1]	Print[1]	Save (Files)[1]	Save To Disk[1]	Save to Tape[1]	Select (Files)[1]	Select (From Disk)[1]	Select (From Tape)[1]	Copy[1]	Copy File To File[1]	Copy Disk To Disk[1]	Copy Disk to Tape Tape to Disk[1]	Rename Files[1]	Merge Files[1]
CURRENT																	
Evans & Sutherland																	
General Electric	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Link	--Standard Interdata 8/32--								Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	N/A
NEXT GENERATION																	
Evans & Sutherland																	
General Electric																	
Link																	
FUTURE																	
ATS	—	—	—	—	—	—	—	—	—	—	—	Yes	Yes	—	—	Yes	Yes
Gould																	
Grumman	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Marconi	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AFWAL Specified	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Generic System	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

[1] Not necessarily part of a CIG Data Base System.

Table B-2 Standard Data Base Commands (Continued)

	Create (Files)[1]	Initial Load (Files)[1]	Update (Files)[1]	Retrieve (Files)[1]	Delete[1]	List (CRT, Printer)[1]	Edit[1]	Unload/Reload[1]	Down Loading[1]	Back Out Capabilities[1]	Command Prompting[1]	Error Detection[1]
CURRENT												
Evans & Sutherland												
General Electric	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes
Link	Yes	Key in Boot-Strap	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	N/A	Yes
NEXT GENERATION												
Evans & Sutherland												
General Electric												
Link												
FUTURE												
ATS					Yes	Yes						
Gould												
Grumman	—	—	—	—	—	—	—	—	—	—	—	—
Marconi	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AFWAL Specified	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
General System	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

---

[1] Not necessarily part of a CIG Data Base System.

Table B-3 Data Base Files

	FILE PROTECTION	SECURITY ACCESS
CURRENT		
Evans & Sutherland		
General Electric	Yes	Yes
Link	Yes	N/A
NEXT GENERATION		
Evans & Sutherland		
General Electric		
Link		
FUTURE		
ATS		
Gould		
Grumman	—	—
Marconi	Yes	No
AFWAL Specified	NS	NS
Generic System	Yes	Yes

Table B-4 CIG Specified Data Base Capacity[1]

	TOTAL EDGE COUNT	TOTAL LIGHT POINT COUNT	TOTAL GEOGRAPHICAL AREA	MODELED DATA BASE SIZE
CURRENT				
E&S				
GE	Varies With Application -- 10K to 100K	Varies With Application	Blocks of 1500 x 500 NM.	Varies -- Depends on Number of Blocks
Link	Limited by Disk Size	1:1 Exchange With Edge	Unlimited (worldwide addressability)	Dependent on Application
NEXT GENERATION				
E&S	100,000 Polygons		300 NM	
CE				
Link				
FUTURE				
ATS	400,000+			
Gould				
Grumman	—	—	—	—
Marconi	No Engineering Limit	No Engineering Limit	No Engineering Limit	—
AFWAL Specified	10^9 (1 Object/64 sq.ft.)	NS	500 x 500 NM	
Generic System	I.D.	I.D.	800 x 800 NM	I.D.

---

[1] Total that can be stored on the Data Base.

Table B-5 CIG Data Base Model Construction

	BASIC PRIMATIVES	COLORING	MOVING MODELS	MOVING PARTS ON MODELS	# OF MOVING MODELS	WORKING SCRATCH PAD AREA[1]
CURRENT						
Evans & Sutherland		250	Moving Targets			
General Electric	Yes	Red,Green,Blue 128 Colors	8 Max	C.P.	Based on Requirements	No
Link	Verticies	64 Colors, 512 Intensities/ Color		If Required	As Many as Real Time Permits/Not Treated Separately	4480 32 bit Words (transparent to user)
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS	Yes	Yes				
Gould						
Grumman	—	—	—	—	—	—
Marconi	Triangular Faces, Cylinders, Rectangles, Cones, Spheres	2 x 10^6 Hues	—	Yes	Limited only by Detail of Models Required	N/A
AFWAL Specified			Yes	NS	7	NS
Generic System	Yes	>64 colors with hues	Yes	I.D.	I.D.	Yes

[1] An area in memory where scenes can be created and modified without affecting the *CIG Data Base*.

Table B-5 CIG Data Base Model Construction (Continued)

	MODELING MACRO COMMANDS[1]	EXISTING MODEL MODIFICATION	MODEL CATALOGS	MODEL BUILDING PROMPTING	DYNAMIC CHARACTERISTICS[2]	ALPHANUMERIC MODEL STATUS INFORMATION[3]
CURRENT						
Evans & Sutherland						
General Electric	No	Some	Some	No	Yes (edges)	No
Link	N/A	Yes - Visual Updating	Yes	Yes	Not at Present	Yes (Complete documentation)
NEXT GENERATION						
Evans & Sutherland						
General Electric					Yes - (circle features)	
Link						
FUTURE						
ATS						
Gould						
Grumman	—	—	—	—	—	—
Marconi	N/A	Yes	Yes	Yes	Yes	Yes
AFWAL Specified	NS	NS	NS	NS	NS	NS
Generic System	Yes	Yes	Yes	Yes	Yes	Yes

[1] A group of elementary commands grouped together to ease the modeling task, i.e. box = 4 straight lines at 90° to each other.

[2] Characteristics that change with respect to a specific variable, i.e. seasonal colors.

[3] Information presented on the screen to the modeler so he knows the details of the model he is viewing, i.e.
1. airplane 2. edges = 3 3. color-black

Table B-6 CIG Data Base Model Construction Modeling Commands

	PRIMITIVE CREATION	PRIMITIVE SAVE	PRIMITIVE PRINT (CATALOG)	MODEL CREATION	MODEL SAVE	MODEL PRINT (CATALOG)
CURRENT						
Evans & Sutherland						
General Electric	Yes	Yes	Yes	Yes	Yes	Yes
Link	Vertices	Some Attributes Saved (color,# of vertices, etc.)	N/A	N/A	Yes	Perspective Line Drawing in Addition to Documentation
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS	Yes	Yes				
Gould						
Grumman	—	—	—	—	—	—
Marconi	English	Yes	Yes	Yes	Yes	Yes
AFWAL Specified	NS	NS	NS	NS	NS	NS
Generic System	Yes	Yes	Yes	Yes	Yes	Yes

Table B-6 CIG Data Base Model Construction Modeling Commands (Continued)

	Select on Model Type (Car, Tank, Aircraft...)	Select on Geographic Area	Select on Model Attributes (IR, LLLTV, Moving...)
CURRENT			
Evans & Sutherland			
General Electric	Yes	Yes	Yes
Link	Uniquely Identified	Yes	Yes on Newer Systems
NEXT GENERATION			
Evans & Sutherland			
General Electric			
Link			
FUTURE			
ATS			
Gould			
Grumman	—	—	—
Marconi	Yes	Yes	Yes
AFWAL Specified	NS	NS	NS
Generic System	Yes	Yes	Yes

Table B-6 CIG Data Base Model Construction Modeling Commands (Continued)

	ROTATE ABOUT ANY AXIS	CHANGE COLORS	NUMBER OF PRIME COLORS[1]	NUMBER OF INTENSITIES	SEASONAL COLORING	SHADES
CURRENT						
Evans & Sutherland						
General Electric	yes	yes	Red, Green, Blue Prime 128 DB/ 16 x 10^6 Total	yes	yes	yes
Link	yes	—	262,144 colors	64 Intensities per Color	By Data Base	Computed to 9 Bits 512
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS						
Gould						
Grumman	—	—	—	—	—	—
Marconi	yes	yes	50 per Menu	N/A	As Selected By Menu	Computed
AFWAL Specified	NS	NS	NS	NS	NS	NS
Generic System	yes	yes	3 Prime Colors	>64	yes	yes

---

[1] Basic colors: Red, green, blue, total possible.

Table B-6 CIG Data Base Model Construction Modeling Commands (Continued)

	ADD SEGMENTS[1]	PUSH/PULL OBJECTS[2]	LENGTHEN SHORTEN	SCALE UP/DOWN	MERGE MODELS	DELETE SUB MODELS FROM MODELS
CURRENT						
Evans & Sutherland						
General Electric	Yes	No	No	Yes	Yes	No
Link	Standard Off-line Updating	No	No	Yes	Yes	Yes
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS						
Gould						
Grumman	---	---	---	---	---	---
Marconi	Yes	Yes	Yes	Yes	Yes	Yes
AFWAL Specified	NS	NS	NS	NS	NS	NS
Generic System	Yes	Yes	Yes	Yes	Yes	Yes

[1] Add new line segments to a scene being constructed.

[2] The ability to deform a circle into an oval, etc. or the like.

Table B-7 CIG Data Base Model Construction Model Attributes

	Moving (Spd.,Hdg,Alt)	Location (XYZ)	Radar	IR	LLLTV	Moving Parts (Algorithms)	Level of Detail
CURRENT							
Evans & Sutherland							
General Electric	Yes	Yes	Yes	Yes	Yes	CP	8
Link	Under software control	Under software control	Separate Data Base, Movement Software Control	An Extra Attribute	Extra Atrribute	Separate Models	As required, Switching Under Software Control By Attribute, Range, etc.
NEXT GENERATION							
Evans & Sutherland							
General Electric							
Link							
FUTURE							
ATS							
Gould							
Grumman	—	—	—	—	—	—	—
Marconi	Yes	Yes	Yes	Yes	Yes	If Required	Several
AFWAL Specified	Yes	Yes	Associated Radar Information	Associated IR Information	Associated LLLTV Information	Yes	Unlimited
Generic System	Yes	Yes	Associated Radar Information	Associated IR Information	Associated LLLTV Information	Change Position as a Function of Main Model	Unlimited

Table B-8 CIG Data Base Special Effects

	TEXTURED BACKGROUND	LIGHT STRINGS	CLOUDS	FOG/HAZE
CURRENT				
Evans & Sutherland				
General Electric	Yes	Yes	Yes	Yes
Link	Yes in Latest System	Yes - Start Point Increment	Yes - Modeled	Video under Software Control
NEXT GENERATION				
Evans & Sutherland				
General Electric	No		Yes	
Link				
FUTURE				
ATS	—	Yes	—	—
Gould				
Grumman	Yes	—	—	—
Marconi	Yes	If Required	Yes	Yes
AFWAL Specified	Yes on Any Object	NS	NS	NS
Generic System	Yes on Any Object	Yes	Yes	Yes

Table B-9 CIG Data Base On Line Debugging

	JOYSTICK, CURSOR, LIGHT PEN -IDENTIFICATION	FLY VISUAL SCENE	DISPLAY ON MONITOR	UPDATE DATA BASE IN REVIEW PHASE
CURRENT				
Evans & Sutherland				
General Electric	Yes	Yes	Yes	No
Link	Cursor-Thumbwheel Switches	Yes (from visual control panel)	Yes	Limited Identification Switching levels, Color Intensity, Resolvability, Nesting (from visual control panel)
NEXT GENERATION				
Evans & Sutherland				
General Electric				
Link				
FUTURE				
ATS	—	Yes	Yes	—
Gould				
Grumman	—	—	—	—
Marconi	Joystick & Cursor Control to Check Models	Yes	Yes	Yes
AFWAL Specified	NS	NS	NS	NS
Generic System	Yes	Yes	Yes	Yes

Table B-9 CIG Data Base on Line Debugging (Continued)

	Control "Moving Models" Dynamic Motion	Change Viewing Aspect	Time Required to Visual Modification	
CURRENT				
Evans & Sutherland				
General Electric	CP	CP	CP	
Link	Yes (From visual control panel)	Yes	Dependent on scene complexity (real time updating instantaneous)	
NEXT GENERATION				
Evans & Sutherland				
General Electric				
Link				
FUTURE				
ATS	—	—	—	
Gould				
Grumman	—	—	—	
Marconi	Yes	Yes	On-line	
AFWAL Specified	NS	NS	NS	
Generic System	Yes	Yes	30 seconds	

Table B-10 CIG Data Base Visual Reports

	ALL MODELS	ALL UPDATES THIS SESSION	ALL MODELS BY TYPE	All MODELS BY LOCATION	PRIMATIVE LIBRARY	VISUAL CATALOG OF ALL
CURRENT						
Evans & Sutherland						
General Electric	CP	CP	CP	CP	CP	CP
Link	Yes - Standard Documentation	N/A (not been required)	N/A (not been required)	N/A (can be done by area blocks in some systems)	No	Not Immediately Available, Exists in Various Forms
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS	—	Yes	—	—	—	—
Gould						
Grumman	—	—	—	—	—	—
Marconi		Available if Required	Available if Required	Available if Required	—	—
AFWAL Specified	NS	NS	NS	NS	NS	NS
Generic System	Yes	Yes	Yes	Yes	Yes	Yes

Table B-11 CIG Visual Data Base

	EXPANSION CAPABILITIES	RELATIONSHIP TO EXISTING DATA BASE[1]	RELATIONSHIP TO SIMULATION DATA BASE
CURRENT			
Evans & Sutherland			
General Electric	Add-on Offline Data Base Discs	Data base provides information for CIG visual, IR, LLLTV	CP
Link	—	Some system data bases are extracted from DMAAC data bases; operation data base supply all data to visual system	Visual data base is offline processed DMA data base
NEXT GENERATION			
Evans & Sutherland			
General Electric			
Link			
FUTURE			
ATS	—	—	—
Gould			
Grumman	—	Data base provides information for CIG and sensors	—
Marconi	Yes	Data base can be derived from DMAAC given suitable source data; data can provide total	—
AFWAL Specified	NS	NS	All data bases correlate
Generic System	25% of storage capability	Related to DMAAC	All data bases correlated

---

[1] The CIG Data Base is a super set of another existing data base, i.e. DMAAC

Table B-12 Real-Time CIG System Capacities

	Total Visible Edges	Total Potential Edges	Elliptical Features	Edges per Channel	Moving Models	Display Channels	Number of Point Light Sources
CURRENT							
Evans & Sutherland	1000 Polygons & 2000 Lights per Chn	2,500 Polygons		1000 Polygons		>5	4,000 Lights
General Electric	8K Edges	4K Faces	1000 Elliptical faces per module	8K per System	2 to 7 plus Viewpoint of observer	5 Expandable to 8	4,000
Link	8192	8192	Under Development	# Edges= Sum of Edges in all chn= 8192	Any in Data Base	7 Chns	Interchangeable with edges
NEXT GENERATION							
Evans & Sutherland	25,000 Polygons all Chns			1,000 Polygons	6+		
General Electric							
Link							
FUTURE							
ATS	30,000	—	—	—	100+	10+	10,000
Gould							2 Edge - 1 light
Grumman	—	—	Yes	—	—	—	—
Marconi	4,000 Explicit Edges Supplemented by 400,000 Implicit Edges	8,000 Explicit Edges	None	Freely Distributed Between Chns	Tanks, Aircraft Ships	Maximum of 8	4,000
AFWAL Specified	I.D.	>24,000		NS	≥ 7	≥ 7	3,000
Generic System	I.D.	>24,000	Yes	I.D.	≥ 7	≥ 7	3,000

Table B-12 Real-Time CIG System Capacities (Continued)

	MIX OF POINT LIGHTS TO EDGES	COLOR	COLOR INTENSITIES[1]	PRIMARY COLORS	MINIMUM RESOLUTION	NUMBER OF DIRECTIONAL LIGHTS
CURRENT						
Evans & Sutherland	400 Polygons & 4,000 Lights Total	Full Color Day, Dusk / Dawn				
General Electric	Independent	3 Primary with 256 Levels Each	6 Foot Lamberts	Red/Green/ Blue	3.1 Arc Minutes	No Limit Perspective, 85 Directional
Link	1:1	—	512 Levels	262,144	Assume 500/ 1024 Window .05°=3 minute	12
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS	1 Light = 2 + Edges	1,000,000+	512 Levels	Red/Blue Green		Yes
Gould						
Grumman	—	—	—	—	—	—
Marconi	1 to 1	2 x 10^6 Hues	Equal to No. of Hues	Red/Green/ Blue	3.1 Arc Minutes for 40° x 30° FOV	4,000
AFWAL Specified	1 to 1	NS	NS	NS	4'	?
Generic System	1 to 1	Yes	I.D.	Red/Green/ Blue	1'	I.D.

---

[1] The levels of intensities of a given primary color.

Table B-12 Real-Time CIG System Capacities (Continued)

	PHASE LAG	LEVELS OF DETAIL	AVAILABLE TEXTURES	NUMBER OF POSSIBLE VIEWING ASPECTS	ALTITUDE RANGE	CORROLATED VISUAL SENSORS, MOTION
CURRENT						
Evans & Sutherland						
General Electric		7	3 Patterns/ Adjustable Num- & Kind Unlimited	1 to 2	100 NM	
Link		As Re- quired	Software Texture 16 Programmable	7 Channels Eyepoints	Eyepoint ± 2^{26}, Data Base 2^{16}	Yes
NEXT GENERATION						
Evans & Sutherland	4 Fields		None			
General Electric						
Link			Hardware Texture			
FUTURE						
ATS		3-8		14+		
Gould						
Grumman	—	—	Yes	—	—	Yes - Sample
Marconi	—	Several	Coherent Solid Surface Texture, Dynamic Water Surface Texture	Unlimited	No Direct Limit	If Required
AFWAL Specified	<100 MS	Unlimited	Applied to Any Object	NS	0-70,000 & Perspective	Yes
Generic System	<60 MS	Unlimited	2D and 3D	>2 (4 for 4 syst.)	0-70,000 & Perspective	Yes

Table B-13 Real-Time CIG System Characteristics

	EDGE CROSSING PER SYSTEM SCAN LINE	EDGE CROSSING PER CHANNEL	MODEL REPRESENTATION	AREA OF INTEREST	RECOGNITION DISTANCES	SIMULATION DATA REQUIRED
CURRENT						
Evans & Sutherland						
General Electric			Polyhedron with Curved Surface Shading	None	—	Location: (x,y,z) (lat,long,z) Attitude: Pitch,Roll,Yaw
Link	256		Planner Surface	Dependent on Application, Can Give Priority to Window	Dependent on Model Itself	All Eyepoints x,y,z Roll Pitch,Yaw,Angular Turn Rates
NEXT GENERATION						
Evans & Sutherland	No Limit					
General Electric						
Link						
FUTURE						
ATS	1024		Edges			Object Classification, Own Vehicle Position
Gould						
Grumman	—	—	Modified Ray Tracing Method	—	—	—
Marconi			Built of Polyhedral Face	Channels Can Be Dynamically Allocated	As Permitted by Resolution	Type, Position, & Attitude & Environmental Condition
AFWAL Specified	2500	400		NS	25,000/5,200/3,600	
Generic System	>10% Syst. Disp. Capacity	I.D.	None Recommended	Yes	25,000/5,200/3,600	x,y,z Roll, Pitch, Yaw, Ang.-rates,etc

Table B-13 Real-Time CIG System Characteristics (Continued)

	Anti-Aliasing	Shading, Surface Smoothing	Overload Recovery	Visual Degradation	Picturing Blanking	Speed per Edge Calculation	Number of Systems Driven
CURRENT							
Evans & Sutherland			Yes-Drop Small Polygons				Total 4 2 Simultaneous
General Electric							
Link	Matrix technique in latest system	Yes for all	Automatic Non-catastropic	Repeat previous scan line	None	8192 Edges 1 Frame	7 Channels
NEXT GENERATION							
Evans & Sutherland							
General Electric							
Link							
FUTURE							
ATS	—	Yes	Yes-Simplification	—	—	32 NSECS	—
Gould							
Grumman	—	NA	—	—	—	—	—
Marconi	—	Yes	Automatic Overload Conditions	On-line Monitoring Provides Graceful Degradation of Detail In Overload Conditions	Provided if Req'd	5 μSEC	As required
AFWAL Specified	Y		NS		NS		4 VIS & SENS.
Generic System	Yes	Yes	Yes	NO	Yes for Target Proj.	I.D.	4 VIS & SENS

Table B-13 Real-Time CIG System Characteristics (Continued)

	SUN	SUN ANGLE	SUN GLINT	CLOUDS	HAZE/FOG	LIGHTNING	RAIN
CURRENT							
Evans & Sutherland							
General Electric		Yes	No	Yes	Yes % to 32 Miles	Yes	Yes
Link	—	Angle and Magnitude, Dynamic Program	No	Yes (moving objects and cloud layer thickness)	Yes	Yes (F-111)	Yes (F-111)
NEXT GENERATION							
Evans & Sutherland	Variable				Yes		
General Electric							
Link							
FUTURE							
ATS	Yes	Yes		Yes	Yes		
Gould							
Grumman	—	—	—	—	—	—	—
Marconi	Yes	Yes	Yes	Yes	Continuously Variable	Yes	Yes
AFWAL Specified	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Generic System	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table B-13 Real-Time CIG System Characteristics (Continued)

	G-RELATED BLACK-OUT	DUST FROM GROUND VEHICLES	WEAPON FLASH TRACERS	WEAPON HIT	DELETION OF DESTROYED MODEL	SMOKE	SMOKE ON TARGET HIT
CURRENT							
Evans & Sutherland							
General Electric	Available But Not Implemented	Translucent Face Representation	Yes	Yes - But Primitive	Yes - On/Off Action	Yes	Yes
Link	No	Not at Present	Yes	Yes	Substitution of New Model	Not at Present	Yes (Scoring)
NEXT GENERATION							
Evans & Sutherland							
General Electric				Elegant "Explosion" with Damage			
Link							
FUTURE							
ATS	—	—	—	—	—	—	—
Gould							
Grumman	—	—	—		—	—	—
Marconi	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AFWAL Specified	NS	NS	Yes	Yes	NS	Yes	NS
Generic System	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table B-13 Real-Time CIG System Characteristics (Continued)

	SMOKE DRIFTING WITH THE WIND	SAM TRAILS	NIGHT INTENSITY VARY AS A FUNCTION RANGE	LANDING LIGHTS
CURRENT				
Evans & Surherland				
General Electric	Yes	No	Yes - Exponentially	Yes
Link	No	No - (SAM Trails are implemented on F-111) SAM Dust on Launch	Yes	Yes
NEXT GENERATION				
Evans & Sutherland				
General Electric		Planned		
Link				
FUTURE				
ATS	—	—	—	—
Gould				
Grumman	Yes	Yes	Yes	Yes
Marconi	Yes	Yes	Yes	Yes
AFWAL Specified	Yes	Yes	Yes	Yes
Generic System	Yes	Yes	Yes	Yes

Table B-13 Real-Time CIG System Characteristics (Continued)

	CONTROL SURFACE REALISTIC SIMULATION	AFTER BURNER, SPEED BRAKE TURRET SIMULATION	CORROLATION OF CIG DATA BASE TO SIMULATION DATA BASE
CURRENT			
Evans & Sutherland			
General Electric	Yes	Yes - Within Moving Model Limit	Yes
Link	Control Arms and Bay SMS if Necessary on Others	If Necessary	Instructor Control
NEXT GENERATION			
Evans & Sutherland			
General Electric			Ground Vehicle
Link			
FUTURE			
ATS	—	—	—
Gould			
Grumman	—	—	—
Marconi	Yes	Yes	To Suit Accuracy Requirements
AFWAL Specified	NS	NS	Yes
Generic System	I.D.	Yes	Yes

Table B-13 Real-Time CIG System Characteristics (Continued)

	HIGH DETAIL	CRT BEAM BLANKING OF BACKGROUND	REAL TIME SELECTION OF AREA OF INTEREST	NUMBER OF SCAN LINES SUPPORTED
CURRENT				
Evans & Sutherland				625
General Electric	7 LOD's and Video Inset	Yes for Insert Area	Helmet Control	875, 809, 905, 763
Link	3,000 Edges in F-111 2,600 in KC135	No	No	1024
NEXT GENERATION				
Evans & Sutherland				
General Electric				
Link				
FUTURE				
ATS				
Gould				
Grumman	—	—	—	—
Marconi	Limited by Resolution of Display & System Capacity	If Required	If Required	Yes
AFWAL Specified	Yes	NS	NS	>1000
Generic System	Yes	Yes for Target Projector if utilized	Yes - To Increase Scene Detail	>1000

Table B-13 Real-Time CIG System Characteristics (Continued)

	INTERLACED, NON-INTERLACED SCAN	UPDATE RATE	DYNAMIC SETTING OF INTENSITIES	REAL-TIME CONTROL OF FIELD OF VIEW	OCCULTATION	DISPLAY FORMAT
CURRENT						
Evans & Sutherland	2:1 Interlace	Field Rate 50 Hz				
General Electric	Interlaced	30 or 60 Hz	—	No	Yes	—
Link	Interlaced	30 or 60 Hz	By Model Angle & Sun Vectors	Yes (Zoom on SMS)	Yes	Vertical or Horizontal Scan Line Video Data
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS	2:1 Interlace	Once/Field at 60 Hz			Yes - Unlimited Levels	—
Gould						
Grumman	—	—	—	—	—	—
Marconi	Yes	50 or 60 Hz	Yes	Yes	Yes	RGB + Sync
AFWAL Specified	Noninterlaced	NS	NS	NS	Yes	NS
Generic System	Noninterlaced	Once/Field	Yes	Yes	Yes	I.D.

Table B-14 Real-Time CIG System CIG Computer

	GENERAL PURPOSE	SPECIFIC APPLICATION	COMPUTATIONAL SPEED	DATA TRANSFER SPEED	MEMORY SIZE	MEMORY EXPANSION CAPABILITY
CURRENT						
Evans & Sutherland						
General Electric	SEL 32/55 Interdata 8/32	FRAME I Control	60 Updates Per Second	800 M Per Second	SEL - 8 K Words Interdata - 512 K Bytes	SEL Interdata 256 K Words
Link	Interdata 8/32	High-Speed Pipeline Processor	Ranges 20-200 NSEC	N/A	All Semi-conductor in Pipeline, 64 Bit Word[1]	Can be Doubled
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS	None	—	32 Nanosec		Main Memory 2,100,000/512,000	
Gould						
Grumman	—	—	—	—	—	—
Marconi	Yes	Visual System Control & Management	1 M Instructions/Second	13.33 M Bytes/Second	Multi-port 1 M Byte Store if Necessary	Modular
AFWAL Specified	NS	NS		NS	NS	NS
Generic System	Indeterminate	Indeterminate	I.D.	I.D.	I.D.	25%

[1] Edge List = 256 K words
Active Data Base = 128 K words

Table B-14 Real-Time CIG System CIG Computer (Continued)

	CPU TIME USE (%)	QUANTITY USED	ATTRIBUTES	WORD SIZE	COMPUTER LANGUAGE(S)	CONTOURING AND CIRCLE FEATURES[1]
CURRENT						
Evans & Sutherland						
General Electric	80-90%	1 on C130	—	32 Bit	Fortran and Assembly	Hardware Implementation
Link	100% (asynchro-processing done in spare time)	1 Usually 2 on SMS	N/A	32 Bit	Assembly in Relative Fortran Data Base	Under Development
NEXT GENERATION						
Evans & Sutherland						
General Electric						
Link						
FUTURE						
ATS	—	—	—	—	—	—
Gould						
Grumman	—	—	—	—	—	—
Marconi	70%	Depends on the Size of System	Highly Modular	16 or 32 Bit	Assembler Within User Program in Fortran IV	—
AFWAL Specified	NS	NS	NS	NS	NS	NS
Generic System	<75%	I.D.	I.D.	I.D.	Fortran/Pascal	Yes

[1] Non-circle features--curved surfaces.

Table B-15 CIG Diagnostic Tests

	MAINTENANCE	PRE-TEST VERIFICATION	REAL-TIME DIAGNOSTICS
CURRENT			
Evans & Sutherland	Designed in Diagnostic Hardware which Allows the User to Locate Malfunctions to Board Level	Yes - Readiness Checks	
General Electric	Vendor Supplied CPU & Peripherals in House for Special Purpose H/W	Use of Developed Diagnostic Software	No On-line Real-time
Link	Yes (Military Required) to Board Level	Yes - Call System Integrity Check	No
NEXT GENERATION			
Evans & Sutherland			
General Electric			
Link			
FUTURE			
ATS	Equipment Test Program Card Tester Programs	—	On-line Diagnostic Program
Gould			
Grumman	—	—	—
Marconi	Extensive - Computer Aided	Computer Aided	Test Programs Available
AFWAL Specified	NS	NS	NS
Generic System	Yes - Card Level Functional Level	Yes - 30 Minutes	Yes

Table B-16 CIG Operator Control

	VISIBILITY	CLOUD TOPS	CEILING	SCUD	FOG	DAY/NIGHT	SEASON
CURRENT							
Evans & Sutherland							
General Electric	Yes	Yes	Yes	Yes	Yes	Yes	By Data Base Change
Link	Yes (Adjustable)	Yes (Adjustable)	Yes (Adjustable)	Not at Present	Limit Visibility	Yes	In Data Base Substitution
NEXT GENERATION							
Evans & Sutherland							
General Electric							
Link							
FUTURE							
ATS	Yes	Yes	Yes			Sun Position	
Gould							
Grumman	—	—	—	—	—	—	—
Marconi	Yes	Yes	Yes	Yes	Yes	Yes and Dusk	Yes
AFWAL Specified	NS	NS	NS	NS	NS	NS	NS
Generic System	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table B-17 CIG Expansion Capabilities

Evans & Sutherland	Additional Channels, Larger Data Base
General Electric	—
Link	Parallel Frame Calculator, Parallel Pipeline Proc., Substitute Faster in Intersection Computer
NEXT GENERATION	
Evans & Sutherland	
General Electric	
Link	
FUTURE	
ATS	Memory 25.8%
Gould	
Grumman	—
Marconi	Yes — Modular Design Extensive - Add Extra Channels
AFWAL Specified	NS
Generic System	Software: 25%; Hardware: I.D.

APPENDIX C

JTCG/SATD ROADMAP THROUGH CIG TECHNOLOGY

JOINT TECHNICAL COORDINATING GROUP (JTCG) SIMULATORS AND TRAINING DEVICES (SATD)

SUBPANEL ON RESEARCH AND DEVELOPMENT FOR AIRCREW TRAINING DEVICES

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This "roadmap" is a program planning tool designed to indicate what tri-service R&D projects are planned in the area of Computer Image Generation (CIG). The purpose of the roadmap is to show how individual CIG projects are interrelated or "linked" together; how they compare to each other on the basis of their resulting products; and how they can be distinguished from each other on the basis of distinctive features. It has been developed for the Joint Logistics Commanders by the Joint Technical Coordinating Group (JTCG) on Simulators and Training Devices (SATD).

The general layout of the roadmap has been designed to permit visual tracking of what CIG products will emerge from which projects at what time, and how these products will be integrated with other concurrent CIG projects. The roadmap is in essence an FY 80 "snapshot" of the anticipated FLOW OF CIG R&D PROJECTS over the next five years.

Each project shown on the roadmap represents a segment of work which results in a distinct output product. A project may contain more than one task. Each project/task is represented on the left side of the roadmap by a horizontal line flowing from left to right. The line terminates in a "bubble" containing the last four digits of the pertinent project number and a subscript to indicate task number (if any).

Each "bubble" has been strategically positioned underneath the QUARTERLY TIMELINE OF TASK COMPLETION DATES to indicate the time at which the product will emerge. The heavy lines drawn vertically between projects indicate where the product of one project "feeds" or provides an input to a subsequent task, thus forming "linkages" between projects.

"Task" lines on the left of the roadmap flow directly into the "product" goals on the right. The goals have been divided into two major areas of CIG technology. These are represented by two separate matrices entitled Data Base/Software and Display/Hardware. The goals have been subdivided into significant CIG PRODUCT FEATURES, such as Data Base (DB) Transformation and Projector Development.

The columns of each matrix represent the significant product features* of each major CIG area. The rows of each matrix correspond to respective project/task "bubbles" drawn horizontally on the left of the roadmap. The "dots" in each row of the matrices on the right indicates the set of the significant "features" of the product coming out of the associated project/task "bubble" on the left.

TRISERVICE R&D PROJECTS ON THE JTCG/SATD ROADMAP THROUGH CIG TECHNOLOGY

Each project on the CIG ROADMAP is identified by a bubble positioned on the left side under the quarterly timeline at its date of completion. Each bubble contains the last four digits of the project number, plus a subscript to indicate a task within a multi-task project (see below). Projects marked below with an asterisk (*) are jointly funded by the Army.

PROJECT/TASK NUMBER	COMPLETION DATE	NAVY PROJECT/TASK TITLE
4781_{U1}	(U1) 12/81	Visual Technology Research Simulator Utilization (VTRS) Pilot perceptual criteria for scene content
$4781_{C1,C2}$		Conventional Takeoff and Landing (CTOL) on VTRS
	(C1) 6/79	Data base for LSO trainer
	(C2) 12/79	Data base for helmet-mounted AOI system
$4781_{V1,V2,V3,V4}$		Vertical Takeoff and Landing (VTOL) on VTRS
	(V1) 12/79	Data base for destroyer landing task
	(V2) 12/79	Optical/geometric distortion correction
	(V3) 12/79	Color modification to VTRS
	(V4) 3/80	Wide angle lens development
$8732_{1,2,3*}$		Pilot Helmet-Mounted Display
	(1) 12/79	Perceptual criteria for detection of motion
	(2) 12/80	Data base with multiple levels of detail
	(3) 12/80	Laser projector/system integration

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*The last column in each matrix, entitled Design Concepts/Criteria and Design Specifications, signifies that the corresponding task will generate only design "concepts" or "specifications" as its product rather than a "hard" prototype piece of equipment.

PROJECT/TASK NUMBER	COMPLETION DATE	NAVY PROJECT/TASK TITLE
$8734_{1,2,3}$		Automated Electro-Optical Processing of Airborne Data
	(1) 9/80	Perspective display of terrain data base
	(2) 9/81	Universal data base with 30 object library
	(3) 9/82	Real-time optical video disc storage
$8741_{1,2,3,4}$		Low Level Daytime CIG
	(1) 12/79	Unstructured, 30 calligraphic data base
	(2) 6/82	Structured, interactive data base for VTRS
	(3) 6/80	Sensor/visual data base for AVEOSS
	(4) 12/80	Real-world, share-line data base for SNAPPOTTS
$8742_{1,2,3,4}$		Automated Data Base (DB) for CIG
	(1) 9/80	Data base language constructs for CIG graphics
	(2) 12/82	Problem Oriented Language for VTRS
	(3) 6/83	Universal DB with Display Procedures
	(4) 9/84	DMA DB transformation to VTRS DB
8743*	9/80	CIG Area-of-Interest (AOI)

PROJECT/TASK NUMBER	COMPLETION DATE	AIR FORCE PROJECT/TASK TITLE
1958-0101	6/79	Holographic Pancake Window Development
0102	6/79	Wide Angle Color Infinity Optics Display
0103	9/79	Liquid Crystal Light Valve Projector (LCLV)
0105	6/80	Diamond Turned Pancake Window Development
0110	12/79	Three CRT Color Television Projector Development
0111	6/80	Wide Angle Refractive Optical Displays
0307	9/79	Non-Linear CIG Real-Time Study (for AEOSS)
0308	9/79	Circular Feature Implementation (for AEOSS)

PROJECT/TASK NUMBER	COMPLETION DATE	AIR FORCE PROJECT/TASK TITLE
6114-2101	9/81	Development & Evaluation of CIG Techniques
2102	9/82	Advanced CIG Visual/Sensor Development
2104	3/80	Advanced CIG Techniques Exploiting Perceptual Characteristics
2106	9/79	Surface Texturing Study Via PRN Codes
2201	6/81	Fiber Optic Techniques for Helmet Mounted Display
2202*	9/80	Helmet Mounted Display Prototype Development
2203	6/80	Psychophysical Criteria for Visual Simulation Systems
2204	3/80	Depth Perception in Visual Simulation
2206	3/82	Simulation for Maintenance of Critical Combat Skill
$2363_{1,2,3,4}$		Advanced Tactical Air Combat Simulation (ATACS)
	(1) 9/82	LCLV projector improvement
	(2) 12/83	In-line optical system with trichromatic holograms
	(3) 12/83	CIG system using non-edge techniques
	(4) 12/84	System integration
$2364_{1,2}$		Advanced CIG Sensor/Visual Simulation
	(1) 6/83	Implementation of non-edge CIG concepts
	(2) 12/85	System integration
$2325_{13,14}$		Simulator Development Activities
	(13) 3/82	CIG Digital Data Base Development
	(14) 6/82	CIG System Optimization

DISTINCTIVE FEATURES OF PRODUCTS FROM AIR FORCE CIG PROJECTS/TASKS

0101	monochromatic, holographic pancake window to replace high cost glass mirror beamsplitter for a display mosaic of three windows
0102	competitive trichromatic, holographic versions of the 0101 lens
0103	liquid crystal light valve (LCLV) projector with capability of writing multiple independent targets
0105	trade-off between diamond-turning and conventional grinding of large mirror beamsplitter from acrylic plastic blank (backup for 0102)
0110	brighter image resolution from one-cube construction of lens with 3 CRT's upgraded to 1000 lines resolution/800 lumens output and increased scan rate
0111	trade-off between using low-cost, low-risk plastic lenses in place of large, high-risk off-axis spherical mirrors for a refractive, multi-viewer display
0307	trade-off between sequential/parallel multiprocessor configurations based on system through-put rates required for real-time implementation of a non-linear CIG algorithm
0308	circular CIG features implemented by modification of existing Fortran routines
2101	evaluation techniques/criteria based on human perceptual characteristics for evaluating circular features and non-linear terrain/texture generation methods
2102	multiple competitive CIG system design concepts using non-edge image techniques to improve the efficiency of DB storage, data extraction, and image generation
2104	evaluation of current CIG system deficiencies based on human perceptual criteria as a function of range for color desaturation, light intensity, familiar object size, etc.
2106	evaluation of pseudo-random-noise (PRN) codes for providing varying degrees of granularity/tonal variations and for correlating textural patterns from frame-to-frame
2201	wavelength multiplexing of binocular image in fiber optic bundle to display a high resolution, 15° FOV inset slaved to viewer eye movement by an IR eye tracker
2202	competitive lens designs with/without aspheric surfaces for the virtual-image VCASS simulator display; one design trades off axial color correction for weight reduction

DISTINCTIVE FEATURES OF PRODUCTS FROM AIR FORCE CIG PROJECTS/TASKS (Cont)

2203	design tolerances/criteria for visual simulation systems based on human perceptual capabilities, including a priority ranking of relevant system characteristics
2204	evaluation of the presentation of depth cues in visual simulation systems based on a task analysis of landing, aerial refueling, formation flight and low-altitude maneuvers
2206	evaluation of alternative design concepts for a part-task trainer implemented on a portable helmet-mounted/inflatable dome visual system
2363_1	improvement of photoconductive surfaces in 0103 LCLV projector, plus comparison of dual and single-beam high resolution CRT's
2363_2	integration of 0102 red/blue/green holograms into single, in-line optical system
2363_3	CIG system with 30K edge capacity as a result of combining edge image generation with the non-edge techniques from 2102
2363_4	system integration of 2363_1 projector, 2363_2 optics, and 2363_3 CIG system by matching optical/CIG system characteristics to projector resolution/update rate
2364_1	evaluation of the non-edge CIG system design concepts from 2102 and expansion of the 2102 DB to include a microstructure of textural detail
2364_2	system implementation of the 2102 design concept evaluated in 2364_1 as demonstrating greatest potential and cost-effectiveness
2325_{13}	transformation of DMA DB levels 1, 2, V and X into a universal format DB with enhanced level of detail for a specified gaming area
2325_{14}	hardware/software discriminator with look-ahead capability for screening on-line DB to maintain image generator at a constant level and to prevent system overload
4781_{U1}	determination of pilot perceptual learning capability as a function of object/texture/altitude cues present at different levels of scene complexity/detail

DISTINCTIVE FEATURES OF PRODUCTS FROM AIR FORCE CIG PROJECTS/TASKS (Cont)

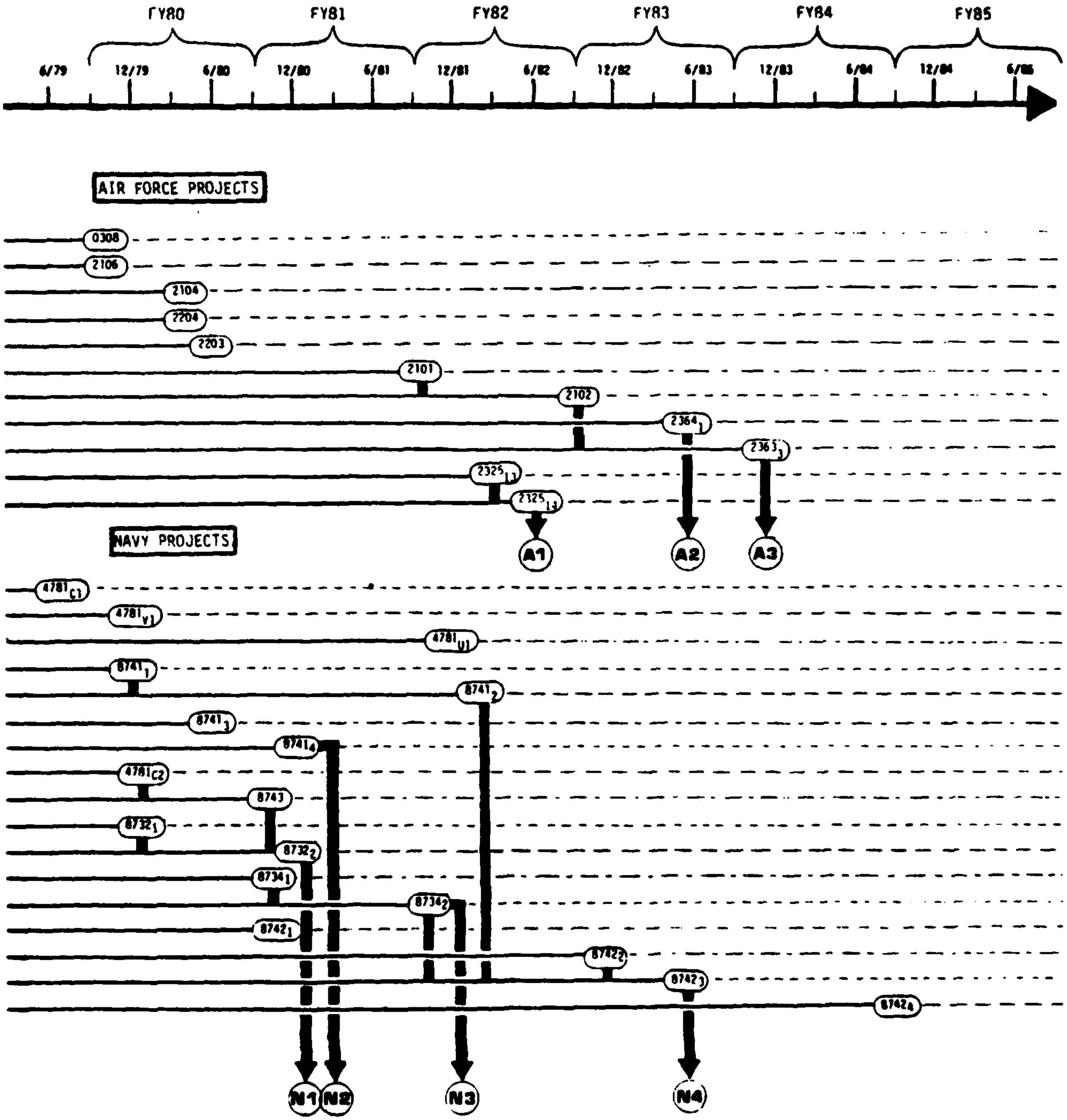
4781_{C1}	DB for CTOL simulation of A-7 glidepath approach for LSO training
4781_{C2}	transformation of the VTRS DB into a 2-level course/fine DB for selecting an AOI image according to viewer helmet position
4781_{V1}	DB for VTOL simulation of landing task on a destroyer
4781_{V2}	pipelined processor for vertical/horizontal correction of both optical and geometric distortion in a 2D linear image projected onto a curved surface
4781_{V3}	color modification to the VTRS hardware by adding red/green video generators and expanding the VTRS DB to include color face parameters
4781_{V4}	high transmission/resolution, wide angle lens having a manual roll prism and changeable aperture, integrated with a real-image, color light valve projector
8732_1	determination of minimum system time constant based on lag time for detection of visual motion after eye fixation
8732_2	transformation of the VTRS DB to vary levels of detail as a function of radius to the point of eye fixation
8732_3	laser projector for helmet mounted eye-coupled AOI display
8734_1	algorithms for perspective display of a terrain DB digitized from recon photos + DMA 30 pt. elevation/reflectance data
8734_2	photogrammetric DB including 30 object library with interactive color/texture face assignments, digitized from real-world stereo photos
8734_3	optical video disc storage for 8734_1 terrain DB used for real-time generation of perspective display
8741_1	off-line generation of 3D calligraphic DB digitized with interactive 2D plotter
8741_2	transformation of unstructured 8741_1 DB into a structured, interactive DB for the VTRS with color/shading face parameters
8741_3	IR sensor/visual DB generated for AVEOSS system definition study
8741_4	highly-detailed DB of real-world shore-line environment and navigation objects generated for SNAPPOTS system definition study

DISTINCTIVE FEATURES OF PRODUCTS FROM AIR FORCE CIG PROJECTS/TASKS (Cont)

8742_1	definition of DB language constructs to extend graphics proposed ACM standard to a CIG DB
8742_2	problem-oriented language based on 8742_1 language constructs, written in a high-order language tailored to generate the VTRS DB
8742_3	universal CIG DB format extending 8741_2 DB and 8734_2 object library to real-time, interactive insert/delete/delete/reposition capability for displayed objects
8742_4	transformation of DMA DB levels 1 and V (including IR sensor data) to the VTRS DB, and validation of DMA DB level 2
8743	4781_{C2} DB increased to 8 levels and partitioned to eliminate discontinuities due to slight changes in viewer orientation

FLOW OF CIG R&D PROJECTS

QUARTERLY TIMELINE OF TASK COMPLETION DATES



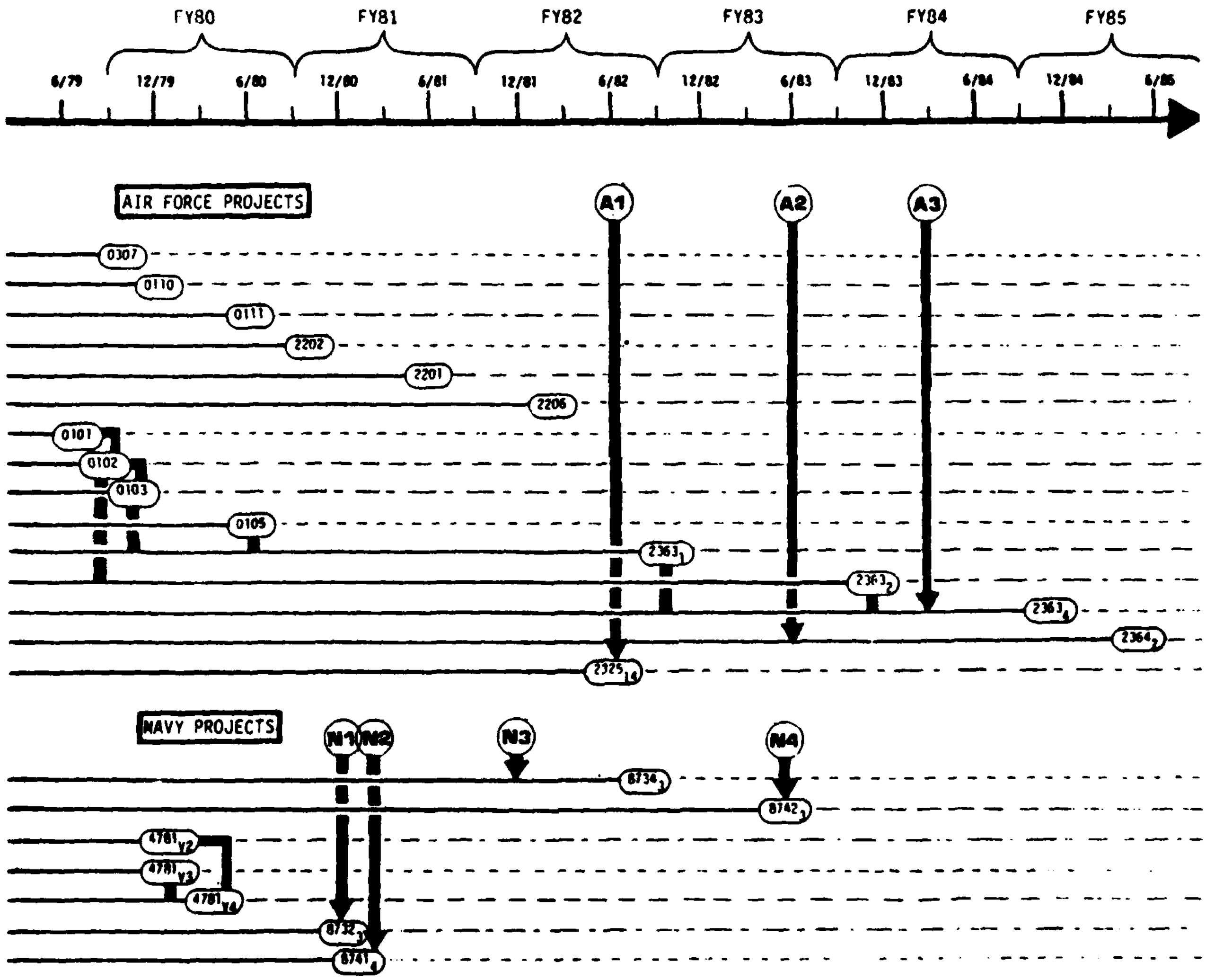
CIG PRODUCTS

DATA BASE/SOFTWARE MATRIX

CIG PRODUCT FEATURES	DATA BASE (DB) TRANSFORMATION	DMA SOURCE INPUT DATA BASE (DB)	VISUAL/SENSOR DB COMPATIBILITY	MULTIPLE LEVELS OF DETIAL	AREA OF INTEREST (AOI) DB	ON-LINE INTERACTIVE DB CREATION	OBJECT GENERATION	NON-LINEAR/CIRCULAR FEATURES	TEXTURE/SHADING	COLOR	3-D/DEPTH	HUMAN PERCEPTUAL CRITERIA	DESIGN CONCEPTS/CRITERIA	
AIR FORCE CIG PRODUCTS														AIR FORCE PROJECT/TASK TITLES
0308	●	●	●					●						CIRCULAR FEATURE IMPLEMENTATION (FOR AEOSS)
2106			●	●					●		●			SURFACE TEXTURING STUDY VIA PRN CODES
2104							●			●	●	●	●	ADVANCED CIG TECHNIQUES EXPLOITING PERCEPTUAL CHARACTERISTICS
2204											●	●	●	DEPTH PERCEPTION IN VISUAL SIMULATION
2203												●	●	PSYCHOPHYSICAL CRITERIA FOR VISUAL SIMULATION SYSTEMS
2101			●					●	●			●	●	DEVELOPMENT & EVALUATION OF CIG TECHNIQUES
2102			●				●	●	●				●	ADVANCED CIG VISUAL/SENSOR DEVELOPMENT
2364_1	●	●	●	●			●	●	●					ADVANCED CIG SENSOR/VISUAL SIMULATION Implementation of non-edge CIG concepts
2363_3							●	●	●					ADVANCED TACTICAL AIR COMBAT SIMULATION (ATACS) CIG System using non-edge techniques
2325_{13}	●	●		●										CIG DIGITAL DATA BASE DEVELOPMENT
2325_{14}		●		●										CIG SYSTEM OPTIMIZATION
NAVY CIG PRODUCTS														NAVY PROJECT/TASK TITLES
4781_{C1}							▲							CONVENTIONAL TAKEOFF AND LANDING (CTOL) ON VTRS Data base for LSO trainer
4781_{V1}							▲							VERTICAL TAKEOFF AND LANDING (VTOL) ON VTRS Data base for destroyer landing task
4781_{U1}				▲			▲		▲		▲	▲	▲	VISUAL TECHNOLOGY RESEARCH SIMULATOR UTILIZATION (VTRS) Pilot perceptual criteria for scene content
8741_1				▲			▲				▲			LOW LEVEL DAYTIME CIG unstructured, 3D calligraphic data base
8741_2	▲			▲		▲	▲		▲	▲	▲			LOW LEVEL DAYTIME CIG Structured, interactive data base for VTRS
8741_3			▲				▲							LOW LEVEL DAYTIME CIG Sensor/visual data base for AVEOSS
8741_4						▲	▲							LOW LEVEL DAYTIME CIG Real-world, shore-line data base for SNAPPOTTS
4781_{C2}	▲			▲	▲									CONVENTIONAL TAKEOFF AND LANDING (CTOL) ON VTRS Data base for helmet-mounted AOI system
8743	▲			▲	▲									CIG AREA-OF-INTEREST (AOI)
8732_1												▲	▲	PILOT HELMET-MOUNTED DISPLAY Perceptual criteria for detection of motion
8732_2	▲			▲	▲									PILOT HELMET-MOUNTED DISPLAY Data base with multiple levels of detail
8734_1	▲	▲	▲	▲			▲		▲	▲	▲			AUTOMATED ELECTRO-OPTICAL PROCESSING OF AIRBORNE DATA Perspective display of terrain data base
8734_2				▲		▲	▲		▲	▲	▲			AUTOMATED ELECTRO-OPTICAL PROCESSING OF AIRBORNE DATA Photogrammetric data base with 3D object library
8742_1							▲						▲	AUTOMATED DATA BASE (DB) FOR CIG Data base language constructs for CIG graphics
8742_2	▲						▲							AUTOMATED DATA BASE (DB) FOR CIG Problem Oriented Language for VTRS
8742_3	▲			▲		▲	▲		▲					AUTOMATED DATA BASE (DB) FOR CIG Universal DB with Display Procedures
8742_4	▲	▲	▲											AUTOMATED DATA BASE (DB) FOR CIG DMA DB transformation to VTRS DB

FLOW OF CIG R&D PROJECTS

QUARTERLY TIMELINE OF TASK COMPLETION DATES



CIG PRODUCTS

DISPLAY/HARDWARE MATRIX

AIR FORCE CIG PRODUCTS

CIG PRODUCT FEATURES	PROCESSOR INTERFACE	PROJECTOR DEVELOPMENT	LENS DEVELOPMENT	HELMET-MOUNTED	EYE TRACKING	WIDE ANGLE DISPLAY	DISTORTION CORRECTION	COLOR	BRIGHTNESS	HIGH RESOLUTION	REDUCED WEIGHT	SYSTEM INTEGRATION	DESIGN SPECIFICATIONS	AIR FORCE PROJECT/TASK TITLES
0307	●												●	NON-LINEAR CIG REAL-TIME STUDY (FOR AEOSS)
0110	●	●	●					●	●	●				THREE CRT COLOR TELEVISION PROJECTOR DEVELOPMENT
0111						●	●	●			●	●		WIDE ANGLE REFRACTIVE OPTICAL DISPLAYS
2202			●	●			●	●			●	●		HELMET-MOUNTED DISPLAY PROTOTYPE DEVELOPMENT
2201	●			●	●		●	●	●	●	●			FIBER OPTIC TECHNIQUES FOR HELMENT-MOUNTED DISPLAY
2206				●							●		●	SIMULATION FOR MAINTENEANCE OF CRITICAL COMBAT SKILL
0101			●			●				●	●			HOLOGRAPHIC PANCAKE WINDOW DEVELOPMENT
0102			●			●		●			●			WIDE ANGLE COLOR INFINITY OPTICS DISPLAY
0103		●						●	●	●				LIQUID CRYSTAL LIGHT VALVE PROJECTOR (LCLV)
0105			●								●			DIAMOND TURNED PANCAKE WINDOW DEVELOPMENT
2363_1		●						●	●	●				ADVANCED TACTICAL AIR COMBAT SIMULATION (ATACS) LCLV projector improvement
2363_2			●					●			●			ADVANCED TACTICAL AIR COMBAT SIMULATION (ATACS) In-line optical system with trichromatic holograms
2363_4	●	●	●			●		●	●	●	●	●		ADVANCED TACTICAL AIR COMBAT SIMULATION (ATACS) System Integration
2364_2												●		ADVANCED CIG SENSOR/VISUAL SIMULATION System Integration
2325_{14}	●													CIG SYSTEM OPTIMIZATION

NAVY CIG PRODUCTS

CIG PRODUCT FEATURES	PROCESSOR INTERFACE	PROJECTOR DEVELOPMENT	LENS DEVELOPMENT	HELMET-MOUNTED	EYE TRACKING	WIDE ANGLE DISPLAY	DISTORTION CORRECTION	COLOR	BRIGHTNESS	HIGH RESOLUTION	REDUCED WEIGHT	SYSTEM INTEGRATION	DESIGN SPECIFICATIONS	NAVY PROJECT/TASK TITLES
8734_3	▲										▲			AUTOMATED ELECTRO-OPTICAL PROCESSING OF AIRBORNE DATA Real-time optical video disc storage
8742_3	▲													AUTOMATED DATA BASE (DB) FOR CIG Universal DB with Display Procedures
4781_{V2}	▲					▲	▲							VERTICAL TAKEOFF AND LANDING (VTOL) ON VTRS Optical/geometric distortion correction
4781_{V3}	▲					▲		▲						VERTICAL TAKEOFF AND LANDING (VTOL) ON VTRS Color modification to VTRS
4781_{V4}			▲			▲	▲	▲	▲	▲				VERTICAL TAKEOFF AND LANDING (VTOL) ON VTRS Wide angle lens development
8732_3		▲		▲	▲							▲		PILOT HELMET-MOUNTED DISPLAY Laser projector/system integration
8741_4	▲													LOW LEVEL DAYTIME CIG Real-world, shore-line data base for SHAPPOTTS

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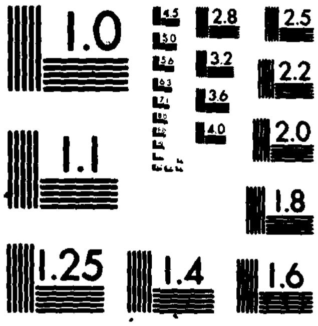

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