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Conceptual Design Study for an Advanced Cab and Visual System
Volume 1

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Boeing Military Airplane Company

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FOREWORD

This report was prepared for the United States Aeromechanics Laboratory, Aviation Research and Development Command (AVRADCOM) and the Ames Research Center, National Aeronautics and Space Administration (NASA). Both agencies are located at Moffett Field, California. The study was performed under NASA Contract No. NAS2-10464 and was accomplished in a 10-month period from 14 November 1979 to 22 September 1980. Colonel Arlin Deel, Aeromechanics Laboratory, was the technical monitor for the contract.

The principal investigators were R. J. Rue, M. L. Cyrus, T. A. Garnett, J. W. Nachbor, J. A. Seery and R. L. Starr of Boeing.

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ACRONYMS

AAH	Advance Attack Helicopter
ACAVS	Advanced Cab and Visual System
ACM	Association of Computing Machines
AFIPS-FJCC	Association for Information Processing – Fall Joint Conference of Computers
AFIPS-SJCC	Association for Information Processing – Spring Joint Conference of Computers
AIDS	Advanced Integrated Display System
ASPT	Advanced Simulator for Pilot Training
CDR	Critical Design Review
CG	Center of Gravity
CGI	Computer Generated Imagery
CGIP	Computer Graphics for Information Processing
CIC	Communications Interface Controller
COMPSAC-77	Computer Software Applications Conference
CRT	Cathode Ray Tube
CWBS	Contract Work Breakdown Structure
DAC	Digital to Analog Converter
DOF	Degrees of Freedom
EADI	Electronic Attitude and Director Indicator
ERU	Equipment Replaceable Unit
FL	Foot-Lambert
FOV	Field of View
HFOV	Horizontal Field of View
HUD	Heads Up Display
IC	Interchangeable Cab
ICD	Interface Control Document
ICWG	Interface Control Working Group
IFIP	International Federation of Information Processing
LCLV	Liquid Crystal Light Valve
LED	Light Emitting Diode
LOS	Line of Sight
LP	Line Pair
LVP	Light Valve Projector
LVS	Laser Visual System
MTBF	Mean Time Between Failure
MTF	Modulation Transfer Function
MTTR	Mean Time to Repair
NASA	National Aeronautics and Space Administration
NOE	Nap of the Earth
PEP	Project Engineer's Control Panel
RADC	Rome Air Development Center
RIOU	Remote Input/Output Unit
RSIS	Rotorcraft System Integration Simulator
RSMG	Rotorcraft Simulator Motion Generator
RSS	Root Sum Square
SEP	Simulation Engineer's Control Panel
SHMS	SPASYN Helmet-Mounted Sight System
SIGGRAPH-ACN	Special Interest Group for Graphics
SOW	Statement of Work
SPIE	Society of Photo-Optical Instrumentation Engineers

ACRONYMS (CONT'D)

V	Velocity
VFOV	Vertical Field of View
VFR	Visual Flight Reference
VLSI	Very Large Scale Integration
VMS	Vertical Motion Generator
VTRS	Visual Technology Research Simulator (Orlando, Florida)
UAIDE	Users Automated Information Display Equipment

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1.0 BACKGROUND

1.1 Purpose

This report documents results of a "Conceptual Design Study for an Advanced Cab and Visual System," performed by Boeing Military Airplane Company, to assist NASA Ames/U.S. Army Aeromechanics Laboratory ARTL (AVRADCOM) personnel in acquiring an Advanced Cab and Visual System (ACAVS).

1.2 Overall Project Description

ACAVS will become an integral part of the Rotorcraft Systems Integration Simulator (RSIS) at the NASA Ames Research Center within the next four years and is under development by a joint NASA/Army task force. The RSIS complex will include a cockpit cab, visual image generator and display system, six-degree-of-freedom motion drive, a development station, and suitable computer interface equipment. When integrated, these components will constitute an advanced flight simulator that will be used to support rotorcraft research and development activities.

The RSIS project plan consists of three separate, independent procurements. The first procurement addresses acquisition of a motion base known as the Rotorcraft Simulator Motion Generator (RSMG) to be delivered in 1982. This is an ongoing NASA Ames activity. The second procurement is the subject of this study, and defines requirements for a Rotorcraft Simulator Cab, a Rotorcraft Simulator Development Station and an Advanced Visual System. The third procurement will address acquisition of the ACAVS hardware. Later, ACAVS will be integrated with the RSMG and Ames Simulation Computer Facility.

After this integration is accomplished, the whole assembly will be incorporated into the existing Ames Vertical Motion Simulator (VMS) facility to form a sophisticated six-degree-of-freedom moving-base rotorcraft simulation capability. Consideration is given to this integration requirement in ACAVS design, but the integration effort itself is not part of the ACAVS Statement of Work.

1.3 Relationship of Study to Overall Project

The overall project objective is to produce an engineering simulator suitable for rotorcraft research studies emphasizing aircraft handling qualities. The goal of this study is to provide guidance for the acquisition of the cab, development station and visual system components. Results of this study will guide the choice of hardware, and its implementation and operation within the total complex.

1.4 Definitions

- Advanced Rotorcraft Visual System – The visual simulation subsystem of RSIS consisting of the electronic, electro-optical and mechanical devices that generates an image of a scene and display it to the pilot. For the purposes of this report it is generally divided into visual image generation systems and visual display systems.

- Advanced Cab and Visual System (ACAVS) – A term describing the three RSIS components covered in this study effort. They are: (1) the Rotorcraft Simulator Cab; (2) the Advanced Rotorcraft Visual System; and (3) the Rotorcraft Simulator Development Station.

- Computer-Generated Imagery (CGI) – A term describing an array of computers, signal processors and display devices that can produce pictures. Sometimes the term is used to describe only the computer and signal processor elements used to generate the signal representing the picture or the process by which these pictures are generated.

- Interchangeable Cab (IC) – A generic or specific simulator cab that can be mounted in a specially-designed area where it may be operated as a fixed-base simulator cab, or mounted and operated on the VMS when large amplitude motions are required for simulation studies.

- Rotorcraft System Integration Simulator (RSIS) – A sophisticated moving-base rotorcraft simulator with a motion base, development station, cab, and an advanced visual system (ACAVS).

- Rotorcraft Simulator Cab – The cab component of the RSIS complex. A generic cab with the features of rotorcraft that contains the crew stations for use in rotorcraft simulation studies.

- Rotorcraft Simulator Development Station – An area containing power, operating consoles and floor pads that can support the development or operation of the Rotorcraft Simulator Cab, the Advanced Rotorcraft Visual System, and the Rotorcraft Simulator Motion Generator; either separately, or as an integrated unit.

- Rotorcraft Simulator Motion Generator (RSMG) – A four-degree-of-freedom (pitch, roll, yaw and longitudinal or lateral translation) motion base that is a portion of the total motion generator of the RSIS complex. The device can carry the Rotorcraft Simulator Cab and the Advanced Rotorcraft Visual System (Image Presentation portion) separately or as a cab/visual unit. It can be operated individually or with the cab and visual system either in the Rotorcraft Simulator Development Station or atop the VMS lateral bridge carriage.

- Vertical Motion Simulator (VMS) – A recently built NASA Ames general-purpose motion generator currently configured with: a large bridge structure which is actuated vertically and carries a lateral track and carriage assembly which, in turn, carries a synergistic six-post motion platform, the six-post device normally used to generate rotational motion only, which will be replaced by the RSMG when the RSIS is implemented.

2.0 SUMMARY AND RECOMMENDATIONS

2.1 Summary

A conceptual design study was conducted to define requirements for the Advanced Cab and Visual System elements of the U.S. Army/NASA RSIS Program. The rotorcraft System Integration Simulator is intended principally for engineering studies in the area of mission associated vehicle handling qualities.

A technology survey and assessment of existing and proposed simulator visual display systems, image generation systems, modular cab designs, and simulator control station designs were performed and are discussed in this report. State-of-the-art survey data were used to synthesize a set of eleven preliminary visual display system concepts. Of these, five of the more attractive candidate display configurations were selected for further evaluation. Basic display concepts incorporated in these configurations included:

- Real image projection, using either
  - Periscopes
  - Fiber optic bundles
  - Scanned laser optics
- Virtual imaging with
  - Helmet-mounted displays

These display concepts were integrated in the study with a simulator cab concept employing a modular base for aircraft controls, crew seating, and instrumentation (or other) displays. A simple concept to induce vibration in the various modules was developed, and is described.

Results of evaluations and trade-offs related to the candidate system concepts are given, along with a suggested weighting scheme for numerically comparing visual system performance characteristics. Preliminary estimates of system availability and relative cost levels are also presented.

A draft preliminary ACAVS Statement of Work (SOW), and a functional specification defining system requirements, are provided in the report appendices. The SOW has been written such that it can be included in a future NASA/Army request for proposal oriented toward ACAVS hardware acquisition in the 1982-84 time frame.

2.2 Recommendations

The principal conclusion of this study is that several viable conceptual design approaches exist which satisfy essential mission requirements for a rotorcraft simulator research tool suitable for evaluating mission related vehicle handling qualities. No concept evaluated is significantly better than the rest in terms of satisfying the total system requirements within cost and schedule constraints. It should be pointed out that schedule and cost constraints, while limiting, are not judged to be critical. That is, no technological break-through seems imminent in this area and there are no significantly better systems available just outside the budget goal. However, one technology that is developing rapidly is that of Helmet-Mounted Display (HMD) systems.

It is recommended that none of the five candidate concepts be excluded in subsequent ACAVS procurement efforts since each has its unique advantages as well as inherent limitations. Because of the newness of the helmet-mounted display system technology, it is further recommended that substantiation of critical HMD parameters be obtained before a final procurement selection is made.

It is also recommended that further study be directed toward obtaining additional data in three areas relating to real image/dome visual displays:

- Extension of the distortion analysis to include a broader range of head and projector positions.
- Modification of the distortion analysis computer program to allow illuminance variation computations and computation of a selected set of values.
- Further modification of this program to allow evaluation of occlusion or shadowing of the projected scene by specified cabin structure or other crew member.

3.0 APPROACH

A set of seven study tasks were accomplished in this study. The specific approach followed in accomplishing each of these tasks is covered in the following paragraphs, which address tasks individually. An overall look at the information flow and decision sequence is shown in Figure 3-1.

3.1 User Defined Operational Requirements

The Boeing ACAVS team conducted interviews with designated research project and operations personnel at NASA Ames Research Center, in order to determine operational requirements for ACAVS pertaining to various rotorcraft being simulated, RSIS program guidelines and baseline requirements. Technologies represented by the team included visual displays, computer image generation, computer hardware, mechanical and structural design and rotorcraft mission/handling qualities analysis and design.

Specific requirements were determined during briefings, facility demonstrations and interview sessions. This information was compiled, organized and subsequently presented to the NASA Ames/Army user's group where it was clarified and supplemented.

3.2 Management and Operational Constraint Evaluation

Coincident with the user-requirement interviews, the Boeing team also gathered information relative to the NASA Ames Research Center simulation facilities. The goal was to acquire an understanding of the physical facilities and management structure through which the facility is operated, as well as the capabilities and limitations of the various support groups. This information was required to properly address the integration of ACAVS into the RSMG as a part of RSIS. Special sessions were held with NASA specialists in computer hardware, simulator hardware and software, and a brief time was spent at the NASA Ames Research Center rotorcraft flight test facility.

3.3 Assessment of Current and Projected Technology

Current technology and, where possible, projected future developments applicable to ACAVS, were assessed through literature searches, visits to major technology centers and potential vendor's facilities, and consultations with various internal Boeing organizations. The visits and related interviews were invaluable in addressing rational assessment of the rapidly advancing visual system technologies.

3.4 Analyses and Design Trade-offs

Analyses and design trade-offs were performed to distill the information concerning advanced simulation technologies, ACAVS mission task requirements and NASA facility requirements into a set of ACAVS preliminary design requirements.

A set of eleven preliminary design concepts were synthesized (using state-of-the-art simulation technology), and each was then reviewed for major flaws. The most promising candidates were evaluated against their ability to satisfy user requirements, cost restraints, flexibility, reliability, maintainability, accessibility and the potential for growth. Specific areas for design trades were identified and investigated.

3.5 Generation of a Conceptual Design

Results of analysis of proposed design approaches were formalized into a set of alternate conceptual designs, each of which could (with a high degree of confidence) be procured in the 1982-84 time frame. Cost estimates and development schedules were generated for all concepts. A draft statement of work with functional specifications and performance requirements was prepared.

3.6 Reviews and Reports

Two design reviews were prepared and presented; the first at NASA Ames and the second at the Boeing Military Airplane Company facility in Wichita, Kansas.

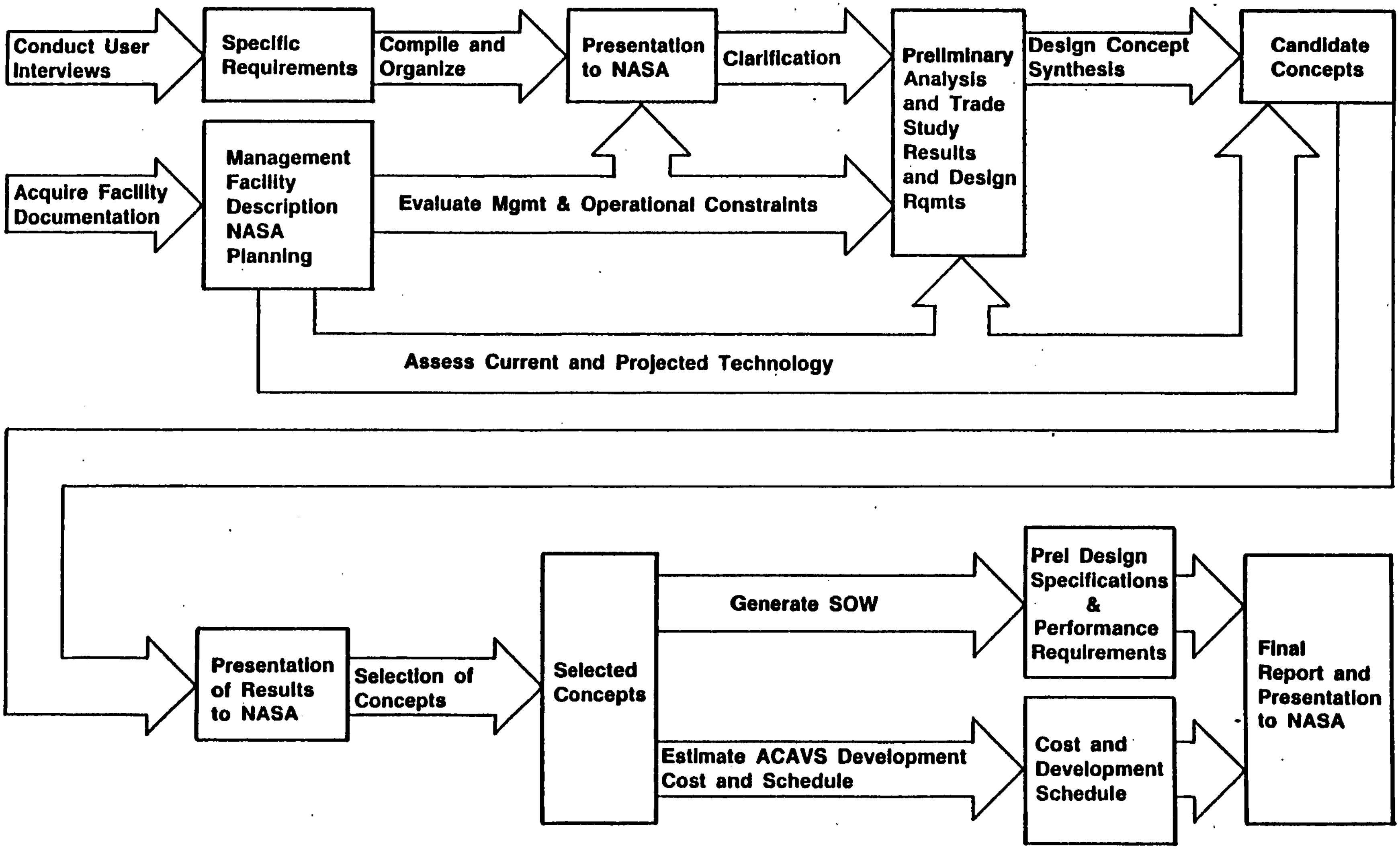


Figure 3-1: ACAVS Study Approach

4.0 REQUIREMENTS

Most of the more stringent design requirements for the Rotorcraft Simulator (and its ACAVS elements) are driven by considerations of the specialized role of the U.S. Army rotorcraft on battlefields of the future. In order to survive the potentially lethal high-threat environment postulated for the mid-intensity battlefield, Army rotorcraft will operate close to the ground, using terrain features, for protection. This type of "terrain flying" brings the pilot in close contact with a world rich in detail provided by both the terrain and atmosphere. As described in Reference 4-1, natural and man-made features, visibility factors of weather and darkness, and atmospheric characteristics of wind, turbulence and ground effect all have to be represented to the helicopter pilot in significant detail to provide a meaningful simulation.

These environmental elements, when coupled with the large variety of rotorcraft to be simulated, suggest a set of very demanding requirements. An overview relating aircraft mission requirements to specific needs of the user is presented in this section, followed by a brief summary of simulation requirements associated with the ACAVS cockpit/cab and visual systems. A description of user facility requirements, which includes discussion of the Development Station is also included.

Details of the various system and hardware requirements for ACAVS are presented later in the report in Section 5.0, Technology Assessment; Section 6.0, Concept Synthesis; and Appendix B, Section 3.0, which covers the system Preliminary Specification.

4.1 Mission Associated Requirements

To define requirements for a rotorcraft flight simulator, it is important to first understand how the aircraft being simulated will operate in the field. In short, mission scenarios and a rough definition of flight characteristics must be established for the aircraft under investigation. Typical Army rotorcraft missions are extremely varied in nature since these aircraft are required to operate anywhere in the world and under all types of environmental conditions.

The most demanding environment for military rotorcraft operation includes the element of combat, where the pilot must conduct his mission in the presence of a potentially lethal and extremely hostile enemy air defense threat. As described in References 4-2 and 4-3, which define tactics and doctrine related to "Employment of Army Aviation Units in a High Threat Environment" and "Terrain Flying," virtually all aircraft will employ elements of the familiar low-level, contour, and Nap-of-the-Earth (NOE) terrain flight modes to survive.

While flying in the corps area at a safe distance from the Forward Edge of the Battle Area (FEBA), rotorcraft will operate at low level maintaining constant airspeed and altitude (usually below 200 feet) to evade enemy detection. As the FEBA is approached, the aircraft drops down and follows the contour of the terrain to evade acquisition and hostile fire. Upon reaching the battalion rear area adjacent to the FEBA, the helicopter descends further to the lowest altitude possible, varying both altitude and airspeed while using natural or man-made shielding to hide the aircraft from the enemy. This maneuver is called masking.

In addition to terrain flying in all weather conditions, tactical combat logistics will often require large transport and utility-type helicopters to carry loads externally, on sling suspensions, in order to minimize forward area exposure during cargo deposit and acquisition, and to accommodate loads too large for internal storage. These logistical support missions will often include requirements for precision hover and low speed translation during load placement; as in the case of depositing artillery tubes, ammunition, etc.

Other mission oriented requirements relate to attack and scout type vehicles which are usually highly maneuverable helicopters performing ground support, protective escort, reconnaissance, target defection, and even air-to-air combat sortie elements. As will be described later, missions of this type require very special consideration in design of the cab and visual system. For example, gunships which engage in air-to-ground and air-to-air encounters with the enemy usually have a tandem cockpit seating arrangement, along with an extremely large undisturbed horizontal and vertical field of view for both the pilot and gunner.

Accommodating these diverse considerations into design of a simulator, which will also be used in evaluating large transport aircraft which requires side-by-side seating and viewing an external sling-load suspended beneath the fuselage, is a challenging task.

4.2 User Requirements

Mission requirements and environmental factors, like those described, collectively establish basic design requirements for any simulation facility. Studies addressing requirements have been conducted by NASA and the Army over the past several years, resulting in a formulation of a user oriented specification for the RSIS program. As currently envisioned, RSIS will be a research development tool aimed at serving both government and industry.

Three principal uses for RSIS are anticipated:

- Development of a handling qualities data base, leading to design criteria rationale for new aircraft
- Conduct of conceptual design studies to establish type specifications
- System development including:
  - Hardware design
  - Flight test support
  - Envelope definition
  - Product improvement

Additional applications for the RSIS are expected to include threat assessment for rotorcraft operating in a combat environment and aircraft accident investigation.

There are two fundamental visual simulation situations:

- Daylight with good visibility
- Night or poor weather

Within each of these situations, helicopters have to perform a range of mission flight phases. Perhaps the most critical is Terrain Flying which in turn has three categories: Low Level, Contour, and Nap-of-the-Earth (NOE), these are defined in Ref. 4.1.

Flight situations will certainly include single helicopter flying but in addition it is desirable to allow formation flight with at least two other helicopters. Air combat, though an exceedingly difficult flight phase to simulate, is a highly desirable capability. The capability of slung load work should also be incorporated.

Other users of the RSIS are expected to include a requirement for V/STOL terminal area simulation and shipboard landings.

From the aspect of visual technology, it is day visual flight conditions that are the most difficult to simulate. Here the requirement is for a wide field-of-view with good resolution and high detail compatible with flight in the NOE environment. Tasks such as air-to-air combat are particularly severe, since in addition to a moving target (or targets) it is a requirement to see as much of the field-of-view as possible to approximate the real aircraft, since this may have an important impact on being able to keep the target aircraft in view and hence on the engagement outcome. The ability to see the target with sufficient clarity may also impose severe requirements on the resolution.

Night and poor weather situations are much earier to simulate. In poor visibility daylight conditions, it should be possible to restrict the distance at which any terrain is visible and detail in the intermediate distances should be reducible. Simulation of the out-of-the-window scene at night requires very low detail. The simulation of vision aids such as forward looking infrared (FLIR), and light intensification devices such as low light level TV is required but should be relatively simple because they inherently have limited field-of-view and limited resolution.

Cab or equipment fidelity requirements are primarily a function of the simulation purpose. In developing the handling qualities data base it is necessary to simulate only a generic helicopter so the cab must be realistic but not a model of some existing helicopter. On the other hand, when simulating a specific helicopter for system development and integration studies, pertinent features of the cab such as controls, displays, switches, etc., must be in the correct location and have the appropriate size and shape, i.e., high equipment fidelity is required. In both instances a capability is required to simulate either one- or two-man cabs, the two-man cab being either side by side or tandem. The primary pilot must have good environmental fidelity (i.e., good visual cues) but these cues can be compromised for the copilot.

The baseline cockpit configuration for ACAVS is a two pilot side-by-side crew station arrangement, with conventional stick and pedal helicopter controls and instrumentation and provisions for alternate controllers and specialized equipment including Heads-Up Displays (HUD), Helmet-Mounted Displays (HMD), fire control displays, etc. A good emulation of the rotorcraft cockpit vibration environment is required, to permit specialized studies such as the effect of vibration on HUD performance; but the capability to evaluate "worst-case" environmental factors is not required. It is very important that vibrations introduced into the cockpit not adversely affect the visual display.

A rudimentary simulation of the cockpit noise caused by engine, transmission, rotor and aerodynamic sources is also required. Because of its principal intended application in handling qualities assessment, RSIS/ACAVS vibration and sound simulator systems must be capable of presenting the pilot with the major vibratory and auditory flying qualities cues associated with aircraft flight conditions, maneuver severity, rotor RPM, engine conditions, etc.

For NOE terrain flight maneuvering studies, a cockpit visual display field of view of 120° horizontal by 60° vertical has been determined to be about minimum for successful obstacle avoidance, as determined by NASA studies described in Reference 4-1. This FOV requirement approximates 17 percent of the full 4π steradian field of view possible. Three to six arc minutes of detail resolution in the scene are desired, along with a minimum luminance of 30 foot-lamberts for daylight VFR flight. Helicopter night operations requiring luminance levels as low as 0.03 foot-lamberts are also anticipated in addition to a desired capability for high quality imaging, to assist in target acquisition through either the (out-the-window) visual scene or through use of forward looking infrared sensor displays, such as FLIRs, etc.

Tandem crew station seating arrangements are desired to permit simulation of most gunship rotorcraft cockpit configurations. Displays including HUDs and both panel- and helmet-mounted FLIRs (along with other sensor outputs) are typical of attack helicopter cockpit equipment which might be installed in the ACAVS cab for air combat studies. Provisions for installation of this specialized equipment are required.

Air combat between helicopters necessitates an unobstructed outside view from the cockpit, with minimal cockpit viewing restrictions desired, and an FOV representing 75 percent of full field (ff) (240°H x 180°V) required for this mode of flight. This 75 percent of full field amounts to the full viewing sphere, with the rear 120° and lower (bottom) 60° removed.

In addition to an extremely large FOV requirement for target acquisition and target simulation, air combat also dictates the need for the presentation of high resolution targeting information to the pilot; a minimum of one to three arc minutes resolution is required. In addition to these requirements, the air combat ACAVS visual display should have HUD compatibility, along with CGI data base compatibility with existing NASA Interchangeable Cab (ICAB) Singer-Link visual system.

Rotorcraft external load studies may require both helmet- and panel-mounted display representations of the load (and its motion). Good unobstructed out-the-window sideward and downward viewing of the load is required, with a minimum FOV of 30° x 30°. This limited FOV should be capable of being oriented in any position required, so as to include any load sway motion excursion anticipated during the simulation study.

Studies of terminal or shipboard operations for helicopters and VSTOL aircraft, require (as with air combat simulations) minimal cockpit viewing restrictions. About 120°H x 60°V FOV is desirable for VSTOL terminal operations, and this increases to 120°H x 90°V (23 percent of full field) for flight to and from nonaviation type naval vessels. VSTOL and shipboard simulation capability requirements are subordinate to those specified for system development, air combat, and external look studies.

4.3 Simulation Requirements

4.3.1 Visual System

Previous NASA studies have established minimum field of view requirements for NOE flight at 2.09 rad (120°) horizontal by 1.05 rad (60°) vertical, or approximately 17 percent of full field. Air combat dictates the upper boundary, requiring up to 75 percent of full field. In addition to these full field requirements a .52 by .52 rad (30° by 30°) sling-load capability is required. In each case the field of view must be located such as to optimize it relative to the task involved.

Resolution requirements are a compromise between what is required for adequate simulation and what can be achieved by state of the art and projected hardware. (Resolution as used here refers to optical resolution in line pairs.) The apparent limit of the current display devices is about 1.74 mrad (6 arc minutes). This limit is imposed by the relationship between field of view and resolution; increasing resolution decreases field of view capability.

Visual system requirements are summarized in Table 4-1.

Table 4-1: Visual System Requirements

Parameter and Measure	Minimum	Goal
Field of View		
Radian	2.09 x 1.05	4.19 x 3.14
Degree	120H x 60V	240H x 180V
Resolution		
Milliradian	1.75	.87
Arc Minutes	6	3
Luminance		
Candles/Meter^2	.10 - 103	171
Footlambert	.03 - 30	50
Constant Ratio	.03 - 30	—
Color	2-Color	Full Color
Slew Rate		
YAW		
Radian/Second	1.05	1.75
Degree/Second	60	100.00
Roll		
Radian/Second	1.05	1.40
Degree/Second	60	80
Pitch		
Radian/Second	1.05	1.40
Degree/Second	60	80
Video Update Rate		
Per Second	30	60
Sling Load		
Radian	.524 x .524	
Degree	30 x 30	

4.3.2 Vibration System

The primary simulation requirement for vibration is for flight cues as they relate to handling qualities. Vibration is also required to evaluate work load and crew ability to perform a task or mission.

Rotorcraft vibration levels are generally at the rotor rotational frequency (1/rev), at the number of rotor blades times the rotational frequency (b/rev), and at twice the rotorblades times the rotational frequency (2b/rev). Limits in the form of allowable acceleration g loads versus frequency in Hertz are specified by government specifications and individual aircraft contracts. Figure 4-1 shows a compilation of these level flight specifications. It includes MIL-H-8501A, the handling qualities specifications; AR-56, the Navy helicopter specification; and an "equation" specification being used by the Army for individual contracts. In general, a typical 4/rev at 20 Hz produces from .10 to .15g. Figure 4-2 illustrates a typical set of level flight vibration compliance data for the CH-47C modified with fiberglass blades. The applicable contract specification is shown, along with the flight vibration measurements treated in the form of top of 85% scatter data.

Maneuvers in rotorcraft are specified as .3g by MIL-H-8501A in acceleration or deceleration from any speed to any other speed within the design flight envelope. As shown in Figure 4-3 (for the example aircraft) the contractual specification is 0.4g for all maneuvers, including transition, partial power descents and acceleration/deceleration as shown.

In light of the above rotorcraft specifications and performance data examples, the upward maximum boundary levels of vibration g level/frequency spectra relationships required to be simulated by ACAVS are approximately .5g at 15 Hz. The primary axis of vibration should be vertical, with the lateral axis secondary. The longitudinal axis is considered of much less importance. Lower boundary levels are determined in practice by the translation required to obtain the .5g acceleration. If translation is limited to 12.7 mm (1/2 inch) the lower boundary is approximately 3 Hz.

Because it is not deemed practical to vibrate visual system projectors and dome screen devices, vibration is required for seat, controls, instrument panels and consoles only. These must be isolated as much as possible from the base structure to minimize the effect on other parts of the simulator. This vibration must be correlated between these vibrating elements such that the proper differential motion and phase relationships are maintained.

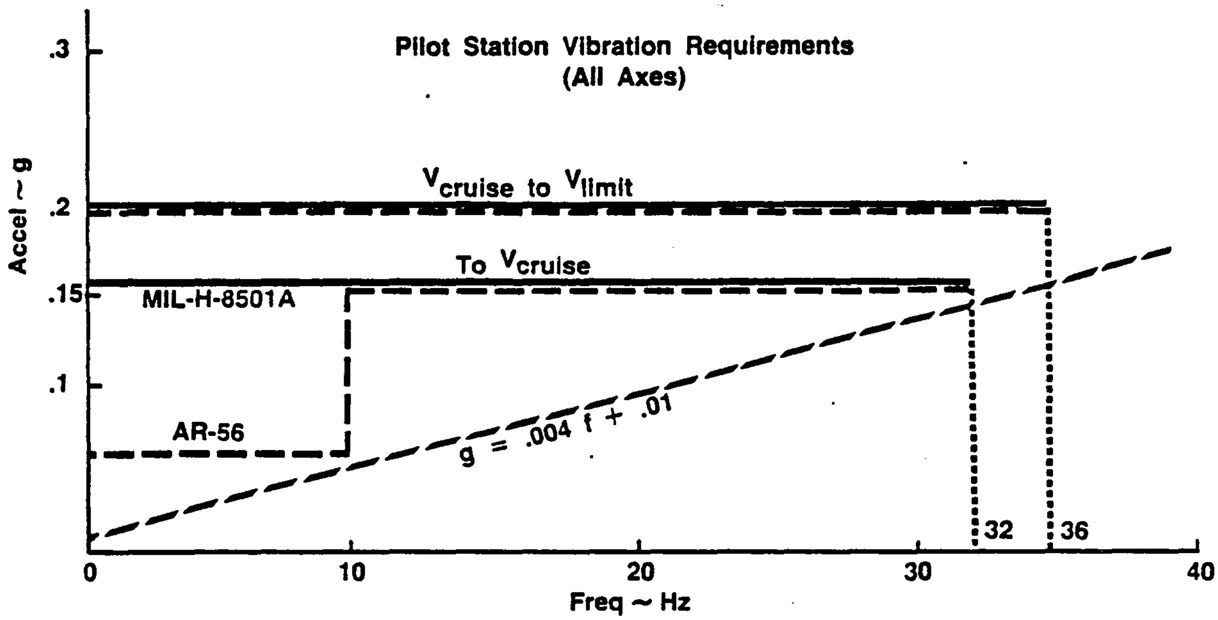


Figure 4-1: Compilation of Level Flight Vibration Specifications

X-156, 35611 LB TOGW, 8.4" Fwd CG, 34800 Lb Test GW, 100' H_D
3/Rev Vibration Level – 85% Levels

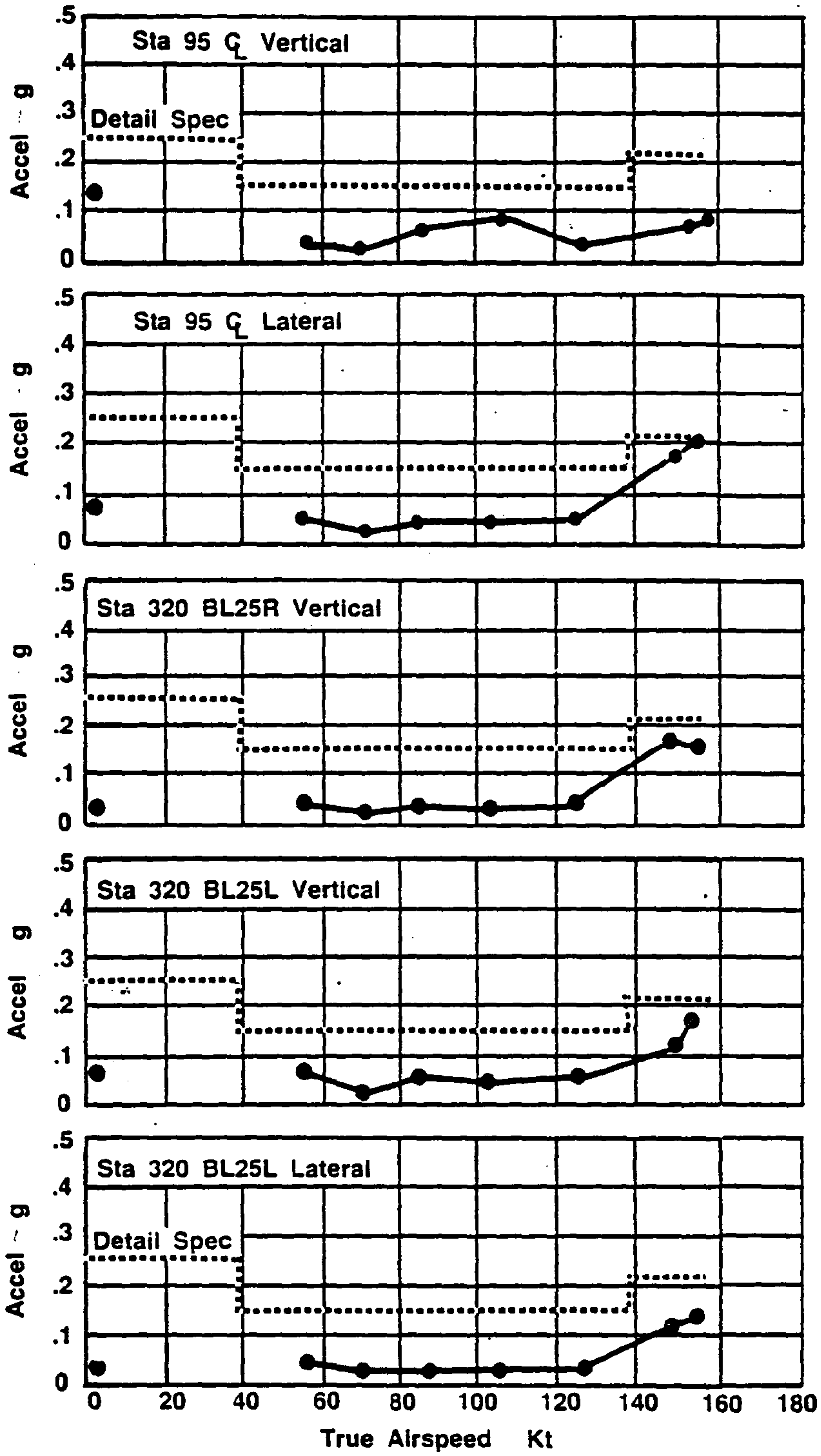


Figure 4-2: CH-47C FRB Specification Compliance – 3/REV Level Flight

X-156, 35611 Lb TOGW, 8.4" Fwd CG

Sta 95 ℄ Vertical. – 3/Rev Vibration Data – 100% Levels

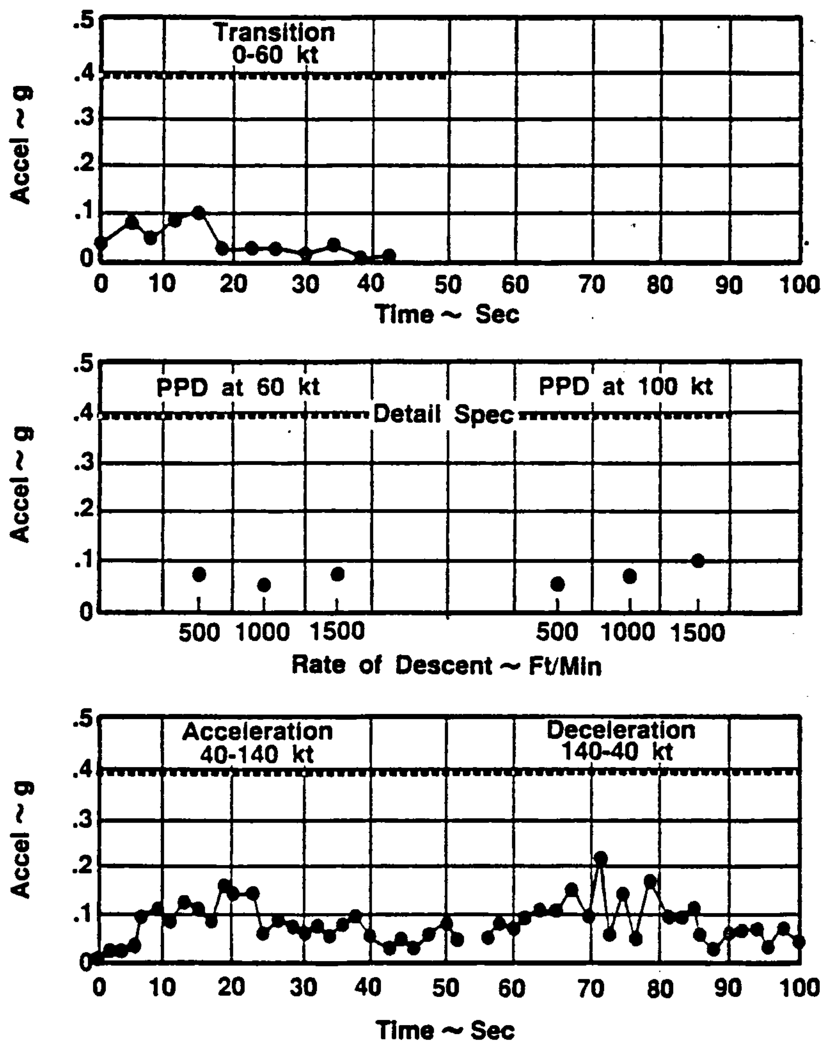


Figure 4-3: CH-47C FRB Specification Compliance – 3/REV Maneuvers

4.3.3 Sound Generator System

Cockpit noise is a primary cue for alerting the pilot to rotor speed variations and is particularly important during autorotation or in the event of engine failure. The noise spectrum of a particular aircraft is made up of rotor, transmission and engine contributions. As in the case of cockpit vibration, rotor noise frequencies occur primarily at multiples of the number of blades times rotor speed. Figure 4-4 is a typical example of transmission noise from the Boeing Model 347 helicopter. Discrete frequency noise appears at the transmission gear mesh frequencies. All of these discrete frequency noise spikes must vary together with rotor speed to properly duplicate the cockpit environment.

4.4 Management Structure

Table 4-2 lists the management structure and support groups at the NASA-Ames Research Center. A flow chart is used (Figure 4-5) to show the relationships between simulation support groups. The operators listed under support service contractors are nonengineer and nontechnician computer operators. Maintenance personnel are also nonengineers. In the visual systems area NASA-Ames maintenance personnel have considerable experience with TV type simulation systems but little optical experience. Shop personnel are involved primarily with the structural areas.

4.5 Facilities Constraints

ACAVS will be integrated into an existing NASA-Ames facility; the VMS complex (shown in Figure 4-6). The VMS supports a number of simulation efforts including the interchangeable cab program. To reduce downtime between simulation task involving the VMS, each simulator cab/visual system is configured and checked out before being placed on the VMS. These reconfiguration and checkout functions take place in an assembly line fashion with each cab/visual system being prepared for a specific simulation task in a scheduled sequence.

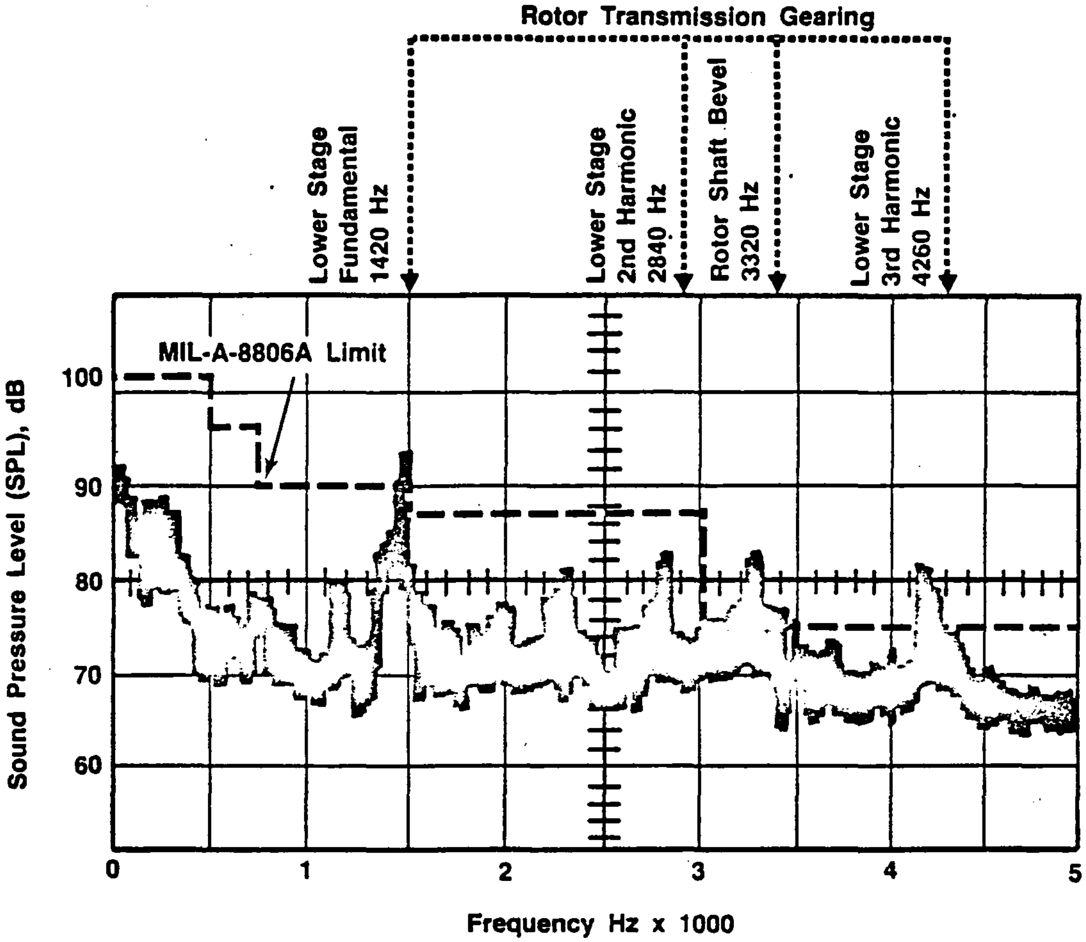
A number of constraints are placed on the design and construction of ACAVS as a result of this integration including:

- Area for cab/visual reconfiguration
- Checkout capabilities
- Transportability

The development station is an area designated for cab/visual system build-up and check out. Figure 4-7 shows the floor plan of the VMS and adjacent areas which will accomodate the development station. Checkout functions require a control room as part of the development station which will contain the necessary equipment to operate and check out the cab/visual systems. Provision must also be made for mounting the cab/visual system within the development station along with appropriate facilities to reconfigure the system for required simulation task.

Provisions must be made for transportation between the VMS and the development station, which involves passage through a number of doorways. This will require the cab/visual system to be constructed such that it can easily be assembled/disassembled and moved from area to area. Transportation devices such as overhead cranes and dollies will be required to facilitate such moves.

Model 347 Helicopter
Center Cockpit Noise Spectrum 154 Kt 220 rpm



Primary Noise Frequency of Forward Rotor Transmission 220 rpm

1.	Upper Stage Planetary Gears (Planet, Ring, Sun)	390 Hz
2.	Lower Stage Planetary Gears (Planet, Ring, Sun)	1420 Hz
3.	Rotor Shaft Bevel and Sync Shaft Bevel Gears	3320 Hz
4.	Oil Pump Pinion and Gear	3640 Hz

Figure 4-4: Typical Helicopter Transmission Noise Parameters

Table 4-2: Typical Simulation Program Personnel

NASA

- Outside Simulation Sciences Division (SSD)
  - Management
  - Research Engineer
- Within SSD
  - Management
  - Facility Operations Manager
  - Support Engineers
  - Designer/Drafter
  - Technicians/Operators

Support Service Contractors

- Computer Science Corp. (CSC)
  - Management
  - Applications Engineers
  - Operators
    - Digital
    - Hybrid
  - Maintenance
    - Digital
    - Analog
    - Systems
      - Instruments
      - Control Loaders
      - Visual Systems
- Northrop Sciences Inc. (NSI)
  - Management
  - Simulator Mechanics
  - Shop Personnel
    - Fabricators
    - Machinists
    - Welders

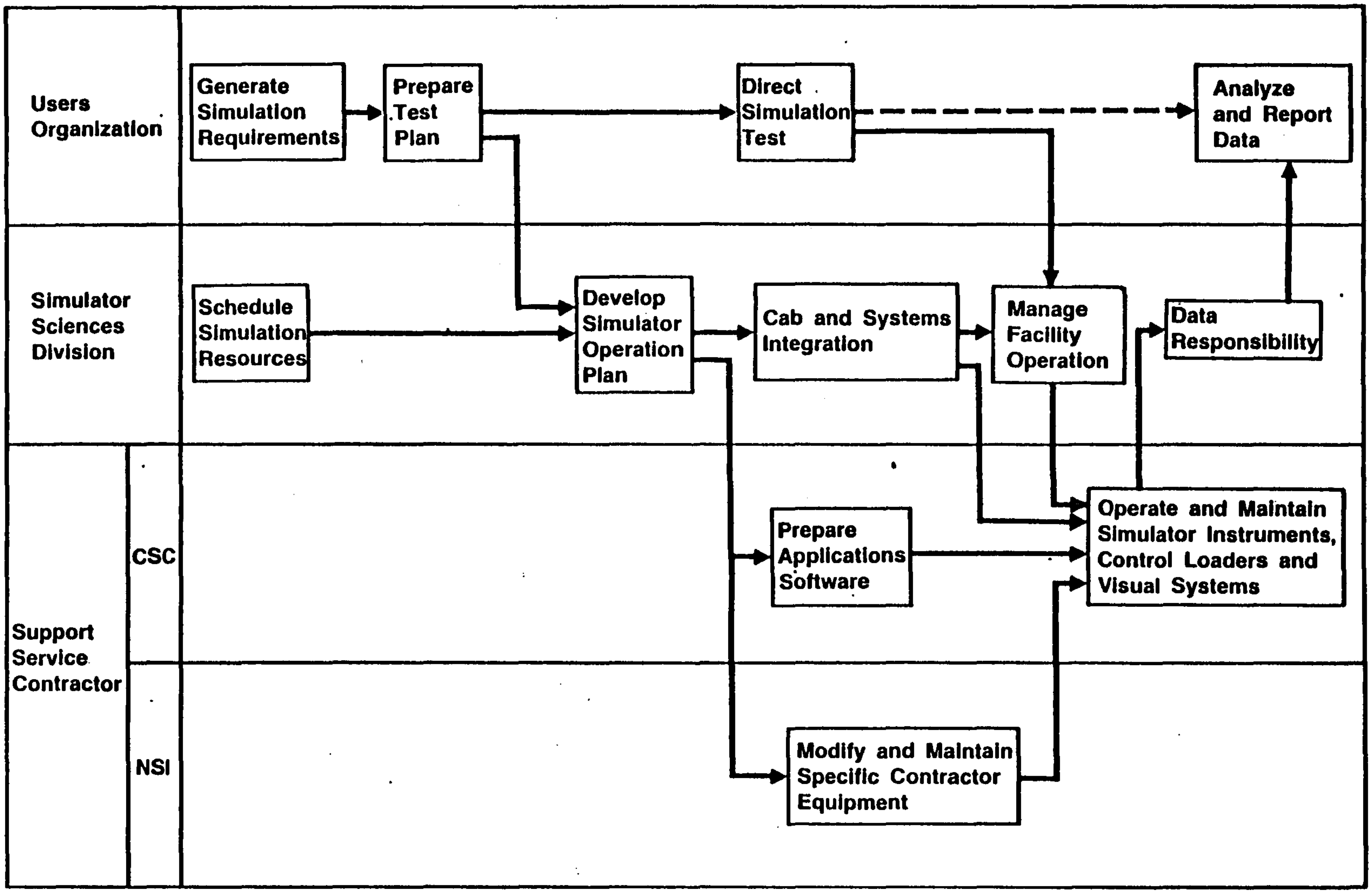


Figure 4-5: Simulation Program Operational Relationships

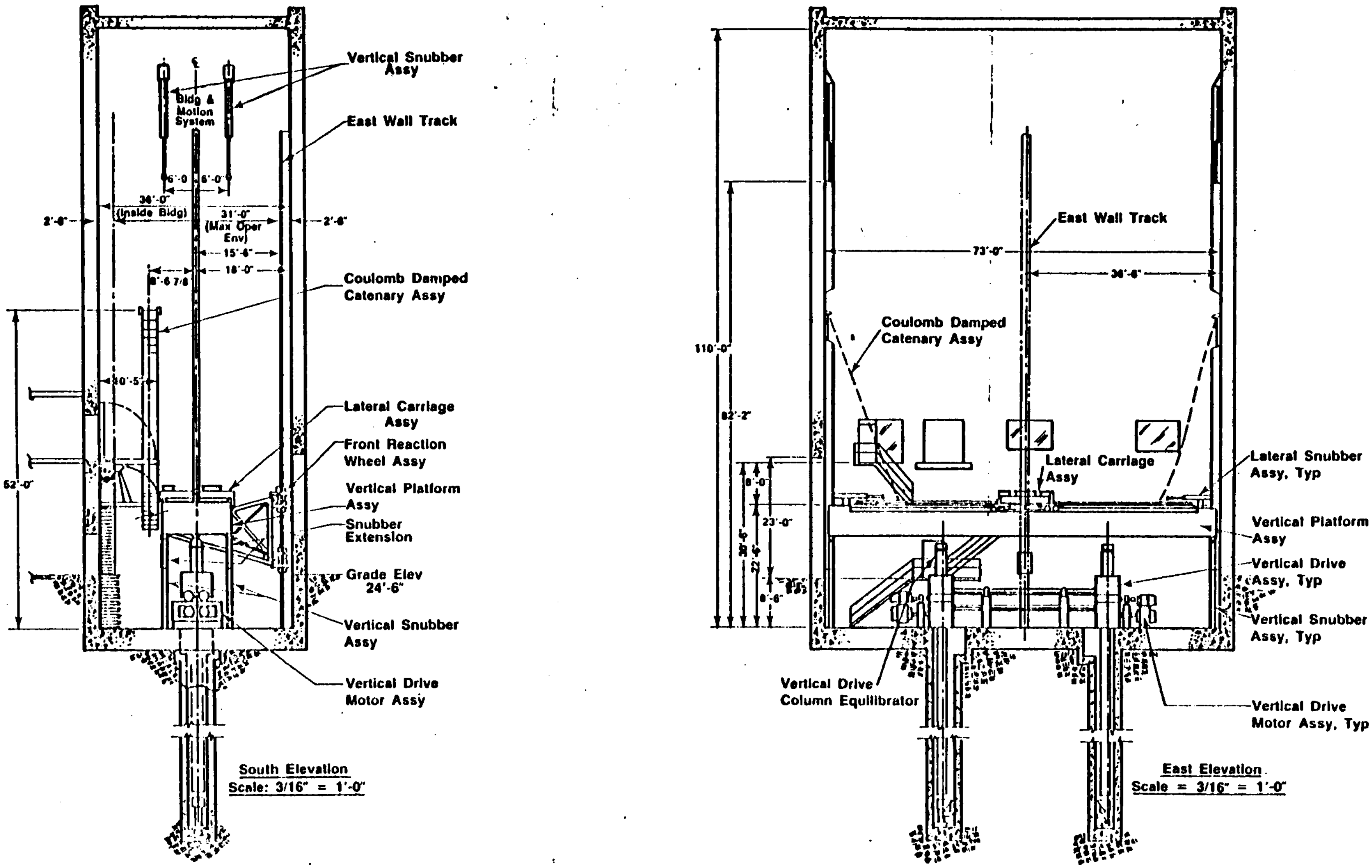


Figure 4-6: Building Layout Showing Operating Limits

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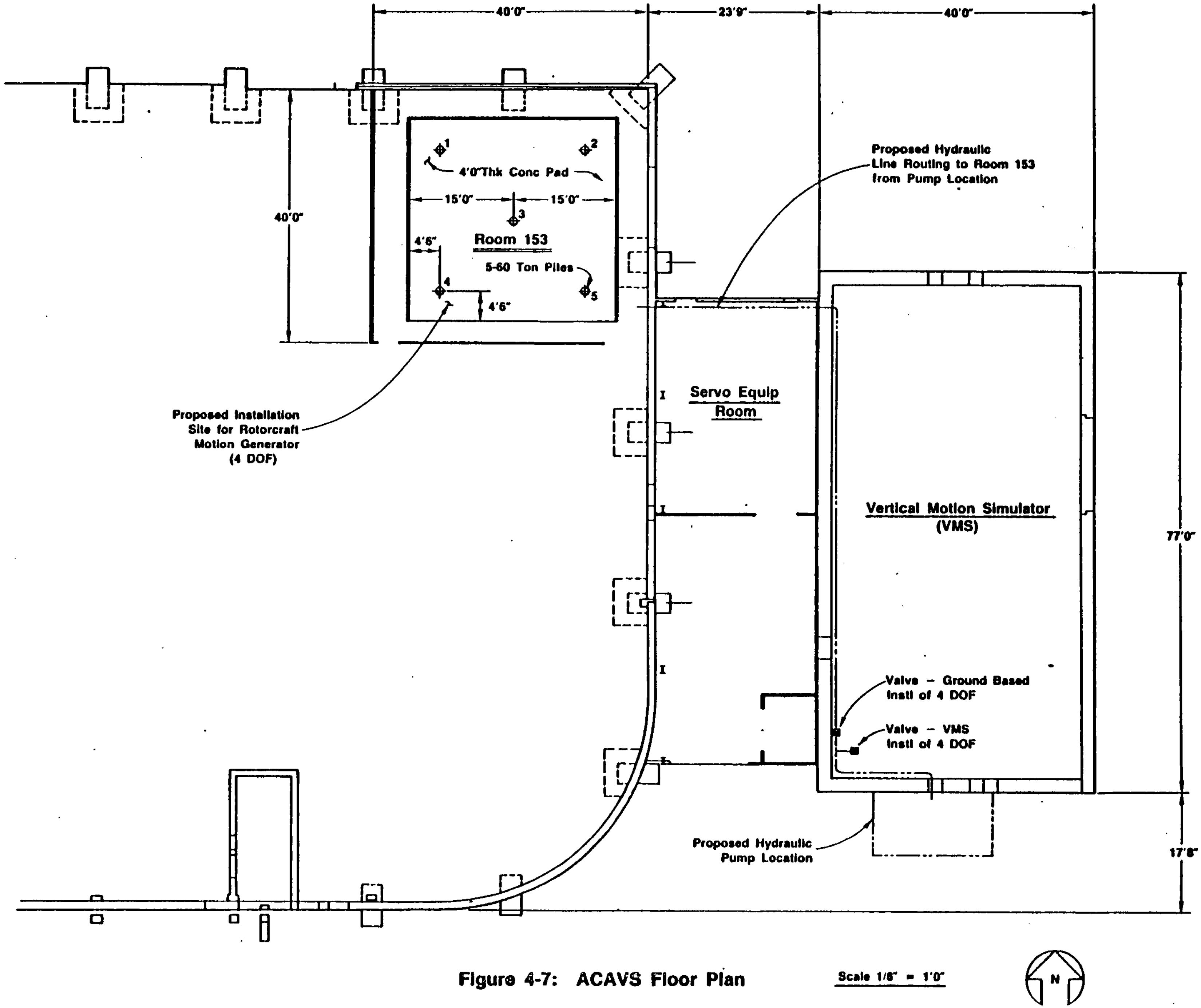

Figure 4-7: ACAVS Floor Plan

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5.0 TECHNOLOGY ASSESSMENT

As discussed in Section 4.0, RSIS requirements place very high performance requirements on some simulator subsystems. To ensure that the latest state-of-the-art advances and capabilities are considered for incorporation into this "handling qualities" research simulator it is necessary to review traditional systems concepts and to investigate new systems concepts. This is done to help ensure that the simulator subsystems recommended would provide the best possible performance at lowest cost and within the scheduled time frame.

Major subsystems considered are divided (for the purpose of this report) into three areas: (1) the visual system, (2) the rotorcraft cab, and (3) the development station. Of the three subsystems areas, visual system technology is considered to have the greatest technical advances. It is thus expected that advances in technology applicable to visual (display and image generation) or computational systems will be more dramatic than advances relating to either the rotorcraft simulator development station or the rotorcraft simulator cab.

Four main techniques are used to access current state-of-the-art. These are literature searches, vendor contacts, on/off-site facility observations and utilization of technology developed and/or acquired from the B-52/KC-135 Weapon System Trainer (WST) Pilot Production Program. Some technologies presented in this section may not be available or mature enough in the ACAVS time frame due to lack of government funding, low priority, cost or need of a technical breakthrough. These technologies are, however, reported here for completeness. Screening of the technologies to assess their application to ACAVS is presented in Concept Synthesis and Evaluation, Sections 6.0 and 7.0 of this document.

5.1 Visual Displays

Regardless how the picture is generated and what level of effort and technologies went into image generation, it is of no avail unless the visual display equipment can reproduce the out-the-window, real-world scene with sufficient fidelity to permit the crew member to successfully perform his tasks. Prime parameters to be considered in the display subsystem design are brightness, resolution, contrast, field-of-view, color capability and distortion. Other parameters to be considered in the technology assessment of visual displays include physical size, weight, reliability, supportability, maintainability, ease of operation, power requirements, computer and mechanical interfaces, costs and schedules. This report will emphasize technical assessment of the primary parameters and will also comment on the lesser characteristics where deemed applicable for additional information and clarity. Display element technology described here will be assessed first on the subsystem components level and then as part of a display subsystem. Existing technical capabilities on a system level will be described in Paragraph 5.1.2 of this report.

5.1.1 Component Technology Assessment

Display assessments are divided into two main categories: real image displays and virtual displays.

Real image displays can be subdivided into those that use a direct view of an image such as provided by a CRT and those with projector-screen configurations. To provide suitable FOVs, direct view displays must be placed near the viewer's eyepoint because of CRT size. Thus, large parallax error can occur with any significant head motion by the viewer. For the same FOV on a flat screen using a projected image provides less parallax than the direct view because the larger image permits a greater viewing distance. Like the direct view displays, they also have a limited field of view. Several of these may be mosaicked, of course, to provide a wider field of view. Spherical screens have been used successfully for very wide FOV displays, but place high demands on the projector to fill them with high-resolution, high-brightness imagery. Several concepts exist to meet these demands but few have been reduced to hardware. A scanning laser image projector is one system that has been demonstrated.

In virtual image displays, the input image is collimated so that it appears to the observer as though it were placed at infinity. This collimation is achieved by use of lenses, spherical mirrors or their holographic equivalents. Advantages of this type of display are reduced parallax with head motion and better eye accommodation. Good optical efficiency available in some virtual image systems permits excellent high-brightness displays within their field of view.

In general, CRT systems will outperform most projectors in the area of resolution, contrast, brightness, color, distortion, cost and reliability. They are not generally utilized in ultrawide displays because of the physical problems of mosaicking the CRT/optics close enough together in either horizontal or vertical FOV without experiencing substantial image loss or image matching problems (e.g. images must be well registered in position and color). Virtual image systems suffer from image distortion at large viewing angles. The viewing exit pupil is only large enough for one observer unless the optical elements are quite large.

To better communicate simulator visual requirements, the following summary of human eye data is presented.

The range of brightness adaptation of the eye is approximately 3.426×10^{4} to 3.425×10^{6} cd/m^2 (10^{4} to 10^{5} foot-lambert). Minimum for close work (reading) requires about 34.3 cd/m^2 (10 foot-lambert).

References 5-1 and 5-2, respectively, state that:

1. 10 foot-lambert of light for a visual display is considered excellent.

2. The U.S.A. Standard (PH 22.124-1961) for indoor theater screen luminance is 10-20 foot-lambert.

   A practical guide to screen luminance for viewing motion pictures may be defined as follows:

	Foot-lambert
Minimum	5
Satisfactory	10
Excellent	15
Maximum	20

For objects with angles between .175 mrad and .105 rad (0.6 and 360 minutes), the eye's contrast threshold for detection of objects brighter than their backgrounds varies from 3×10^{3} to 0.01 (see Reference 5-3). A display contrast of 0.03 would appear to be nearly undiscernible to most individuals.

The extent of a scene as seen by the eye and limited by the window (aperture), defines the angular field-of-view. The eye's acuity drops to 10 percent of that of the center of fovea at approximately ≈ .35 rad (≈ 20°) from center. A plot of the eye's visual acuity versus degrees from the fovea is given in Figure 5-1 (Reference 5-4).

Color vision is characterized by the ability to distinguish among stimuli by their hue, saturation, and brightness or lightness.

Prime visual parameters are defined in Table 5-1 to aid in comparison of corresponding characteristics of various systems. Human eye capabilities and the corresponding ACAVS requirements are included for reference.

The following paragraphs describe the basic capabilities and current technology status of existing visual displays (Reference 5-5).

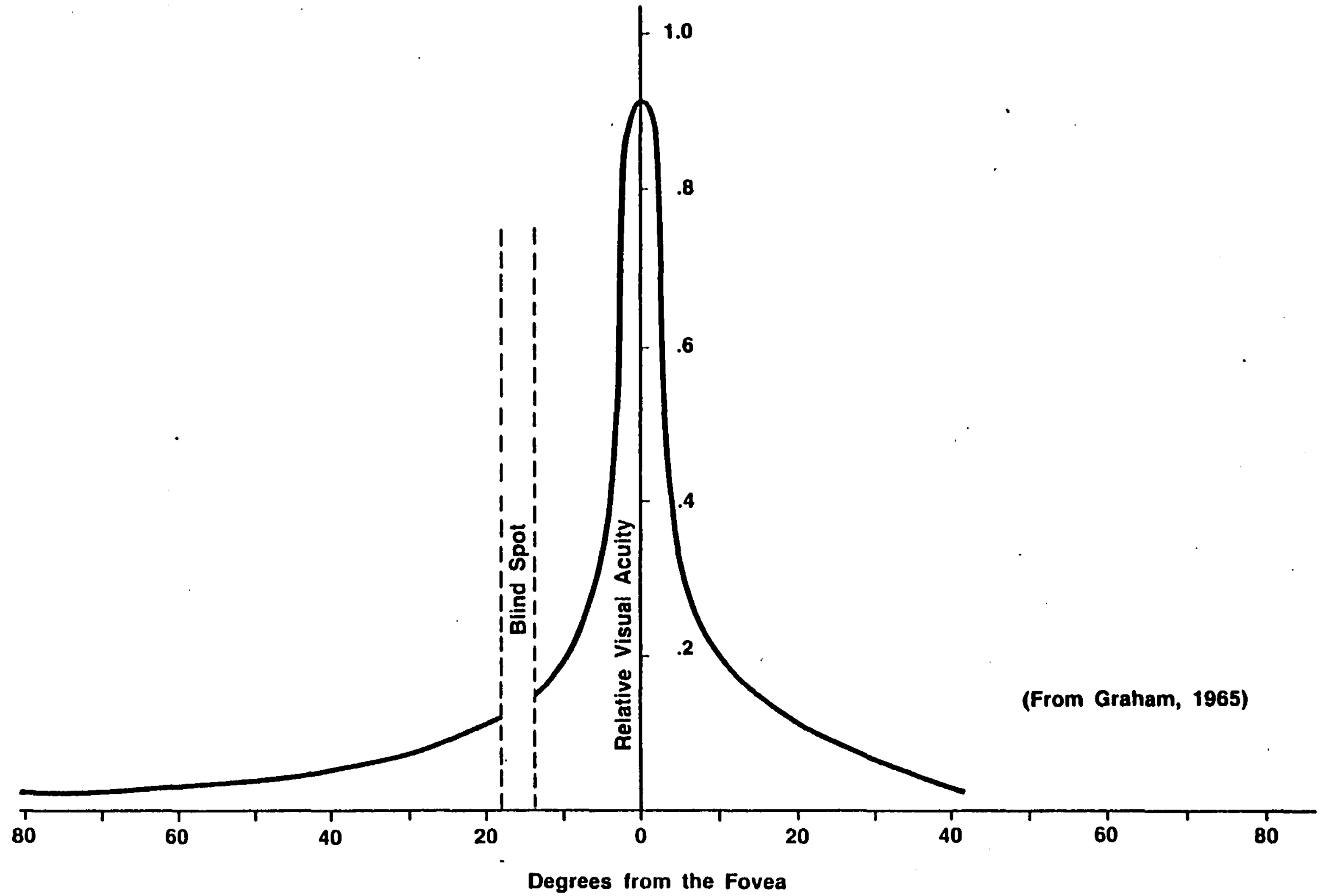


Figure 5-1: Relative Visual Acuity

Table 5-1: Capability Assessment Summary

Parameter	ACAVS Requirement	Existing Systems	Human Eyes
Brightness	.03 – 30 F.L.	10 F.L.	$10^{-5} - 10^{4}$ F.L.
Resolution	3 – 6 Arc Min	5 – 20 Arc Min	1 Arc Min
Contrast	.03 – 30	to 50	.1 – 3000
Field of View	60°H X 120°V to 180°V X 240°H	150°H X 50°V Instan 300°H X 115°V Total	190°H X 180°V*

*Rigid Torso LOS FOV Per MIL-STD-1472B

5.1.1.1 CRT Displays

The conventional color CRT is the most common color display in use today. There are two basic types, one the three-gun shadow mask tube, the other the beam penetration tube.

The conventional shadow mask tube employs triads of red, blue, and green dots that are excited by three separate electron guns. A shadow mask is incorporated into the tube to permit only one gun of the three to excite a single color of the triad. These tubes are presently available in sizes up to .66m (26 inches), although some larger experimental versions have been produced. They are capable of faceplate brightnesses from 171.3 cd/m^2 (50 foot-lamberts) to as high as 342.6 cd/m^2 (100 foot-lamberts). The limiting resolution of these tubes at brightness levels below phosphor saturation and blooming effects depends upon the number of triads of dots or bars in a linear dimension of the tube. These triads exhibit a quantizing effect on the displayed information.

High resolution capability is available at the expense of lower illumination levels. Resolution range available for high line rate tubes is from 800 to 900 TV lines per picture width. High-brightness tubes lower this resolution to approximately 650 TV lines. These tubes have wide color capability. CIE color coordinates (see Figure 5-2) and wavelength of peak radiant energy for red (R), green (G), and blue (B) colors are:

X	Y	Meter $\times$ 10^{-7}	Angstrom
0.670	0.330	6.19	6190
0.303	0.587	5.30	5300
0.146	0.052	4.50	4500

Beam penetration CRTs work on an entirely different principle from that of shadow mask CRTs. In the beam penetration CRT, different transparent color phosphors are arranged in overlaying layers on the inner surface of the tube. An electron beam excites a particular color by varying its penetration depth into the phosphor layer sandwich. This is done by varying the high voltage across the tube, typically between 7 and 15 kV. Since the phosphor is a continuous layer, resolutions comparable to high-quality monochrome systems are possible. However, at present it is possible only to layer two-color phosphors on top another, typically red and green although red and white phosphor combinations are available. This makes it impossible to generate full color pictures in this system. Furthermore, heat dissipation within the phosphor layers is less efficient than with a single layer, as in a shadow mask tube. Thus beam penetration systems are capable only of about 51.4 cd/m^2 (15 foot-lamberts) of brightness at the tube screen. When these tubes are integrated into a visual system, light levels generally run much lower than this with maximum visual intensities in the 6.9 to 17.1 cd/m^2 (2-5 foot-lambert) range. Typical phosphors for these displays are JEDEC-P50 and -P51.

Other direct view CRT systems include the CRTs with beam splitters and/or flat surface mirrors placed between the observer and the CRT to help solve some physical placement and orientation problems and to optically mix video data provided to an observer.

5.1.1.2 Projectors

There are three principal electronic devices used in current television projectors. These are: (1) high-brightness projection CRTs, (2) light valves, and (3) the recently developed laser scanner systems. Images from these display devices are projected onto a screen which is then viewed by the observer. These screens may be flat, curved or rear projection type. Most CRT and light valve projectors have line rates up to 1 000 TV lines. At least one system has 1 205 line rate capability. Laser systems can go as high as 5 280 lines. Image resolution is closely tied to image brightness and displayed field of view. Illumination output levels range from 250 lumens to about 2 500 lumens per projector (excluding laser projectors). This illumination is spread over the desired FOV. Some units are available with raster correction for use on window mosaic systems. All CRT and light valve projectors considered have full color capability either existing or to be available in the 1984 time period. Systems

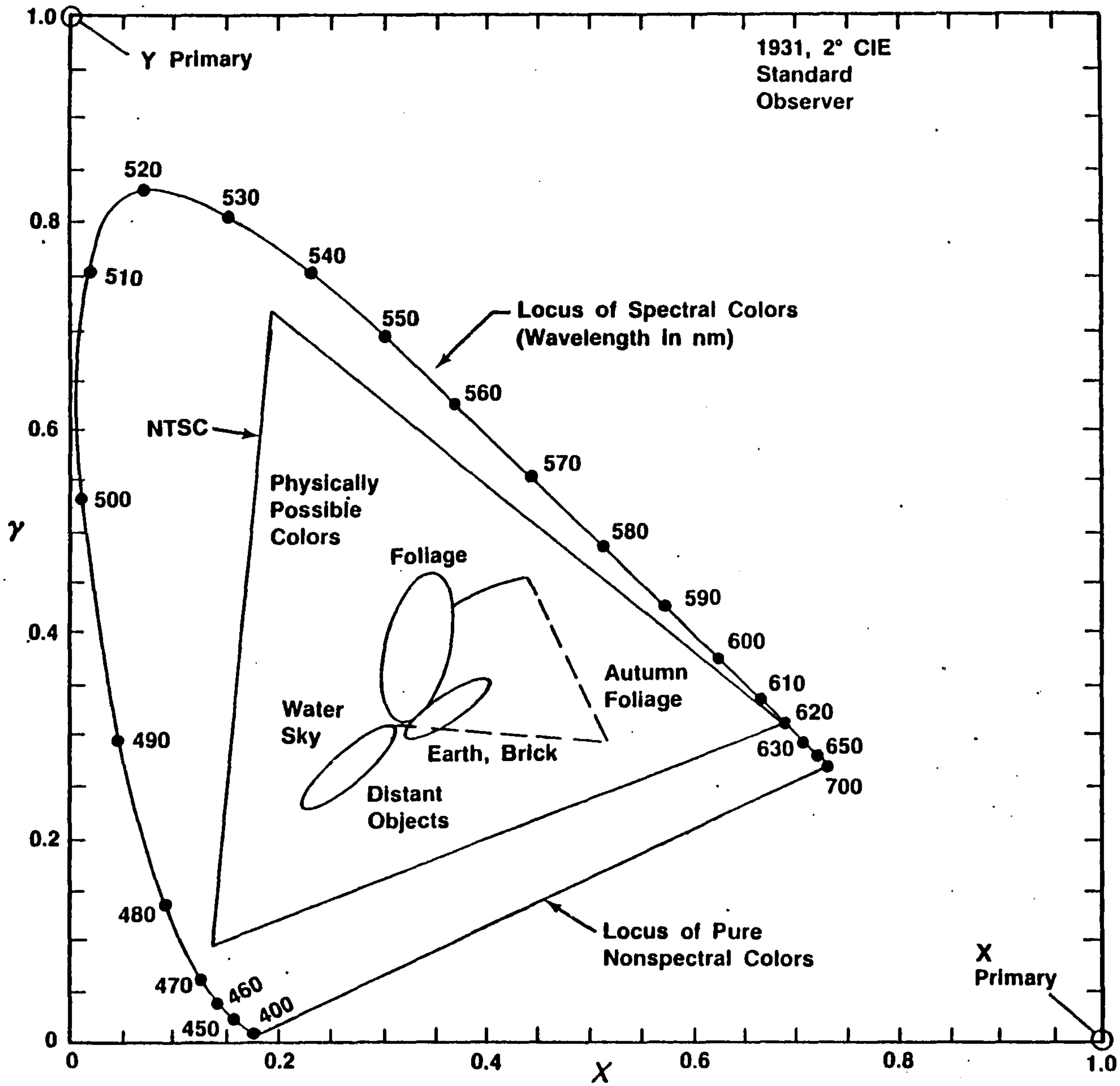


Figure 5-2: Chromaticity Diagram – NTSC and Natural Objects

vary in reliability but the average MTBF for some units is specified at greater than 5 000 hours with proper routine maintenance. The projectors surveyed varied widely in price and have greater than a 200:1 cost ratio. CRT projectors are on the low end and laser projectors are on the higher end of the cost spectrum with light valves distributed in the lower middle range.

5.1.1.2.1 CRT Projectors

This type of projector employs high-resolution, high-brightness CRTs utilizing a monochrome phosphor. Projectors may contain from one to three CRTs depending upon color content required. Generally they operate at relatively high power and voltages, and hence often require special cooling and radiation shielding. Color spectrum for this type of projector is similar to the direct view CRT phosphors (Paragraph 5.1.1.1). Two types of CRT projects were surveyed. One utilizes three cathode ray tubes, each having a high output color phosphor projecting superimposed images, and the other unit uses a field sequential system that utilizes a single high-brightness CRT and a rotating color wheel. An example of the first system is a three-CRT projector being built by Electronic Systems Products Inc. (ESP) that is expected to be available in the 1982-84 time period. This unit will be available with 525 to 1 205 TV line rates at a brightness of 550 peak lumens (this is at 1 000 TV line rates and with a resolution of 1 000 TV lines horizontal at 5 percent Modulation Transfer Function (MTF). Contrast ratios greater than 28:1 are anticipated. This unit also will be available with raster distortion correction and provision for either 3:4 or 1:1 vertical to horizontal raster ratios. Physical size is expected to be .254 by .838 by .762m (10" x 33" x 30").

Figure 5-3 illustrates the full color concept and physical arrangement of the RGB CRTs and lens.

The field sequential TV projector system has application in closed circuit field-sequential TV systems. One system that has been designed employs a single high-power, high-resolution projection CRT and a color wheel to provide a compact high-resolution and low-distortion system with moderate light output (10.3 cd/m^2 (3 fL) at the displayed scene). The field rate is sequential at 135 Hz (45 fields/sec $\times$ 3 colors). This projector is being developed by Grumman but is not anticipated to be available during the ACAVS time period.

5.1.1.2.2 Light Valve Projectors (LVP)

In light valve devices, light production and modulation are performed in separate components as opposed to CRT projection systems where the modulation is made at the light production stage. This allows each component to be designed for maximum efficiency. The light source is generally a high-powered xenon lamp with light output up to 80 000 lumens. Light modulation components, since they are removed from the high power requirements of producing illumination, may now be optimized for parameters that affect image quality, i.e., resolution, distortion, contrast and color. Also, lower voltage and power requirements minimize any X-ray emission problems. Various principles for image generation have been used in light valves and include: (a) selective diffraction, (b) liquid crystals, and (c) Pockel's electro-optical effect in solid crystals. All these principles, except (a), involve the utilization of electric fields/charges to produce an image in the light valve material (generally through the polarization of the material). When polarized light impinges upon the surface, the reflected source takes on the modulation characteristics of the input data. Color is produced by passing the reflected light through a dichroic filter. Multicolor systems divide the light from one lamp and utilize different reflective paths from up to three different light valves (RGB) before it is recombined via mirrors and lenses to form the colored image.

- Selective diffraction light valves are similar in principle but full color capability is achieved in one light valve by obtaining colors via controlled diffraction of the light. Light valve projectors all have fairly good reliability (4 000 to 5 000 hrs) but have a xenon tube life from 500 to 1 000 hours depending upon what brightness quality one is willing to accept. Orientation of the xenon lamp cathode-anode axis with respect to the horizontal is critical for extended lamp life, thus this must be taken into consideration when projector mounting is being designed. Long-term operational orientations of the lamp cathode-anode axis must not be greater than 20 percent below the horizon.

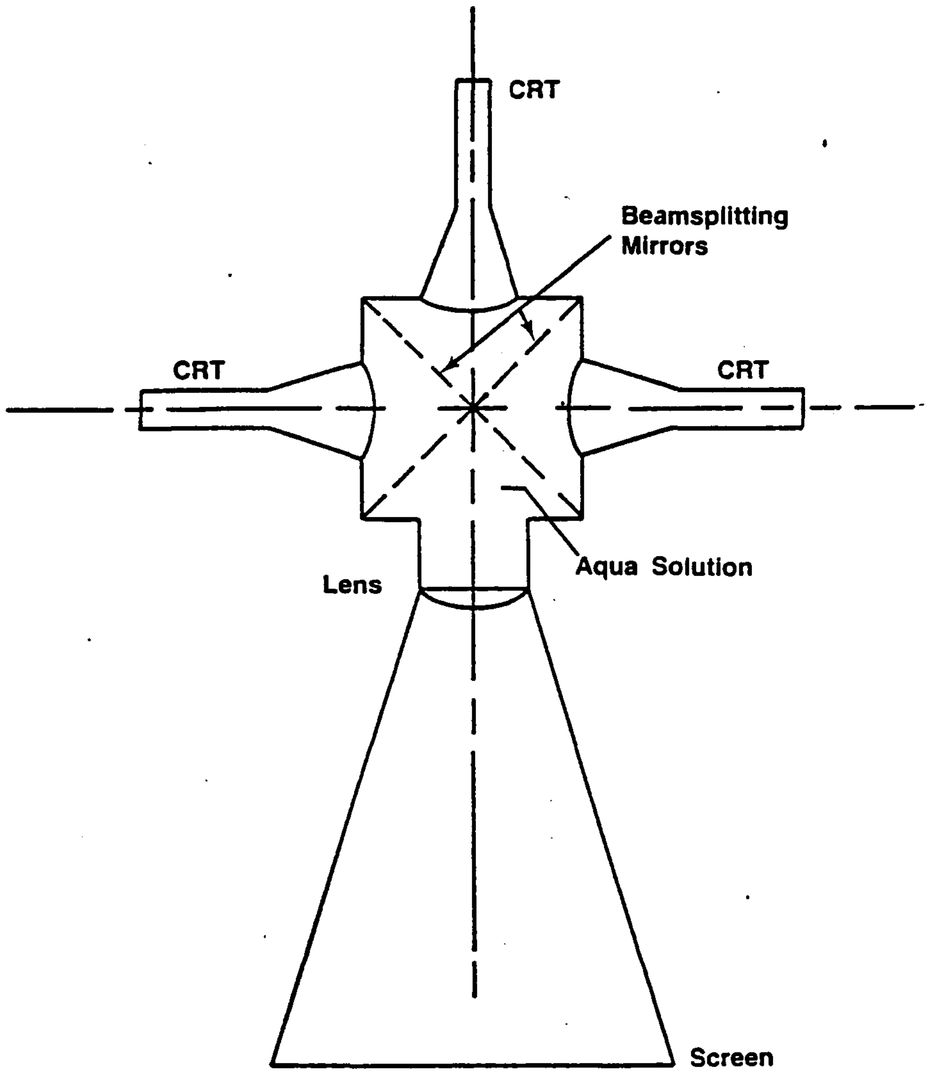


Figure 5-3: ESP Cyclops CRT Projector Diagram

Selective diffraction projector technology is rapidly becoming mature and is currently available "off the shelf" for three color (RGB) in TV systems with line rates up to 1 029 per frame. These projectors have the advantage of relative small size and weight when compared to other available LV projectors. One significant advantage of these projectors is that the problem of color convergence is eliminated via the way the colors are reproduced, i.e., color registration is excellent. This type of projector has been developed by General Electric and has been in use for several years in various flight simulators. Figure 5-4 shows the light valve's physical layout. Luminous flux output of the projector ranges up to 650 lumens when modulated by a TV image and resolutions available range up to 800 TV lines per picture width at 5 percent MTF. It is not possible to maintain the same resolution for all three colors. In fact, the 800 TV line resolution refers to the green field, the red and blue fields being of somewhat

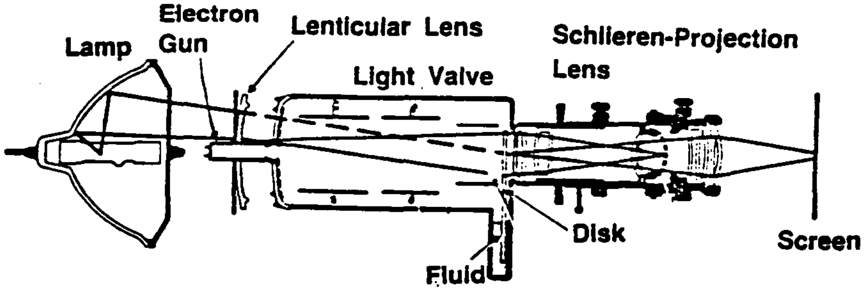


Figure 5-4: General Electric Light Valve Diagram

poorer resolution. Field of view is dictated by the final lens assembly. For ACAVS displays there will probably not be a standard lenses available. A disadvantage of this type of projector, other than maximum limits of projector orientation statically and dynamically (less than .524 rad (±30°) recommended), is the light spillover at the extreme edges of the projected image caused by the diffraction process (i.e., color fringing). If this type of LV projector is mosaiced for a wider field of view display, special provisions must be made in the optical output path to eliminate this effect. Another disadvantage of this type of light valve is its inability to tolerate any type of raster correction (very important when matching edges of images in multiple projector concepts). Color output of this projector is not quite as saturated as the current color direct view CRT and is shown in Figure 5-5.

Spectrum data is as follows:

	Wavelength (nm)	% Saturation
Red (R)	606	90
Green (G)	530	70
Blue (B)	450	90

Future growth areas will be mainly in system refinements and brightness.

- Liquid crystal technology is still in the development stage in many areas. Black and white versions have been developed for displaying images in real time but image lag is currently a problem. The Hughes Liquid Crystal Light Valve (LCLV) is the first of a new generation of light valves that operate by using liquid crystal phenomena, (see Figure 5-6 for physical component diagram). The modulation portion of this type of light valve uses the twisted-nematic effect of the liquid crystal to vary the degree of polarization of incident light which impinges upon the surface of the liquid crystal.

The basic liquid crystal light valve assembly consists of a small diameter CRT (the input to the LCLV in electrical/light form), a fiber optics faceplate which efficiently couples the light energy to the LCLV via a dielectric mirror, and the LCLV which changes polarization of incident light reflected from its output surface as a function of the input light illumination levels received from the input side. Thus when light from the xenon lamp source (that has been collimated and polarized) is transmitted through the liquid crystal material (on the output side) to the dielectric mirror and is reflected back through the output surface, it has changed polarization from zero to 1.57 rad (0° to 90°) depending upon the input illumination from the CRT. This varying degree of polarized light upon passing again through a polarizer will either be fully transmitted or stopped depending upon the TV electrical signal intensity applied to the CRT. This polarized light is then processed optically and is available for projection onto a screen surface.

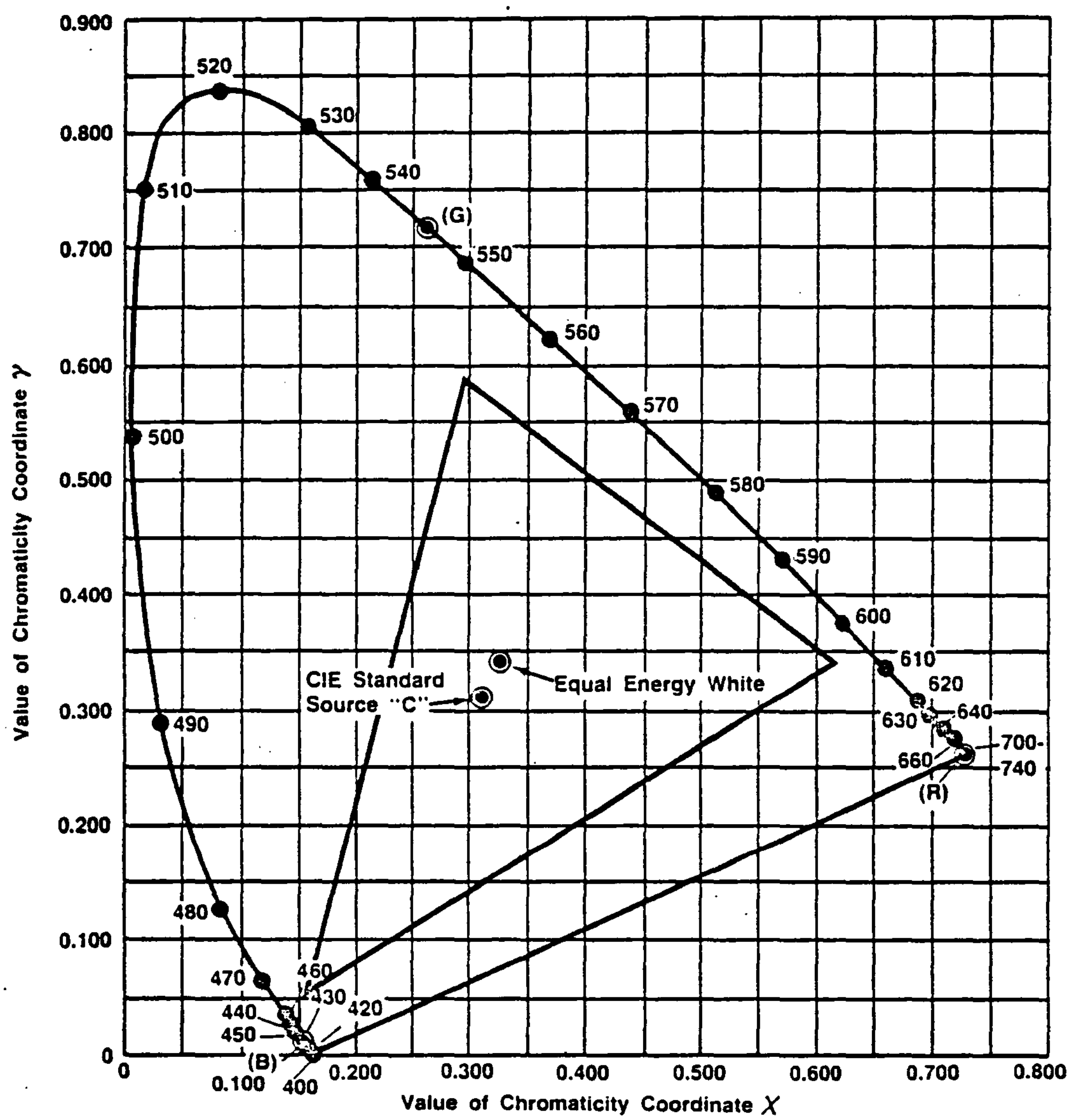


Figure 5-5: Chromaticity Diagram – System Capability (GE LV)

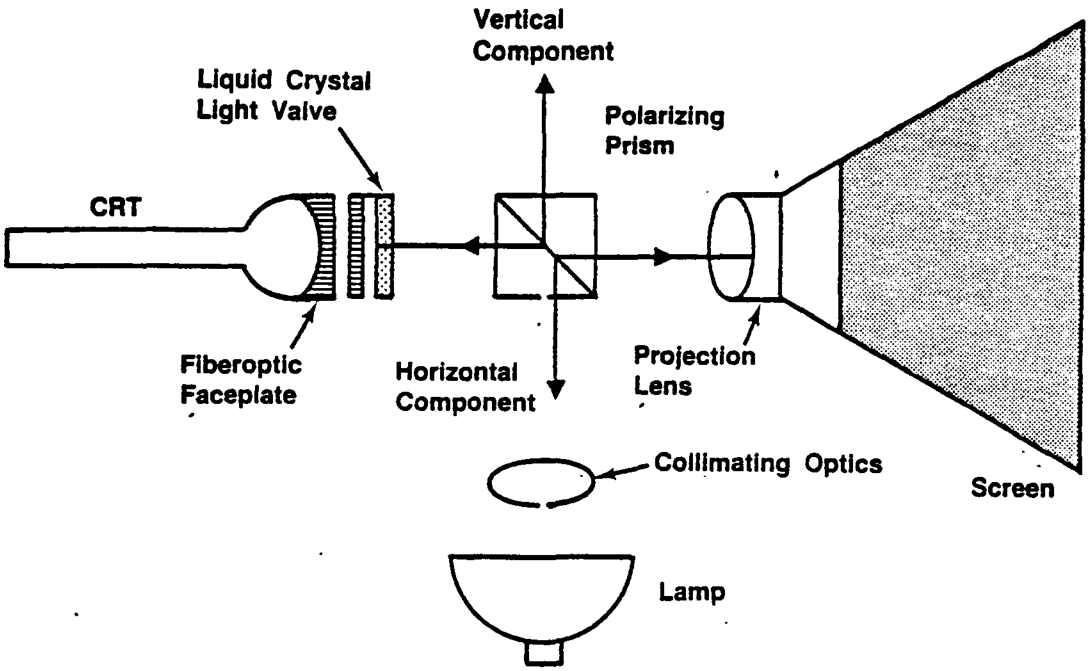


Figure 5-6: Hughes Liquid Crystal Diagram

The LCLV color projector concept uses this same principle but the projector assembly consists of three LCLV assemblies (RGB) with associated dichroic mirrors to separate the polarized beam into its three color images.

Projected capabilities of a full color LCLV look very impressive. The projector which is basically a small optical bench containing the three LCLV assemblies, lamp, optics, electronics and cooling fans has high illumination levels up to 500 lumens output from the lens. Resolution is greater than 2 700 TV lines when the device is used in the high resolution target mode. The basic full screen resolution is around 1 350 TV lines. Contrast ratios up to 30:1 are expected. Since dichroic mirrors are used to obtain the color coordinates of the projector, the spectrum may be chosen for a two or three color system where desired. Typical dichroic spectrums available are shown in Figure 5-7. Three color systems will use the following color characteristics:

	Wavelength (nm)
R	620
G	550
B	480

The projector has distortion correction and programmable capability which allows the projected image to be distorted to correct for image projection problems such as keystone, barrel and linearity distortions. Raster programmability permits the user to adjust the aspect ratio to the type of raster format desired, i.e., 1 × 1, 3 × 4 or pentagon-shaped for mosaicked window displays. Programmable raster controls also permit target inset stroke writing possibilities. Reliability of this projector, since it has no moving parts, is expected to be very good with the xenon lamp being the weakest part requiring changing at 1 000 hour intervals if brightness levels are to be maintained. Estimated MTBF is 5 000 hours for the projector unit. Real-time image projection is one area that is of concern. Existing

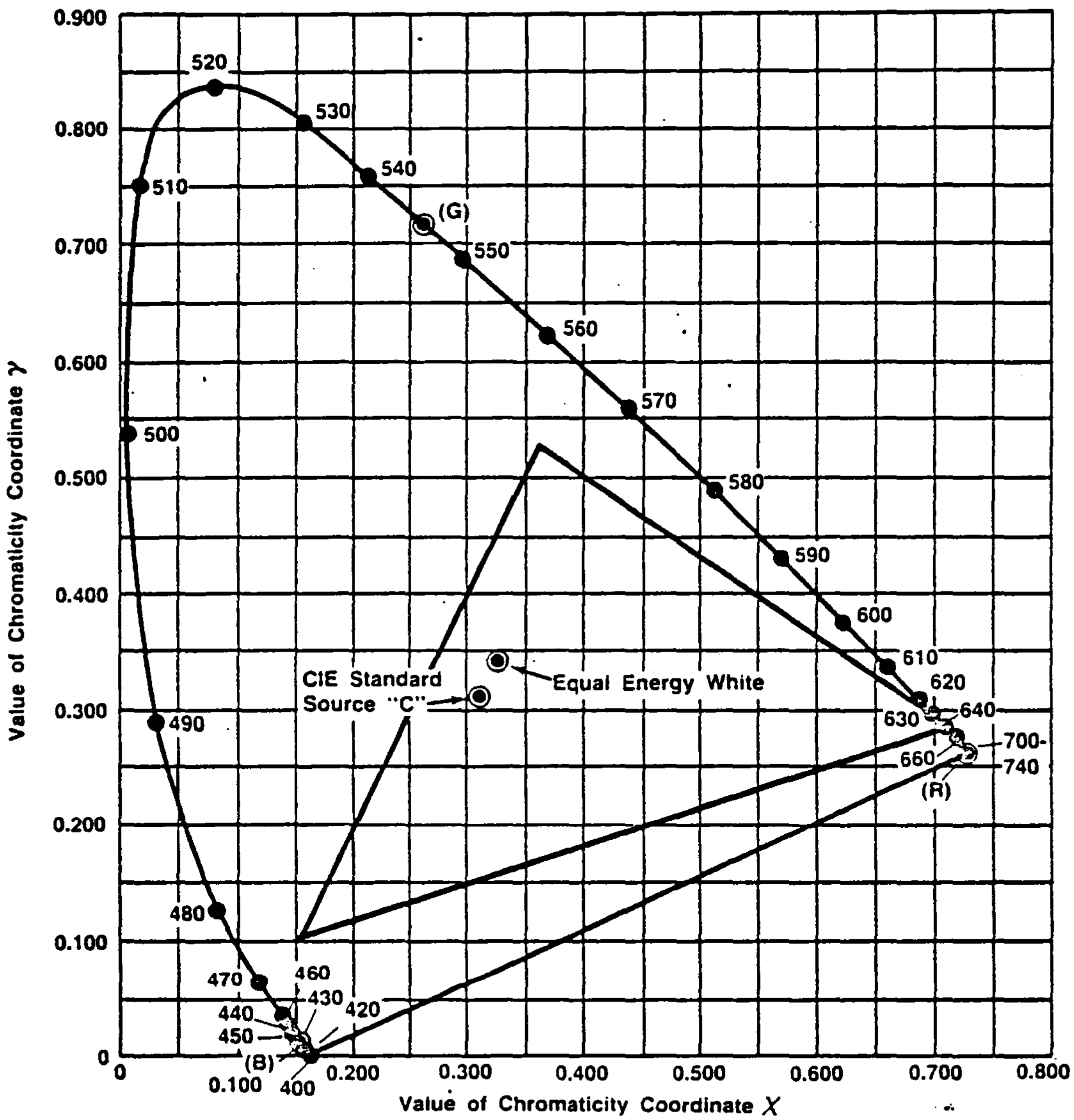


Figure 5-7: Chromaticity Diagram – System Capability (Schott 1mm Thick Filters)

technology uses a cadmium sulfide (CdS) photosensor which is not responsive enough to input light changes to prevent image lag. A new silicon (Si) photosensor is currently under development which will eliminate this image lag/smear problem but it is not expected to be available in the ACAVS time period.

Image registration with this type of color light valve is not as maintenance free as the previously mentioned diffraction approach. This concept requires three precision CRT/light valve assemblies with their associated electronics to be adjusted to provide image registration, color balance and brightness tracking. This must be maintained throughout the dynamic brightness and contrast range of the projected image if input images are to be reproduced with good fidelity. Orientation of the projector can be zero to 1.05 rad (0° to 60°) below the horizontal as long as the projector xenon lamp cathode/anode orientation is less than .35 rad (20°) below the horizon. Projector size for the full color unit is anticipated to be 1.12 × 1.12 × .76m (44" × 44" × 30" deep) and a weight of 118 kg (260 pounds). A prototype full color projector using a CdS (three inch) light valve is expected to be demonstrated in July 1980. The low lag 7.62 cm (three inch) silicon version is expected to be prototyped in late 1981.

- Light valve projector technology utilizing Pockel's electro-optical effect in a solid crystal has been under development since 1975. This type of projector is based upon the variation of birefringence in a crystal when an electrical field is applied through the crystal in the same direction as the source light propagation. The TITUS light valve projector built by Sodern (in France) utilizes this principle. The basic light valve assembly consists of a small CRT coupled electrically to a wafer of crystalline deuterated potassium di-phosphate. The rear surface of this wafer is scanned by an electron beam which is modulated by the TV video signal. This modulation takes place locally between the front face of the wafer and the CRT signal grid directly behind the wafer. When a collimated polarized light source is passed through the wafer and is reflected from a dielectric mirror on the rear surface of the wafer, the polarization status of the reflected light beam is varied according to the applied video signal. This light is then passed through polarizing optics to the projection lens. Since the wafer target is an insulating material providing an electrical capacity capability per unit area, it is possible to store the electrical image upon the wafer between scanning frames and thus prevent any image flicker normally associated with TV images. This full-frame storage can be as long as 200 seconds without any scanning update. In order to increase the mechanical strength and heat conductance of the wafer, the light valve target area requires cooling to −52°C. This target wafer produces no image lag or smear.

  The TITUS light valve color projector utilizes this principle three times (for RGB). The basic components and dichroic beam splitter are shown in Figure 5-8. Current projector capability consists of a prototype full-color, high-brightness projector running at the European standard line rate of 625 lines, 50 fields per second in a 3:4 aspect ratio.

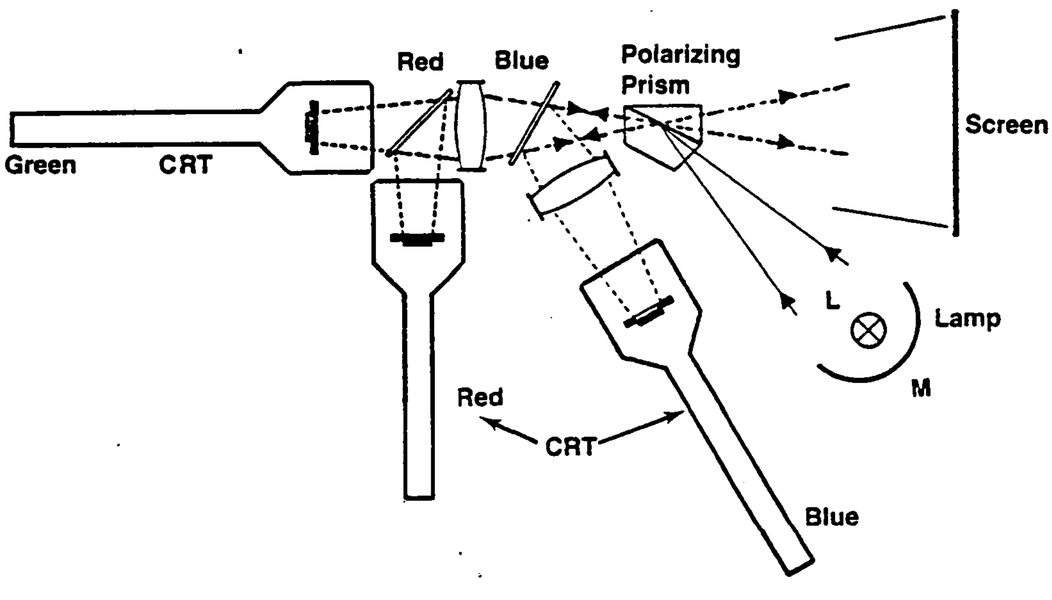


Figure 5-8: Sodern Titus Light Valve Diagram

The color brightness and contrast capability of this projector is very impressive (see Figure 5-9) for the CIE projector color coordinate capability). Sodern is currently working on an improved version of the projector which is expected to be available during the ACAVS time period. The projector head, containing the basic elements depicted in Figure 5-8, is driven by a supporting electronic rack and small water cooling system. The projector head will weigh approximately 99.8 kg (220 pounds) and has a volume of 1m (39.37 inches) long by .7m (27.6 inches) wide by .8m (31.5 inches) high; the equipment rack is a standard .5m (19 inches) rack 1.8m (6 feet) high.

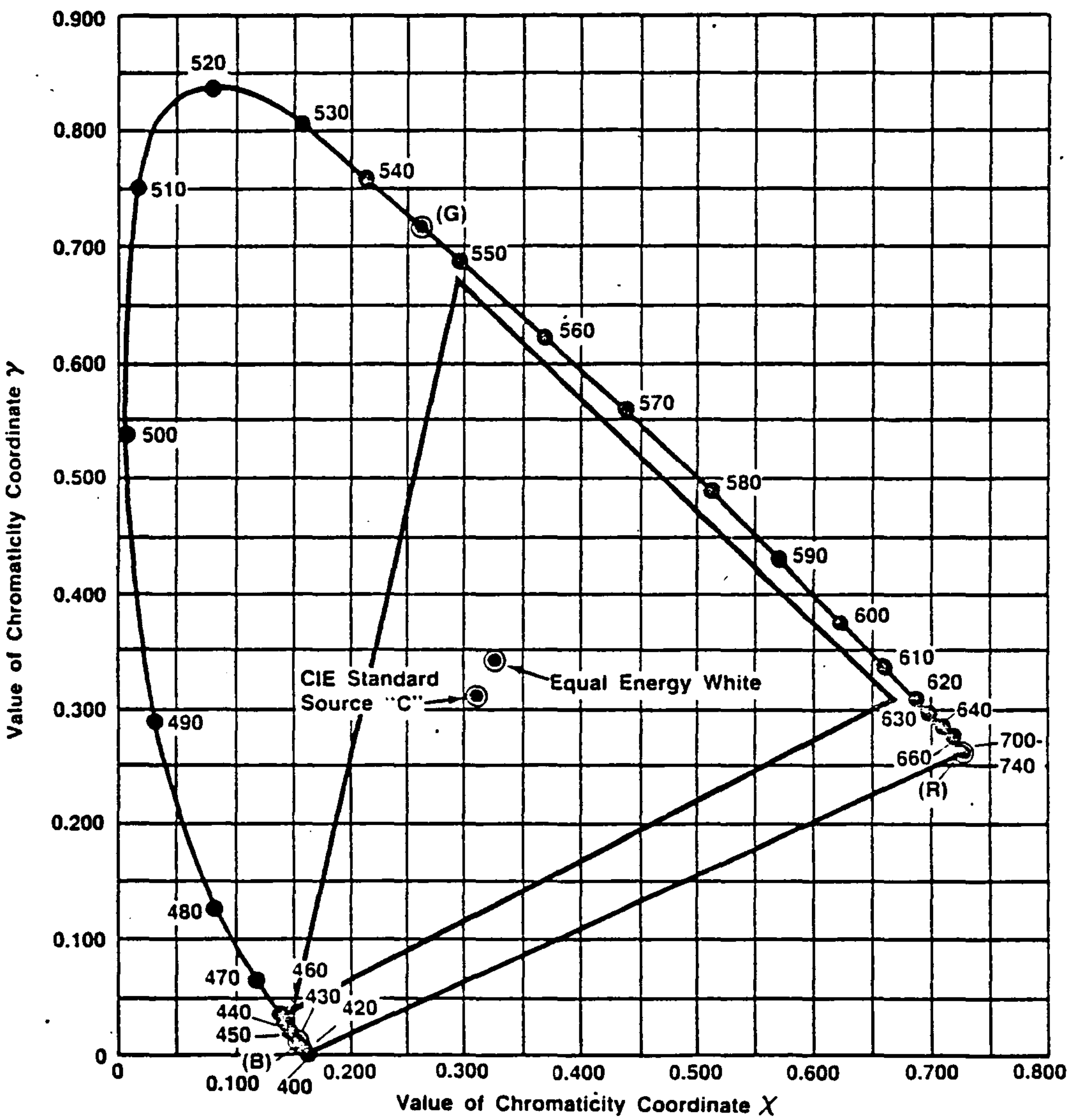


Figure 5-9: Chromaticity Diagram – System Capability (Titus LV)

This projector has a brightness output, depending upon the xenon lamp used, from 1 000 to 2 500 lumens and a contrast ratio of 60:1. The new version will have a square raster with 1 000 by 1 000 addressable points and either will be compatible with 1 029 line/60 field rates, or may be raster programmed similar to the LCLV previously described. The electronics provide distortion corrections and adjustments necessary for overlapping images and raster edge matching which is important in multiple projection of images. Since the light output is polarized, it, like the LCLV, is readily adaptable to the window mosaic display technology (see Paragraph 5.1.2.2). Its distortion correction capability can reduce 20 percent keystoning distortions to a two percent level.

Resolution for the 1 029-line version of this projector will be approximately 750 TV lines in both horizontal and vertical at 20 percent Modulation Transfer Function (MTF); this increases to 1 000-line horizontal limiting resolution at five percent MTF. Brightness uniformity (flatness of field) of the projected image decreases at the sides to approximately 60 percent of the center illumination valve. Depth of field for this projector ranges from six to 15 meters.

Due to the image storage capability of the light valve the projected image is entirely free from flicker even in a vibration environment. This capability lends itself to high resolution target insertion by stroke writing or minirasters, since the only part of the image field that need be updated is the target. This hybrid capability is possible by stealing retrace time now and then and writing high resolution targets (up to 1.5 times better resolution) during this time. Up to one percent of the raster area may be written in one ms, thus allowing targets to be displayed in high resolution and later displayed in normal system resolution as the target size increases.

Vibration environment for this projector should not exceed 100 Hz for very long periods of time. System reliability is similar to the LCLV with the xenon lamp being the weakest link. Light valve tube life is expected to be greater than 5 000 hours with a system MTBF of 600 hours. Mean time to repair is expected to be 30 minutes. Xenon lamp orientation requires the same precautions as previously stated.

5.1.1.2.3 Laser Projectors

Laser display technology has been under development for the last decade, yet only within the last few years has laser projector technology been successfully developed for real-time wide field-of-view displays. This technology has ranged from a monochrome 6.28 by 1.57 rad (360° × 90°) FOV laser projector (this projector system development has been canceled due to technical difficulties and lack of funding) to the development of a 3.14 by 1.22 rad (180° × 70°) full color real-time system. (It should be noted that the actual displayable active raster may be less than the FOVs indicated due to raster blanking/retrace considerations.) Manufacturers displaying real-time wide FOV color laser display technology are Singer-Link and Redifon Simulation Limited of England.

The laser projector basically consists of the lasers, light modulating devices, optical elements, mechanical optical scanning and scanner timing controls. Laser light from the R (krypton) and GB (argon) lasers are modulated by the input video signals. The video input may be from either a CGI or that operated by laser camera and model board. The modulated colored light is combined and relayed via optical elements to the high-speed vertical line scanner and horizontal deflector frame scanner, which is then projected upon the external screen (see Figure 5-10).

The laser visual display scanning elements orient the display raster such that the continuous lines scan vertical and the field/frame scans horizontally. To achieve the high-resolution capabilities required for quality imagery on wide field-of-view displays, high line rates and data rates are mandatory. Optical scanner timing tolerances are held to within five nanoseconds to insure raster stability for the visual image.

The horizontal field, depending upon the approach, is made up of one continuous field or a horizontal field made up of four separate segments. To achieve a resolution of 1.74 to 2.62 mrad (6-9 arc minute) video data rates greater than 100 MHz are required. Scanning line rates to attain this horizontal resolution are as high as 5 280

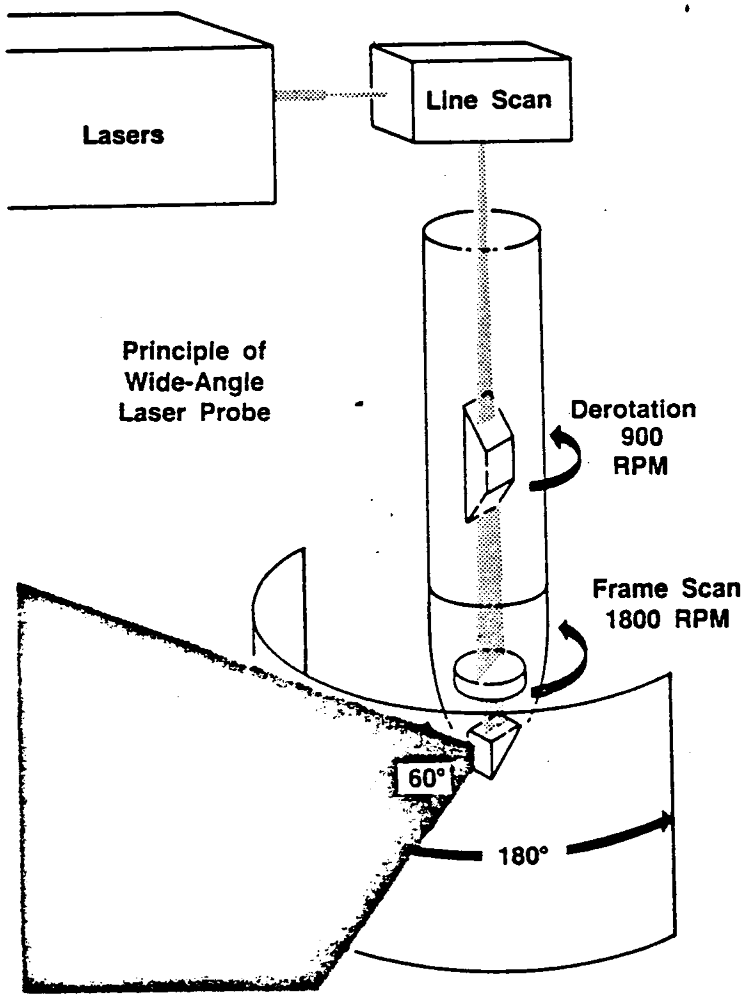


Figure 5-10: Redifon Wide Angle Laser Probe

lines per horizontal frame. Field rates are generally interlaced. Current laser projector technology at best has 1.45 to 1.74 mrad (5-6 arc minute) resolution in both the horizontal and vertical field of view. Brightness specifications range up to 34.3 cd/m^2 (10 foot-lambert) although some prototype units have difficulty in attaining values greater than 6.9 cd/m^2 (2 foot-lambert). Some of this difficulty is attributed to optical alignment and dust accumulating on the lens in the prototype breadboard arrangement. Contrast ratios possible from the projector unit extend from a minimum of 18:1 to a maximum of 50:1. Color characteristics of the laser projector are dependent upon the specific lasers installed; data for lasers currently used are listed below:

	Wavelength (nm)
R	647.0
G	514.5
B	457.9

These data points are also shown in Figure 5-11.

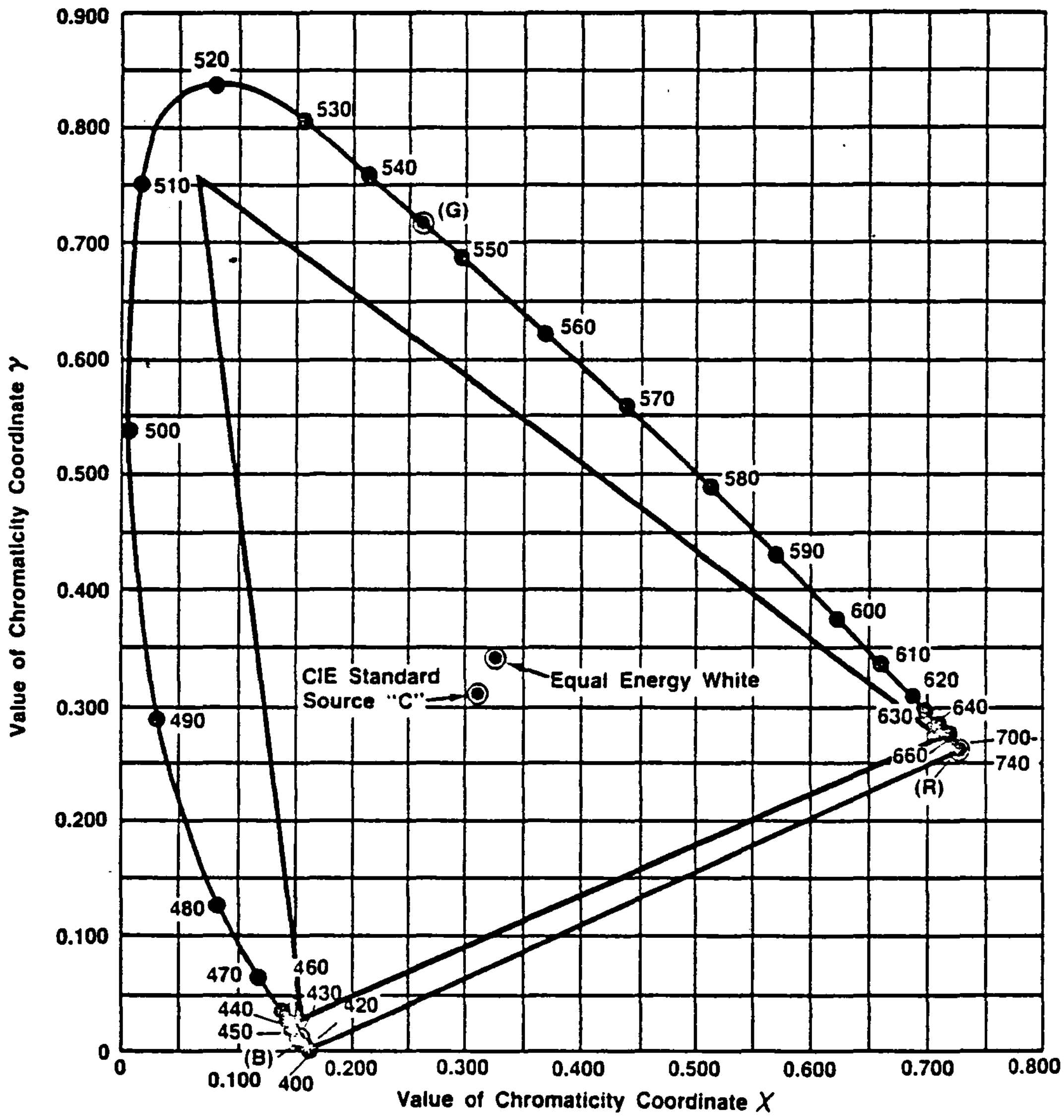


Figure 5-11: Chromaticity Diagram – System Capability (Redifon Laser)

Laser displays have a very uniform flatness of field within a specified viewing area and images appear to the eye to be relatively distortion free. Distortion levels can be as low as 1/2 percent for some configurations. Laser projection is the only projector technology surveyed that has the capability of presenting a real-time color image in such a wide field of view from one projector system. Laser projectors also have the capability of positioning and slaving the display raster as a function of pitch and roll. This capability is important in displaying some visual situations where visual information translates off the raster area during projected scenes of aircraft pitch and roll maneuvers. Laser speckle, though not very objectionable to this viewer, is reported to be somewhat discernible in projector laser displays and should be minimized.

Laser projection system maintenance requires frequent checks of power outputs and other white beam characteristics. The laser beam outputs are servo-controlled to help keep the light beam optically aligned and thus maintain image brightness over the short term. Beam orientation adjustment must be checked daily to insure maximum system operations. Output power losses occur over the lifetime of the plasma tube thus necessitating tube replacement. These tubes can be broken easily and must be replaced carefully. Other parameters to be checked include magnetic checks, plasma tube mirror alignments, pressure (water and air) and electrical measurements in the 600 volt/50 amp range. These are standard maintenance procedures. Tube life in excess of 1 000 to 2 000 hours can be expected. To insure that these units operate cool and efficiently, water cooling is required. System MTBF (with regular maintenance) is anticipated to be greater than 900 hours with an MTTR of about one hour.

Laser systems present a potential safety problem to the user and are classified by OSHA as Class IV-Medium Power Lasers. These projectors fall into this class because they can emit an average power in excess of .5 watt for periods longer than .25 seconds. Safety control measures for a Class IV system must be provided to prevent exposure of the eyes and skin to the directly reflected beam.

Wide angle color laser displays appear to be one of the display technologies of the future. As of now, prototype laser displays have been demonstrated, but to our knowledge none have been fabricated and installed on simulation systems. Maintenance and reliability problems when laser projectors are installed on motion systems are yet to be assessed.

5.1.1.3 Projector Display Screen Technology

The ADAVS display screen should maintain contrast in the imagery, give uniform luminance to the observer and provide portability from one location to another without losing its integrity of radical (or conic) dimension.

In a conventional projection system, the light emitted from the projection lens is the same as the light arriving at the projection screen (with no atmospheric losses). The goal of visual display screen design is that of maximizing reflected light back to the observer(s) and simultaneously providing uniform scene illuminance over the observer's viewing field while maintaining a high contrast image. Good screen efficiencies permit lower illumination levels which result in good operational projector efficiency, extending its time between maintenance, and allowing a higher contrast setting. In general, screens with a small degree of curvature give better contrast then spherical screens.

Current display screen technology can provide reflective surfaces, such as flat white paint, that are 90 percent efficient over a wide viewing angle, or it can provide 200 percent efficient screens, such as "Scotchlite" brand reflective sheeting (#5870), over narrow viewing angles. The latter material is said to have "gain." Gain can occur over limited solid angles, typically, .175 to .349 rad (10-20 degrees). Flat white diffuse reflecting spherical screens begin to suffer from loss of contrast as the total angle of projection becomes large. Secondary reflections can become most severe as this angle approaches ± 1.57 rad ($\pm 90°$). Reducing the basic screen reflectance ratio to below unity is one method of controlling this loss since each reflection is reduced by this ratio. Another possible solution to this loss of contrast involves the use of screen material with directional reflective properties. While overall contrast is good for spherical screens with high gain in the direction of the incident illumination, contrast falls off rapidly as projection angles near ± 1.57 ($\pm 90°$). Areas of uneven luminance or "hot spots" will also occur at these angles. However, screen materials are available in which this directional preference can be biased to occur in directions other than that of the incident illumination. This property can be used to reduce these "hot spots."

Figure 5-12 depicts a directional preference spherical screen with gain at a bend angle of .262 rad (15°) right. Figure 5-13 depicts a design with direction preference split between the right and left quadrants at a bend agle of

.175 rad (10°) right for the left quadrant and .175 rad (10°) left for the right quadrant. As shown by the arrows in these figures, the reflected light level at the observer will be uneven and the "hot spots" will be shifted toward the center of the screen, obviously an unsatisfactory result. Loss in brightness at spherical screen edges can be compensated somewhat by shaded neutral density filters at the projectors or by image generation techniques, but degraded contrast cannot be corrected easily at the large field angles.

5.1.1.4 Other Display Devices

Other devices that have potential uses in simulator displays include LED matrix display, plasma discharge devices and electroluminescent devices. Technology assessment in these areas revealed that these technologies are not currently in use in visual system large screen displays nor are any breakthroughs seen in the near future. Therefore, they will not be covered in detail in this report. These devices do, however, have application for new panel displays and special purpose displays in research simulators.

LED x-y displays are currently available in sizes as large as .08 by .10m (3 × 4 inches). Resolutions range from 64 to 100 lines per inch. Some devices are available in only one color while other approaches house multicolor LEDs to give red, green and yellow digital images made up of thousands of LEDs per square inch.

Plasma displays which are made in flat screens as large as .61m (2 feet) square have a resolution of about 100 lines/inch. Color capability is monochrome. This type of display is generally utilized for panel displays of alphanumeric and special vector graphics.

Electroluminescent technology has been evolving for many years. It is a method by which electrical energy is converted directly to light. These devices are made in flat thin panels and are available in several colors. Their application in simulator technology would be for panel edge lighting and interior lighting strips. To our knowledge these devices have not been used in real-time visual displays.

5.1.1.5 Imaging Fiber Optics for Visual Displays In Simulators

The feasibility of transmitting a sufficient quality image through a fiber optic bundle has recently been realized. The technique is known as wavelength multiplexing. One method utilizes spectral dispersing elements (prisms) at each end of the imaging fiber bundle. These prisms have zero deviation to one wavelength, like the sodium D line. Therefore, light from point A in the object, at this one wavelength (yellow), is not deviated. Blue light is deviated and is passed through another fiber; similarly, red light is deviated in an opposite direction and passes through yet another fiber. At the other end of the fiber bundle, the yellow light emerges from its fiber and passes undeviated through the second prism to point A: the blue and red lights which pass through other fibers are deviated back to a ray focal point with the yellow light. Another object point B has its spectral components traversing separate fibers similarly to point B.

Blue light from object point A can traverse the same fiber as yellow light from point B, when A and B are contiguous. Thus, each fiber can transmit numerous colors of light from different object points. This technique is called "wavelength multiplexing." The beneficial outcome of this technique is that information from point A is carried by numerous fibers; and if one is broken it will not be evident on a macroscopic scale. Also, the cladding and liner around each fiber is not visible in the final image.

Our calculation of the optical throughput of an American Optical imaging fiber is shown in Table 5-2.

This fiber bundle would be limited to a 1.2m (4 feet) length and have an approximate size of 12.7 by 15.9 mm (1/2" by 5/8"). One fiber diameter is 7×10^{-6} meter; this would give 1 100 fiber pairs across the 5/8" dimension.

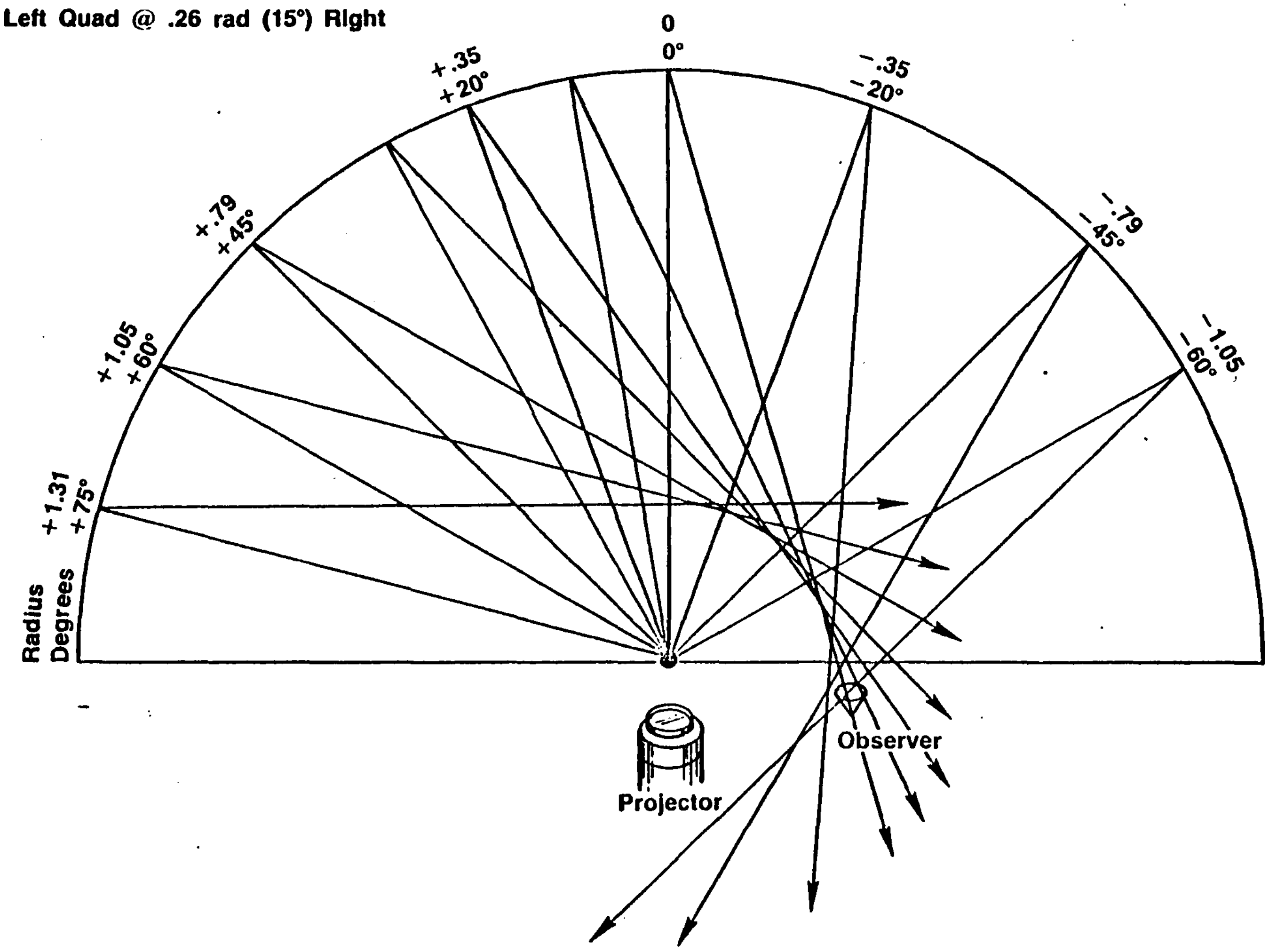


Figure 5-12: Hemispheric Screen Gain Reflective Bias

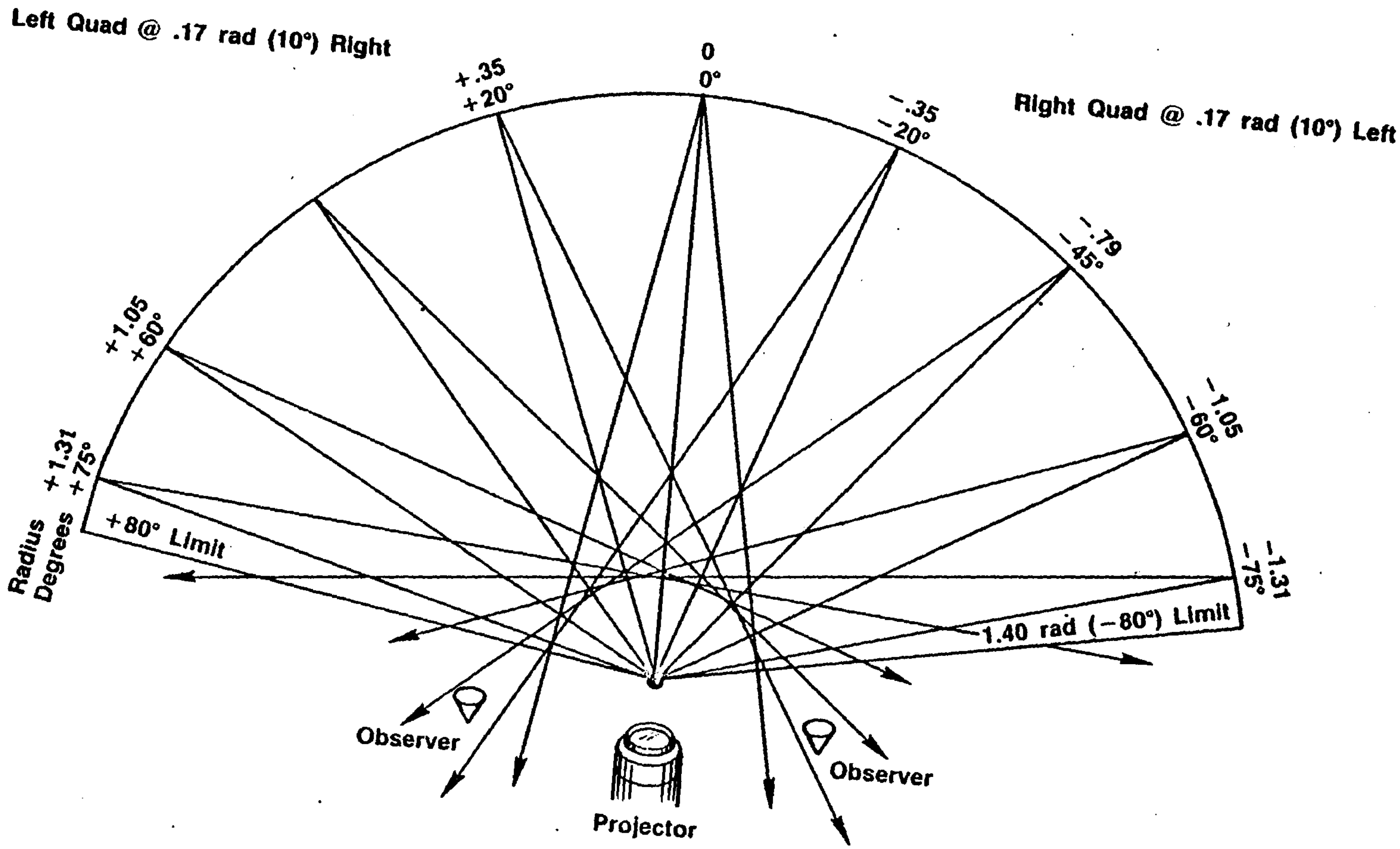


Figure 5-13: Hemispheric Screen Gain Reflective Bias

Table 5-2: Imaging Fiber Transmission

Numerical Aperture		Packing Fraction	Fresnel Reflection	Intrinsic Fiber Loss $\left(\frac{dB}{Km}\right)$	Resultant Fiber Loss (dB)	Resultant Fiber Transmission
Lens	Fiber					
.57	.56	.50	.84	20	−4.13	.39
.57	.56	.50	.84	100	−4.45	.36
.42	.56	.50	.84	20	−3.84	.41

A preliminary fiber bundle temperature rise test was performed at BMAC on 22 April 1980 to assess the effects of high brightness data being transmitted via fiber optics. The fiber bundle was 7 mm diameter, (nonimaging). The projection optics on a color G.E. light valve, Model 5800, were removed and Cannon lens (f/.95, 50 mm focal length) substituted. This lens imaged a test pattern on the end of the fiber optic bundle, and the fiber temperature rise was measured. The ambient temperature was 26.7°C (80°F) and the fiber temperature rise was 11°C (20°F) (well within usable limits).

If fiber optics are utilized in a visual display system, it is recommended that a prototype optical system be constructed for verification testing. Such things as acceptance of wide angle rays, limiting resolution, image distortion, color, luminance, and edge-of-field effects need to be investigated. Also, mechanical considerations such as flexure, flexure rate, weight, maximum usable lengths and fiber separations require the establishment of a level of tolerance. Paper studies and designs (CAE, Farrand Optical, etc.) have verified the feasibility of fiber optic coupling of visual projectors to displays, but no fiber optic visual simulation hardware has been discovered in this technical survey.

5.1.1.6 Extension Optics Technology

A unique imagery concept which permits projectors to be effectively placed very near the observer's head is shown in Figure 5-14. This device consists of lenses, mirrors, and a prism to optically relay the collimated light from a light valve projector onto an image plane (where it may be modified in size by masking and in intensity by special optical filter) before it is projected via the objective lens onto the external image screen. This "periscope" has provisions to rotate the light entrance and exit portions of the assembly with respect to the main assembly thus permitting the device to be off-set and skewed at any angle. This flexibility permits the projector to be remoted several feet from the projector view point. A roll prism is incorporated to provide roll correction for roll introduced by the rotation of the extremity sections; the aperture/focal plane area provides an area to physically introduce special parameters into the image to modify the image. Image modification is especially important when several projected images from separate projectors are to be joined together. This capability permits neutral density/color filters to be placed in the image plane to correct for flatness of field problems, etc. It also allows the raster edges to be tailored for best optical fit when viewed on the image screen. This capability is very important in light valve projectors that do not possess raster variation control capability.

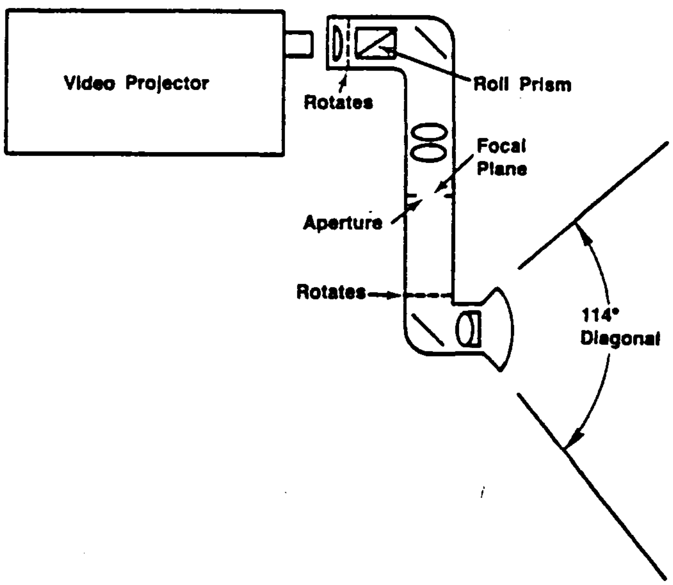


Figure 5-14: Current Technology Video Projector Periscope

A visual display system utilizing this "periscope" imagery concept is being developed to NTEC's Visual Technology Research Simulator (VTRS) facility. The NTEC simulator laboratory proposes to use two periscopes with two projectors imaged together to provide a wide FOV display. G.E. (Daytona) has designed and built lenses for attachment to a video projector. The present periscope has been designed to a 70° × 90° field of view, but other options are available.

The NTEC extension optics design has the following characteristics:

- Light transmission 80 percent
  70 percent with roll correction prism
- Good depth of field
- 114° diagonal field of view
- 1.5 arc minute resolution in optics path
- Intermediate image plane for image shaping and color fringe correction
- Weighs 50 pounds
- Roll correction prism to orient a tilted image correctly on the display screen
- Projection lens linear with angle (f θ mapping)
- Removable filter/stop
- RGB color-balanced optics

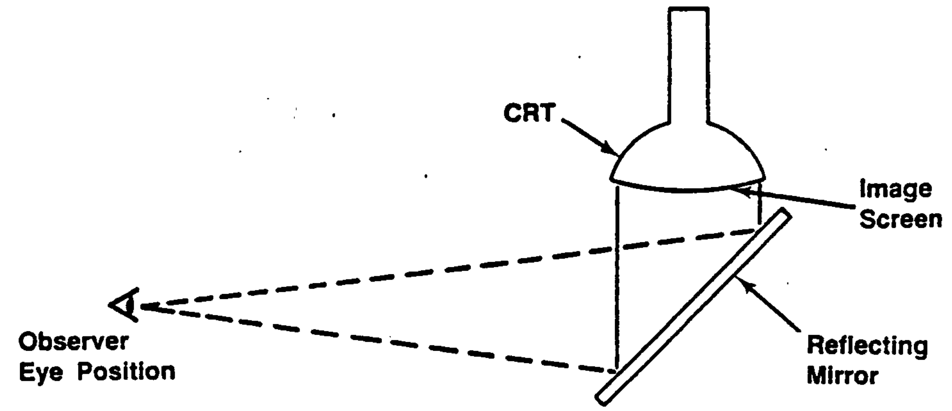
5.1.2 Visual Display Systems Technology Assessment

Technology assessment in this section will discuss visual display technologies available on a systems level. The visual systems assessed utilize the technologies described in Paragraph 5.1 in various configurations. These technologies have been configured in the simulation community in single and multiple combinations, in varying degrees of success, to meet each system's visual requirement.

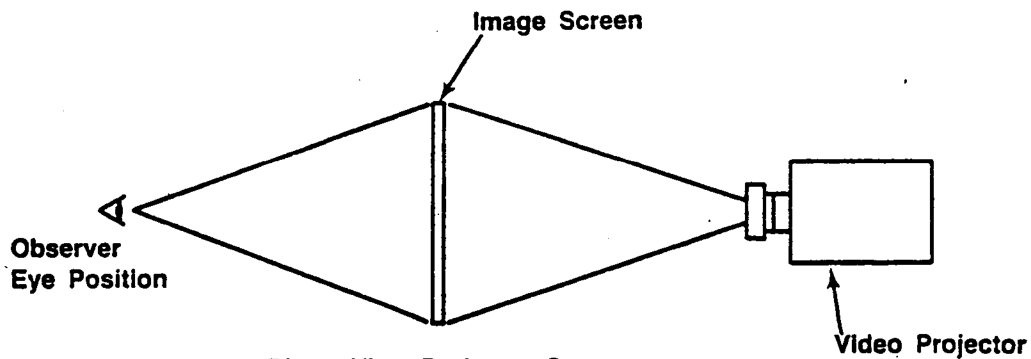
System specifications are usually trade-offs in subsystem capability, simulator requirements, and costs. The following visual display systems are a collection of new and existing visual display techniques that will potentially meet the ACAVS requirements.

5.1.2.1 Real Image Displays

Real image displays as mentioned in Paragraph 5.1.1 are made up of direct view devices and images which are projected on flat or spherical screens. This may be a direct view CRT/beam splitter, mirror arrangement or a front or rear projection system (see Figure 5-15). This approach has been used many years with good results yet it still possesses parallax and field-of-view problems which need to be considered in systems design. Image resolutions are determined by the CRT and projector bandwidth, line rate and the viewing distance of the observer from the image screen. For image display systems a trade must be made between resolution and FOV (a function of viewing distance from the screen) to obtain the best compromise in meeting system requirements. Image resolution within the observer's main area of interest, for the display systems assessed, all had a visual resolution quality better than 4.36 mrad (15 arc minutes).



Direct View CRT



Direct View Projector Screen

Figure 5-15: Real Image Displays

Direct view CRT systems are limited in field of view by how close the observer can comfortably view them and how large the CRT display screen is. The viewing distance seldom is closer than .76m (30"), thus a .64m (25") display CRT 1 000 line TV system provides a vertical FOV of .49 rad (28°) at a viewing resolution of 1.45 mrad (5 arc minutes) per line pair. Here the resolution is good but the FOV and the viewing distances are poor for wide angle displays. These systems are generally used in small window visual displays where parallax due to operator head movement and the requirement for images seen at far distances is not critical.

Real image displays obtained by image projection onto a viewing screen works the trades on the other side. Screens are placed at a distance of 2.44 to 3.05m (8 to 10 feet) away from the viewer to make the image appear at a distance farther from the eye and to reduce the parallax problem. Screen distance limits are determined by FOV, resolution, brightness and the enclosure envelope of the simulator. Thus for a screen-projection throw distance of 3.05m (10 feet) (assuming the projector and operator are equidistant from the screen) and 700 effective TV line vertical resolution is available from a 1 000 line system, it is impossible to attain a visual resolution better than 3.14 mrad (10.8 arc minutes) per line pair in a 1.05 rad (60°) vertical FOV. This resolution may be improved in the vertical by reorienting the projector 1.57 rad (90°) utilizing the aspect ratio maximum distance in the vertical, but at a sacrifice in horizontal FOV.

Brightness is another parameter which must be considered when a real image projection system is developed. The brightness (B) (in foot-lamberts) of the displayed scene, viewed on a unity gain screen, is equal to the illumination (L) available from the projection source (in lumens) divided by the image area A on the screen.

$$B = \frac{L}{A}$$

Thus for the example cited above, if a brightness level of 34. cd/m^2 10 foot-lamberts) is required, a projector illuminance output of at least 1 600 lumens would be specified. This illuminance level is difficult to achieve. Contrast is another area of concern when using projection systems with spherical domes (see Paragraph 5.1.1.3). Here the contrast ratio of the scene is reduced by an increase in the ambient light level in the viewing environment. This is caused by the light which impinges on the screen being not only reflected to the viewer but also being diffused and dispersed to all other areas of the screen. For screen gains greater than one this becomes a real problem.

Surveys of existing wide FOV visual systems using real image projections indicated use of a mix of various types of projectors within spherical domes. Except for the laser projection system all simulators utilized either a point light source projector (high altitude sky/earth scenes) or a low resolution wide angle black and white TV projector to give the peripheral cues. Projectors, up to as many as four, are being used to superimpose higher detailed target data upon the wide angle display. The target projector is servoed in pitch and yaw to provide target motions upon the dome scene. To attain the high resolutions required in some applications the target video is projected through a zoom lens (electrical/optical zooms up to 20:1) to permit reduction of the target image and still maintain image resolution. This method produces acceptable results but requires a projector per target and in some cases two or more per target if wide angular movements on the screen are to be allowed. Image brightness also changes with zoom. Problems associated with this approach are: (1) it requires different projectors and image generation systems, (2) inaccuracies develop in pointing as well as image motions encountered in zooming the target (it is difficult to zoom without some wobble being introduced from optical misalignment and servo tolerances). Current target servo pointing accuracies are 17.45 mrad (1°) error or less. The existing traditional real image dome displays of this type have the following range capabilities:

	Background (Nonpoint Light)		Target	
	Radian	Degree	Radian	Degree
FOV_H	1.57-2.79	90-160	.06-.63	3.6-36
FOV_V	1.22-1.40	70-80	.08-.84	4.8-48
	Miliradian/LP	Arc Minute/LP	Miliradian/LP	Arc Minute/LP
Resolution	3.49-8.73	12-30	.58-1.75	2-6
	Candela/Meter^2	Foot-Lambert	Candela/Meter^2	Foot-Lambert
Brightness	.69-6.85	.2-2	23.98-27.41	7-8
Contrast	8-10		8-10	

Point light systems have larger fields of view up to 4.19 rad (240°) but are very low in illumination and imagery is not possible in real time.

Two approaches surveyed that appear to be solutions to the problems are: the utilization of head slaving the wide FOV projector's position to the operator's area of interest (thus a better resolution can be obtained from one projector), and the transmission of several projectors via optical extension light pipes to keep image efficiency high while getting the source of the projected image close to the operator's head. This latter capability is being implemented at NTEC's VSTOL facility. This technique improves brightness and reduces distortion and distortion correction problems drastically.

Northrop is utilizing the first concept in a full-color display with a CGI image system and will be able to cover a 2.62 $\pm$1.31 rad (150° $\pm$75°) horizontal FOV by .87$\pm$.52 rad (50° $\pm$30°) area using the head tracking technique. Illumination levels and resolution of this concept are within the upper ranges previously stated for projected real image displays.

Real-time color laser visual systems are a new technology now emerging (see Paragraph 5.1.1.2.3) and are expected to improve wide angle displays in resolution and FOV. Current technology is utilizing the laser projector in a cab-mounted configuration where the laser projection system is mounted above the observer's head and projects the image onto the screen. This projector head may be implemented to pitch and roll the visual raster to help maintain visual orientation during aircraft maneuvers. It may also be head slaved in these axes to incease the total operational FOV. Prototype systems have been built on nonmotion base platforms but none as of yet have been implemented in working simulators. Problems of optical alignment, placement of laser sources, etc., under vibration conditions have yet to be assessed. Another concept for using the laser/scanner technology is emerging; this application utilizes the laser beam in conjunction with a helmet and head tracker. This concept uses a color laser system source coupled via fiber optics to a helmet/head tracker. The modulated color laser light is projected from the operator's helmet via a miniature optical scanner and is distributed across a special spherical screen to project a minimum instantaneous FOV of 1.57 rad H by 1.22 rad V (90°H by 70°V). This display concept requires helmet/head tracking capabilities to permit the visual generation system to know what data is to be supplied to the laser modulator and thus permit the visual scene to be correctly updated with the operator's head motions, as well as the aircraft motions. Visual parameter goals expected are a resolution better than 1.16 mrad (4 arc minutes) per line pair at a contrast ratio of 70:1. The maximum brightness expected is 17.13 cd/m^2 (5 foot-lamberts).

Though this system is in the conceptual stage and not expected to be available in the ACAVS time period, the advantages and disadvantages of this concept will be discussed for completeness.

Helmet-mounted projection will keep the image distortion low because the source is located very close to the observer's eye. Resolution is good and the dynamic area-of-interest FOV is as wide as the head tracker capability. Head trackers and eye trackers have been suggested for use in helmet displays to generate the control signals relating to where the operator is looking. Our technology assessment indicates that the state-of-art capability of eye trackers is still too developmental to be considered for the ACAVS program. Although helmet trackers can tell only where the head is pointed and not the exact position of the eye, they are available now and offer a very high degree of accuracy and reliability.

Head tracking units provide the pointing angles, LOS of the pilot's head relative to the aircraft body coordinates and orientation in simulation space. The simulation space resides in a data base computer. For new head pointing angles, a new perspective of the scene in simulation space, as limited by any aircraft window or structure, will need to be provided to the video projectors by the CGI system. A Polhemus unit provides LOS to an error of 0.37° (RMS) and roll angle to an error 0.55° (RMS).

Disadvantages associated with helmet-projected displays are many. The optical scanner may produce a helmet buzz that could be objectionable to the operator. This system requires a high gain, high quality spherical screen. Laser light may reflect from cabin instruments and present readability as well as safety problems. There are also potential problems with optic fiber breakage which reduces image quality. Since the instantaneous FOV is less than the peripheral vision of the operator, some type of horizon cues may be required. Each helmet projection is acceptable only for one observer due to the falloff of the high gain screen. To provide a usable image for a second crew member, it would require another helmet/laser system; but this approach would provide additional visual problems when the projected light from one crew member's display intercepted the other crew member's visual FOV in reading instruments or in eye-to-eye contact.

5.1.2.2 Virtual Image Displays

Virtual image displays as mentioned in Paragraph 5.1.1 are made up of CRT or projector sources that are optically processed to produce the object at infinity and thus reduce image parallax problems associated with head motion. Field of view and image resolution trades, as described in 5.1.2.1, still apply, although the FOV now is not associated directly with distance from the observer, but is a function of the radius of curvature of the spherical mirror. The virtual image display generally serves only a single user whose head motions must be rather limited. Because of this limited solid angle viewing area, this system does have some brightness advantage. Three virtual image optical configurations for display viewing are shown in Figure 5-16.

A virtual image can be observed directly or may suffice as a source to be reimaged by a subsequent lens system, but it cannot be produced on a screen. Virtual displays can have the same brightness and resolution as any real image display when configured as a mirror display. The CRT source and mirror/beam splitter arrangement (used quite extensively in simulator window displays) is less than 25 percent efficient because of the light losses encountered when the image is reflected from and through the beam splitter.

The virtual image in-line optical system shown has light transmission efficiencies of about 1.2 percent.

Technologies surveyed in virtual image systems covered all three of these types of systems and will be discussed as follows.

- The CRT beam splitter's mirror configurations are well known and in wide use. Image FOV is generally limited to .63 by .84 rad (36° × 48°) and is limited by the resolution capability requirements. Maximum horizontal FOV capability per display is limited to about .96 rad (55°) maximum; the limitation arises from the physical interference of the beam splitter and the mirror. These systems may be color or monochrome.

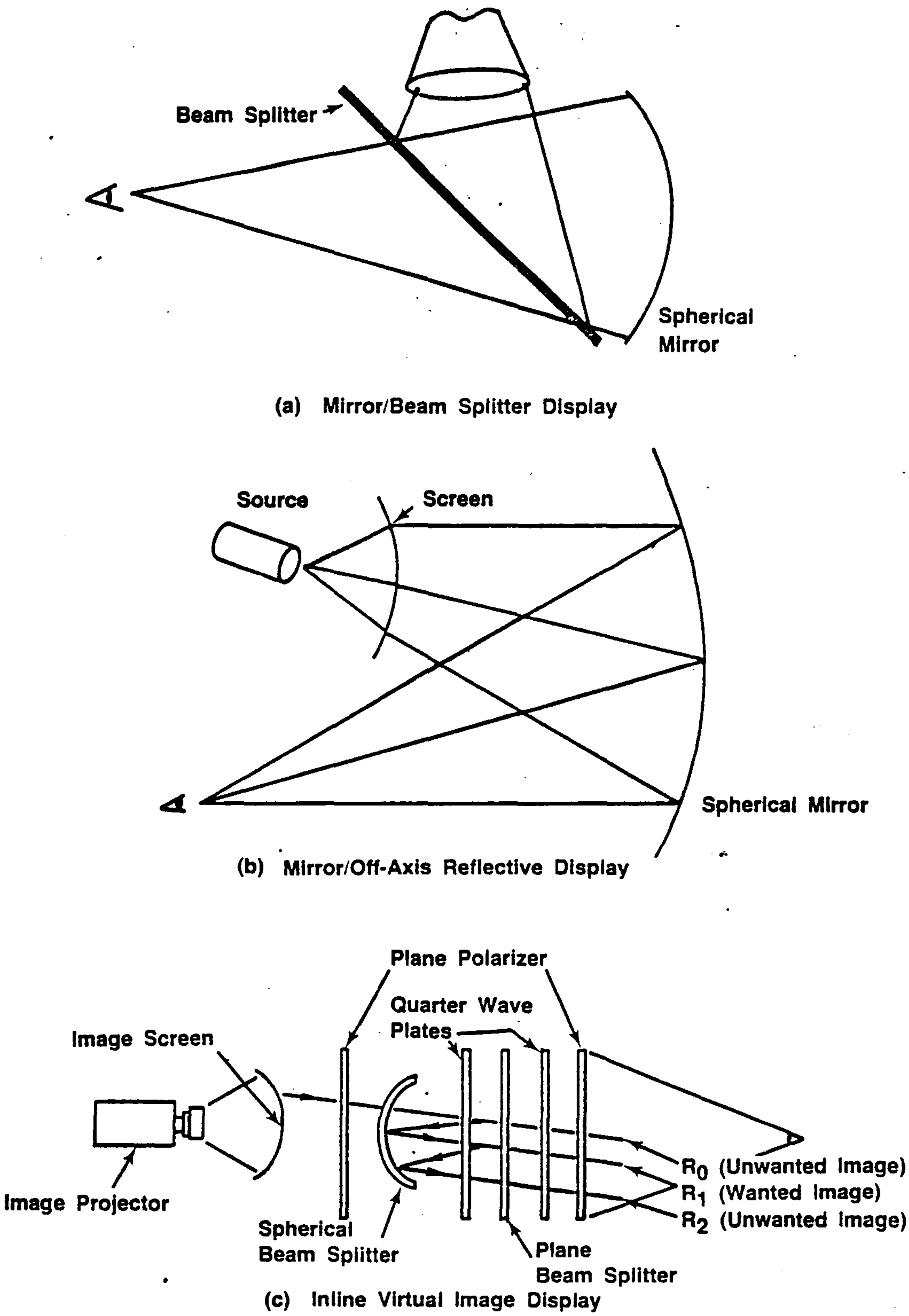


Figure 5-16: Types of Virtual Image Displays

Image brightness outputs available as seen by the eye, depend upon the source capability; these range from about 6.85 cd/m^2 (2 foot-lamberts) for beam penetration systems, at 2.03 mrad (7 arc minutes) resolution per dot, to greater than 85.66 cd/m^2 (25 foot-lamberts) from high brightness color tubes. Contrast ratios are good. These units may be clustered together to provide a fairly wide field of view. As many as five or more units have been used. Although this may be done to extend the horizontal FOV, the number of units that can be placed to increase vertical FOV is limited due to the physical size of the CRT supporting structure. Thus, if wide horizontal FOV displays are required, the maximum possible vertical FOV will be limited unless image area loss between CRT units can be tolerated. Typical weight per display unit is about 295 kg (650 lbs).

- The mirror/off-axis reflective display (the type utilized in Redifon's Duoview) has the image placed off-axis to the observer. This optically-designed arrangement permits a greater eye relief, thus making the virtual scene visible to more than one viewer. The image is rear-projected onto an intermediate surface from a projector and is reflected from this position via the concaved mirror to the observer's eye where it is seen as a virtual image at infinity. In addition to the increased eye relief, the elimination of the beam splitter is possible, thus permitting an increase in brightness. The maximum FOV available is .63 rad V by .84 rad H (36°V × 48°H) with a resolution of 2.33 to 2.91 mrad (8 to 10 arc minutes) per line pair, brightness (with a 500 lumens source) is up to 34.3 cd/m^2 (10 foot-lamberts), contrast ratio of 15:1 and an eye relief of 2.29m (7.5 feet). This type of virtual image display is currently in existence but lacks the wide FOVs necessary to meet the ACAVS requirements.

  An expansion of this concept is currently being investigated and is termed "Multiviewer." The multiviewer concept (Figure 5-17) consists of a rear-projected image and spherical screen arrangement that will provide a 1.05 rad (60°) by 3.14 rad (180°H) FOV to two side-by-side operators. To keep the resolution within acceptable limits this wide horizontal FOV will require at least three projectors.

Multiviewer concept design capabilities (Reference 5-4) with the 3.14 rad H by 1.05 rad V (180°H × 60°V) FOV is being designed for a viewing volume to the operators of 1.52 meters lateral by .91 meters longitudinal by .46 vertical [5 feet × 3 feet × 1½ feet] with a geometric distortion less than five percent throughout the FOV within this viewing volume. Image resolutions of 2.33 to 2.91 mrad (8-10 arc minutes) per line pair are envisioned with a 1 029 line rate TV visual system input. The brightness is expected to be at least 20.56 cd/m^2 (6 foot-lamberts); brightness variation within the FOV is expected to be about 25 percent. This variation is dependent upon the construction of the screen material and the projected flatness of field of the image. A system contrast ratio of 20:1 is expected from a projector with a contrast ratio of 25:1.

Image registration and mosaicking of the image are not insurmountable problems; the discontinuity of the joints and image registration should not be objectionable to the viewer. Image registrations must be held to 1.75 mrad (six arc minutes).

The multiviewer spherical mirror radius of curvature is to be 3.35m (11 feet) with the existing design recommendations. Total system weight including the mirrors, screen, TV projectors, and supporting structure is about 1528 kg (3370 pounds).

The current status of this concept is still developmental; a screen/mirror system of this size and type has yet to be produced. It is very doubtful if this visual system will be operational in the ACAVS developmental period.

- In-line virtual image displays, as the name implies, are constructed such that the image source is positioned in-line with the viewing axis rather than off axis as in the previous virtual image display types. The physical arrangement permits this type of virtual image display to be mosaicked together in multiples, thus growing to the desired FOV.

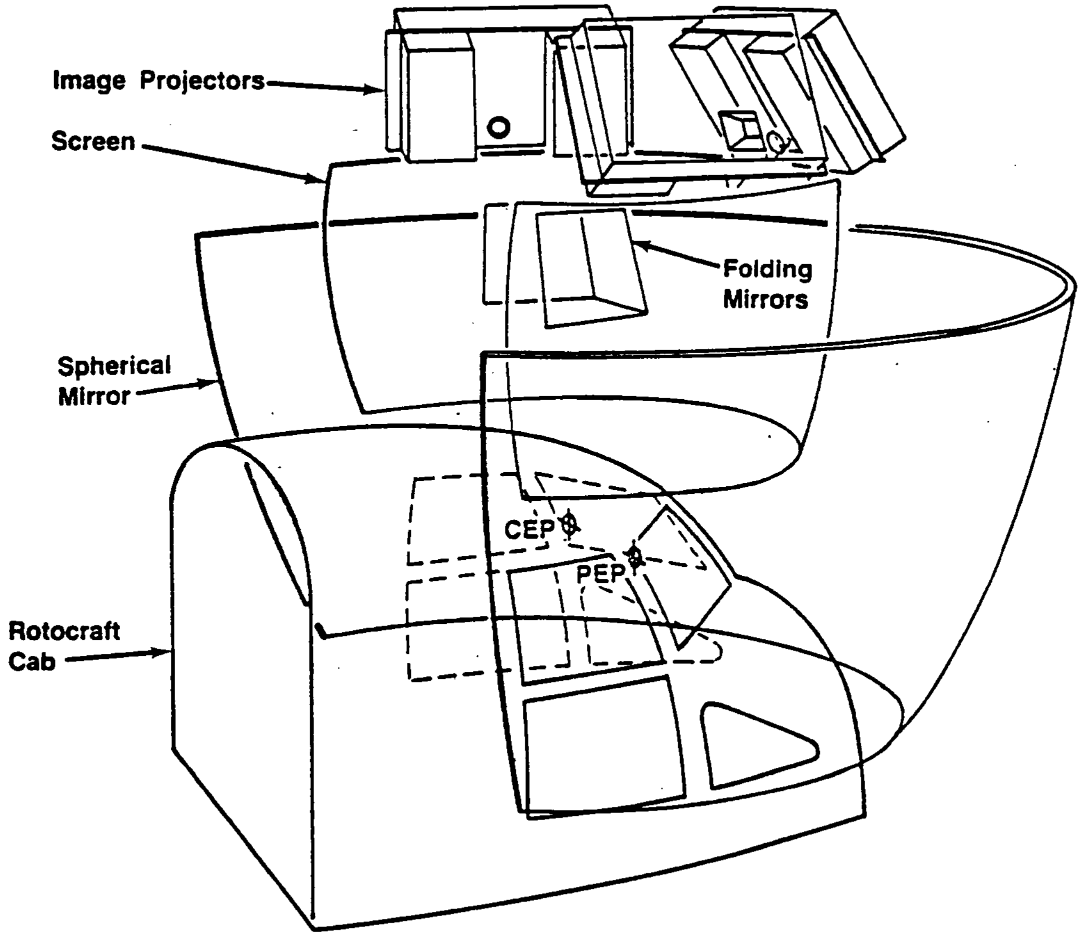


Figure 5-17: Conceptual View of the Multiviewer Off-Axis System

The basic in-line virtual image display (shown in Figure 5-16c) consists of an image source, spherical beam splitter, polarizers and quarter wave plates. The image source illumination (either a high-brightness, large screen CRT or a high-brightness projector that is imaged onto a rear projection screen) is polarized and passed through the spherical beam splitter. This image data is collimated by the spherical beam splitter and passed through the quarter wave plates and a final polarizer to produce a virtual image to the observer. The purpose of the quarter wave plates is to reject image reflections that occur from the various elements within the display system, thus allowing only those image components that are wanted to be viewed; the flat beam splitter permits the input image to be placed at the focal surface of the spherical beam splitter. This type of display has utilized a large 36-inch monochrome CRT and spherical beam splitter/mirror configuration.

The in-line infinity optics element is produced by Farrand Optical Co, Inc., and is termed the "Pancake Window."™ This in-line virtual image display has been incorporated into the USAF Advanced Simulation for Pilot Training (ASPT). Here the display mosaic has been configured into a dodecahedron which has utilized seven pentagonal faces of a maximum of 12; if all 12 were used a full sphere of imagery would be possible.

This display configuration, although permitting quality full color images at infinity and wide FOV capability, has several drawbacks. The most undesirable characteristic is the brightness loss caused by the number of times the image is transmitted through the polarizer and quarter wave plates; image brightness as seen by the eye is only about 1.2 percent of the light illumination at the image source. Thus, very high illumination is required by the image source. Another drawback is the generation of unwanted ghost images which occurs from the quarter wave cancellation process and polarizer because these elements are not 100 percent effective in blocking the unwanted images. These images, though not desirable, are not always a problem because they are not focused at infinity and thus are not always seen by the observer. Other areas of concern in some applications are the 12-inch viewing envelope restriction of this display to the observer's normal head motion and the weight of this display configuration arrangement. The weight of this system is largely due to the large quantity of glass in the spherical beam splitter/mirror and supporting structure which must be incorporated to ensure that the visual components stay rigid for quality images.

Resolution of this display system is limited by today's image display source resolution when the units are combined in the dodecahedron mosaic configuration. The FOV of this system is fixed per window, thus the image source determines the resolution of the system; the maximum scene resolution in line pairs will be approximately

$$\frac{12000}{\text{visible TV lines/frame}}$$

The ASPT simulator at Wright-Patterson Air Force Base has a 36-inch monochrome CRT with 600 foot-lamberts highlight brightness giving a resultant image illumination of six foot-lamberts brightness. Image resolution with the 1 023 line rate TV is approximately 14 arc minutes per line pair over each 70° × 70° image window mosaic element (total for the entire mosaic is 115° horizontal by +110°, −40° vertical). This visual display has an 18-inch eye relief and a 20:1 contrast ratio.

The latest technology improvement for this type of display is the replacement of the large heavy spherical beam splitter/mirror with a newly developed three-color holographic flat lens.

A 21.5" × 24" × 1" prototype holographic window has been fabricated by Farrand and its feasibility has been demonstrated in full color. This holographic lens system will provide substantial size and weight reduction in this display concept. New improvements expected are slight tilting of the birefringent package with respect to the viewing axis during the fabrication of the holographic window to permit a reduction in image bleed-through and image ghosting. Full size holographic windows (48" diagonal) are not expected to be available until 1984 and are thus not expected to be available for use in the ACAVS time period.

Virtual image displays are also utilized in Helmet-Mounted Displays (HMD). Small-field, helmet-mounted display systems and some concepts are operational today. One example is the Integrated Helmet and Display Sight System (IHADSS) by Honeywell. This system is used for infrared avionic display/pointing and weapon pointing. The infrared viewing system has a .70 rad (40°) horizontal field of view. The final optical element is positioned in front of the eye to provide 1:1 magnification. As the helmet turns, the viewing system pointing is slaved to the helmet pointing over a ±2.09 rad (±120°) azimuth and +.70 rad to −1.22 rad (+40° to −70°) elevation. The viewed display is real-time video with the characteristics of 875 line rate EIA Standards. Maximum brightness is 514. cd/m^2 (150 foot-lamberts).

Expansion of this technology to provide wide field-of-view visuals for simulation is being accomplished by government and industry laboratories. The AMRL facility at WPAFB, Dayton, has an ongoing research program, "Visually Coupled Airborne Systems Simulator (VCASS)," to develop helmet-mounted visuals with a computer-generated imagery (CGI) data base input. The optical resolution is about 2.62 to 2.91 mrad (9-10 arc minutes)/line pair in a 2.09 rad (120°) two-eye field. The system has utilized standard Honeywell instrumented HMDs, but is currently developing special helmets, extensively modified electronics and processing. Recently, a high-accuracy, helmet-mounted sight system was designed and built for VCASS by Polhemus Navigation Sciences. This system is being integrated with the very wide field of view, helmet-mounted display at AMRL. The characteristics of the visual display are 15 mm exit pupil with ~45 mm eye relief. The helmet weight is about 1.70 kg (60 ounces).

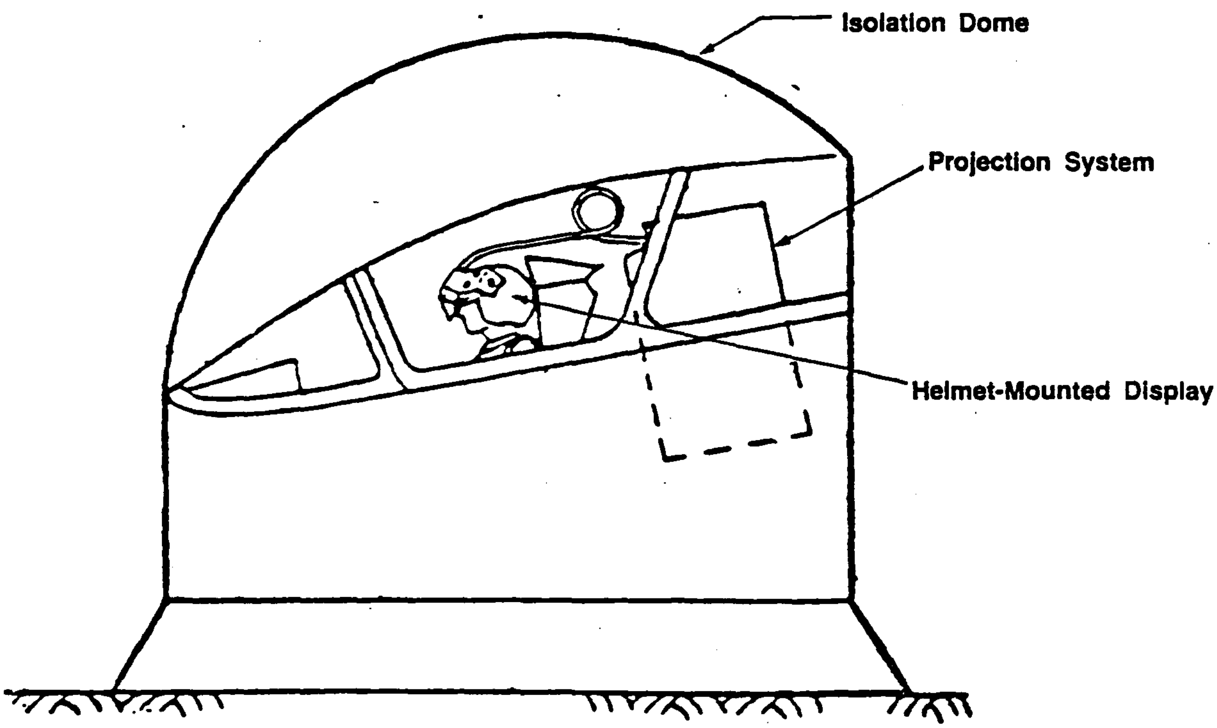
Another helmet-mounted display system has been designed by Farrand Optical. This HMD utilizes the Pancake Window™ technology in miniature. The helmet's optical system is configured such that image data is coupled with room illumination, thus making it possible for the subject to adjust the image scene brightness relative to the background illumination and thus optimize one's visual display. Characteristics for this HMD are listed in Figure 5-18. This display technology has an 80° FOV per eye with up to 25° overlap possible in stereo viewing applications, thus a total of at least 135°H × 60°V instantaneous FOV is possible to the viewer without any head tracking inputs. Image illumination sources are transmitted via a coherent fiber optics system to the Pancake Window™ input.

Naval Air Development Center (NADC) at Warminster, Pennsylvania, has investigated helmet-mounted display systems utilizing the helmet visor to give a real world scene. In the past the purpose of the display was to present a visual scene below a VSTOL aircraft during landing. The system has a small field TV camera for the scene input. The current research has concerned several programs centered around the Advanced Integrated Display System (AIDS) simulator. To date, the visuals have not been expanded to a wide field of view capability. NADC has installed a Polhemus head tracking unit to provide line-of-sight data and the capability of visual target acquisition which is integrated with other aircraft avionics.

The following statement is a quote from a Polhemus project statement:

> Helmet-Mounted Sight for EVAR Program: Contract DAAXB07-76-M-130 and M-137, U.S. Army Electronics Command, Ft. Monmouth, N.J. A PNSI system is being used to slave a TV monitor so that a pilot in an enclosed compartment in the helicopter can fly the aircraft using the TV's video imagery viewed on a helmet-mounted display. Additionally, this system will soon be installed in a UH-60 Blackhawk helicopter for further related studies.

Other variations of HMD visuals are forth coming such as visual systems which utilize head/eye tracking capabilities to optimize CGI processing and to concentrate detailed data in the foveal area of the eye while displaying only those data necessary for peripheral cues outside this area.



Helmet Mounted Display

1.	Size	10 × 8 × 5 inches on helmet
2.	Weight	2 lbs on helmet, counterbalanced, 200 lbs for one projector cables, etc., 350 lbs for two projectors (one per eye)
3.	Brightness, Ft-L/80° solid angle using 750 lumen projector	Up to 100 ft lamberts with screen gain = 2
4.	Brightness uniformity	±5%
5.	Field of view available	360°H × 360°V (full sphere)
6.	Distortion	None regardless of head motion
7.	Resolution	Limited by image generator and projector
8.	Stereopsis	Readily provided
9.	Apparent image distance	All of scene at infinity or from 15 ft to infinity with stereo option
10.	Color	Yes
11.	HUD capability	HUD usable "as is"
12.	Motion base adaptable	Yes, full size cockpit only requirement
13.	Portability	Fully portable
14.	Adaptability to different projection systems	Fully adaptable
15.	Exit pupil volume (allowable head motion)	Unrestricted
16.	Realism (environment and scene)	Cockpit: acceptable; external view: excellent

Figure 5-18: Farrand Helmet-Mounted Display

The growth capabilities of helmet-mounted displays for simulators was discussed with CAE in Montreal, Canada. The combination of imaging fiber optic bundles, HMDs, and a head tracking unit can provide a visual scene to a person with a minimum of heavy, power-consuming, lab-support hardware. This is accomplished by coupling the HMD video processor to a CGI data base. One area of growth in simulator visuals would be stereoscopic viewing of perhaps four channels of CGI. A block diagram is shown in Figure 5-19.

CAE has indicated eye tracking to 34.9 or 52.4 mrad (2 or 3 degree) line-of-sight accuracy is feasible in the HMD concept. Another growth feature of fiber optics with an HMD is the concentric placement of separate scenes before the eye. An example is shown in Figure 5-20.

The combination of an HMD, Polhemus-type head tracking unit, and color video data base generation by computer appear feasible. A simplified discussion of equipment lag time follows. The characteristics of an SHMS-IIIA-2 (12-Bit) Polhemus head tracker (abbreviated) are:

- LOS determined over ±1.57 rad (±90°) elevation and ±3.14 rad (±180°) azimuth angular range.

- LOS coverage over the following sensor translations:

  x axis: 0 to +.41m (0 to +16 inches)
  y axis: ±.25m (±10 inches)
  z axis: ±.15m (±6 inches)

- LOS static circular error is 13.96 mrad (0.8°) or less at the 95 percent confidence level when the sensor translations are:

  x axis: +.30m (0 to +12 inches)
  y axis: ±.20m (±8 inches)
  z axis: ±.10m (±4 inches)

- LOS dynamic error (instantaneous) is 1.15 mrad/mrad/sec (1.15 degree/degree/sec) without rate-aided filters.

- Roll angle sensing of the LOS, when the roll is less than ±1.31 rad (±75°) and the elevation angles are less than ±1.31 rad (±75°), is 17.45 mrad (1.0°) or less at the 95 percent confidence level.

- At a .70 rad/sec (40 degree/sec) tracking rate, approximately a 13.09 mrad (0.75 degree) lag error occurs, or 19 millisecond. Greater lag occurs at greater tracking rates.

- Two computation cycles are required to settle within 1.75 mrad (0.1°) of null for a .70 rad (40°) azimuth step size, or 0.033 seconds.

The standard video update time for a full frame is 33.3 milliseconds. This number matches well with the settling time characteristic for the head tracker. However, tracking rates equal to or greater than 1.40 rad/sec (80 deg/sec) could create a scene flicker while moving. Total system throughput delay is the delay in milliseconds between the time upon which calculation of image position is based and the time at which it is used. Another common term for this simulator lag time is transport delay. If the flight simulator computer samples the pilot actions at 30 Hz, then a Root Sum Square (RSS) time interval for position lag would be RSS = $\sqrt{(19)^2 + (33)^2}$ or approximately 38 milliseconds.

In 1978, the nominal time to create each true-perspective image took about 100 msec for CGI (Reference 5.5). Some improvement in this number has probably occurred. The combination of these lag intervals and computation times could be additive RSS, and in actuality are beyond the scope of this report, but this example indicates 100+ msec lag could occur.

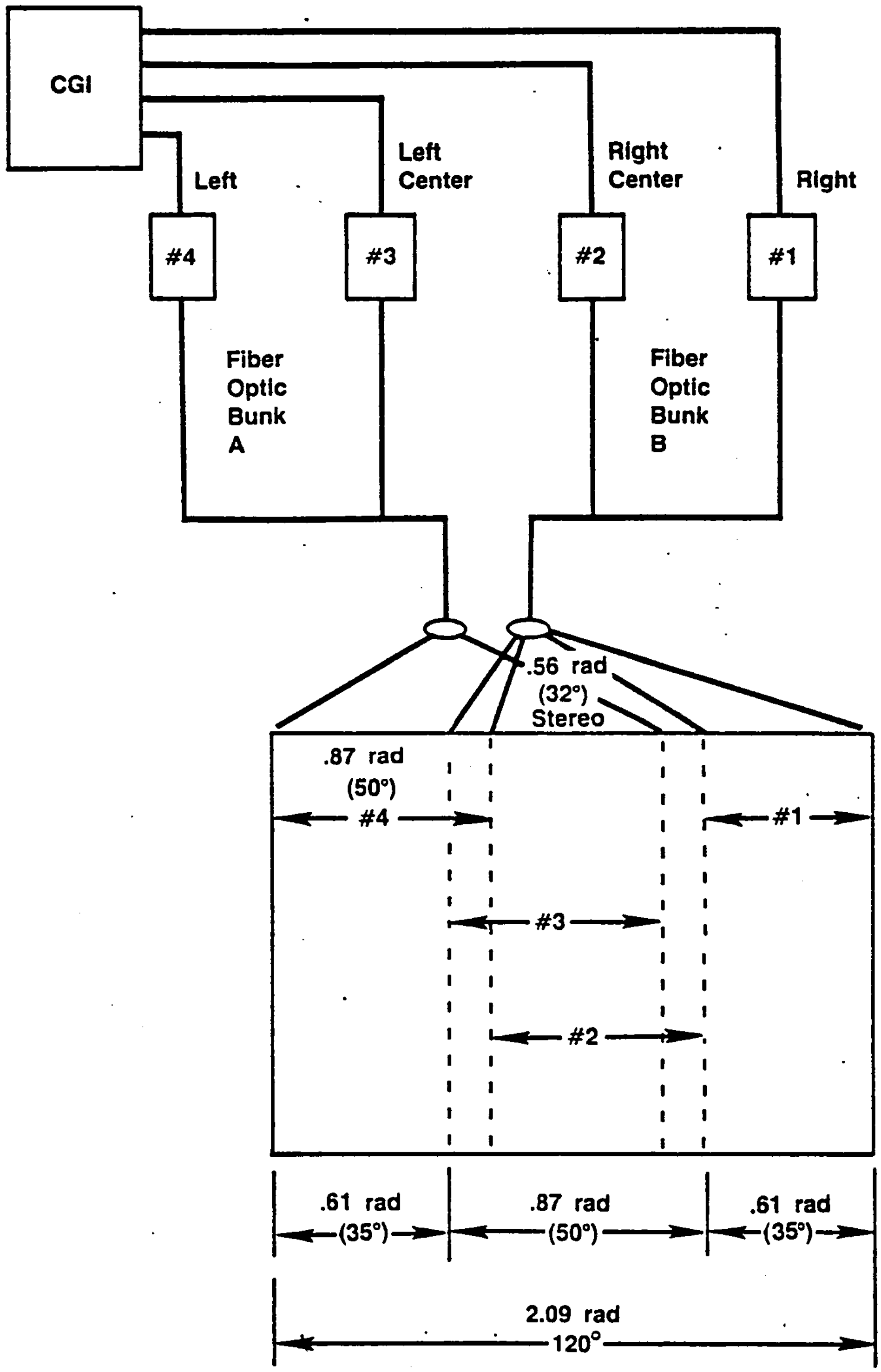


Figure 5-19: Stereoscopic Visual Display Concept

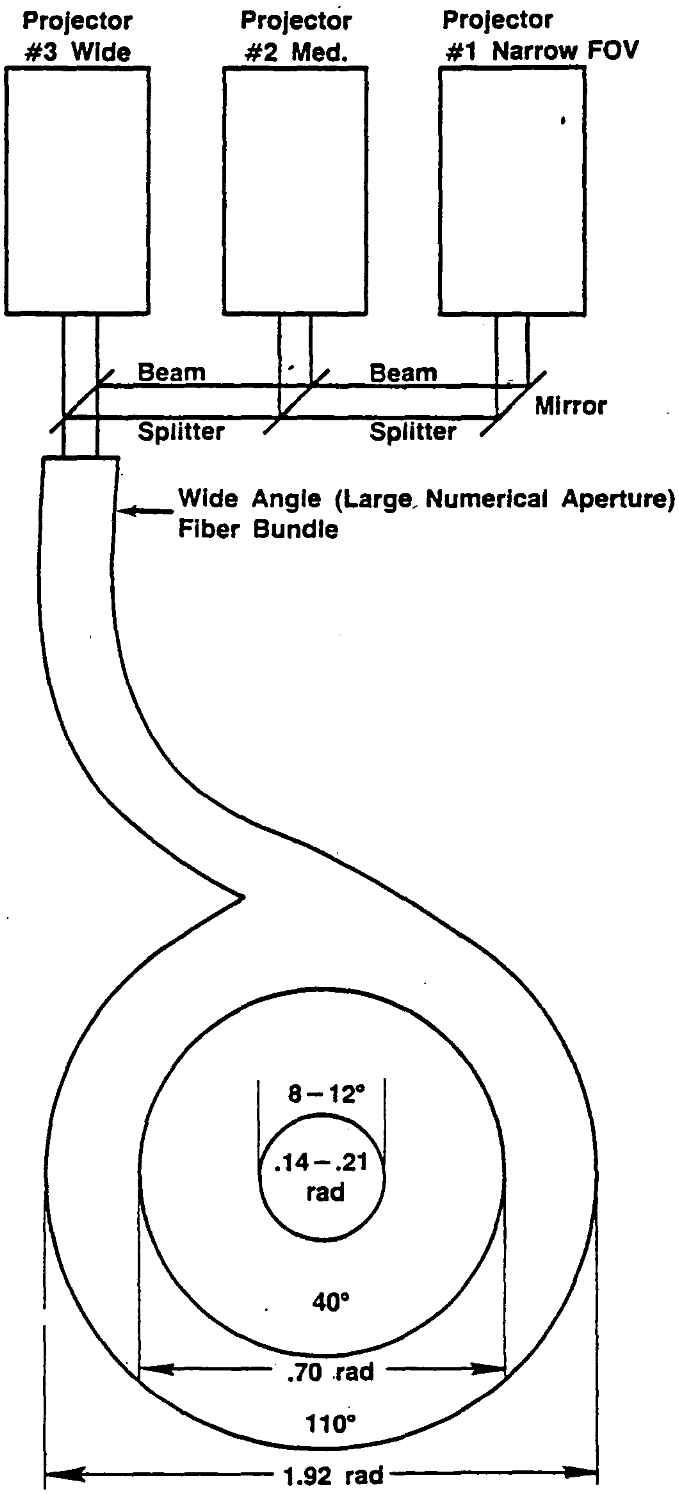


Figure 5-20: Variable Resolution Display Concept

Problems that are common in all HMD approaches are those of occulting the external scene where normal cockpit structure or special instrumentation is placed. Two methods to solve this problem are considered. One approach is to "map" the cockpit area and store data into a computer which then knows where all occulting structures are. This data is used in conjunction with head tracker data to determine where the display image raster should be occulted. This approach is currently in operation but requires that a map of the cockpit area be redone each time cockpit configurations are changed or internal devices are rearranged. This is time consuming and costly if it is required to change configurations frequently.

Another method for image occulting, which is still developmental, is an approach similar to that which is done in commercial TV where image keying is performed. Here one visual scene is permitted to control another visual scene. Thus, real cockpit and internal structure can be utilized in controlling the visual scene occulting in real-time and thus eliminating the need to remap the cockpit each time cockpit configurations are changed. This approach has merit but to our knowledge is not yet operational.

5.2 Visual System Generation

Many factors must be considered when designing wide field-of-view display systems. Image generation is one important factor in attaining capabilities necessary to meet total visual system requirements. Image generators consist of those mechanisms by which the visual scene is generated and consist of the image storage medium (which contains the characteristic features of the gaming area) and an information retrieval system for reformatting the stored data into a usable format for the visual display equipment. Image generation systems include computer generated imagery, camera/terrain model boards, earth/sky image generation projections an imaging film systems.

5.2.1 Computer Generated Imagery (CGI)

5.2.1.1 CGI Technology Overview

- Display Algorithms

  The basis for current CGI systems lies in theoretical algorithm investigations beginning two decades ago with an analysis of point and wire frame models, and proceeding to the creation of hidden surface algorithms. Virtually all theoretical work relevant to the ACAVS program, excepting work in texture generation, was complete by the early 1970s. The two major (competitive) philosophical approaches consist of list priority algorithms and depth priority algorithms.

  List priority algorithms are the "oldest" in the technological sense, with the best established real-time operational base. List priority algorithms make use of polygonal coherence by attempting to render scene priority at the surface level, rather than a scan line segment or pixel level. By properly preprocessing the data base, low complexity environments can be rapidly scanned and displayed in real time. The major shortcomings of priority systems are:

  1. As image complexity increases, the list of depth ordered faces becomes unwieldy and costly to process.
  2. As data base densities (environmental densities) increase, the cost of generating data structures becomes unmanageable.
  3. Object construction is highly structured, severely limiting modeling flexibility.

  It is our view that list priority algorithms and associated architecture, while dominant at this time (and for perhaps five more years), have a limited future life expectancy and will eventually disappear. Depth priority algorithms offer greater flexibility in data base construction since the restrictions normally associated with list priority algorithms (object convexity, listability, etc.) do not apply. Either depth priority algorithms or list priority algorithms can be implemented on a scan line or frame buffer basis. As requirements for scene complexity increases, the overhead associated with scan line oriented systems (e.g., sorting in Y and X) will increase and the scan line coherence will diminish. The scene capacity requirements of nap of the earth are high enough that a system utilizing a frame buffer (not serial processing of scan lines) is attractive, especially when considering expansion requirements for the ACAVS mission.

- CGI Architecture

  Assessing the direction of computer image generation architecture was much more difficult. There is considerable controversy within the computer graphics community concerning the development of real-time architectures, and particularly the impact of VLSI design methods. As stated, current structures are dominated by the polygon processing/list priority methods and are likely to remain so for the foreseeable future (five years or more). It is Boeing's view that in the mid- to late-1980s simulation of visual systems will turn to pixel-based rather than polygon-based systems; however, none of the projected charges can have much impact on the ACAVS program. It is our opinion that the most modular, expandable and flexible approach currently belongs to Evans and Sutherland. In the 1980-85 time frame, few architectural advances over the systems currently in use are expected. An exception to this will be the innovative development of texture generation methods.

- CGI Texture

  CGI texture is loosely defined as any method of CGI scene generation or modification that increases the apparent image complexity at a computational cost lower than that expected by conventional modeling methods. This definition differs from both the standard image processing definition of texture and the psychophysical definition of texture. Texture may be generated as correlated sequences with given image planes or frequency domain statistical properties, as maps or change functions, or as procedural functions. Although the engineering literature in texture analysis and (to a less extent) synthesis is growing, the psychophysical base on the effects of dynamic texture is sparse.

5.2.1.2 ACAVS CGI Technology Assessment

The ACAVS CGI technology assessment was undertaken with the following assumptions and restrictions in mind.

- Due to schedule and budgeting restrictions, major CGI components must be representative of proven production technology in the 1982-84 time frame.

- The CGI system should be modular and expandable. This means that the system should be capable of providing additional capability (e.g., number of channels, number of edges and texturing) beyond the initial configuration with a minimum of cost and disruption of ongoing ACAVS utilization.

- The procured system is desired to be compatible with the existing LINK Visual System at NASA Ames, in the sense that each can, with some manipulation, use the other's data base.

- The principal task of the CGI system is to develop complex, wide field-of-view raster scan scenes for terrain flight and Nap-of-the-Earth (NOE) missions.

5.2.1.3 CGI Manufacturer Assessment

Six computer image generation manufacturers and five additional computer graphics research centers were evaluated as part of this study effort (see Appendix E). Each organization was ranked low (1) to high (11) in terms of its technological and economic base, as well as its current status within the computer graphics community as a real-time graphics supplier. The rankings are the subjective evaluations of the Boeing study team. Technology base rankings were a function of two criteria, existing (or actual) technology base, and theoretical base. The latter is our evaluation of the research and development thrusts of the organization. Thus a product driven organization does not score as highly as a research house. The economic base factors are more direct, and were given higher weighting because they have a larger bearing on the success or failure of production technology projects. The business base refers to the CGI real-time related base. The R&D base refers to the size, not the quality, of the research program, and the hardware base is determined from the degree which each organization constructs its own hardware. A rank sum score of 24 is average. Based on our assessment, we can expect a narrowing of the competitive gap in the CGI marketplace, with a corresponding slip in position by the current market leaders. Thus, the likelihood that a serious mistake can be made in vendor selection for the ACAVS program is remote. Of the eleven institutions considered, we believe only five possess the overall experience, technical base, financial strength, and manufacturing capacity required to accomplish the ACAVS program.

5.2.2 Model Board

Camera/model board systems have long been used as a source for visual information in simulator displays. This combination consists of a TV camera/optical probe assembly (which represents the observer's eye point) mounted upon a movable gantry and a physical terrain model board, which is made to scale and representative of the real world. The visual image is positioned in 6 degrees-of-freedom with respect to the model terrain as a function of computer controlled inputs, thus making the generated image to the visual display appear in real-time to the human observer.

This technology assessment will not go into great detail on the camera/model board technology, as such, except to bring to the surface those areas where technology appears to be advancing for use on ACVAS. Currently TV cameras used in these systems are limited to about 1 229 line rates in black and white. These cameras may be utilized with a single wide FOV optical probe or may utilize a wide FOV probe and optically split the image into as many as four separate image display channels. The latter approach is preferred to keep image resolution and brightness up at the display but image mosaicking and edge matching give rise to special problems. Maximum image FOVs available from todays optical probes go as high as 360° in 8 video channels but probes better suited to rotorcraft simulator requirements seldom exceed 140° FOV in three video channels; with this FOV capability resolutions of 13 arc min/Lp are possible.

Map model technology has improved over the years. Terrain model boards have been made in various scaled sizes from less than 90:1 to greater than 10,000:1 depending upon the detail and the desired usable area. Current map technology has the capability to provide visual information with moving and pop-up targets. This visual data, fabricated in a 200:1 scale, makes possible the use of very intricate detailed objects that may be seen at the display with daylight or infrared characteristic. The latter is a function of the TV camera/illumination spectrum response and the secondary lighting characteristic utilized in model board illumination. This state-of-the-art multispectral concept is utilized by the Night Vision Laboratory at Ft. Belvoir, Virginia and has been developed by Independence Scaled Model Corporation.

An extension of the TV image sensor is the new laser camera technology that is emerging. This technology was developed as the image generation counterpart for the laser projection display concept previously described. This system utilizes the standard model board, decorated in color, and a laser scanner arrangement similar to the laser projector. Instead of banks of flood lights illuminating a map model for the TV camera/probe to view, the laser light is scanned out of a special optical scanner probe and the light thus emitted is picked up by large arrays of photo sensors. These photosensors are placed in the position of the illuminating source in the standard approach. If color capability is required, up to four lasers are optically combined prior to the scanner assembly and then a corresponding number of light sensing elements are placed in arrays parallel to the map surface to detect the reflected components of light. The electrical signal obtained from the light sensor is then transmitted to the visual display at video frequencies greater than 100 mHz. To insure the display image appears steady and is not displaced angularly with respect to the laser camera scanner position the two scanners (camera and display) must be synchronized and stable to within 5 nanoseconds. This image generation technology shows promise for realistic terrain data input for laser projectors. This technology can be tailored to operate with existing model board systems, but extensive rework would be required to replace the existing lighting with photo sensors and the gantry configuration would require modification to permit the laser camera to be utilized. In areas where both types of capability are desired, it is recommended that a separate facility be installed.

The main disadvantages of the model board approach are that mechanical devices are subject to mechanical inaccuracies, lag, overshoots and backlash; the gaming areas are also restricted, due to the physical constraints in fabricating the gantry and map models. Another problem is physical contact with map objects by the probe when the system malfunctions or there is pilot error. The laser camera does not have the FOV restrictions of the TV optical probe and may be used at the same FOV as the laser display, i.e., at least 60V x 180°H. One potential problem with the laser camera is producing an adequate horizon/sky that is illuminated for daytime scenes. Special provisions will be required to ensure that adequate illumination is received by the photo sensors above the horizon or that fill in data be supplied for above horizon scenes.

5.2.3 Other Image Generation Techniques

Other image generation techniques that have been used for years in special applications are earth/sky projector and film image generation (either from film projection or film flying spot scanner techniques). Earth/sky projector technology has not changed much except for hardware refinements. The image from this type of projector is permanently made on some type of transparent colored (usually blue on top and brown on bottom) dome or twin half domes. The image is illuminated via a point-source light which allows sharp images to be projected at low light levels, less than 2 fL, in extremely wide FOV, but they are static in content except for pitch, roll and yaw motions. This technology has very limited use in a research simulator which requires large amounts of real-time imagery in color, except to be utilized for horizon data and peripheral vision cues.

Film image generation techniques suffer from some of the same problems that exist with the earth/sky point light system. The data is generated on film and either projected onto a screen for the observer to view or generated via a flying spot scanner arrangement where the images on the film are translated with respect to the scanning beam and then displayed via TV to the observer. The main advantage of the film projection technique is that the scene is of film quality and may be in color and of high resolution. Some techniques are available where beam splitters are used to mix film and real-time images for a limited number of real-time targets. Range data, i.e., motion translations, are accomplished via optical image magnification with lenses. Draw backs of film techniques are that the imagery is "canned" and can be modified only slightly to produce perspective and translated motions before it appears fake. This type of image generator is used mainly for displays in special trainer type simulators where real-time imagery is not critical to aircraft handling qualities, long missions, etc.

5.3 Rotorcraft Cab

Rotorcraft cab requirements suggest enough flexibility in one cab structure to simulate numerous rotorcraft, both tandem and side-by-side. This demand on cab design requires an innovative approach. In most instances current simulation cabs fall into one of three groups:

- Cabs built to simulate a given aircraft
- Cabs built to simulate a type of aircraft (such as a tandem fighter or side-by-side transport)
- Multiple cabs, each representative of a type of aircraft, which are installed and removed from a motion system as simulation requirements change

A primary source of technology for the ACAVS cab structure is NASA Ames' existing interchangeable cab program. The I-cab base is similar in structure to that required for ACAVS. Both cabs will share a common interface with the VMS, the RSMG, and will have similar constraints on weight, clearance, center of gravity, etc. Although the majority of the simulation cabs assessed were conventional in design, a few innovative concepts merit consideration for ACAVS.

The MITL AHH is a tandem attack helicopter simulator cockpit located at the Martin Marietta simulation facility in Orlando, Florida. The cockpit is designed such that it can be separated, moving the forward crew position, to form independent or side-by-side configurations. This allows a large degree of flexibility in the placement of the cab(s) on a motion base(s). Each section of the cab is a self-contained unit or module which is capable of independent operation. The base of the simulator cab is constructed of 12-inch wide aluminum channel which allows for component placement within the base structure.

CAE in Canada incorporates their rack-mounted support equipment for CAB instruments into the perimeter of the simulator cab base structure. This arrangement makes for ease of access and keeps the weight and center of gravity as low as possible on the cab base.

Most of the force-feel systems assessed lacked the flexibility required for ACAVS. Typical systems are custom built for a particular simulator using actual aircraft hardware. One system, developed by McFadden Electronics, appears to have the flexibility and versatility to simulate a large number of rotorcraft configurations.

Information was gathered on a number of current rotorcraft to determine basic rotorcraft hardware requirements. The Sikorsky UH-60A Black Hawk was used as a base line configuration for the ACAVS simulator. The Black Hawk is intended to serve as the U.S. Army's primary combat assault helicopter. It is a twin turbine combat assault squad transport with a four-blade main rotor. The AH-64 was selected as a typical tandem helicopter. Appendix K contains a list of instruments and controls found in the UH-60A and AH-64.

5.4 Development Station

NASA Ames Research Center currently has a fixed-base and development station area which is part of the interchangeable cab program. Details on both the operation of the current interchangeable cab station and projected needs for the ACAVS development station were acquired during on-site interviews with NASA Ames personnel. The interchangeable cab fixed-base and development station concept consists of two functionally identical stations which provide for cab mounting, cab/station interconnect and cab testing and checkout. With two identical cab stations, the distinction between the development station versus the fixed-base station depends upon the status of the cab occupying the station. Usually the station occupied by the cab which is fully interfaced with the control computer would be designated as the fixed-base station and would be capable of simulated flight.

A raised floor is used in the development station area with all electrical, hydraulic, and utility connections routed beneath the floor. The development station control room is housed in an area adjacent to the cab buildup area, with glass windows providing visual contact between the two areas. The basic arrangement of the development station is shown in Figure 5-21.

The development station is used to reduce the motion base downtime by permitting cockpit/cab configuration changes prior to occupying the VMS. This is achieved by providing space and equipment for the removal and storage of specific equipment from previously completed projects, the installation of specific equipment for a new project and off-line checkout and testing of cab equipment.

The control room hardware and interfaces shown in Figures 5-22, 5-23, and 5-24 consist of the hardware required to connect the development station to a host computer and control and monitor simulations and checkouts. A Computer Input/Output Unit (CIOU) is used to link the control room to the host computer (a Sigma 7). The Sigma 7 interfaces several simulation areas through a number of CIOUs. The CIOUs are a NASA Ames-designed custom interface using a 10 megabit/sec serial data link. A CIOU is required at each end of the data link. At the control room it connects to a general purpose minicomputer, a PDP-11/55, which serves as a communication control during a host computer controlled simulation and off-line as a diagnostic computer. The minicomputer is interfaced to other simulator hardware through a Communications Interface Controller (CIC).

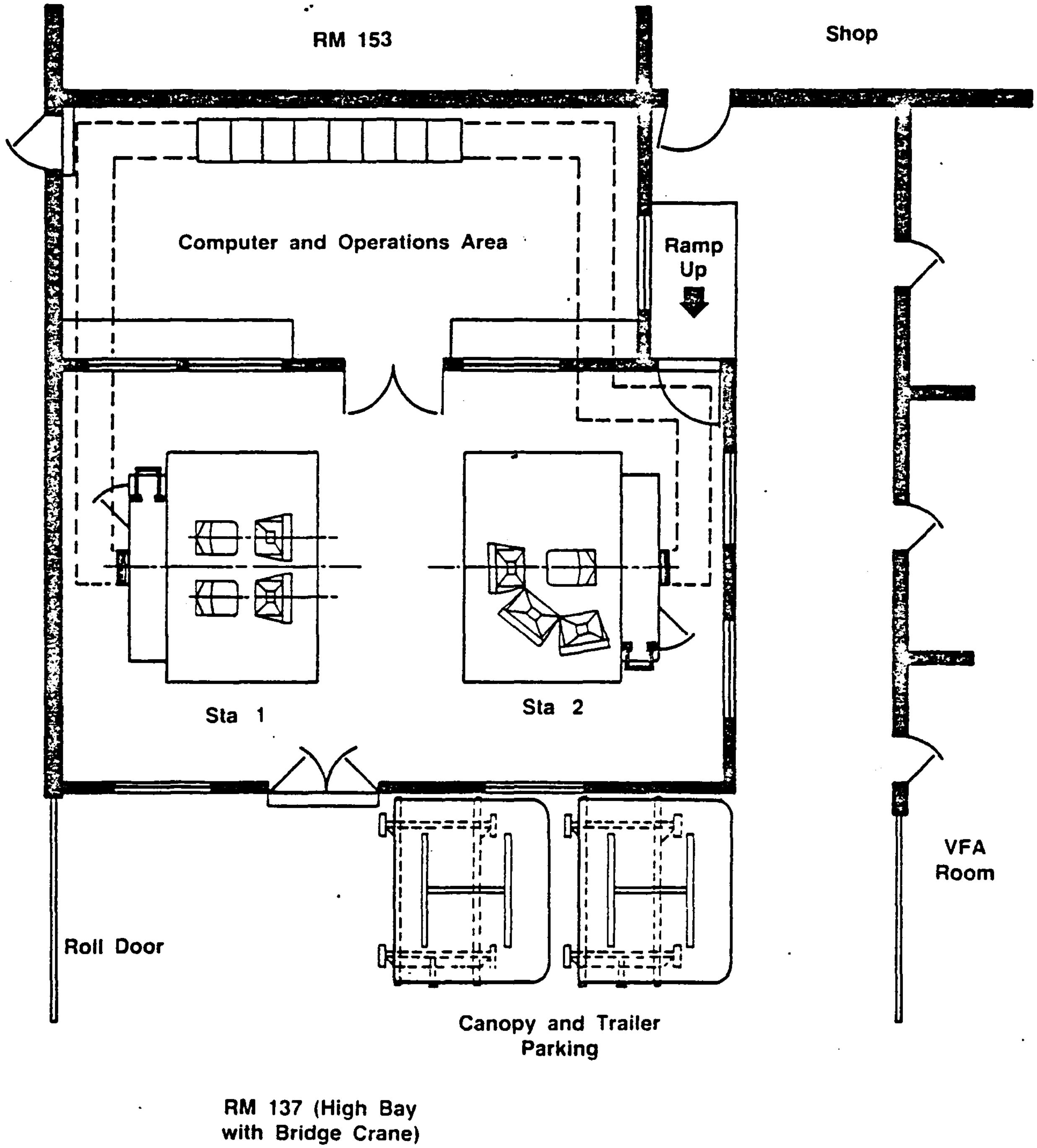


Figure 5-21: Interchangeable Cab Fixed Base and Development Stations

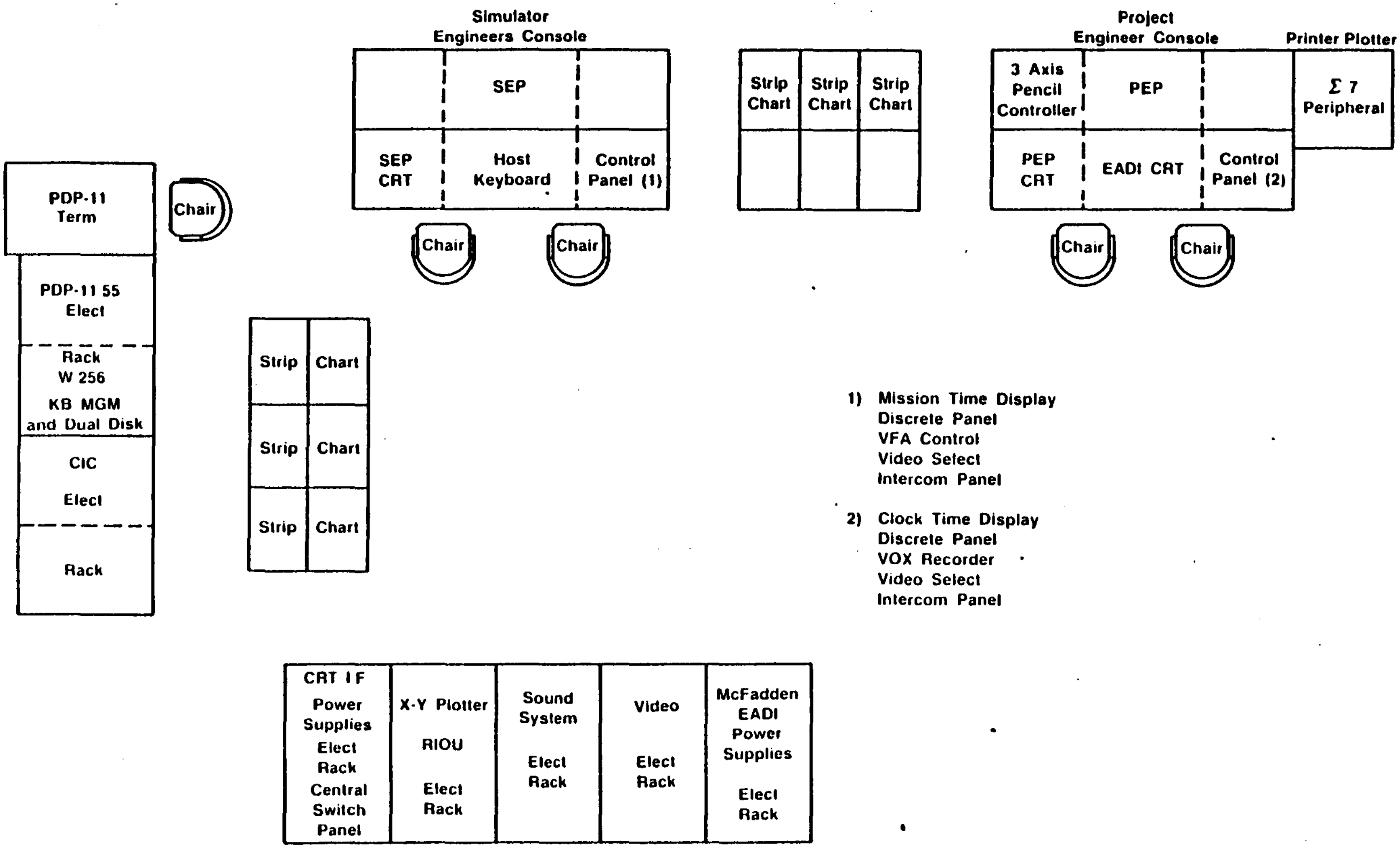


Figure 5-22: Interchangeable Cab Control Room Hardware

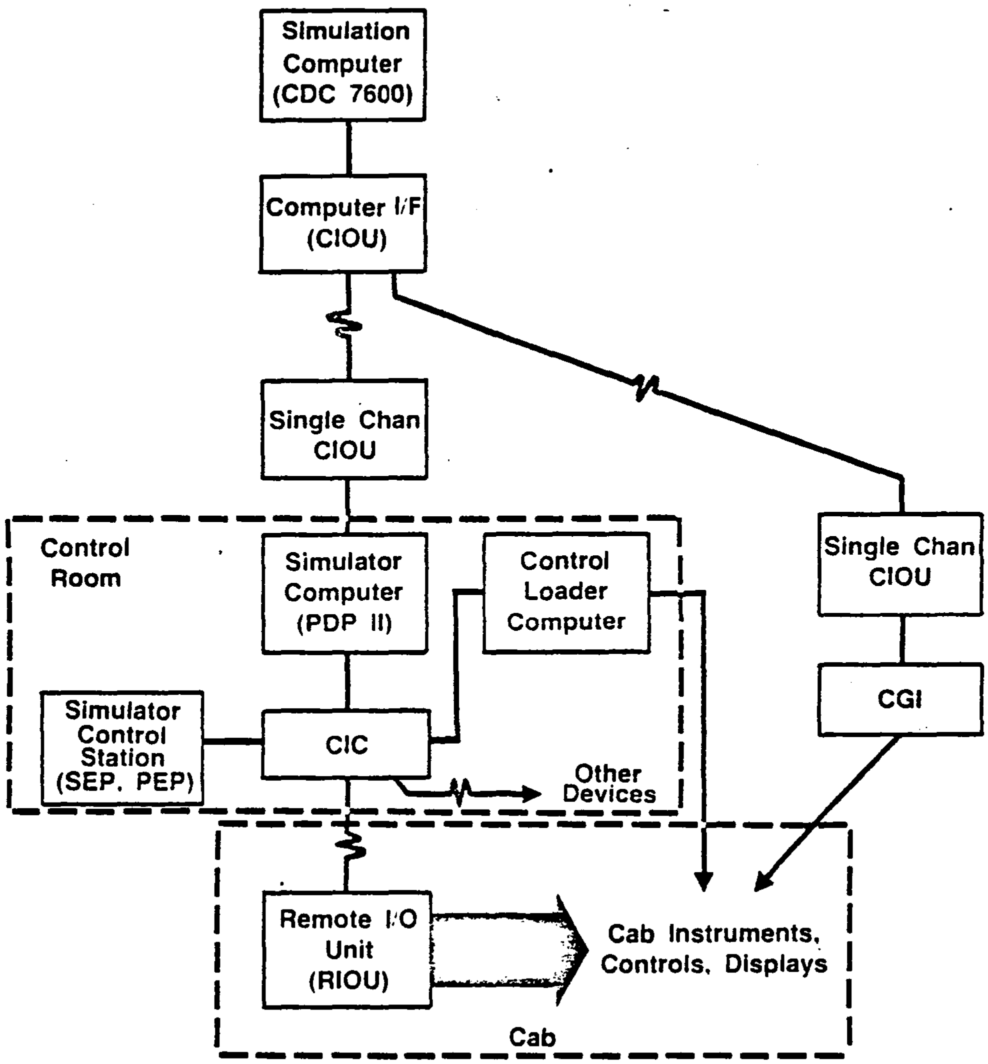


Figure 5-23: Control Room Interfaces

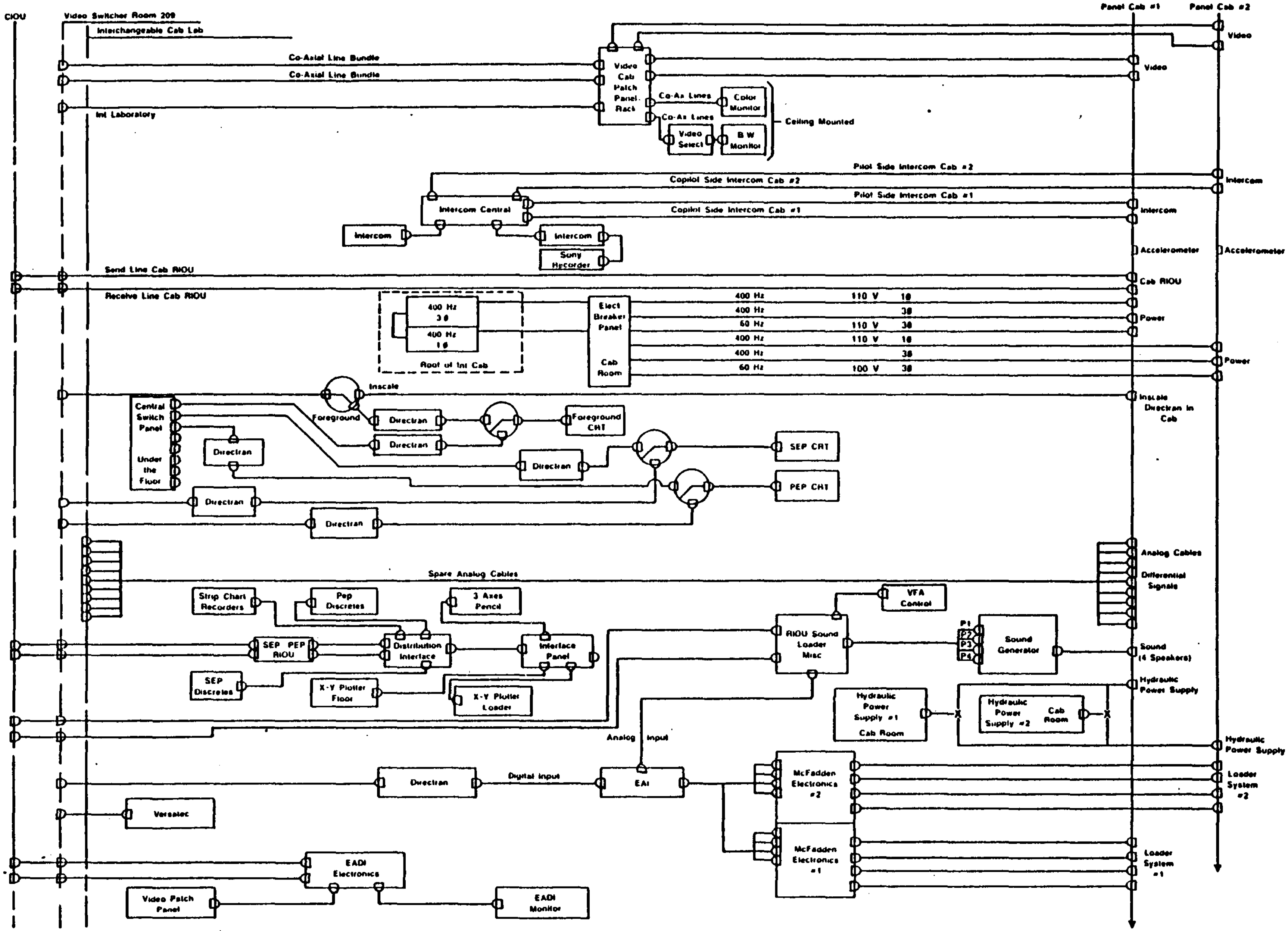


Figure 5-24: Control Room Signal Flow

The Communication Interface Controller provides one to 16 channels of serial bi-phase encode data at a 10 megabit/second data rate. Data is transferred in the DMA mode from the PDP-11/55 memory to the Remote Input/Output Unit (RIOU) memory. The CIC is also a NASA Ames-designed unit composed of a standard PDP DR-11B DMA interface and NASA-designed circuit boards.

The Remote Linkage System is composed of the CIC and one to 16 RIOUs of NASA Ames design. Each RIOU provides a general purpose interface that performs digital to analog, analog to digital, and digital to synchro conversions, and also provides for discrete digital inputs and outputs. They are intelligent controllers whose activities are directed by a Motorola 6800 microprocessor. Remote input/output units interface the PDP-11/55 to the simulation engineer's console, project engineer's console, peripheral hardware, control loader system, EADI, and the cab sound system.

Peripheral hardware for the PDP-11/55 includes:

- Disk drive (dual drive)
- Line printer
- CRT keyboard
- 256K bytes of memory
- Strip charts (6)
- 3-axis pencil controller
- x-y plotter

The simulation engineer's console allows for the monitoring, control and checkout of the cab/visual systems. It is composed of:

- Simulation Engineer's Control Panel (SEP)
- Mission time display
- Discrete simulation control panel
- VFA control
- Video select panel
- Intercom panel
- Host computer keyboard
- SEP CRT

Similarly, the project engineer's console allows the project engineer to monitor, control and check out the cab/visual system. The project engineer's console contains the following:

- Project engineer's control panel
- Clock time display

- Discrete simulation control panel
- Video select panel
- Intercom panel
- PEP CRT
- EADI CRT
- 3-axis pencil controller
- VOX recorder

The console room also contains the following support hardware and electronic equipment racks:

- McFadden force-feel system electronics
- EADI electronics and power supplies
- Video electronics
- Sound system electronics
- CRT interface and power supplies
- Control switch panel
- RIOU equipment racks

5.5 Sound Simulation Technology Assessment

Sound systems for rotorcraft simulators must be able to reproduce the characteristic sounds that eminate from the rotorcraft. These sounds are very important to the operator because they provide cues which impact his handling of the aircraft. Sounds which are being reproduced in current rotorcraft simulator systems are listed below:

- Engine
- Transmission
- Undercarriage hydraulics
- Ancillary/auxiliary equipment
- Rotorblade
- Taxiing and braking
- Landing and ground reflection
- Airflow

- Excessive aerodynamic loading
- Weapon fire

Simulators surveyed utilized at least three large speaker/amplifier systems to reproduce the characteristic sounds. Power amplifier systems used had ratings as high as 100 watts; this capability is necessary to effectively reproduce the magnitude of sounds emitting from some rotorcraft systems.

In all simulators surveyed, the speakers were placed at the primary noise location of the equipment it was to simulate. Thus one sound system was primarily engine, one transmission and another system mounted to reproduce those sounds emanating below the rotorcraft. Data source for the initial sound characteristics is usually developed from source audio tapes of the specific rotorcraft. A spectrum analysis is then performed to identify the frequency components and characteristics of each sound source.

Sound system technology today is primarily composed of voltage controlled oscillators and many spectral filters for generating the characteristics of the individual sounds (see Figure 5-25). Today's technology is integrating these devices into systems that are microprocessor controlled. This new technology permits the rotorcraft sound parameter data to be transmitted via digital code from the main aircraft simulation computer to the "smart" sound system. The microprocessor stores the last data update in memory and then proceeds to decode this data into the necessary wareform, frequency and amplitude changes that are required.

In some cases this is accomplished by performing real-time sampling and table lookup data for special functions. Thus frequencies and special harmonic characteristics are under direct control of the microcomputer and hardware. This flexibility also speeds system checkout and sound system maintenance.

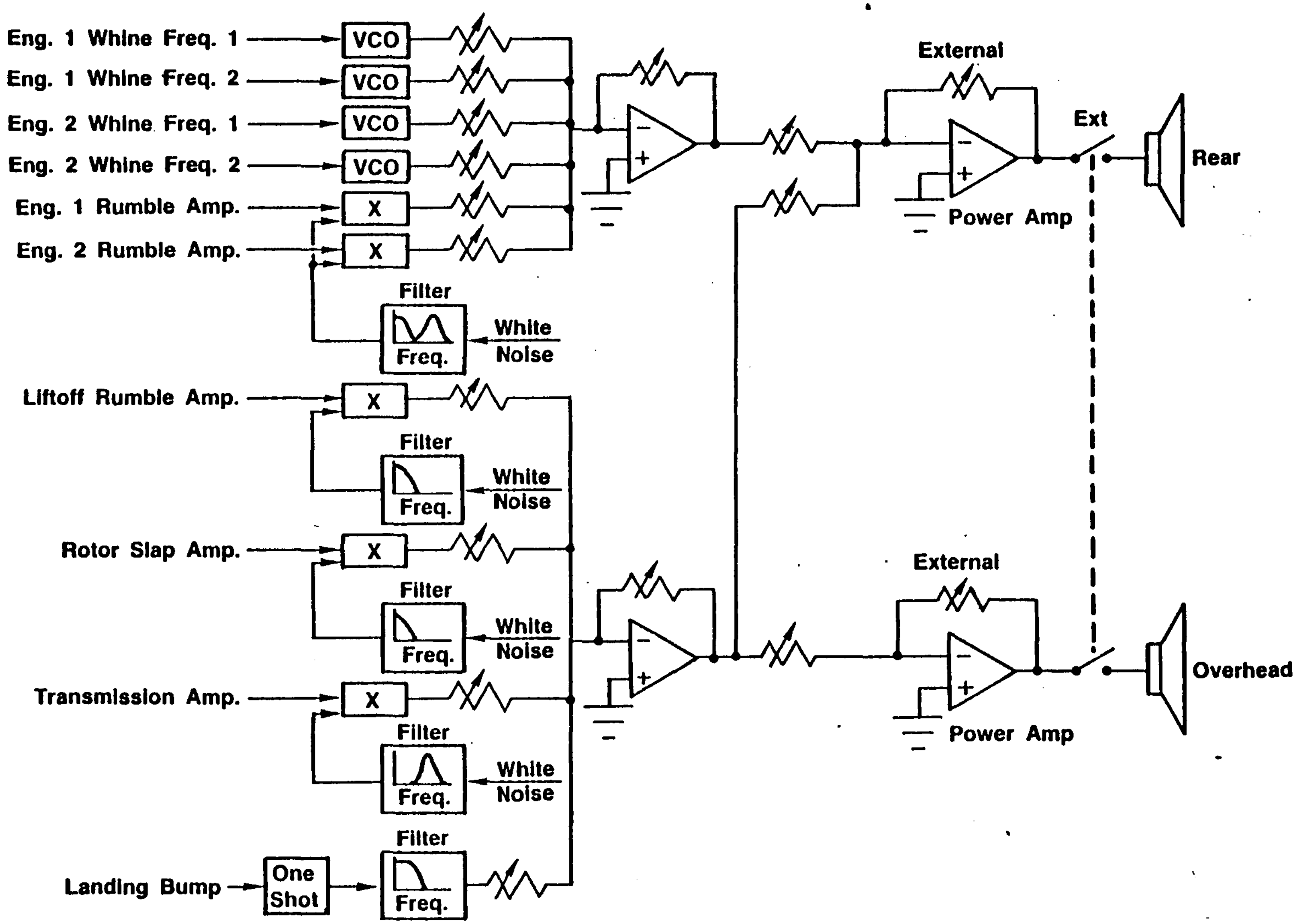


Figure 5-25: Rotorcraft Sound System

6.0 CONCEPT SYNTHESIS

A multistep process was used to develop viable candidate concepts for ACAVS. First a team session was held to synthesize a set of preliminary design concepts. Team members were encouraged to contribute freely, using analyses, trade studies, NASA interviews and the SOW as guidelines but not totally limiting innovative ideas by ACAVS requirements. An attempt was made to consider all plausible combinations. The resulting concepts were organized and used as source material for follow-on sessions in which available information was used to evaluate and reduce the previously generated preliminary design concept to candidate concepts that satisfy user requirements. A systems approach was taken and each system optimized considering cost, flexibility, reliability, maintainability, accessibility, and potential for future growth. Further analyses and trade-offs were identified and performed to arrive at the recommended candidate concepts. (See Figure 6-1.)

Because the visual systems tend to be the area which places the most stringent requirements on the system as a whole, each concept is identified by the visual system incorporated. For convenience it seems appropriate to discuss the systems by area: cab, development station and visual systems. This does not imply that the systems' concepts were conceived and developed in this manner, for it is only as the components are brought together as a complete, integrated simulation system that a workable concept can be considered.

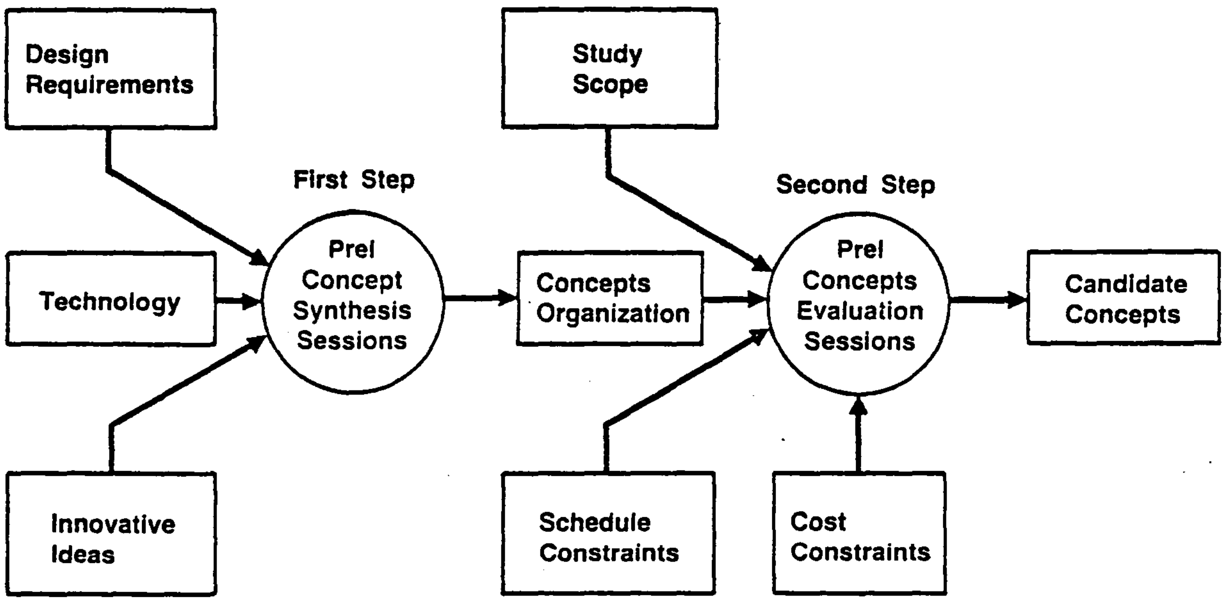


Figure 6-1: Design Concepts Development

6.1 Rotorcraft Simulator Cab and Development Station

6.1.1 Rotorcraft Simulator Cab and Cockpit Hardware

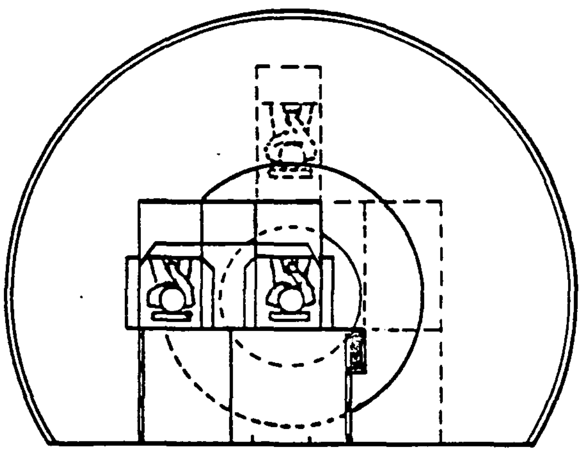
6.1.1.1 Rotorcraft Simulator Cab Structure

The physical arrangement of the cab structure is dependent, in many areas, on the visual presentation system selected. The presence or absence of a display screen or dome can be used to divide proposed cab designs into two groups. Visual presentation systems which require a display surface (screen), also require a large degree of flexibility in the cab structure. If the display devices are fixed in a given position relative to the motion base (which is required in most cases to maintain alignment, focus, etc.) the simulator cab must be repositioned keeping the primary pilot aligned with the display devices to achieve the crew station flexibility need for ACAVS (see Figures 6-2 and 6-3). With a display system not requiring such rigid alignment, such as a helmet-mounted display or CRTs, the display devices can move with the primary pilot and the simulator cab remain fixed relative to the motion base.

One exception could be the laser projector. Because of the large depth of field, the projector is not constrained to the center of a dome screen. Thus, the laser could possibly be mounted between the pilot and copilot, eliminating the need for structural repositioning of the cab components. More study is needed in this area to determine feasibility.

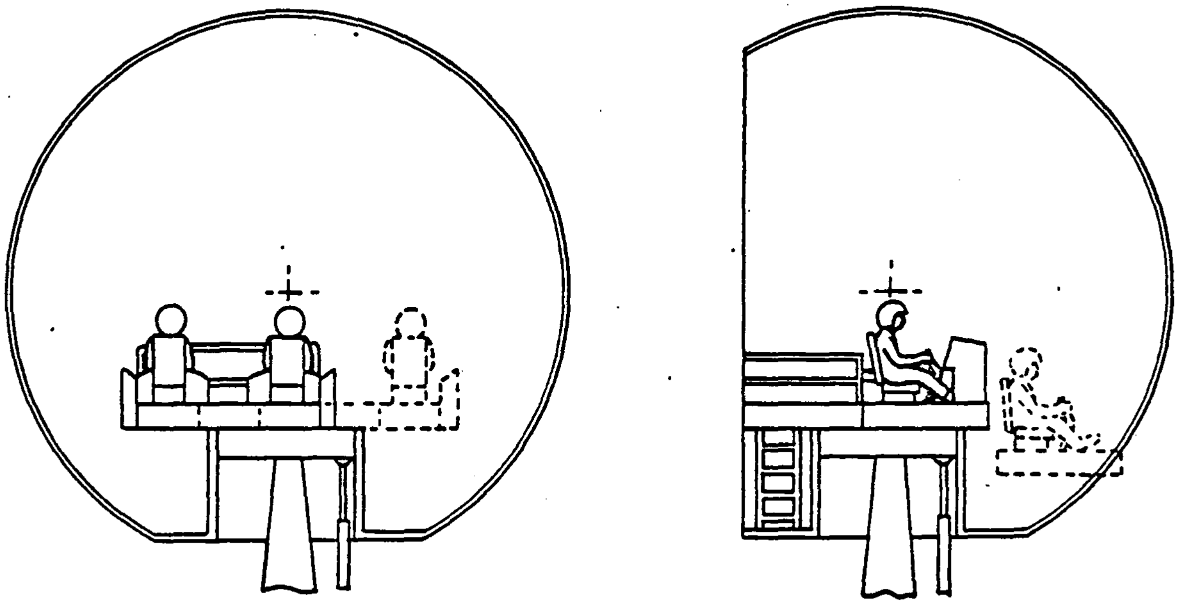
6.1.1.1.1 Simulation Cabs Requiring Module Repositioning

To meet both the requirement for crew station flexibility and alignment of the primary pilot with the visual presentation system, a modular approach was selected for the cab design. Each module would be a self-contained unit; that is, it would contain all the hardware which would require movement, during cab reconfiguration, in one "packaged" unit (see Figure 6-4). Modular units then bolt together to form a simulator cab. Such units would include a pilot, copilot, aisle stand, left and right side consoles, and visual mounting modules. Each module could be connected in a number of ways to form various configurations achieving, pilot on right, pilot on left and tandem or single pilot arrangements as shown in Figures 6-2 and 6-3 (also see Figures 6-12 through 6-16 in Paragraph 6.2). The visual system mounting module would remain fixed relative to the motion base and display screen, and provide proper alignment for the other modules.



Top View

Figure 6-2: Cockpit Flexibility and Accessibility (Top View)



Rear View Side View

Figure 6-3: Cockpit Flexibility and Accessibility: Rear View and Side View

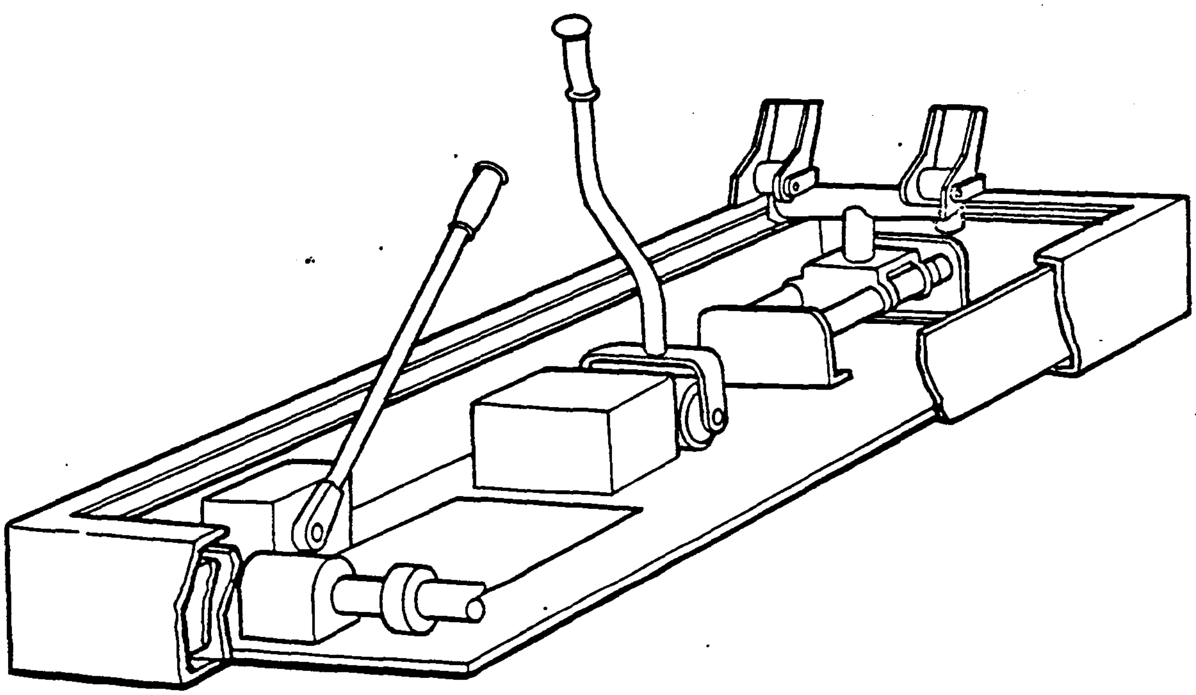


Figure 6-4: Modular Unit Concept

6.1.1.1.1 Continued

A spherical dome is proposed for the visual display surface. The dome would be attached to the motion base at the cab/RSMG interface. A walkway around the base of the dome would provide access to various components and facilitate maintenance and assembly/disassembly. Safety considerations also suggest a walkway and exit from inside the dome.

Pilot and copilot modules would contain a seat, primary flight controls, forward panels, and vibration system. Twelve-inch aluminum channel will form an outside framework with an inner box constructed of aluminum plate and connected to the outer frame with rubber mounts. Rubber mounts are required for isolation of the vibration system contained within the modular unit and decrease the transmission of vibrations into the visual system and RSMG. The aisle stand module will contain the aisle stand, secondary controls and the center forward panel. It would also be of double frame construction to isolate vibrations. The visual mounting module would require a different type of construction such that it would provide maximum support and rigidity for the visual presentation hardware and physical alignment for the other modules.

6.1.1.1.2 Simulation Cabs Not Requiring Module Repositioning

With a visual display system not requiring repositioning of the cab, as the primary pilot is repositioned, a different cab design approach can be taken which is simpler and more compatible with the interchangeable cab program. In the case of a helmet-mounted display or CRTs, a screen is not required and a cover over the cab would be all that is needed. Visual alignment with a screen is not required as the visual system can move and be repositioned with each primary pilot move. For such display systems the basic cab configuration would be very similar to the current interchangeable cab and require deviation only in those areas which are peculiar to ACAVS, such as the vibration system and increased crew position flexibility (see Figure 6-16, Paragraph 6.2).

6.1.1.2 Vibration System

The proposed vibration system would be self-contained within the pilot, copilot, aisle stand and side console modules. Isolation is provided by the double box design and rubber mounts explained above. Additional research is required to determine the exact design and material required for the rubber mounts. They should be designed such as to isolate vibrations originating with vibration system from other system components, but not degrade the motion cues to crew members. (This area may present some problems in the vibration system's overall design and require some modifications.)

The vibration source could be hydraulically or electrically derived (such as an eccentric weight on a shaft) but would require attachment to only the inner box base plate to insure maximum isolation from the simulator cab base. The vibration system would be programmable for the frequencies and amplitudes required (see Figure 4-1) and aligned to provide amplitude inputs in the vertical and lateral directions. A lower bound on the frequencies is required to limit the amount of translation provided (amplitude). Such translation, for safety and design considerations, should probably be limited to around 6.35 mm (.25 inch) which would occur around 3 to 5 Hz, depending on the final weight of each module.

6.1.1.3 Sound System

The sound system would consist of a number of speakers housed and mounted such that they could be moved or repositioned for special sound requirements. A basic placement layout would be used as derived from baseline and typical rotorcraft to achieve an optimum speaker arrangement. Such an arrangement would place the speaker so as to give sufficiently oriented sound cues to be representative of engine, transmission, and rotor contributions. All of these discrete frequency noises would vary together according to rotor speed. Figure 4-4 shows a typical noise spectrum for a rotorcraft. In addition to above mentioned noise sources, weapon fire would be programmed into the sound system.

6.1.1.4 Primary Flight Controls

A McFadden force-feel system is proposed for a number of reasons. The first is compatibility with existing NASA Ames equipment. Secondly, it appears to be the only system currently available which meets the force-feel system requirements of ACAVS and also provides the flexibility and versatility needed. Vibration on the primary flight controls would be provided through two sources, the base plate of the inner box of the pilot's and copilot's modules; and programmed through the hydraulics to the controllers. The inner box is designed to provide a fluid-tight sump to contain any hydraulic leaks. Hydraulic connections would be flexible with quick disconnects at the module interfaces. Clearance holes would also be provided to route hydraulic lines between various modules to accommodate rearrangement of the modules.

6.1.1.5 Air Conditioning

Initially, a self-contained air conditioning system was considered which would remain with the cab structure. But because of compatibility considerations and the problems (both physical and safety) involved with attempting to carry a compressor with refrigerant on board the cab, a system similar to the interchangeable cab was selected. Air conditioning will thus be piped in from the interchangeable cab system or one similar using a flex-hose connector. Such a system will also require an air conditioning hookup at the development station.

6.1.1.6 Safety and Egress

Safety and egress considerations were incorporated into each cab system design. Visual presentation hardware is placed to not restrict crew member exit or present a safety hazard. With the dome-type visual system the mounting module includes safety railing and a ladder to a walkway around the base of the dome (see Figure 6-3). Egress openings and knockouts are provided at the base of the dome structure to allow passage to the VMS carriage. In the event the cab sphere does not settle to the VMS carriage, an emergency escape ladder is provided. The interchangeable cab-type cockpit would have an egress system similar to the one currently being used on the interchangeable cab.

An emergency override panel would be incorporated into the cockpit which would allow the pilot to override the motion system. The panel would also allow the vibration system and force-feel system to be overridden.

A fire safety system would also be built into the cab/visual structure. The fire suppression agent must not produce a toxic effect within a confined space in the event of use while crew members were still within the cab structure.

6.1.2 Development Station

The proposed development station would consist of:

- RSMG mounting area
- Rotorcraft simulator cab buildup area
- Overhead crane
- Control room
- Simulator entrance/exit ramp

The development station would be located in Room 153 of Building 243 at NASA Ames Research Center. The proposed location for the control room is on top of the existing interchangeable cab control room which is adjacent to Room 153.

6.1.2.1 RSMG Mounting Area

The RSMG will be temporarily located in the development station requiring a mounting area. Construction of the RSMG mounting is part of a separate NASA Ames contract. When the RSMG is permanently moved to the VMS, a mounting adaptor would be installed between the cab/visual system and the RSMG floor mount, maintaining the original height. The RSMG will be mounted to allow for clearance of a 20.5-foot diameter spherical clearance envelope. This clearance must also allow for the dynamic motions of the RSMG (see Figure 6-5). Access to the cab/visual system would be provided by a boarding ramp (see Figures 6-6 and 6-7) during operation and checkout and by a system of custom-built scaffolding.

6.1.2.2 Rotorcraft Simulator Cab Buildup Area

A rotorcraft simulator cab buildup area would be located in Room 153 adjacent to the RSMG floor mount. The buildup area would provide rigid mounting of the cab/visual system either as a unit or separately. Storage provisions would be provided along the walls to store cab/visual system hardware when it is not in use. The entire floor of the development station would be covered with a raised (computer-type) floor and all utilities, power and hydraulics routed under the floor. Air conditioning ducts would also be routed under the floor with provisions made for an interchangeable cab-type interface with the cab/visual system available at both the buildup area and the RSMG mounting area.

Electrical and compressed air outlets would be provided for the operation of power tools. Sufficient lighting would also be installed. Telephone connections would be provided at all locations requiring telephone communications.

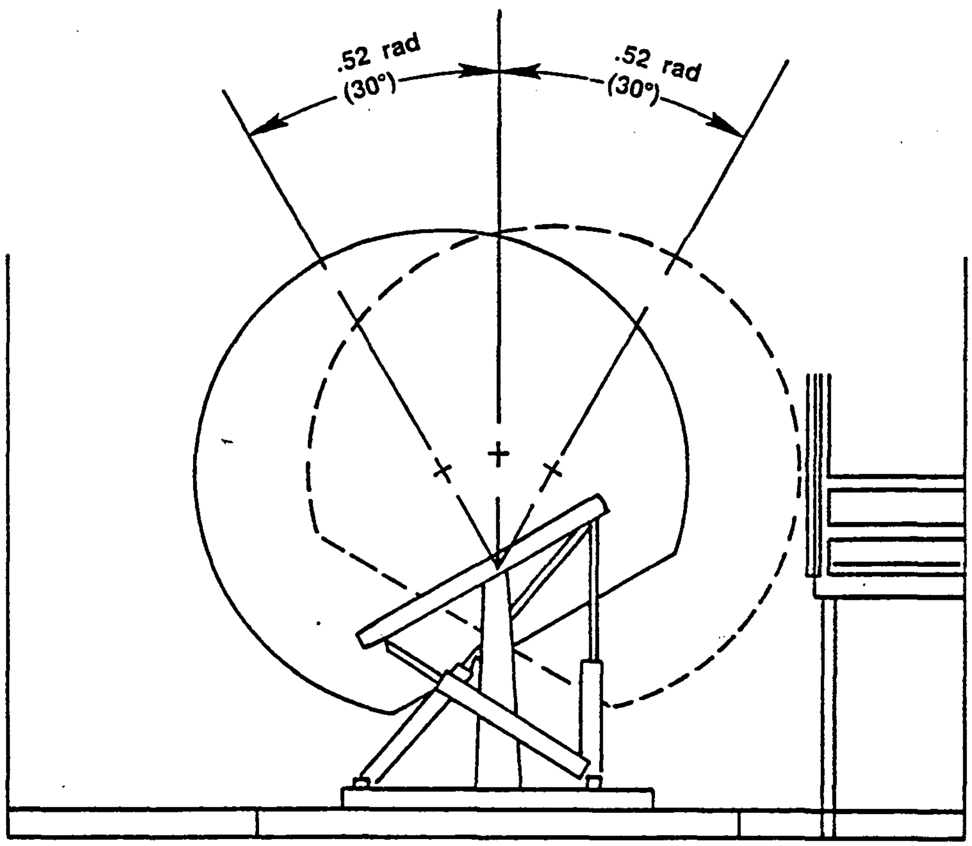


Figure 6-5: Development Station Preliminary Concept: Clearance for RSMG

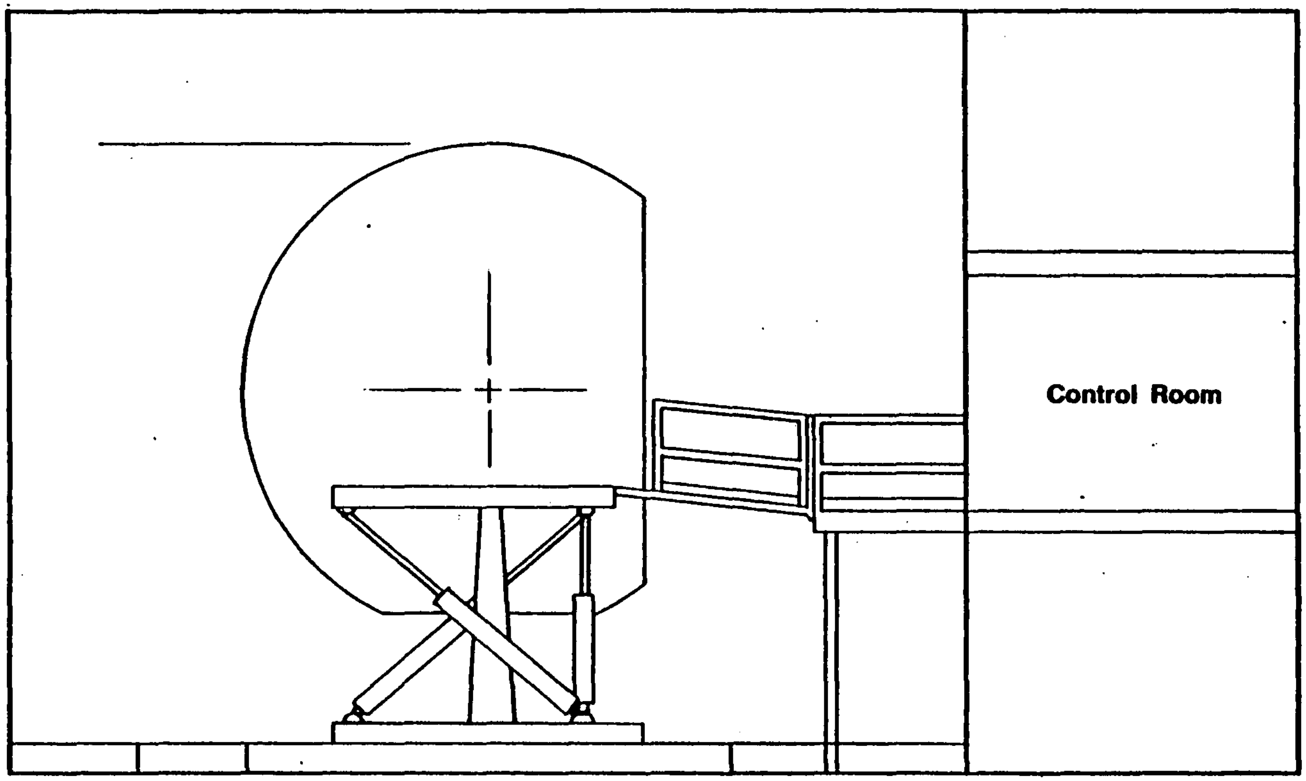


Figure 6-6: Development Station, Preliminary Concept: Elevated Platform and Control Room

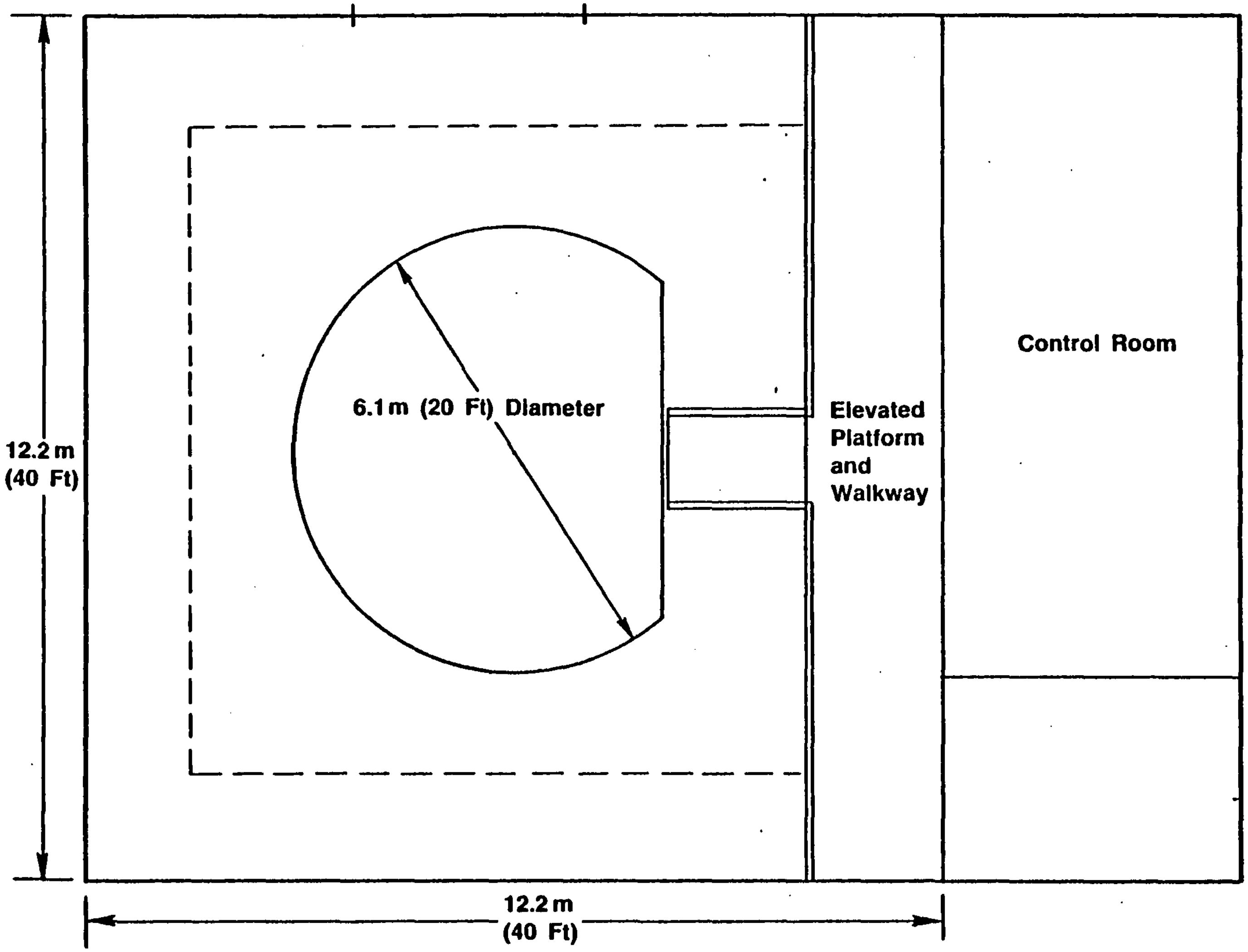


Figure 6-7: Development Station, Preliminary concepts: Space Requirements for 6.1m (20 Ft) Sphere

6.1.2.3 Overhead Crane

An overhead crane system would be installed in the development station to lift the cab/visual system on and off the RSMG, buildup area floor mounts and transportation dollies.

6.1.2.4 Control Room

The proposed location for the control room is on top of the current interchangeable cab control room. A stairway would be provided from the first floor to the control room with a walkway along the control room/development station shared wall. Two sets of double doors would allow entry/exit to the control room. A number of large windows would provide visual contact between the control room and other areas of the development station (see Figure 6-8). A computer-type floor would be provided with all utilities routed under the floor. Air conditioning would be supplied to the bottoms of all computers and equipment racks. Hardware listed in Section 5.0 which is similar to that currently being used in the interchangeable cab control room would also be included in the ACAVS control room.

As stated above, a walkway would be constructed along the development station wall adjacent to the control room at the control room floor level. Such a walkway would provide an entry/exit to the control room and an entry ramp for the cab/visual system while on the RSMG or adaptor. In addition, the walkway could possibly be connected to an existing stairway and landing outside of Room 231.

6.1.2.5 Simulator Entrance/Exit Ramp

An entrance/exit ramp is proposed to extend from the control room walkway to the cab/visual system when located on the RSMG or adaptor. The ramp would be moved out of the path of the motion system by hydraulic devices.

6.2 Visual Display Systems

Eleven concepts were considered during the initial synthesis effort. Table 6-1 presents a summary of these concepts with an initial evaluation. Several concepts were rejected because of obvious incompatibility with ACAVS requirements. The remaining concepts were developed more thoroughly. Detailed evaluation of those remaining is presented in Section 7.0. Those 11 concepts are as follows:

6.2.1 Small Beam Splitter Using Fixed Miniature Spheres

A small dome, 4 to 5 feet in diameter, was postulated, using one dome for each crew member. Each screen was illuminated by three projectors which were fiber optically coupled to a projection lens. This configuration resembled an enlarged helmet-mounted concept with the helmet detached from the crew member and fixed in space. The concept was rejected because of restrictions on crew member's motion and excessive distortion which would be introduced by head movement.

6.2.2 Back Projected TV

All back projected TV systems which could be conceived during the preliminary synthesis were too large to fit the clearance envelope required by ACAVS. A structural problem also existed in supporting a number of projectors at a considerable distance from the center of rotation.

6.2.3 Back Projected Laser

The same problems existed for the back projected laser concepts as given above for back projected TV. In addition, stability of the laser table and lack of mobility of support hardware presented severe problems.

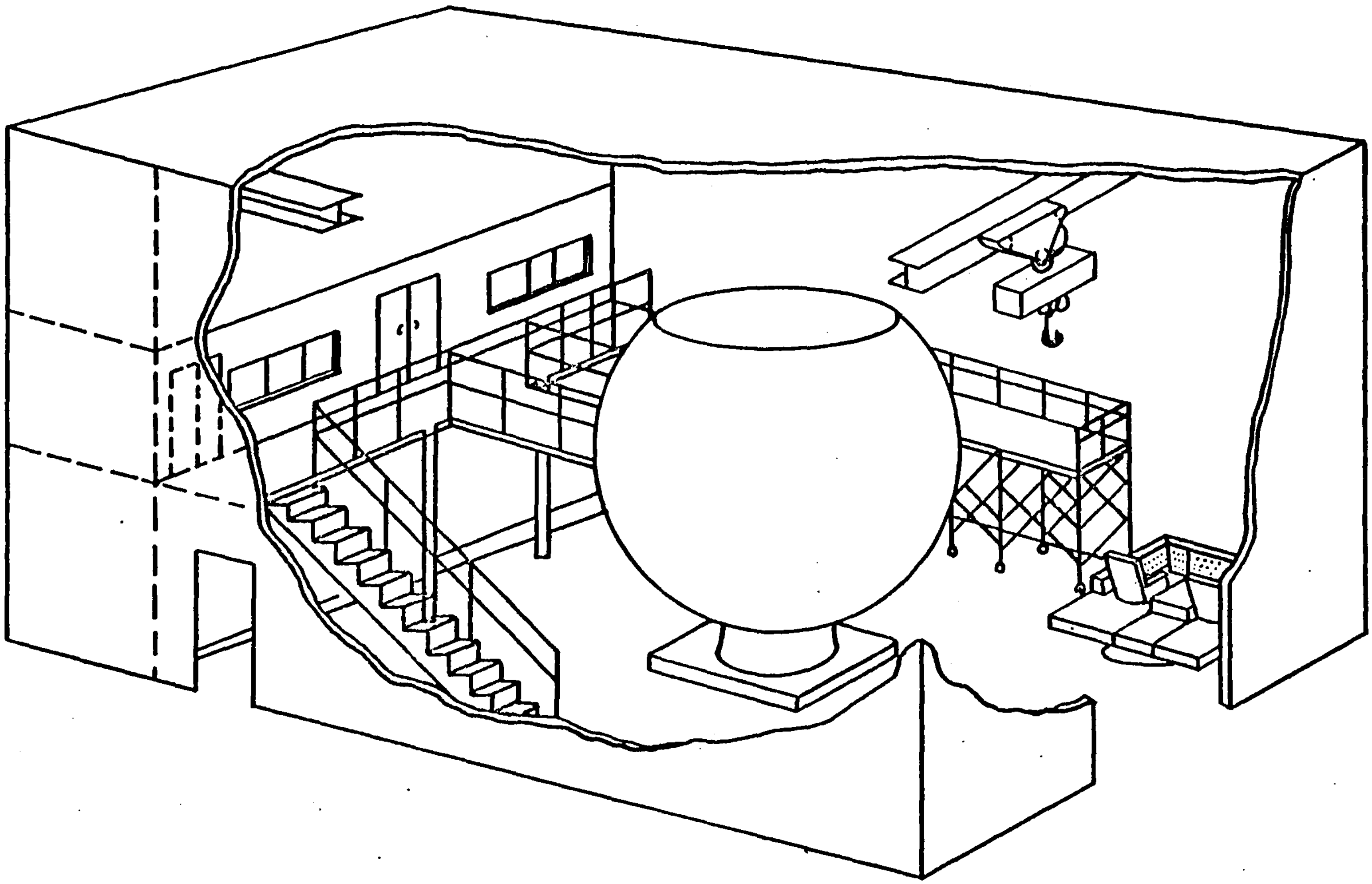


Figure 6-8: Proposed Development Station Layout

Concept	Strengths	Weakness	Action
Small Beam Splitter Using Miniature Spheres	Good Brightness	High Head Motion Restriction, Large Developmental Risk	Rejected
Back Projected TV	Low Complexity	Exceeds Maximum Envelope	Rejected
Back Projected Laser	Low Complexity, Good Brightness	Exceeds Maximum Envelope	Rejected
Multiviewer	Large Exit Pupil	Alignment Problems, Large Size, Very High Alignment Requirements	Rejected
In-line Pancake Window Mosaic	Large Field of View	Low Resolution/High Cost	Rejected
Helmet-mounted Projection with High Gain Screen	High System Configuration Flexibility	High Developmental Risk	Rejected
TV Projector/Periscope (Servoed) with Dome	Low Developmental Risk, High Brightness	Low Reliability, High Alignment Requirements	Accepted
TV Projector/Fiber Optic (Servoed) with Dome	Good System Configuration Flexibility	Some Developmental Risk	Accepted
TV Projector/Fiber Optic (Fixed) with Dome	Good System Configuration Flexibility	Limited Field of View	Accepted
Laser Projector with Dome	Good Picture Continuity, Good Flexibility	High Cost, Some Development Required	Accepted
Helmet-mounted Display	High Sys Config Flexibility, Low Cost, High Brightness, Low Total Weight	Some Development Required	Accepted

Table 6-1: ACAVS Display Concepts Considered

6.2.4 Helmet-Mounted Projection with High Gain Screen

A helmet-mounted projection system would consist of a projection device located on the crew member's helmet and projected onto a high gain screen. Low brightness projection is used to reduce the reflection off cockpit hardware. Advantages of such a system include system configuration flexibility and a slewable area of interest without expensive head tracker and servo equipment. The problem is such that a display device is not currently available, even in prototype form. In addition, a high gain screen would present special problems with the ACAVS requirement of transportability which would require assembly/disassembly of the screen. This concept is considered a high developmental risk at the present.

6.2.5 Multiviewer Concept

The multiviewer concept described in Paragraph 5.1.2.2 is a wide FOV virtual image concept that was proposed for use in the ACAVS configuration. The basic display concept has a 180°H by 60°V FOV and has a wide viewing volume that potentially permits various visual configurations to be arranged inside the cab area. Major equipment required for this visual concept is as follows:

- One spherical mirror that is 25 percent of FOV
- One wide-angle rear projection screen
- Three folding mirrors to reflect projector illumination to the rear projection screen
- Three 1 000 line TV high-brightness color projectors
- Three CGI channels providing at least 1 000 x 1 000 pixels at 1 000 line TV rates
- System supporting structure

The initial evaluation of this concept uncovered several fatal flaws which impaired the multiviewer's use on the ACAVS project. Initial parameters considered were size requirements within the motion envelope, weight, disassembly problems, growth potential and availability. Figure 6-9 illustrates the physical problem of integrating the existing AFHRL conceptual design of the multiviewer into the ACAVS operating envelope.

The radius of curvature (as currently conceived) of the spherical mirror is 11 feet; with supporting structure this extends to 13 feet. The weight of this display configuration with supporting structure is estimated at 3370 pounds. An attempt was made to tailor this conceptual design to ACAVS requirements. A scaled-down version was considered to permit the spherical mirror and supporting structure to fit within the motion envelope. Figure 6-10 shows the layout; here the working envelope available to the crew is too small to be useful along with a reduced viewing envelope and no growth potential. Overall, the multiviewer concept for ACAVS presented two other disadvantages that were fatal flaws; these were, the requirements for display disassembly and reassembly in the VMS environment; and it is not believed that a working prototype of this system will be operational in the 1982-84 time period. The multiviewer concept was eliminated as a candidate conceptual design.

6.2.6 In-Line Virtual Image Window Concept (Mosaic)

This display concept utilizes the in-line virtual image display concept discussed in Paragraph 5.1.2.2. To meet the ACAVS FOV requirements it is only necessary to keep mosaicking the windows until the design coverage location and percent of full field are attained. The visual system would be similar to ASPT in approach and would provide a maximum of 72° per window, thus requiring a minimum of five windows to cover the required ACAVS FOV. This number is required because of the way the pentagon-shaped windows mosaic into the dodecahedron. A five-window arrangement is shown in Figure 6-11. These windows would be modular and could be rearranged to provide coverage in different areas as required. In the initial evaluation of this concept it was considered usable

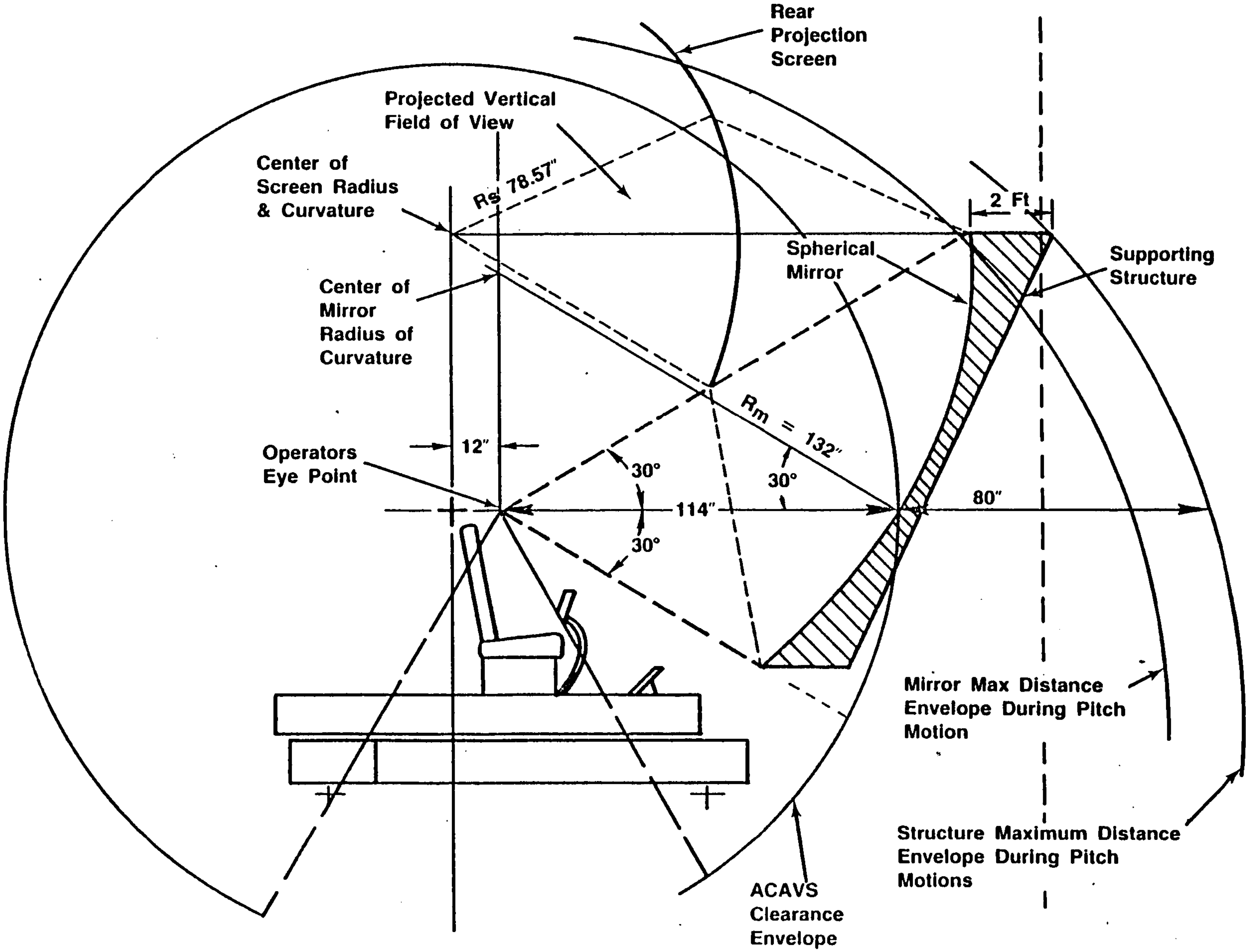


Figure 6-9: Multiviewer Conceptual Design Applied to ACAVS (Side View)

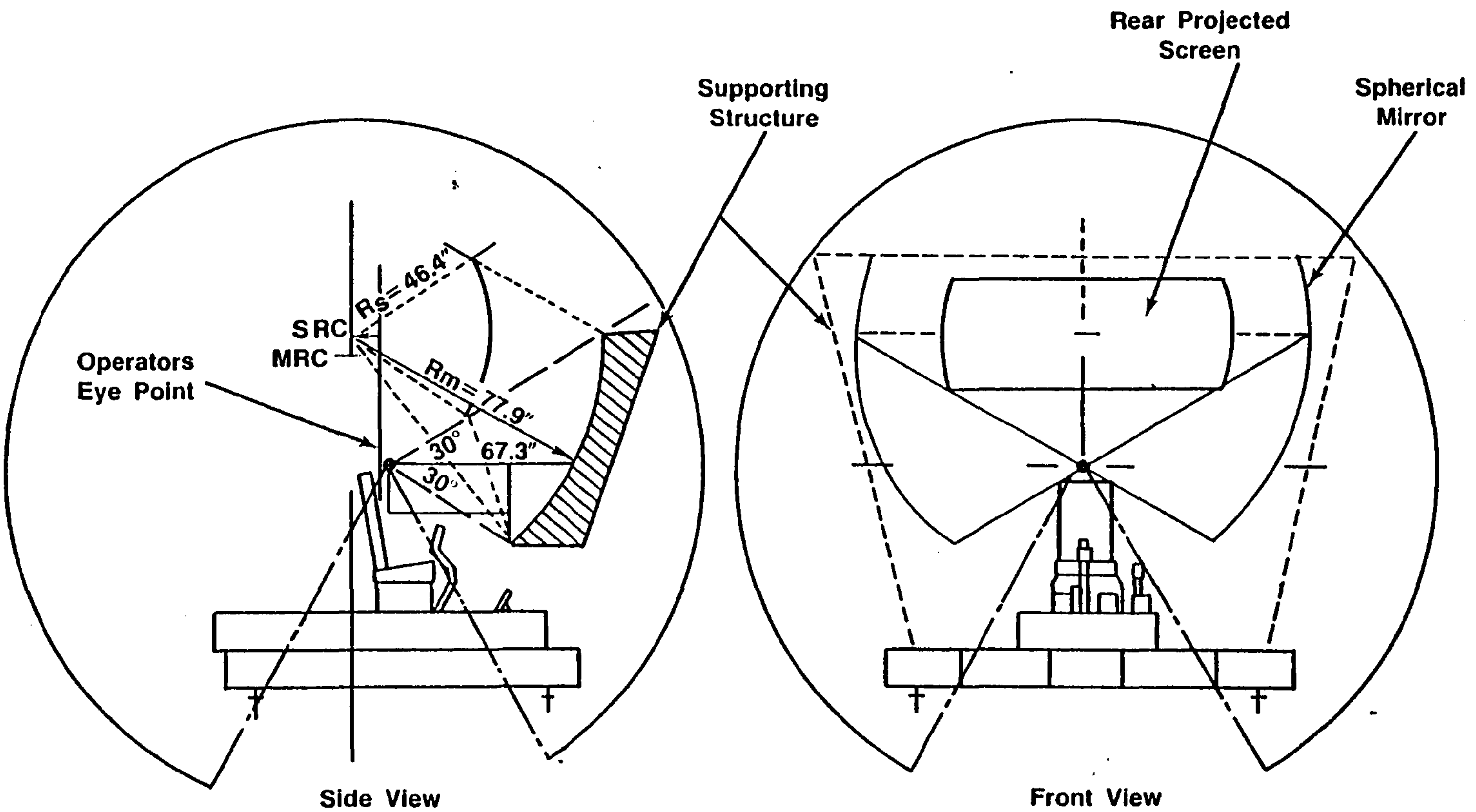


Figure 6-10: Scaled Down Multiviewer Concept to Fit RSIS Motion Envelope

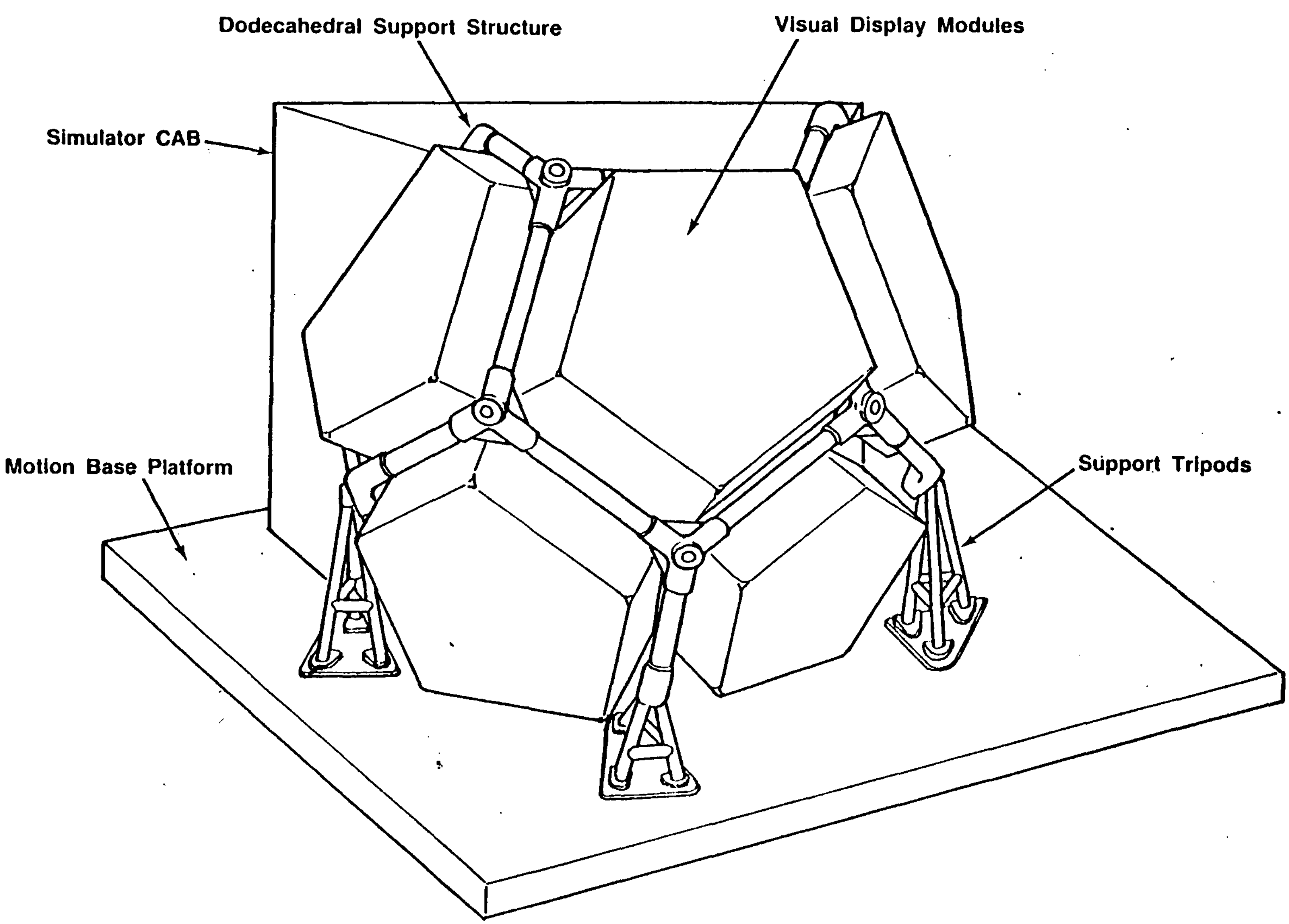


Figure 6-11: ACAVS In-Line Virtual Image Window Concept (Mosaical)

from the standpoint of size but only if it utilized the holographic window approach. The flexibility of cab arrangements are somewhat limited due to the 12-inch exit pupil but it still was considered usable. Weight of this system was very high but is still within the RSMG limits with the holographic window concept. The requirement for resolution was the fatal flaw along with the technology status of the holographic window and the high-resolution, high-brightness light valve projectors. As it currently exists, the 72° maximum FOV per window could only attain a resolution of about 11 arc minutes per line pair for the background display. It would require two projectors and two CGI channels per window to make this approach meet the resolution requirements and this was considered too costly and too risky to pursue in this 1982-84 time period. Therefore, this concept was eliminated from the candidate conceptual design.

6.2.7 TV Projector/Periscope (Servoed) with Dome

This candidate system utilizes a three-light valve projector combined with extension optics (as described in Paragraph 5.1.1.6) in a cab/dome configuration. The visual display has an instantaneous field of view up to 55°V × 165°H statically. Servoed capability in the Vertical Field of View (VFOV) allows the instantaneous field of view scene to be positioned under head tracker control thus effectively increasing the VFOV's usable dynamic range. This dynamic FOV capability increases the effective (total) display scene FOV to 110°V × 165°H by allowing the instantaneous FOV to be positioned throughout the position servos' range.

The three projectors are arranged on a servoed platform directly behind the operator's head and thus projects the image forward upon the dome screen. The concept is depicted in Figure 6-12. The extended "periscope" design of the optics allows the placement of lenses near the center of a spherical screen to minimize distortion, channel matching and focus problems. A head tracker, on the crew member's head, controls the servoed platform and thus the motion of the projector and optics in the pitch axis. Projector images are edge matched by masking inside the extension optics and corrected for raster flatness of field. The projector/stand assembly is mounted directly behind the primary crew member such that adequate room is available for adjusting the periscope optics center to rotate at the center of the spherical screen. A walkway is possible, for entrance/egress, on one side of the assembly and to provide an area for an observer's seat. A safety screen/railing is provided to insure crew member safety from the moving mechanical parts.

The cab is configured to be subdivided into modules thus allowing placement of each crew member in a tandem or side-by-side arrangement but the primary crew member will always stay with the projector gantry at the center of the dome. The dome is constituted such that it mounts to the RSMG base and provides for a walkway about the lower portion of the cab for ease of maintenance; its also possible to unbolt the dome at the seams (out of the prime viewing area) so it may be disassembled for movement to other areas.

Equipment for this system includes the following components:

- Three light valve TV projectors (nominal 1 000 line rate)
- Three periscope lenses, approximately two inches in diameter
- Three computer image generation channels, color, and nominal 1 000 × 1 000 pixel field at 30 frames per second
- Servo electronics
- Single-axis gimbal
- Focus compensation hardware in the plane of pitch and servo electronics
- Head tracking unit with helmet
- A CRT/CGI system for sling load and HUD displays
- Sound system

PARAMETER	SYSTEM
RESOLUTION	8.0 ARC MIN/LP
FOV	165°H x 55°V
BRIGHTNESS	23 FL
CONTRAST	45:1
COLOR	RGB

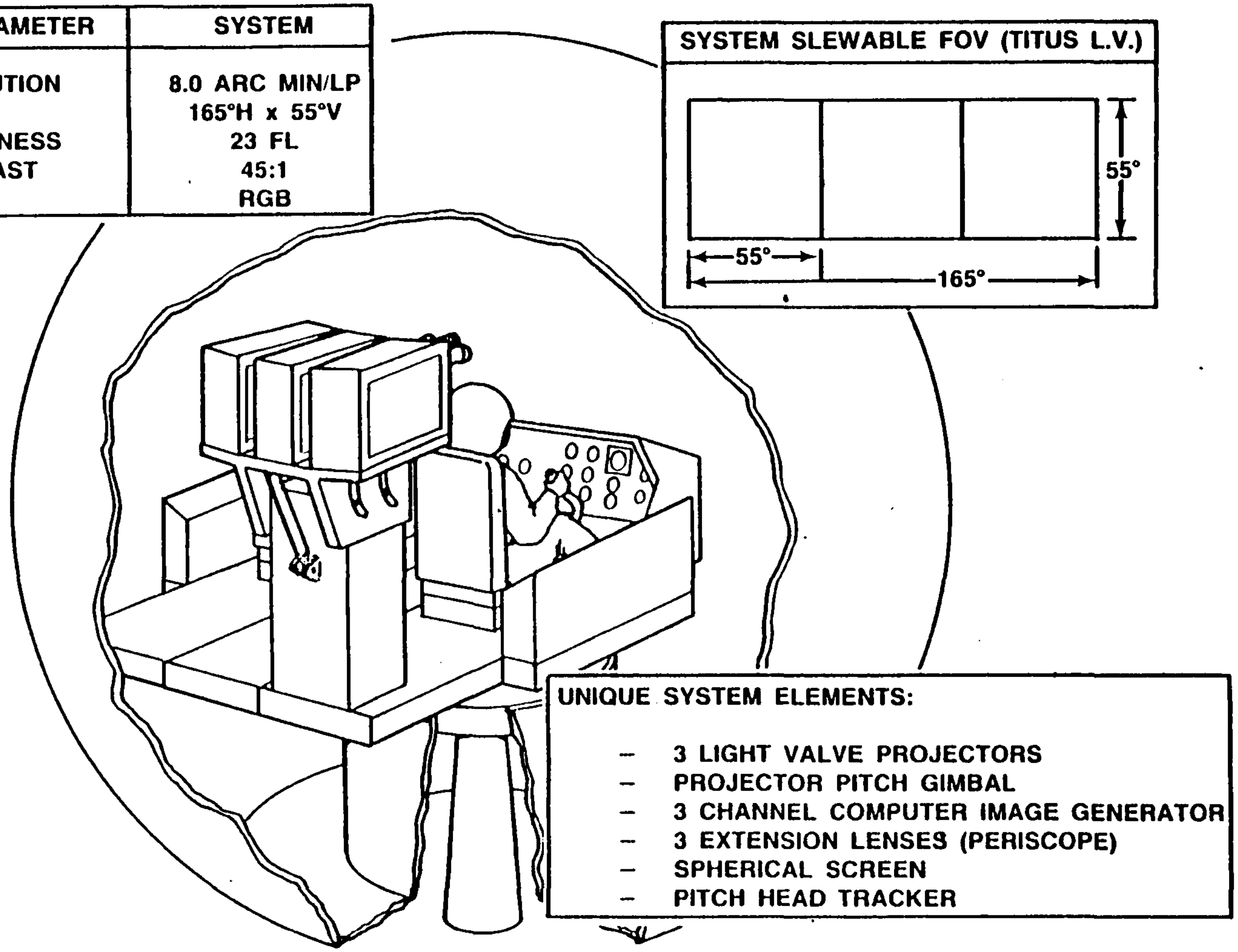


Figure 6-12: Light Valve and Extension Optic (Servoed) Visual System Concept

- Seat modules and vibration system
- Cockpit shell and console instruments
- Dome and supporting structure
- Interface electronics and support system

6.2.8 TV Projector/Fiber Optic (Servoed) with Dome

This system concept is very similar in the construction of the cab and dome to the system described in Paragraph 6.2.7 except in the servoed arrangement of the object lens. Flexible coherent fiber optic bundles are used to transmit the light from the three light valve TV projectors to an optical head placed behind and slightly above the operator, as shown in Figure 6-13. The image data are transmitted via a frequency multiplexing scheme (see Paragraph 5.1.1.5) to a gimballed optical head that is capable of being positioned in pitch and yaw to increase the dynamic FOV of the projected image. The gimballed mechansim is slaved to the position of the primary crew member's helmet. Thus, asthe operator moves his head the gimbal rotates about the exit pupil of the optics. The projected image in one configuration is of composite design, i.e., it has a high resolution area inset into the central viewing area of the total FOV. By sharing the projectors in this manner it is possible to optimize the resolution of the central area of the total displayed FOV for foveal viewing at high resolution while still obtaining good resolution capability for orientation and motion cues in the peripheral areas. Image matching and overlap fading are required of this system to minimize the effects of insetting.

FOV capabilities of this system provide up to 186°H × 70°V (using projectors with a 3 × 4 aspect ratio, e.g., GE L.V.) for the instantaneous FOV viewed statically and peak at approximately 240°H × 144°V for the overall dynamic FOV. This dynamic FOV is similar to that described in Paragraph 6.2.7 but is servoed in both the VFOV and HFOV in this concept.

This candidate system also has provisions for an observer in the area behind the secondary crew member. Dome construction, mounting, and disassembly features are identical to that previously described.

Equipment for this concept includes:

- Three light valve TV projectors (nominal 1,000 line rate)
- Fiber optic bundle with three imaging fields (three single ends and one common end)
- Projection lenses integrated into the fiber optic common end
- Servo electronics
- Two-axis gimbal
- Focus compensation in a projection lens element and servo electronics
- Three computer image generation channels, two·large field and one small field, color, and nominal 1,000 × 1,000 pixel field at 30 frames per second
- Head tracking unit with helmet
- A CRT/CGI system for sling load and HUD displays
- Sound system

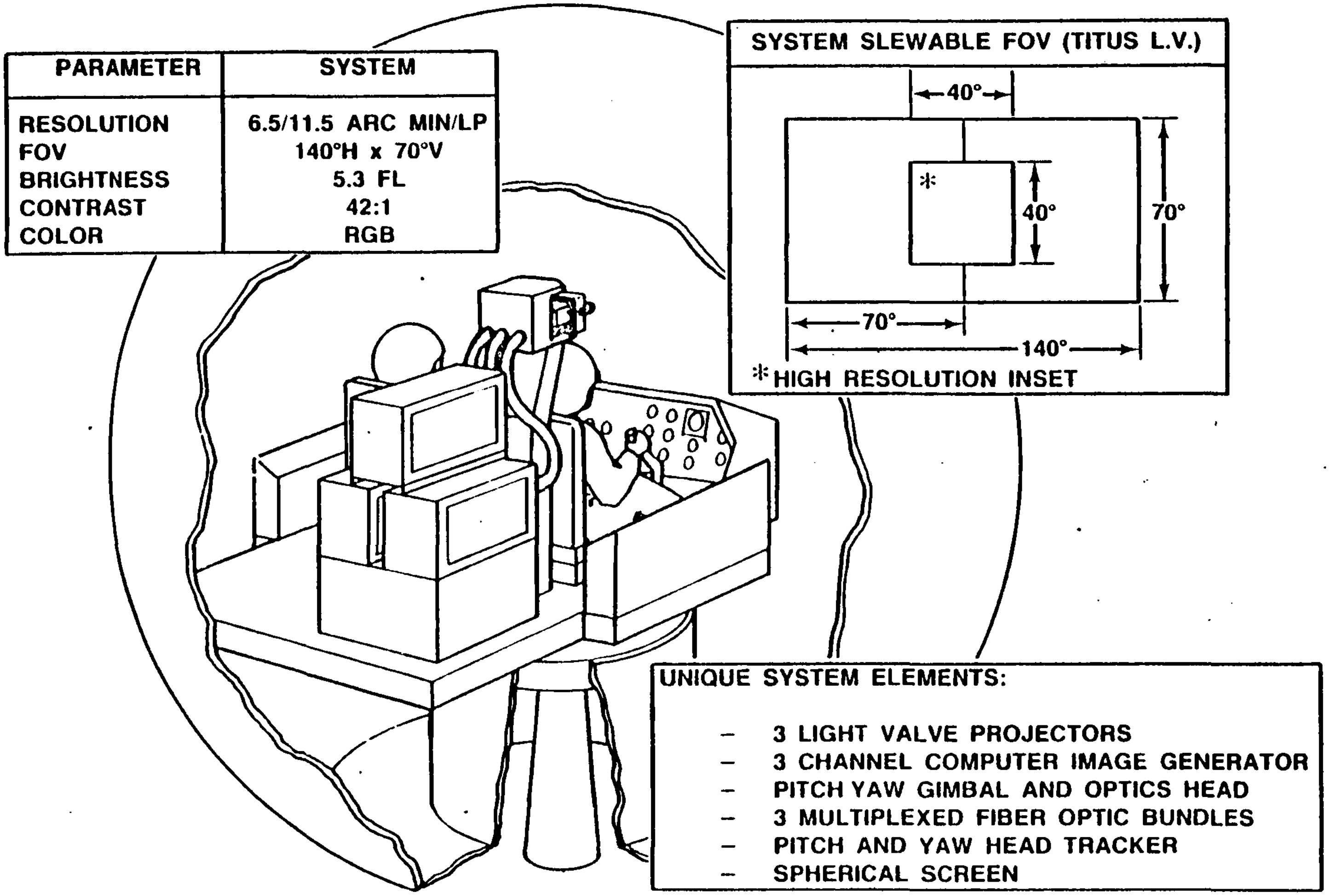


Figure 6-13: Light Valve and Fiber Optics (Servoed) Visual System Concept

- Seat modules and vibration system
- Cockpit shell and console instruments
- Dome and supporting structure
- Interface electronic and support systems

6.2.9 TV Projector/Fiber Optic (Fixed) with Dome

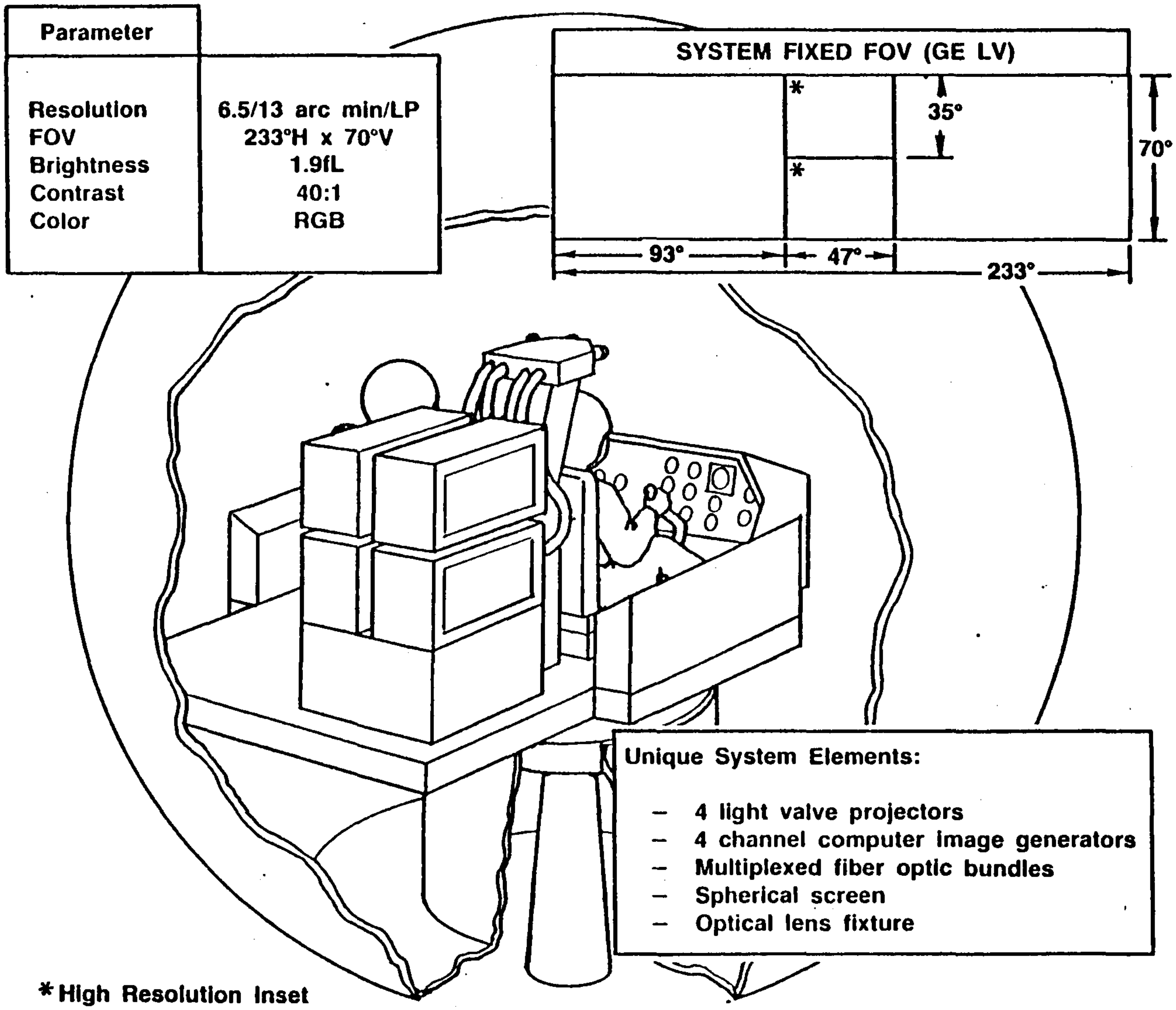
A second configuration of the system described in Paragraph 6.2.8 is shown in Figure 6-14. This approach uses the same light valve projectors and fiber optics configuration but eliminates the servoed gimbal arrangement and head tracker equipment. To compensate for the loss of the dynamic FOV capability, a fourth channel is added to widen the instantaneous field of view. This arrangement provides a 233°H × 70°V FOV capability with the two center fields providing high resolution images in the foveal area but only for dead-ahead scenes. Since image uniformity is required across the field it is also necessary, in this configuration arrangement, to adjust image overlap and crossover between the individual projected areas.

Equipment for this system configuration includes:

- Four light valve TV projectors (nominal 1 000 line rate)
- Fiber optic bundle with four imaging fields (four single ends and one common end)
- Projection lenses integrated into the fiber optic common end
- Four computer image generation channels, two large field and two small field, (see Figure 6-14), color, and nominal 1 000 x 1 000 pixel field at 30 frames per second.
- A CRT/CGI system for sling load and HUD display
- Sound system
- Seats/modules and vibration systems
- Cockpit shell and console instruments
- Dome and supporting structure
- Interface electronics and support systems

6.2.10 Laser Projector with Dome

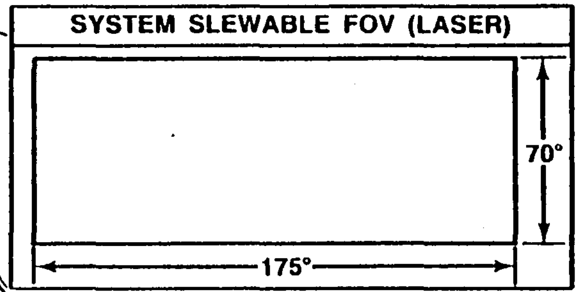
This candidate system is also very similar to the other three systems described except that the display hardware utilizes the newly developed laser color projector and scanner system (see Paragraph 5.1.1.2.3). Here the output optics lasers and laser scanning assembly is positioned near the center of the spherical dome and may also be positioned between the two operators in the side-by-side cab configurations as shown in Figure 6-15. The supporting equipment for the laser projector is mounted behind each operator. These units contain power supplies, water cooling systems and control, very high frequency video amplifier, servo control electronics, timing logic and controls as well as special interface for CGI/model board inputs. The laser projector optical head is servoed and has the capability to position the display raster in pitch and roll via position inputs obtained from a helmet/head tracker system. The raster control signals are taken from the primary crew member helmet.

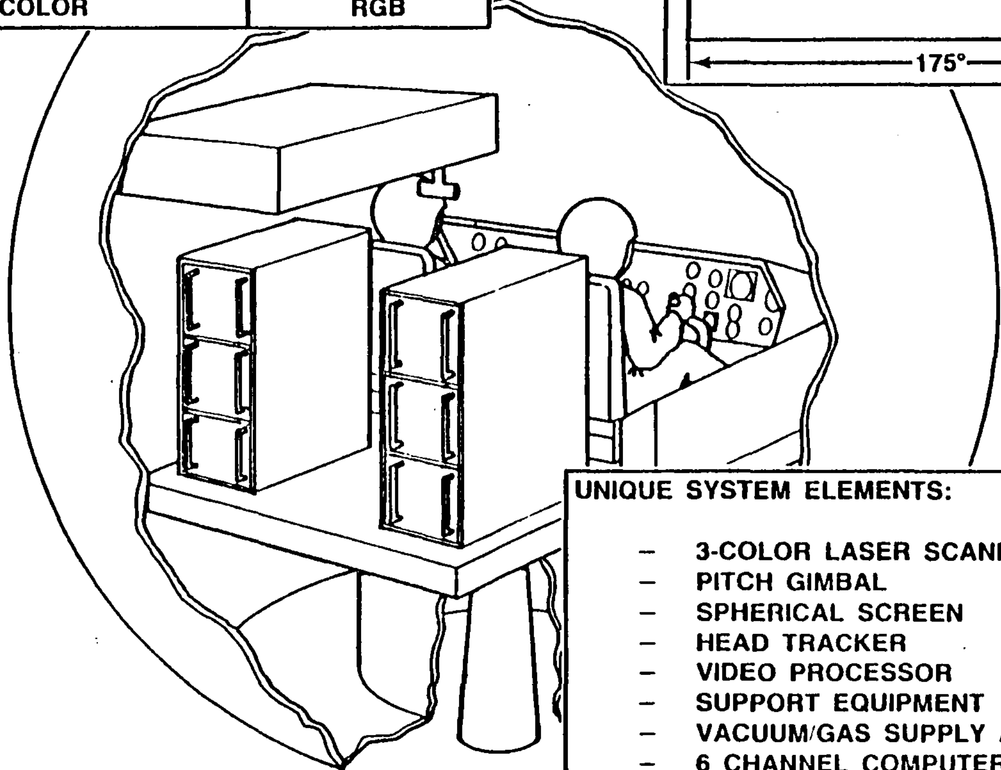


Parameter	
Resolution	6.5/13 arc min/LP
FOV	233°H x 70°V
Brightness	1.9fL
Contrast	40:1
Color	RGB

Figure 6-14: Typical TV Projector/Fiber Optics (Fixed) Visual System Concept

PARAMETER	SYSTEM
RESOLUTION	6 ARC MIN/LP
FOV	175°H x 70°V
BRIGHTNESS	5 FL
CONTRAST	50:1
COLOR	RGB





UNIQUE SYSTEM ELEMENTS:

- 3-COLOR LASER SCANNER
- PITCH GIMBAL
- SPHERICAL SCREEN
- HEAD TRACKER
- VIDEO PROCESSOR
- SUPPORT EQUIPMENT
- VACUUM/GAS SUPPLY AND WATER SUPPLY
- 6 CHANNEL COMPUTER IMAGE GENERATOR

Figure 6-15: Scanning Laser Visual System Concept

Image and pitch/roll servo data are compensated for translational differences between the crew member's eye point and the projector head. This computation insures that the displayed images are correct in prospective for the primary crew member (any distortions introduced are corrected for dynamically in the CGI visuals if CGI image generation is used). Special shielding is incorporated around the optical head to insure that the laser light cannot be projected below the maximum down look angle.

The cab/dome capability is essentially that of the previous system, i.e., each operator's seat/base is modular and contains his seat, controls and vibrating elements. A walkway is provided under the platform for ease in maintenance and cab configuration changes. As in the other dome configurations it is possible to disassemble the spherical dome for relocation to another area; parting seams will be located in areas out of the prime viewing area. An observer's seat in this configuration will require its location in the aisle and will be removable for ease in entering/egress as well as for safety when not required.

Equipment for this candidate system include the following components:

- Laser beam power and alignment monitoring equipment
- Laser beam pupil control optics
- Line scanners
- Focus optics
- Pupil rotation optics
- Wide angle lens
- Scanning optical elements
- Two lasers, providing red, green and blue illumination for visual displays
- High bandwidth light modulators
- Relay and focusing optics
- Two line scanners
- Projection lens
- Six channels of CGI and interfaces for the laser projection format
- * Full-color, 200:1 scaled, terrain model board and gantry
- * Two lasers and scanners providing red, green and blue illumination on map model
- * Laser camera support equipment
- * Photomultipler tube sensor equipment
- Scanner timing electronics and controls
- Special support equipment and racks

- Head tracking unit with helmet
- A CRT/CGI system for sling load and HUD displays
- Sound system
- Seats/modules and vibration system
- Cockpit shell and console instruments
- Dome and supporting structure
- Interface electronics cab support systems
- Safety interlock equipment

* Equipment required in place of CGI channels if the image generation is obtained from a laser camera/model board approach.

6.2.11 Helmet-Mounted Display Concept Description

This candidate system utilizes a different display concept than any of the previous four systems. The cab, consoles, instrumentation, seats and seat modules are basically the same as in the other systems but that is where the similarity ends. There is no dome/visual scene in this configuration that can be seen by any crew member or observer unless one is wearing helmet-mounted display. This new display technology (described in Paragraph 5.1.2.2) when integrated into the ACAVS rotorcraft system concept provides many unique capabilities. One system conceptual configuration is shown in Figure 6-16. Each observer's visual system consists of a helmet/helmet-mounted display and head tracker, coherent fiber optic image transmission cables coupled to three high-brightness, high-resolution TV projectors which are driven via three CGI image channels. The three images are processed optically into two scanners, one for each eye at the output of each projector. The HMD has optical combiner lenses which permits reviewing of the internal cab and instruments in areas where the CGI image is blanked. This combiner also permits cab illumination to be matched with the visual display. One set of visual system components are required for each independent observer crew member.

Each crew member observing an out-the-window display scene will be required to wear a helmet during simulation requiring external visuals. This concept permits complete independent viewing and correct prospectives optimized for each operator and thus no visual distortions or degradations are encountered. The TV projection systems are mounted directly behind the corresponding crew member in this design but may be remoted off the main cab area to the RSMG/VMS interface if room is available. Since cockpit structure cannot be placed between the operator and the visual scene, image occulting representative of the cockpit structure must be done in the CGI visuals as they are supplied to the visual display, this is done as a function of the type of aircraft simulated and the position of the observer's head in 6 DOF. This positioning information is obtained from each crew member's helmet tracker sensors. An artists conception of a visual scene depicting this electronic structural occulting is shown in Figure 6-17.

If preferred, this concept has the potential for stereo vision. All that is required is the helmet optical design be given up to 25° image overlap and the CGI data base be required to compute the correct offset and angular prospectives for the visual scenes. Full-color capability is realized with this system without sacrifice of resolution and image brightness. Sling load capability is inherent because the CGI computes the sling load data in the correct position when the observer's head is positioned at that viewing angle. As with the other visual systems this one also provides greater image resolution in the foveal area of the eye than in the peripheral area. In this FOV configuration since the visual picture is computed in real-time and can detect every motion of the head, this high-resolution area is constantly in the prime viewing area.

PARAMETER	SYSTEM
RESOLUTION	7.5/13.2 ARC MIN/LP
FOV	186°H x 70°V
BRIGHTNESS	120 FL
CONTRAST	20:1
COLOR	RGB

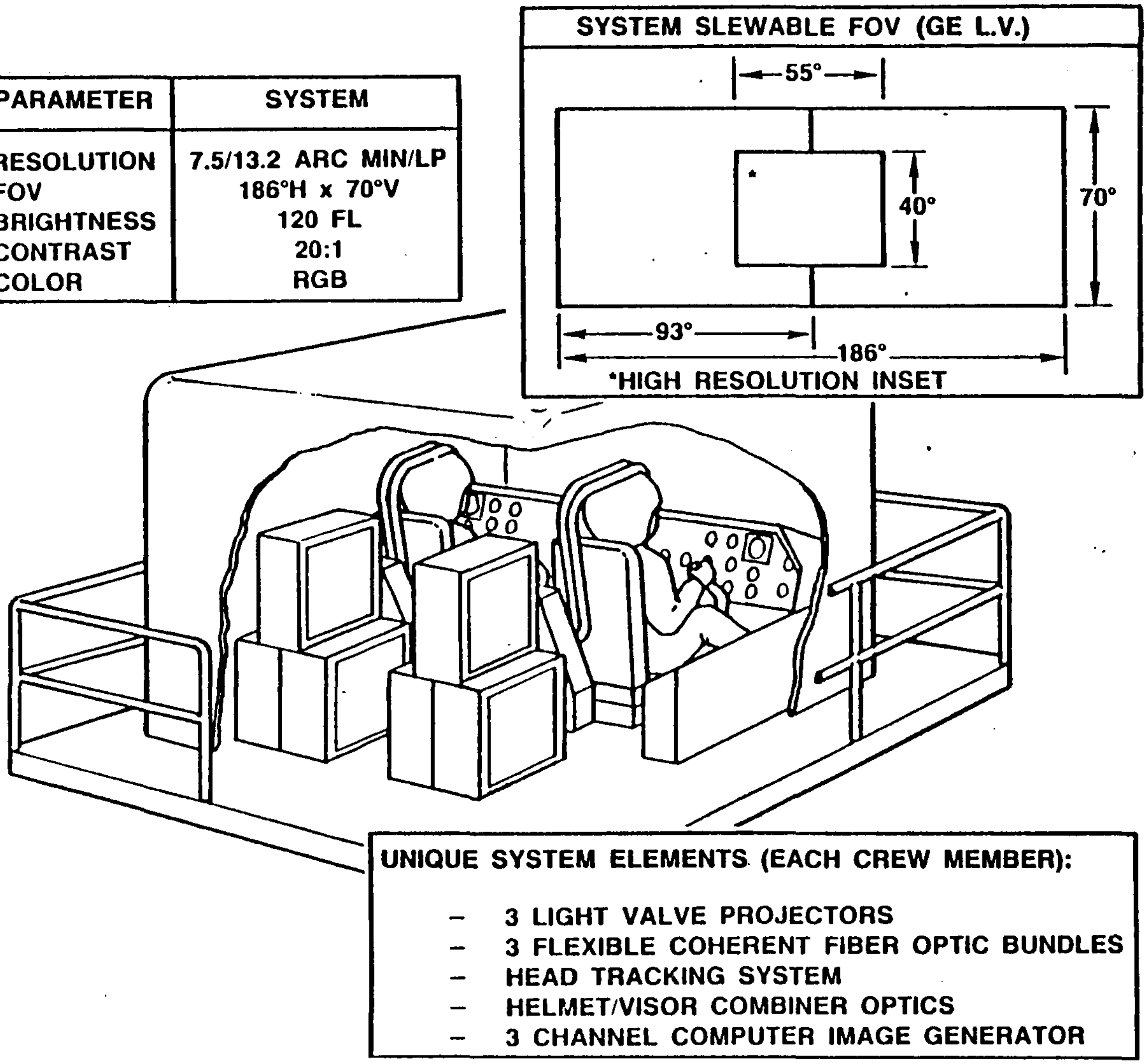


Figure 6-16: Helmet-Mounted Display Visual System Concept

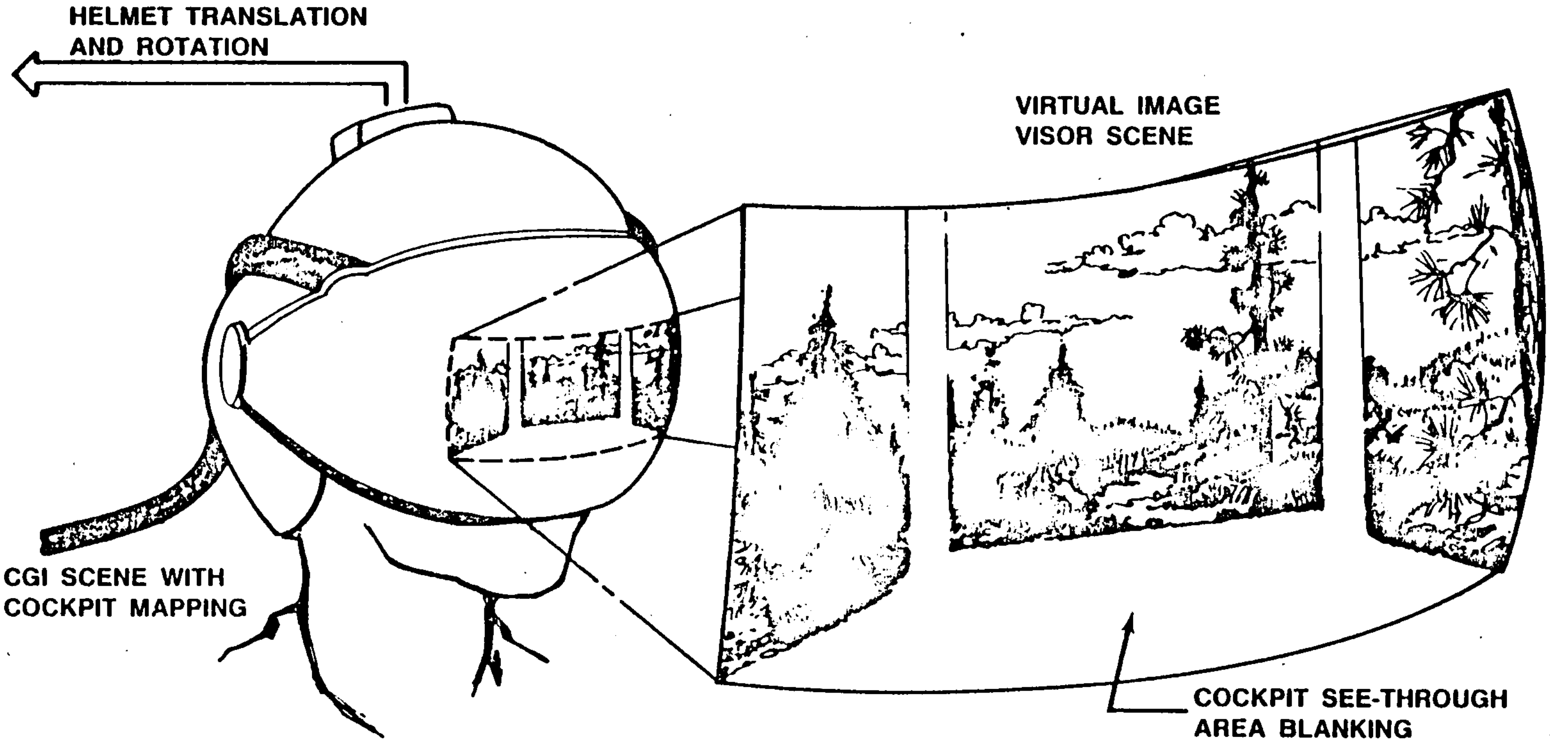


Figure 6-17: Helmet-Mounted Visor Display Blanking

The cab configuration, since it has no dome to be removed, is identical to the existing ICAB configuration and will mount on the RSMG mounting plate. An observer's seat can be placed anywhere on the ICAB floor but will require additional visual displays and helmets.

Equipment for this candidate system requires the following components;

- Three high-brightness, high-resolution TV color projectors per observer/crew member
- Three-CGI channels per observer/crew member
- Coherent fiber optic assemblies
- Helmet/helmet-mounted display
- Head tracking unit
- ICAB base and overhead enclosure
- HUD displays
- Sound system
- Seats/modules and vibration system
- Console instruments
- Interface electronics and support systems

6.3 Image Generation Systems

6.3.1 CGI Systems

During the preliminary concept phase of the study it became apparent that none of the current CGI systems available were capable of meeting ACAVS requirements. Because of the important relationship between the CGI and the visual systems, and expected advances in CGI technology within the 1982-84 time frame, a hypothetical CGI system was conceived. This hypothetical system was specifically set up to meet ACAVS requirements. The technical factors utilized in this hypothetical model are composed of scene content factors, bandwidth factors and computational complexity factors and are defined as follows: Table 6-2 contains a summary of the hypothetical CGI system. The displayed scene content does not include texture. Static models include items such as terrain, building, and cultural features. Moving models are typically aircraft, missiles, etc. The breakdown given is hypothetical only and does not represent a recommended configuration, but one which could be used to construct viable systems.

Table 6-2: Displayed Scene Content

Object Type	Static (Fixed Model)	Dynamic (Moving Model)	Total Edge Equivalents
Points (P)	1000	200	620
Edges (E)	0	0	0
Faces (F)	7000 (4)*	500 (4)*	15,200
Curved Surfaces (CS)	100	300	3,680
			19,500

* Assumes 7000 faces with 4 vertices per face (V_F) in the static scene content and 500 faces with 4 vertices per face in the dynamic scene content.

- Displayed Scene Content Factors

Scene content in most real-time CGI systems is comprised of combinations of primitive structures, each representing a storage allocation cost and an implied processing cost. In order to facilitate a direct comparison, we will adopt the following conventions:

1. Point – A point is defined as a single vertex and color. Each vertex is comprised of three 32-bit words, corresponding to x, y, and z locations in a local euclidean reference frame. Each point is counted as one-half edge.

2. Edge – The edge is the basic unit of scene content, defined as two location vertices and a single color level.

3. Face – A face is defined as a convex, coplanar set of vertices, including, at a minimum, the face color. This information can be augmented by a normal, color level, and transparency value per each vertex. The number of faces is counted as one-half the number of its vertices as edges. Thus, a triangular face counts as one and one-half edges, and a rectangular face as two edges. It is anticipated that only objects that will be smooth shaded (such as aircraft) will carry more than one normal per face, and that the standard face will contain a single color, normal, and vertex information.

4. Curved Surface – A closed, convex two-dimensional surface is defined as computationally equivalent to eight edges. A surface patch in three dimensions also is defined as equivalent to eight edges, but is restricted so that its vertex-to-vertex curvature does not exceed 45 degrees. For example, given a three-sided (triangular) surface patch with n_1, n_2, and n_3 the outward facing unit normals to the surface at each vertex, then we have the conditions that

   $$n_1 \cdot n_2 \geqslant \sqrt{\frac{2}{2}}, \qquad n_1 \cdot n_3 \geqslant \sqrt{\frac{2}{2}}, \qquad \text{and } n_2 \cdot n_3 \geqslant \sqrt{\frac{2}{2}}.$$

   (See Figure 6-18,.)

5. Moving Models – Moving models are not primitives in the same sense that points, edges, faces, and curved surfaces are. However, each moving model requires approximately 20 percent additional processing over and above standard objects. This additional processing applies directly to the sum of their edge equivalents. Thus, if a moving model contains 400 edges of scene content, it is treated as though it contains 480 edges.

In this hypothetical model, scene content is defined by the effective number of potentially visible points, edges, faces, and curved surfaces in the viewing field. It additionally includes the effects of moving models and texture generation. Hidden faces (those oriented away from the viewer eyepoint, such as the back sides of buildings) are not included. The variables for scene content include the number of points in the static scene (P_S), points in the moving model(s) (P_M), edges in the static scene (E_S) and moving models (E_M), the number of faces in the static scene (F_S), and moving models (F_M) and the corresponding vertices per face (V_F), and the total number of curved surfaces (2-D and 3-D) in the static scene (CS_S) and moving model (CS_M). The number of moving models is M_M and the score for texture generation is T. Then the scene content (S_C) is: (See Table 6-2)

$$S_C = [\underbrace{(\frac{P_S}{2} + E_S + \frac{F_S \cdot V_F}{2} + 8CS_S)}_{\text{Static Models}} + 1.2\,\underbrace{(\frac{P_M}{2} + E_M + \frac{F_M \cdot V_F}{2} + 8\,CS_M)}_{\text{Moving Models } (M_M)}]\,T$$

The number of moving models (M_M) is not explicitly in the scene content equation, but is part of the expanded breakdown of moving points, edges, faces, etc.

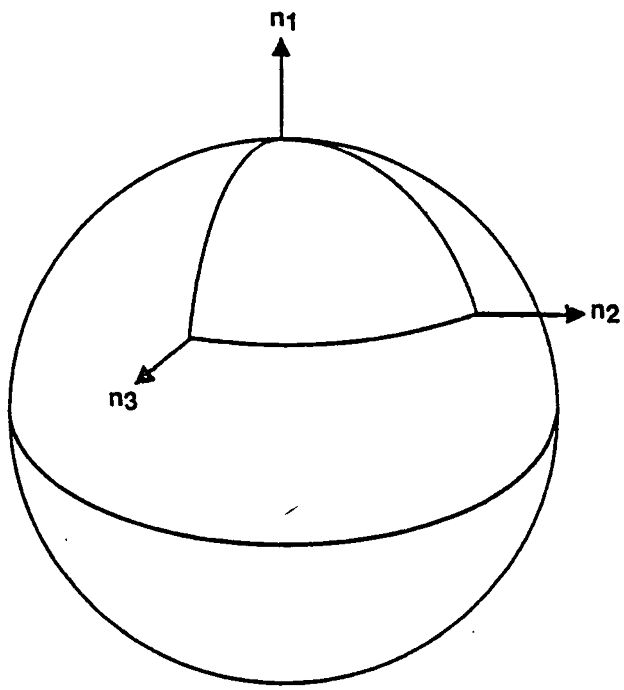


Figure 6-18: Curved Surface Definition

- Displayed Scene Bandwidth Factors

  Scene bandwidth factors are those factors which directly affect the processing bandwidth of the visual generation system, usually in a multiplicative fashion. Nap-of-the-earth simulation demands unusually high scene bandwidth factors and a requirement for high complexity. These factors are:

  1. Field of View (FOV) – In this model, field of view is the ratio of the instantaneous field to that of an entire sphere. For example, a 120 degree horizontal by 60 degree vertical display field constitutes one-sixth full field (ff). (This is defined by the equation $FOV_{ff} = (\psi/360) \sin(\theta/2)$ where ψ = horizontal FOV and θ = vertical FOV symmetrical about the horizon).
  2. Image Resolution (IR) – Image resolution is the perceptual resolution of the display system including all of the effects of physical resolution, modulation transfer function, brightness, etc. Image resolution is defined in terms of equivalent pixel size for the purpose of this report.
  3. Color (C) – Color refers to the logarithm base two of the number of discriminable hue, saturation, and brightness levels. For example, 256 "colors" implies C = 8.
  4. Frame Rate (F) – Frame rate is defined as the rate at which each new perspective scene is calculated for an entire frame.
  5. Transport Delay (T) – The total time from when a new perspective viewpoint is received by the CGI system until the entire scene raster thereby generated is displayed.

It should be noted that the definition for image resolution and color were not (directly) in physical terms. This is to ensure that, in terms of the eventual technical scoring, credit is not given for a computational system producing, say, three arc minutes resolution per pixel when the associated display can effectively render only a five arc minute resolution. Likewise, it would not make sense to score a color capability of twelve bits when only eight bits were discriminable. Of the five factors, all are multiplicative in effect except for transport delay. Transport delay, however, defines the maximum computational span allowed to provide the picture.

- Computational Complexity Factors

  Computational complexity factors are those factors which affect the structure of the hardware and software required in the system. The degree of "intelligence" in the system, the timing requirements (especially the need for synchronous operation) are examples of computational complexity. These factors represent not only design and development cost, but also maintainability and expandability. The definitions of these factors are as follows:

  1. Level of Detail (LOD) – The number of distinct representations of the same data base object, texture, or area. As data base densities and image complexity increase, the need for intelligent level of detail selection becomes crucial.
  2. Image Breakup (IB) – The apparent decomposition of the visual scene due to high angular or translational motion within the data base environment.
  3. Dynamic Light/Shadow (L/S) – The apparent change in the luminosity of objects in the visual scene due to the simulation of a moving light source and the shadows they create.
  4. Curved Surface Shading (CCS) – The rendering, through algorithmic approximation, of the appearance of a curved surface to objects which are composed of planar faces.

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16. Abstract

A conceptual design study was conducted to define requirements for the Advanced Cab and Visual System elements of the U.S. Army/NASA RSIS Program. The rotorcraft System Integration Simulator is intended principally for engineering studies in the area of mission associated vehicle handling qualities. A technology survey and assessment of existing and proposed simulator visual display systems, image generation systems, modular cab designs, and simulator control station designs were performed and are discussed in this report. State-of-the-art survey data were used to synthesize a set of eleven preliminary visual display system concepts. Of these, five of the more attractive candidate display configurations were selected for further evaluation. These display concepts were integrated in the study with a simulator cab concept employing a modular base for aircraft controls, crew seating, and instrumentation (or other) displays. A simple concept to induce vibration in the various modules was developed, and is described. Results of evaluations and trade-offs related to the candidate system concepts are given, along with a suggested weighting scheme for numerically comparing visual system performance characteristics. Preliminary estimates of system availability and relative cost levels are also presented. The Background, Summary and Recommendations, Approach, Requirements, Technology Assessment, and Concept Synthesis are contained in Volume I.

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