NASA CONTRACTOR REPORT 166236

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

R. J. Rue
M. L. Cyrus
T. A. Garnett
J. W. Nachbor
J. A. Seery
R. L. Starr

Boeing Military Airplane Company

CONTRACT NAS2-10464
July 1980

NASA

NASA CONTRACTOR REPORT 166 236

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

R. J. Rue
M. L. Cyrus
T. A. Garnett
J. W. Nachbor
J. A. Seery
R. L. Starr
Boeing Military Airplane Company
Wichita, Kansas

Prepared for
Ames Research Center
under Contract NAS2-10464

NASA
National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

N82-25267

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.

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

TABLE OF CONTENTS (CONT'D)
VOLUME II

TABLE OF CONTENTS (CONT'D)

VOLUME II

TABLE OF CONTENTS (CONT'D)

VOLUME II

APPENDIX B (CONT'D)

TABLE OF CONTENTS (CONT'D)

VOLUME II

LIST OF FIGURES

(APPENDICES)

VOLUME II

Pages 1 - 106 Missing

7.0 · CANDIDATE SYSTEM EVALUATION

Section 7.0 is an evaluation of the candidate system concept described in Section 6.0. This evaluation is performed at an integrated system level and discusses the capabilities, advantages and disadvantages of each system. Performance data generated during the concept selection phase is utilized in scoring for the purpose of selecting the best candidate system approach to fulfilling the ACAVS requirements. This system parameter data was generated from vendor component specifications when integrated into the particular concept configuration, and these data vary accordingly to the trades that were done for best optimization. A hypothetical CGI system was used for the reasons given in Section 6.3. This CGI system, when integrated into the candidate systems evaluation, differs only in the number of channels required and is not a measure of any available system capability. This number is thus used as part of the overall score and is an indicator of required hardware and costs.

Paragraph 7.3.1 is our recommended criteria to NASA to be used to score and evaluate the CGI capability of companies desiring to supply the CGI systems for ACAVS.

7.1 Evaluation Approach

The approach used to score candidate systems included evaluation factors of the visual and CGI systems, visual system compatibility between the CGI and the visual display (i.e., interface problems, speed, etc.), system operability, development risk, crew station flexibility for crew configurations, Reliability, Supportability, Maintainability (RSM), cab and visual display system weight, and facility and aircraft systems compatibility. These factors are utilized (as shown in Figure 7-1) to develop a figure of merit for ranking one concept with another.

Each multiplicative factor was given a range from 0 to 1 and each additive factor was given a percentage of the total 1 000 points. Since the visual and CGI components were considered to be the driving factors, they were given 80 percent of the total points and shared this amount equally. Weight/inertia, crew station flexibility and system compatibility shared the remaining 20 percent of the total scene: 40, 70, and 90 points respectively.

Scoring points were broken down further within the visual display system with a spread distinction being given to items such as resolution, FOV, luminance, contrast ratio and color capabilities. These parameters were reduced further to give credit to those configurations that gave visual advantages to more than the primary operator. The evaluation for these parameters is initially done on a percentage basis, i.e., the system parameter capability is scored as a percentage of the parameter goal. These percentage scores are then utilized in the evaluation/scoring criteria given in Figure 7-1.

The multiplicative parameters are all assigned values (between 0 and 1) depending upon the candidate system's ability to meet the overall design requirements. These parameters are weighted according to meeting the time schedule, cost, compatibility with NASA's facility, etc. A breakdown of the major areas is given below.

- Visual System Compatibility

  How well does the visual and CGI system interface with each other in all visual parameters? Thus are they matched in resolution; slew rates contrast and color capability. In the case of the laser concept, has CGI ever been interfaced to the real-time laser scanner? Other areas considered are internal visual systems (HUD, etc.) compatibility with the candidate display concept.

- Operability

  This parameter includes such areas as bringing up the total simulator for testing use. Therefore, how easy is it to get it operational; what checks must be made daily; is it easy to get in and out around the equipment; how well does the system operate in a vibration environment and does it degrade the visuals? Another area considered in determining the operability weighting value, is safety.

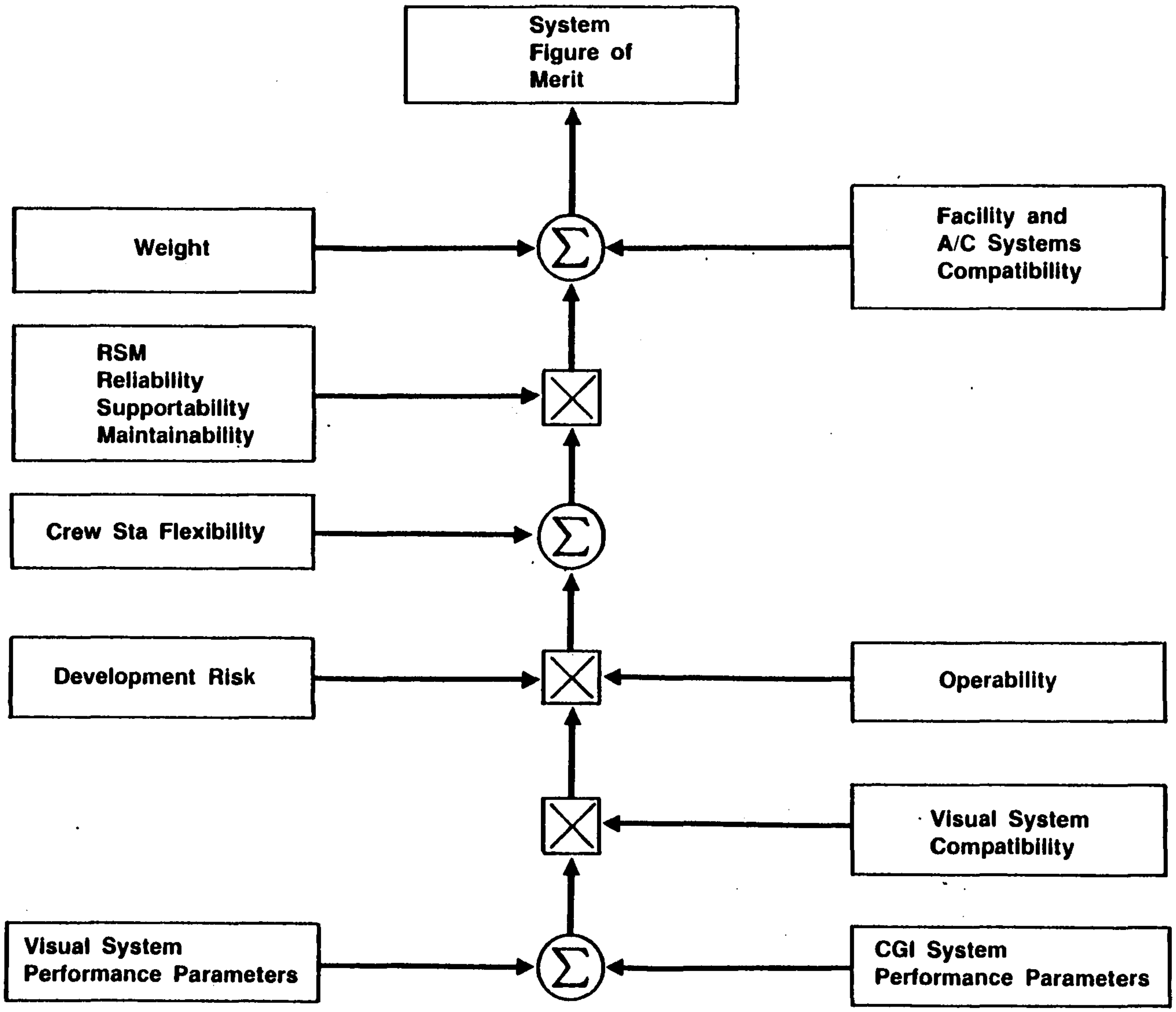


Figure 7-1: ACAVS Concept Evaluation Block Diagram

- Development Risk

  Has this display concept or the components ever been built; will it meet the requirements? Is it possible to utilize new technology approaches in the available time period and meet the program schedule?

- RSM

  How reliable is this concept in operation; will it provide 95 percent uptime with only minimum maintenance? Is it easy to support this system; does it require specially trained personnel and special equipment to keep it in operational status? Is the firm who built the equipment reliable and will they be around and supportive when equipment fails and requires their support? If a dome approach is used how reliable will the visual screen be after repeated assembly and disassembly? Will it require extensive repairs?

Other areas of concern which impact scoring when evaluating the candidate system concepts are:

- Crew Station Flexibility

  Items considered here are: How easy is it to configure the cab and seating arrangement with respect to each other and to the visual display system? Does it require long shutdown periods, special equipment or removal of some cab/visual equipment to make system changeovers?

- Facility and Aircraft Systems Compatibility

  Items evaluated here include the interface of the cab and visual system to the NASA VMS facility. Does the concept design approach have provisions for handling the environmental problems of VMS noise and atmospheric temperature? How difficult is this cab and visual display system to be transported from the VMS area to the development station and reconfigured? Are there any special requirements of the system that will require additions to the existing NASA facility (e.g., laser camera/model board)?

- System Weight

  Are the system weights of the candidate concepts within the limit of the operational specification of the RSMG?

All these data are considered in the evaluation of the candidate concepts; scoring results for the candidate systems are given in Appendix E.

7.2 Concept Evaluation

Concept evaluation is the method by which the good/bad and strong/weak points of a candidate system are brought out and identified such that it may be compared with another system to give best advantage in a particular approach for concept selections.

Each candidate system described in Section 6.0 has special requirements and characteristics which are necessary to fulfill the ACAVS system requirements. The visual system is the driving area in the determination of the simulator configuration; the following description of candidate systems utilizes the best trades in display system components and FOV configuration to achieve these results. Various projector systems are available, as described in Section 5.0, yet some types are better suited for certain FOV and brightness, compatibility, etc., than are others. Projector orientation has been rotated 90° in some configurations to optimize the vertical FOV and thus add visual channels to increase the horizontal FOV capability. The approach is less costly than utilizing the conventional raster orientation. Figure 7-2 is a collection of the various FOV configurations utilized in the individual candidate system. Here FOV formats, orientation and actual FOV angular capabilities are depicted. Specific projectors are associated with these formats which bring out the best system characteristics at the lowest cost. The percent of total spherical FOV of these systems is shown in Figure 7-3.

7.2.1 Concept No. 1 – TV Projector/Periscope (Servoed) with Dome

Concept No. 1 as described in Paragraph 6.2.7 is configured with two different composite fields of view to optimize current light valve technology. The configuration 1.1 and 1.2 FOVs are given in Figure 7-2; system characteristics are given in Figure 7-4.

The basic differences between the two configurations reflect projector differences in resolution, FOV, brightness, and raster correction capability. The two types of light valve projectors used are General Electric and Sodern. Three light valve projectors are tied optically via three lens/mirror (periscope) arrangements allowing the projected images to be placed as close to the operator as possible. This reduces image distortion as seen by the operator and illumination losses. Optical capability of the periscope devices are 114° FOV and 1.5 arc minutes resolution.

To optimize the FOV capability of this arrangement and meet ACAVS vertical FOV requirements a pitching mechanism is used. The projectors are mounted on a common platform which allows the visual presentation system to be pitched about an axis through the center of the periscope lens exit pupils. This axis is located at the center of a spherical screen.

This system, as with all dome systems, has good flexibility for cab/operator configurations except for the tandem arrangement. This arrangement is marginal, as the front crew member will be extemely close to the viewing screen. When configuration changes are to be made it will be necessary, in all projection/dome configurations, to keep the main operator at the visual design center of the screen. This must be done to maximize the viewing quality of the display to the observer and to keep image distortion and projection mosaicking matching problems at a minimum.

The visual performance of this system has good brightness and has uniform image resolution over the total viewing field. To obtain a greater vertical FOV the projector/gimbal assembly is controlled via signals derived from a helmet head tracking system. While this increases system FOV capability, it also introduces special helmet/head tracking alignment requirements and setup procedures that must be performed each time the control helmet is worn. This approach enhances the pilot's usable FOV but restricts the other crew member to that of their partners.

This system has several advantages. It is developed from proven technology that has been utilized in simulators before; risk is considered to be low in the ACAVS time period. The periscope configuration permits the projectors to be placed effectively at the operator's head, thus keeping distortion low. There is no apparent variation in image resolution across the visual field of view except those normally encountered in projector displays (i.e., no inset area of interest). The configuration utilizing the Sodern projector does have the advantage of greater light, no flicker, higher resolution targets and raster control capability to reduce image mosaick problems. On the other hand, the G.E. unit has the advantage of lower cost and greater FOV and is off-the-shelf technology.

System disadvantages are numerous. Large gimbal and servo drive will generally reduce or limit the crew station flexibility. Servo motor noise may be objectionable and give cueing information of upcoming rotorcraft responses. This is undesirable for handling quality testing. The gimbal and holding fixtures would have to be placed on one base floor module, behind the pilot station. Only the pilot can observe a good quality scene on the screen and is restricted in usage of overhead controls to those that can be used without casting shadows on the viewing screen.

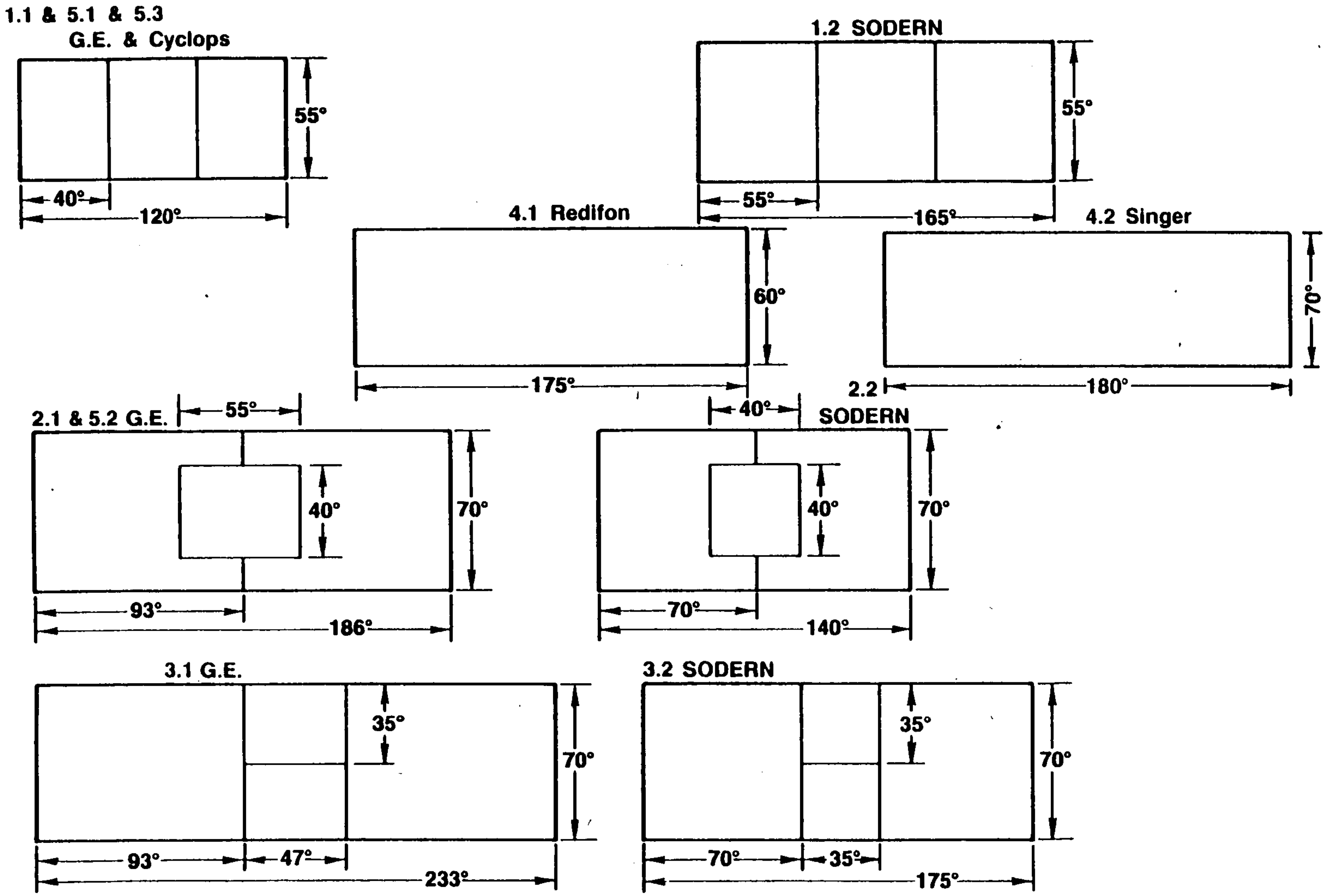
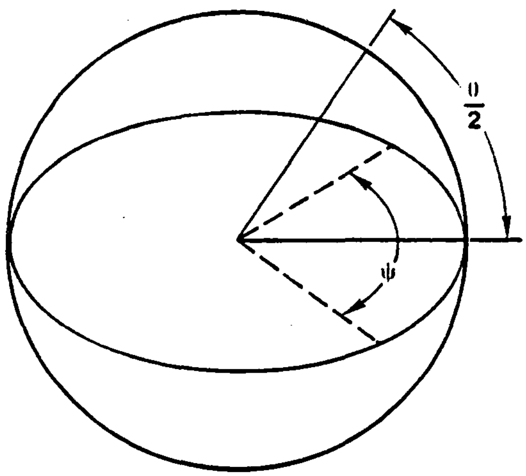


Figure 7-2: Display Fields-of-View Configurations



$$\left(\% \; FOV_R = \frac{\psi}{6.28} \; SIN \frac{\theta}{2}\right)$$

$$\left(\% \; FOV_D = \frac{\psi}{360} \; SIN \frac{\theta}{2}\right)$$

Configuration Concept	FOV (Rad) θ	FOV (Rad) ψ	FOV (Deg) θ	FOV (Deg) ψ	% Full Field Inst***	% Full Field Total
1.1	.96	2.09	55	120	15.4	36.2*
1.2	.96	2.88	55	165	21.2	41.7*
2.1	1.22	3.25	70	186	29.6	46.8**
2.2	1.22	2.44	70	140	22.3	42.8**
3.1	1.22	4.07	70	233	–	37.1
3.2	1.22	3.05	70	175	–	27.9
4.1	1.05	3.05	60	175	24.3	43.2*
4.2	1.22	3.14	70	180	28.7	50.9
5.1	3.14	4.19	55	120	15.4	62.2
5.2	3.14	4.19	70	186	29.6	62.2
5.3	3.14	4.19	55	120	15.4	62.2

* Pitch
** Pitch and Yaw
*** Instantaneous

Figure 7-3: Percent of Full Field Viewing

Focus compensation may be required to correct for scene distortion due to the pitch angle movements. The compensation hardware could either be optical or mechanical. Mechanical positioning stability, repeatability and smoothness of operation will affect image resolution. Pointing accuracy will be limited to about .3" at best; to maintain system tolerance the helmet, head tracker and servo system must be aligned each time the configuration is changed to insure visual alignment.

Wide field-of-view projection on a screen from within a dome is generally incompatible with an HUD. The accommodation of two crew members in a tandem arrangement is marginal; a crew placement similar to the AH-64 will fit; however, the front man (gunner/copilot) would have a very distorted visual scene.

7.2.2 Concept No. 2 – TV Projector/Fiber Optics (Servoed) With Dome

Candidate concept No. 2, as described in Paragraph 6.2.8, is configured with two different composite fields of view which are portrayed in Figure 7-2, Configurations 2.1 and 2.2. As mentioned earlier, configurations were chosen to optimize each projector's display capability as well as to maximize FOV capability to meet ACAVS requirements. A summary of this concept's characteristics is shown in Figure 7-5.

This concept is similar, in cab and visual display design, to the servoed periscope arrangement, but this design remotes the servoed control from the projector/extension lens assembly to servo just the final objective lens assembly. By doing this, several parameter characteristics are changed. First the mass of TV projectors may now be remoted at a convenient location behind the crew members or off the cab area proper to the VMS/RSMG physical platform interface. The fiber optics interface, which is flexible, permits the gimballed head to be maneuvered more readily, with less power and greater accuracy (due to lower mass), and has pitch and yaw capability. With recent improvements in coherent fiber optics technology (see Paragraph 5.1.1.5), it is possible to image and mosaic different fields of view together without fear of illumination losses in some areas due to individual fiber breakages. Other improvements gained by this approach are greater portability of the equipment modules and quicker setup and system alignment.

The optical center of the objective lens, as in most dome configurations, must be placed in the center of the dome to decrease disortions; thus, the added modular flexibility aids this requirement when different cab configurations are made (see Paragraph 7.2.6).

Helmet tracking capability is required in the pitch and yaw axis to generate the control signals for the gimballed platform. Each time a crew member is positioned in the seat for a mission flight, the crew member's helmet (that is in control of the display) must be "zeroed" and "aligned" for the way the helmet is worn and for the operator's body positions (height, etc.). These alignments, although not difficult, are time consuming and must be reinitialized each time a different cab configuration is made.

Areas of potential concern with this concept's FOV configuration are the areas of image edge matching and image blending. Although no such FOV configurations were found in the technical assessment, it is considered feasible in today's technology to inset a high resolution FOV within lower resolution fields and still do edge matching with resolution/brightness blending that will not be objectional to the viewer. This concept not only keeps the high-resolution area within the operator's foveal FOV but allows CGI detailed data to be maximized in the area of most concern.

Advantages are the very wide FOV for both crew members. The fiber optics extension remotes the projector to a position that will entertain a better location for observers as well as keeping the overall center of gravity of the cab low. This coupling between the projectors and the optical head require no optical alignment once installed and should not be prone to misalignment due to mechanical vibrations. Should this image umbilical cord develop excessive fiber breakage or be damaged, it is considered a replaceable item. Image FOV alignment of the gimballed head should not be required each time the cab/dome arrangement is disassembled or reconstructed as long as the module is positioned back in the exact relationship with respect to the spherical screen. The advantages and disadvantages of the two light valve projectors are the same as those described in the previous concept. Visuals for the secondary tandem crew member are distorted and of very close focal viewing distance.

Light Valve/Periscope/Dome

Unique System Elements:

- 3 light valve projectors
- Projector pitch gimbal
- 3 channel computer image generators
- 3 extension lenses (periscope)
- Spherical screen
- Pitch head tracker

Special Features:

Three projectors have extension lenses so that they can be rotated with the center of a low gain spherical screen at the lens exit pupils. The projected images are edge matched by masks inside the extension lenses. A pitch head tracker drives the position of the projector gimbal.

System Characteristics:

Parameter	Reqm't	Goal	Config. 1.1	Config. 1.2	Comments
Resolution	6 arc min/LP	3 arc min/LP	7.0 arc min/LP	8.0 arc min/LP	
FOV	120°H × 60°V	240°H × 180°V	120°H × 55°V	165°H × 55°V	
Brightness	30 FL	50 FL	5.3 FL	23 FL	
Contrast	30:1	30:1	50:1	45:1	
Color	2	3	RGB	RGB	

Figure 7-4: No. 1 Concept Description

Fiber Optic Coupled Projector, Servoed/Dome

Unique System Elements:

- 3 light valve projectors
- 3 channel computer image generators
- Pitch/yaw gimbal and optics head (+42° −32°)
- 3 multiplied fiber optic bundles
- Pitch and roll head tracker
- Spherical screen

Special Features:

Three projectors fixed to the RSMG platform, are coupled to flexible coherent fiber optic bundles. These bundles carry the images to an optics head mounted on a pitch and roll gimbal. The head rotates about the exit pupil of the optics at the center of the spherical screen.

System Characteristics:

Parameter	Reqm't	Goal	Config. 2.1	Config. 2.2	Comments
Resolution	6 arc min/LP	3 arc min/LP	7.5/13.2 arc min/LP	6.5/11.5 arc min/LP	Dual Resolution
FOV	120°H × 60°V	240°H × 180°V	186°H × 70°V	140°H × 70°V	Composite FOV
Brightness	30 FL	50 FL	1.9 FL*	5.3 FL	* Marginal
Contrast	30:1	30:1	40:1	42:1	
Color	2	3	RGB	RGB	

Figure 7-5: No. 2 Concept Description

Another disadvantage is the low (1.9 to 5.3 foot-lamberts) brightness capability that is introduced because of the losses in the fiber optics coupling system. Image brightness is lost in the foveal inset area because it must be reduced in brightness to make it blend with the very wide peripheral FOV areas which are limited in brightness because of their size. Special optical provisions will be required with this and other dome concepts to ensure visual compatibility with HUD as stated in concept No. 1. Restricted usage of overhead controls will be encouraged to keep unwanted shadows of the arms from being placed in the operator's viewing areas. This problem arises from the fact that the projector head must remain close to the prime operator's head to keep distortions low in a small radius (10 feet) dome.

7.2.3 Concept No. 3 – TV Projector/Fiber Optics (Fixed) With Dome

Candidate concept No. 3, as described in Paragraph 6.2.9, is also configured with two composite fields of view which are portrayed in Figure 7-2, Configurations 3.1 and 3.2. The variation between these FOVs is due to the particular projectors utilized in each FOV configuration. A summary of this concept's characteristic is shown in Figure 7-6. This concept is identical with that of concept No. 2 except for FOV changes and that the optical head is now rigidly fixed and is not slavable. The FOV of this concept is very wide, giving up to 37 percent of full visual field. Since this concept is completely stationary, it is not prone to requiring optical alignment as a function of assembly/disassembly or problems encountered with servo positioning systems. As in the previous concept, the center of gravity of the cab can be kept lower than in concept No. 1 because the light valve projectors can be placed behind the crew member on the cab floor, or better yet on the RSMG/VMS physical interface. Even though this system has a very wide static FOV, it is more reliable from the standpoint that there are no servoed gimbals, head trackers and cockpit mapping problems. Although it is a simple approach, it does carry its share of problems. On the surface it would appear to be less costly because of less peripheral hardware, but this is offset by the addition of another LV projector, fiber optics and lens assembly plus the requirement for an additional CGI system.

The FOV in this concept, being fixed, does not permit high resolution imagery to be viewed outside the center 35°-47° area (depending upon the configuration) and has an image edge matching area, between projector scenes, taking place in the horizon area. The peripheral resolution of 13 arc minutes/line pair is considered marginal for detailed viewing, but adequate for motion cues. Cab/dome configuration capabilities and problems are identical with those previously stated in candidate concept No. 2.

7.2.4 Concept No. 4 – Scanned Laser Projection System With Dome

Candidate Concept No. 4 as described in Paragraph 6.2.10 is configured as one large continuous panoramic field of view (60°V × 175°) as shown in Figure 7-2, Configuration 4. A summary of this concept's characteristics that currently exists is shown in Figure 7-7.

This candidate concept is considered to be very unique in meeting the ACAVS system requirement in that it has good visual resolution, a wide field of view, raster rotational capability, full color potential and low distortions. This system approach utilizes the conventional projection dome as discussed in previsous concepts except that this system is not quite as critical in dome uniformity or curvative as far as focus is concerned. The laser projector system surveyed may be assembled in two different physical configurations. One is to mount the laser projector head above the crew members as discussed in Section 6.0 and mount the support electronics at the rear of the cab or below the cab on the RSMG/VMS platform area. This configuration requires that the lasers and optical scanning equipment be housed overhead. The other mounting approach is to place the lasers and support equipment at the rear of the cab or off the cab area on the RSMG/VMS platform area and then relay the laser light from the sources via an umbilical light pipe to the laser scanning projector head positioned above the crew members. This latter approach puts lasers and the bulk of the laser hardware out of the overhead position but requires space for the umbilical routing from the lasers to the optical projector head. At this point it is not considered of any more risk to have the assemblies placed in one position over the other because as of yet none of the laser systems have been placed on a motion base and in an environment similar to ACAVS.

Fiber Optic Coupled Projector, Fixed/Dome

Unique System Elements:

- 4 light valve projectors
- 4 channel computer image generators
- Multiplied fiber optic bundles
- Spherical screen
- Optical lens fixture

Special Features:

Each projector is coupled to a coherent fiber optic bundle that carries the image to a fixed optical lens fixture. The images are combined and displayed on a spherical screen.

System Characteristics:

Parameter	Reqm't	Goal	Config. 3.1	Config. 3.2	Comments
Resolution	6 arc min/LP	3 arc min/LP	6.5/13 arc min/LP	5.5/11.5 arc min/LP	Dual Resolution
FOV	120°H × 60°V	240°H × 180°V	233°H × 70°V	175°H × 70°V	Composite FOV
Brightness	30 FL	50 FL	1.9 FL*	5.3 FL	* Marginal
Contrast	30:1	30:1	40:1	42:1	
Color	2	3	RGB	RGB	

Figure 7-6: No. 3 Concept Description

Scanned Laser Projection System Dome

Unique System Elements:

- 2-color laser scanner
- Pitch gimbal (+55° −30°)
- Conic screen,
- Head Tracker
- Video processor
- Support equipment
- Vacuum/gas supply and water supply
- 6 channel computer image generator

Special Features:

The laser scanner projects a collimated beam of light on the conic screen with a vertical raster scan. The scanner is positioned well above the pilots head. 2-color ion lasers are acousto-optic modulated by a computer image generator. Moving optical elements are used to provide the scanning raster.

System Characteristics:

Parameter	Reqm't	Goal	Config. 4	Comments
Resolution	6 arc min/LP	3 arc min/LP	6 arc min/LP	
FOV	120°H × 60°V	240°H × 180°V	175°H × 60°V	
Brightness	30 FL	50 FL	5 FL	1 FL presently available
Contrast	30:1	30:1	50:1	
Color	2	3	red/green	3-color growth potential

Figure 7-7: No. 4 Concept Description

The laser display approach has many advantages to offer, especially when interfaced to a laser-camera model. This configuration yields very good image detail in full color and is the only camera/model board/display technology that can handle this type of data in such a uniform, continuous-wide FOV. Whether the imagery is supplied via video, generated from laser camera/model board, or from CGI data inputs, it is of concern that the interface capability for this system may be marginal. Current NASA video interfaces provide video data rates up to 30 MHz. This capability is considered excellent for normal high line TV rates but the laser system video rate requirements exceed this value by at least a factor of four. This means that to interface a laser system on the ACAVS facility will require special high frequency interfaces to be installed or requires that several high-speed digital parallel interfaces be utilized for transmission of CGI image data from the CGI computer area to the rotorcraft cab. Here the data must be decoded in a very high-speed DAC for controlling the laser modulators and scanner timing circuits.

Another area of special concern is the ability to display the laser field to a control room operator and thus monitor the CGI/visual system operation without actually viewing the actual laser display (which most likely will be located several hundred feet from the control room/development station area). This problem arises because the laser system has no known maintenance display format other than the laser scanner format unless special TV format provisions are incorporated within the design to reformat the laser camera or CGI visual to multichannel TV capability. Power requirements for this system are also considered to be quite high and range up to 80 kilowatts of power for a three-color configuration. Special cooling requirements are also necessary with this display system. Another area for concern is safety of the operating personnel from unshielded laser light.

Reliability, maintainability and supportability of the laser concept were rated lower than that of most other display systems. This was felt to be necessary because of the problems that have been encountered in prototype systems developed to date. Future capability is expected to be more reliable but this cannot really be documented until a system has been subjected to the vibration environment of motion base simulators.

In summary, the laser system like the previous candidate concepts has its own unique set of advantages and disadvantages. As stated, the advantages are very wide FOV with uniform brightness, low distortion and good image resolution as well as pitch and roll capability of the laser raster via signals from head tracker or aircraft inputs. This capability enhances handling quality capabilities under some flight configurations and prevents pilots' loss of motion and aircraft orientation cues during low altitude maneuvers.

Disadvantages associated with the laser concept are relative low image brightness levels, laser speckel, and image banding introduced by optical misalignment. Physical size of the overhead scanning and support assemblies may hinder some cab configuration changes to a greater extent than other system concepts although the overhead projector arrangment does open up aisle areas. Support equipment for the laser system will be more sophisticated and require personnel with special expertise to maintain the system in peak operating status. Head trackers utilized for raster orientation control will require cockpit mapping and operation calibrations. As with all dome approaches, depth of focus is incompatible with existing HUD, thus some equipment modifications will be required for imaging HUD systems. Finally, cost for the laser concept exceeds all other approaches. This is partly due to a new technology system and the number of CGI channels required.

7.2.5 Concept No. 5 – Helmet-Mounted Display

Candidate Concept No. 5 consists of three display FOV configurations using two different TV projector systems. The system's FOV arrangements are shown in Figure 7-2, Configuration 5.1, 5.2 and 5.3. A summary of these concept's characteristics is shown in Figure 7-8.

The HMD concept, as described in Paragraph 6.2.11, has a much greater versatility than any of the previous concepts and will provide the crew member with a wide undistorted instantaneous FOV complemented by an overall FOV limited only by the head tracker capability; this concept also provides maximum crew station design and configuration flexibility. With this virtual image presentation capability, HUD displays can be viewed directly by the crew member. Since the helmet is being utilized to hold the display system/head tracker sensors and

Helmet Mounted Display (HMD)

Unique Systems Elements:

- 3 light valve projectors
- 3 flexible coherent fiber optic bundles
- Head tracking system
- Helmet visor combiner optics
- 3 channel computer image generator (CGI)

Special Features:

The head tracking system provides pilot head position to the CGI visual system. Each visual projector relays the visual image to the Helmet Mounted Display (HMD) via flexible coherent fiber optic bundles. The HMD has optical combiner lenses which permit "see-through" of the internal cab and instruments in the areas of view with the CGI image blanked. Cockpit mapping provides cab interior polar plot information to blank the CGI visual scene.

System Characteristics:

Parameter	Reqm't	Goal	Config. 5.1	Config. 5.2	Config. 5.3	Comments
Resolution	6 arc min/LP	3 arc min/LP	7.5' arc	7.5/13.2* arc min/LP	7.5 arc min/LP	* Dual resolution
FOV	120°H × 60°V	240°H × 180°V	120°H × 55°V	186°H × 70°V*	120°H × 55°V	* Composite FOV
Brightness	30 FL	50 FL	30-40 FL	30-40 FL	28 FL	
Contrast	30:1	30:1	20:1	20:1	34:1	
Color	2	3	RGB	RGB	RGB	

* Each projector is coupled to a flexible coherent fiber optic bundle which carries an image to the helmet optics.

Figure 7-8: No. 5 – Concept Description

normal intercom function, etc., it is extremely important that the helmet weight be kept low. In good helmet display design, helmets should not appear to weigh (to the observer) more than 3.5 pounds maximum. Thus, in some design configurations it may be required to support the fiber optics umbilical of the helmet assembly with negator spring technology, thus removing any weight that may be noticeable to the crew member. This approach, though, still leaves helmet inertias uncompensated.

Since this system will be more prone to flexing the fiber optic bundles, i.e., helmets being positioned about and removed, it is more likely that fiber breakage will occur and thus reduce image brightness to undesirable levels. When this occurs, fiber optic cables will need to be replaced. It is recommended that if this concept approach is used, that several spare umbilical fiber optic bundles be purchased at the same time. This will ensure minimum system downtime and reduce image alignment problems because each replacement bundle will have been made off the same production run.

Helmet tracker LOS errors less than or equal to .37° (RMS) and roll angle errors of .55 (RMS) are possible with this concept; head tracker positioning signals may require position lead compensation and dead bands up to 1° to ensure that CGI visuals are positioned correctly in space and do not jitter unnecessarily with slight movements of the operator's head.

As mentioned earlier, the FOV configurations are dependent upon the type of projectors used. Since the visual image display is of relative small viewing area (although optically it encompasses a substantial FOV), it does not have the brightness problems normally associated with the other visual display concepts. Configurations 5.1 and 5.3 are identical in image format; the only difference being Configuration 5.1 utilizes the G.E. color light valve whereas Configuration 5.3 uses ESP's "Cyclops" projector which reduces costs. Configuration 5.2 is of a different format utilizing a high-resolution image inset. The advantages and disadvantages of these types of wide FOV inset displays have already been discussed in previous concept evaluation sections, except as they impact HMD design.

HMD can be manufactured in two ways. One approach is to project the image onto a continuous image screen and view the scene with both eyes. The other approach is to split the projected image into each eye's prospective with about 25° overlap in the center area and thus project the image to each eye independently. This approach requires minor individual eye alignments, but has growth potential to 3-D vision.

An advantage of the HMD concept is no exterior dome or viewing screen is required; therefore, dome maintenance, moving, teardown/buildup time and labor are eliminated. The entire cab and visual system can be modular and represent both tandem and side-by-side arrangements without any viewing restrictions. This is especially true if the on-line type of cockpit mapping is utilized for image occulting. Thus, in a tandem arrangement, the forward crew member will correctly occult the visual scene to the pilot on-line and in real time; this capability is impossible to accomplish with only head positioning/cockpit mapping devices. Other advantages include the highest brightness and widest total FOV (62% of full field) of any concept.

Sling load and air-to-air combat is a natural for the HMD concept. Images from the CGI system are always available to the crew member in the correct prospective (within the CGI's capability and within the transport delay of the CGI system; this is typically .1 sec).

Disadvantages of this concept include some areas of undemonstrated ability. It appears that this technology is feasible today, and many companies are pursuing the art but it is believed that a working unit should be demonstrated before complete acceptance of this method is made. Other disadvantages include problems of using helmet-mounted HUD with this concept. Some equipments may not be compatible. Also, crew members in a research facility may object to having to wear the helmet at all times to view the outside scene. Image occulting appears to have a workable solution, but has yet to be observed by this assessment.

One of the biggest disadvantages to this concept is that it requires at least three channels of CGI and three color TV projectors per crew member and observer. This requirement substantially increases costs and reduces cockpit available space. One possible alternate cockpit configuration with growth potential is to utilize the HMD for the primary crew member under test and to provide the remaining crew member with a CRT display window. This compromise would give full capability to one crew member and still provide some adequate display capability for the other crew member at a substantial cost reduction. While not considered in detail, preliminary calculations indicate that efficiencies associated with optically matching of shadow mask color monitors to low loss fiber optics would result in illuminance levels too low to be useful. If large monitor (≈ 15") fiber optic faceplates become available, this approach should be examined more closely.

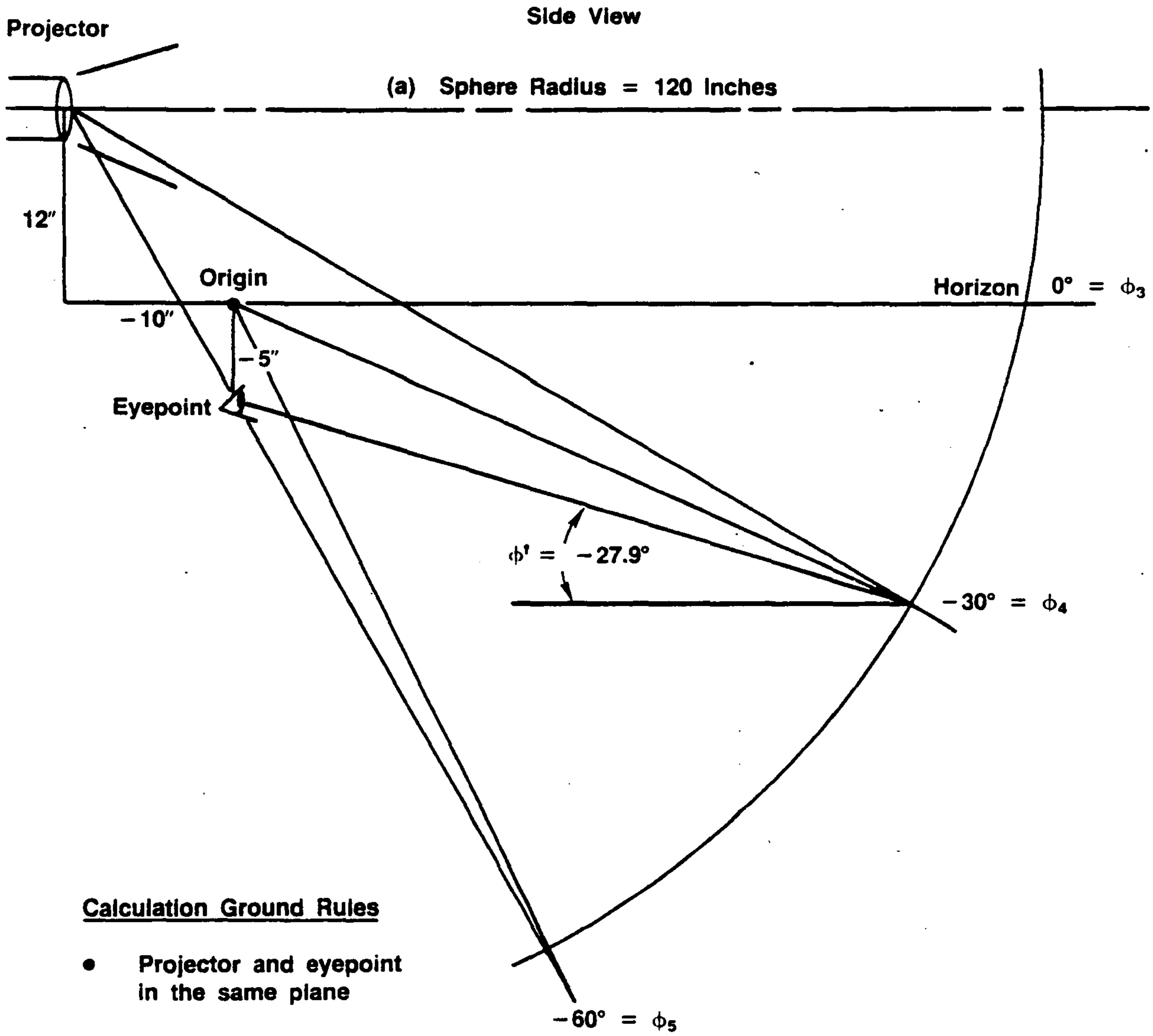
7.2.6 Concept Evaluation Summary

Several items mentioned in the concept evaluation description need to be expanded upon. Some advantages and disadvantages given are common to all dome approaches and all approaches when it comes to some projector capabilities. Video interfaces from the CGI area must be buffered and in a balanced configuration to ensure that signals from the source arrive at the display system undistorted; this is especially true of the 100 MHz signals for the laser concept.

In this evaluation, certain areas of concern are anticipated due to some of the unconventional FOV configurations. These represent potential problem areas but are not considered of such high risk as to eliminate the utilization of these approaches in attaining the display system requirement. Most instantaneous FOV for the concept system do not quite meet the 60°V FOV system requirement. A 55°V FOV (in this report) was considered a small compromise for meeting the overall resolution requirements without increasing the number of display and CGI channels that would have been required. This compromise keeps cost levels down as well as minimized space requirements and system downtime.

One area of major concern in all dome concepts is sound problems encountered within the dome when the simulator sound system is on in addition to sounds that are received into the dome/cab area from the VMS hardware. Special sound masking is possible and required to remove unwanted external sounds. Simulated sounds of rotorcraft noise generated within need to be dealt with differently. Special provisions will be required in the dome internal design to ensure that a "barrel" sound effect does not occur in the centroid of the sphere where the prime crew member is located. One workable approach is to construct the dome only as large as necessary in angular dimensions and apply flat black sound deadening material on all other surfaces except those necessary for image viewing. This approach will help solve the problems of loss of contrast due to reflected images (see Paragraph 5.1.1.3), sound introduced from outside the dome, "in the barrel" sound effects, and the size and bulk of the dome.

Dome systems can present a problem in that image distortion for a small diameter dome can become large unless the effective source of the image projection is near the observers eye and near the center of the dome. This placement gives rise to occulting of the image if upper portions of typical rotorcraft cabs or canopies were to be simulated. In the event that these items need to be simulated, CGI systems have the capacity to "mask" portions of the outside scene which would normally be obscured by such things as window posts and overhead controls. With head tracking, even parallax encountered between cockpit structure and the outside world could be simulated. HMD concepts have illumination matching problems in that the cockpit interior must be internally illuminated to insure the crew member can read the internal instruments through the occulted external scene areas without the internal illumination losing contrast and thus washing out the HMD displays. Some HMD approaches allow for internal/external background illumination balancing.



<u>Calculation Ground Rules</u>

- Projector and eyepoint in the same plane
- Projector positioned to give observer a nonobstructed ~ 60° downlook
- Calculations @ ϕ_1 = 60°, ϕ_2 = 30°, ϕ_3 = 0°, ϕ_4 = 30°, ϕ_5 = 60°, in elevation
- ϕ' is elevation angle from viewpoint to eyepoint

Figure 7-9: Distortion Calculation Geometry

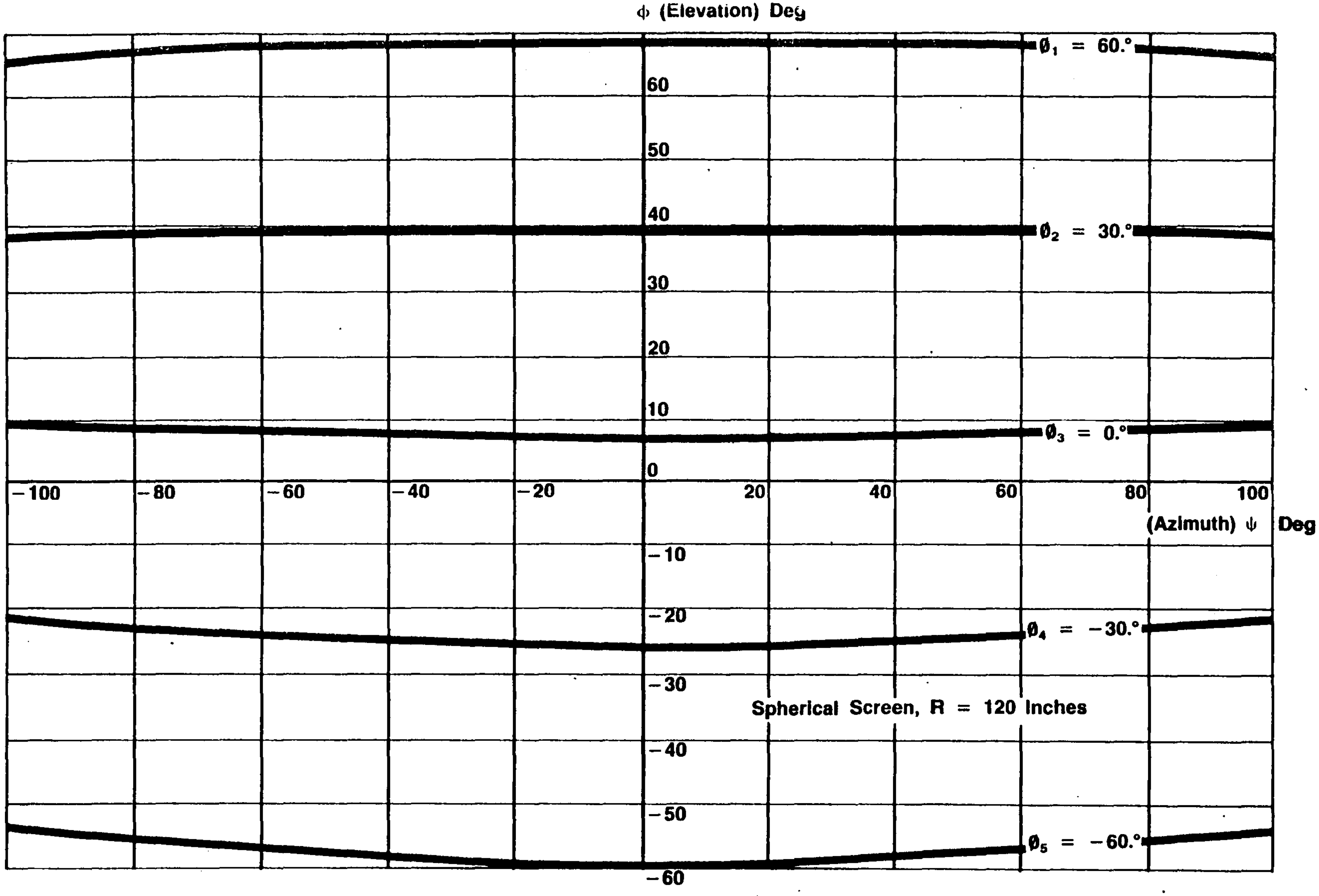


Figure 7-10: Spherical Screen Distortion

As previously stated, all dome systems inherently require the projector to be placed close to the center of the dome and close to the crew member's head. Distortion data has been generated for this evaluation to provide insight to the positional range a projector can be moved from the center of the screen before distortions are unacceptable.

A preliminary calculation was made for the displacement and distortion an observer would experience when viewing a spherical screen. The geometric conditions are described in Figure 7-9 with distortions being plotted in Figure 7-10. Only spherical screens were considered here. Nonspherical screens can pose a serious problem in edge matching of composite scenes if these scenes are not projected from a common point. For an elevation angle of $\phi = 30°$, the distortion varies from 4° to 0° azimuth to 8° to 100° azimuth. This is a lateral (tangential) distortion of four percent over the half azimuth field.

Similarly if $\phi = +30°$, the distortion will vary from 10° error to approximately 8° over the viewing angles of 0° to 100° in azimuth. The distortions increase quickly for projector/head viewing position off-the-center position. CGI systems can be programmed to compensate for these errors. More distortion analysis is given in Appendix I.

7.3 Visual System Evaluation

7.3.1 CGI Systems Evaluation

As mentioned in Paragraph 6.3.1, a CGI hypothetical system was established as an aid in ACAVS system concept synthesis. There is no existing hardware today which will simultaneously fulfill all of the ACAVS requirements. Also there is no reason to believe that in the future there will be only one specific CGI hardware approach that will satisfy all of the ACAVS mission. Therefore, the following paragraphs suggest a comparison model for evaluation of CGI systems as they become available or are proposed.

7.3.1.1 Computer Generated Image Comparison Model Overview

The purpose of this model is to provide a general framework for evaluating alternative CGI design approaches for the ACAVS program. It is recognized that no weighting system is capable of taking into account even a small percentage of the numerous trade-offs completely understood only by the individual competing firms. This model is, therefore, developed to allow each potential manufacturer maximum flexibility in optimizing their strengths, while still meeting minimal ACAVS requirements. The model itself is divided into two major factors which are considered equally important: technical factors and management factors. Technical factors are comprised of scene content factors, bandwidth factors, computational complexity factors, and special technical factors specifically related to the ACAVS program. Management factors include technical risk assessment, financial risk assessment, and schedule risk assessment.

Several of these factors are described in more detail in the following paragraphs.

7.3.1.1.1 Technical Factors

- 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

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

   (See Figure 6-18, Volume I.)

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.

- 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.

7.3.1.1.2 Technical Risk Assessment Overview

Two viable methods of technical risk assessment are presented:

- Knowledgeable Individuals Method

  It is highly preferable that technical risk be evaluated by a group of not less than three individuals knowledgeable in the general hardware and software characteristics of computer image generation, and thoroughly familiar with the ACAVS mission requirements.

- Process Complexity and Development Stage Method

  Should this not be possible, we recommend a comparative evaluation of technical risk built upon the process complexity and development phase of the image generation system or subsystem being analyzed.

  1. Process Complexity – An analysis of process complexity is required only if a new method of image generation is proposed. Should this occur, a crude estimate of complexity can be made by breaking the CGI process into independent "stages" and each stage into its constituent components. A "stage" is one complete hardware building block of the overall CGI pipeline characterized by its single functional responsibility, physical compactness, and sometimes independent (internal) timing. The number, function, and redundancy of each stage can then be analyzed. Component by component simulation data is superior to all but actual operational experience. Lacking either, a distinctly less preferable approach is for a relative comparison between systems containing comparable components and performing the same or similar functions be made by taking the ratio of the component count times the ratio of the algorithm base two of those same counts. A ratio of "1" indicates the same relative complexity, while a ratio of "2" indicates roughly twice the complexity. Thus, if C_1 is component count one and C_2 is component count two, the relative complexity between them is

  $$\frac{C_1 \log_2 C_1}{C_2 \log_2 C_2}$$

  2. Development Phase – Another (and sometimes more accurate) indication of technical risk is the development phase of the project. For convenience, we list the following phases:

     – Technical Assessment – This is the initial step in the solution of any design problem. If the problem is simple enough, such as the modification of a commercially available interface (say an RS-232 interface), then this step should be sufficient.

- Conceptual Development – Conceptual development represents the next phase in design evolution, wherein a "top level" design approach is considered. Normally only the organizational philosophy and general configuration of the design are known.

- Design Simulation – Any design needing more than a few printed circuit boards or possessing questionable logic, timing, or interface characteristics should be simulated. A computer analysis performed on a function-by-function basis is a minimum requirement.

- Partial Breadboard/Simulation – Designs that reach this phase of development have a majority of the "bugs" worked out of them. Partial breadboarding of critical processes is a standard means for improving product design while minimizing development cost and risk.

- Prototype – The prototype is the first "complete" system constructed and is often a laboratory-only model. Any contractor having a working prototype has eliminated enough risk to warrant serious consideration in the ACAVS program.

- Mark I Product – This is the first marketable version of the new system and a natural follow-on to the prototype unit. Nearly all the design flaws have been removed, but there is still no operational experience with the product, and its reliability and maintainability, as well as performance, are unproven.

- Off-the-Shelf Product – One of many identical designs built and delivered. The product represents considerable accumulated technology and logistical base experience and extremely low risk, unless substantial modifications are made.

- Product Line – A field-supported product group, comprised of similar designs, representing a broad technical and logistical base. It is considered the lowest possible technical risk.

For the purpose of ACAVS, no consideration is given to any process that has not reached the prototype development phase in this method of assessment.

7.3.1.2 CGI Scoring Approach Rationale

There were several reasons for selecting a functional scoring system with floating requirements replacing solid specifications for the design and development of the ACAVS CGI system. First, it is well known that available CGI hardware is incapable today of producing complex imagery suitable for realistic terrain flight or nap-of-the-earth simulation. The depth complexity and the resulting number of edge crossings per raster line become too great in certain segments of the scene (e.g., trees) so that real-time capability of the processors is overloaded. Secondly, it is unlikely that any breakthrough in CGI architecture will occur prior to 1982. Additionally, the ACAVS system must be procured within rigorous financial and schedule constraints. It is, therefore, extremely important that each contractor have the freedom to optimize individual designs and to provide for future growth potential, while ensuring that the basic ACAVS mission requirements are met.

We have, therefore, provided for two types of functional specifications: basic requirements and functional goals. Basic requirements are those considered essential to the successful performance of the ACAVS mission. All offerers are expected to fulfill the minimum requirements, irrespective of design emphasis. Functional goals, on the other hand, constitute a variably scored set of capabilities emphasizing the ACAVS mission but left to each contractor to determine design approach in such a way as to optimize overall technical rating. Parameter scoring criteria are given in the following paragraphs.

7.3.1.2.1 Field of View (FOV)

Basic requirement: The minimum acceptable configuration is 120 degrees horizontal by 60 degrees vertical, which constitutes one-sixth full spherical field.

Functional goal: Additional credit will be given as follows:

$$\text{SCORE (FOV)} = 6.\text{X}\left[\frac{\text{Instantaneous Field of View}}{\text{Full Spherical Field}}\right] \quad \text{(limited to 6).}$$

Figure 7-12 shows a plot of percent of full field for various horizontal and vertical fields of view using the equation, $FOV = \frac{\psi}{360} \sin \frac{\theta}{2}$ where ψ is the horizontal (azimuth) angle and θ is the vertical (elevation) angle.

7.3.1.2.2 Image Resolution (IR)

$$1/2 \left\{ \left(\frac{6}{IR}\right)^2 + \left(\frac{6}{IR}\right) \right\}, \text{ if IR is in line pairs, or}$$

$$1/2 \left\{ \left(\frac{3}{IR}\right)^2 + \left(\frac{3}{IR}\right) \right\}, \text{ if IR is in pixels}$$

(See Figure 7-13)

Scored image resolution is the square root of the product of the vertical resolution (IR_V) and the horizontal resolution (IR_H) given in the formula

$$IR = \sqrt{(IR_H) \times (IR_V)}$$

The value of IR used in scoring a composite field-of-view scene consisting of areas A_1 and A_2 becomes

$$IR = \frac{A_1 \sqrt{(IR_1)} + A_2 \sqrt{(IR_2)}}{A_1 + A_2}$$

7.3.1.2.3 Color (C)

Basic requirement: The contractor shall provide at least 256 color levels, C = 8 bits.

Functional goal: Credit for additional capability will be provided as follows: SCORE (C) = .9 + C/80, limited to 1.2.

7.3.1.2.4 Frame Rate (F)

Basic requirement: The minimum acceptable frame rate shall be 30 Hz with 60 Hz interlaced field rate.

Functional goal: The score shall be SCORE (F) = F/30, upper limited to 2.

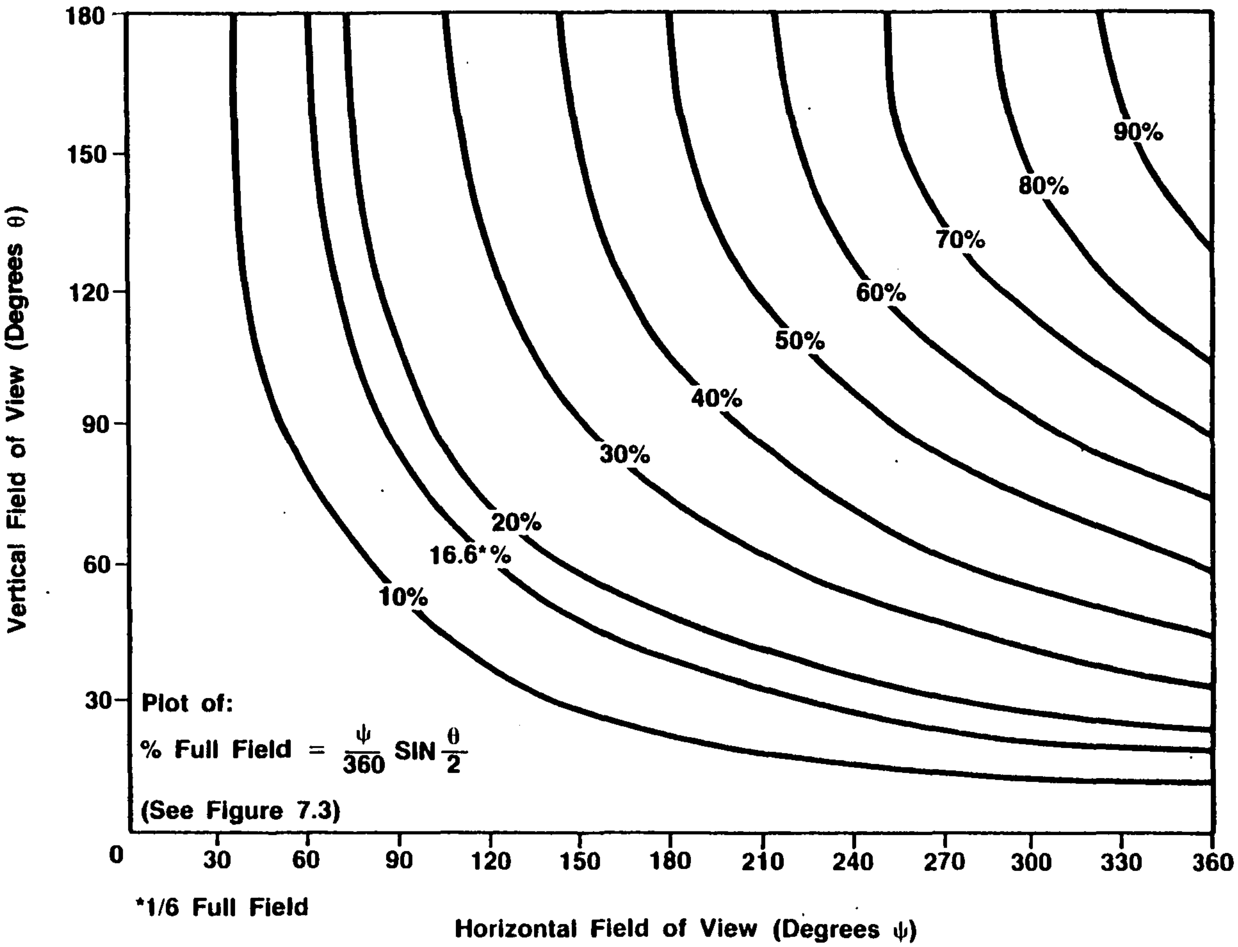


Figure 7-11: Percent of Full Field of View

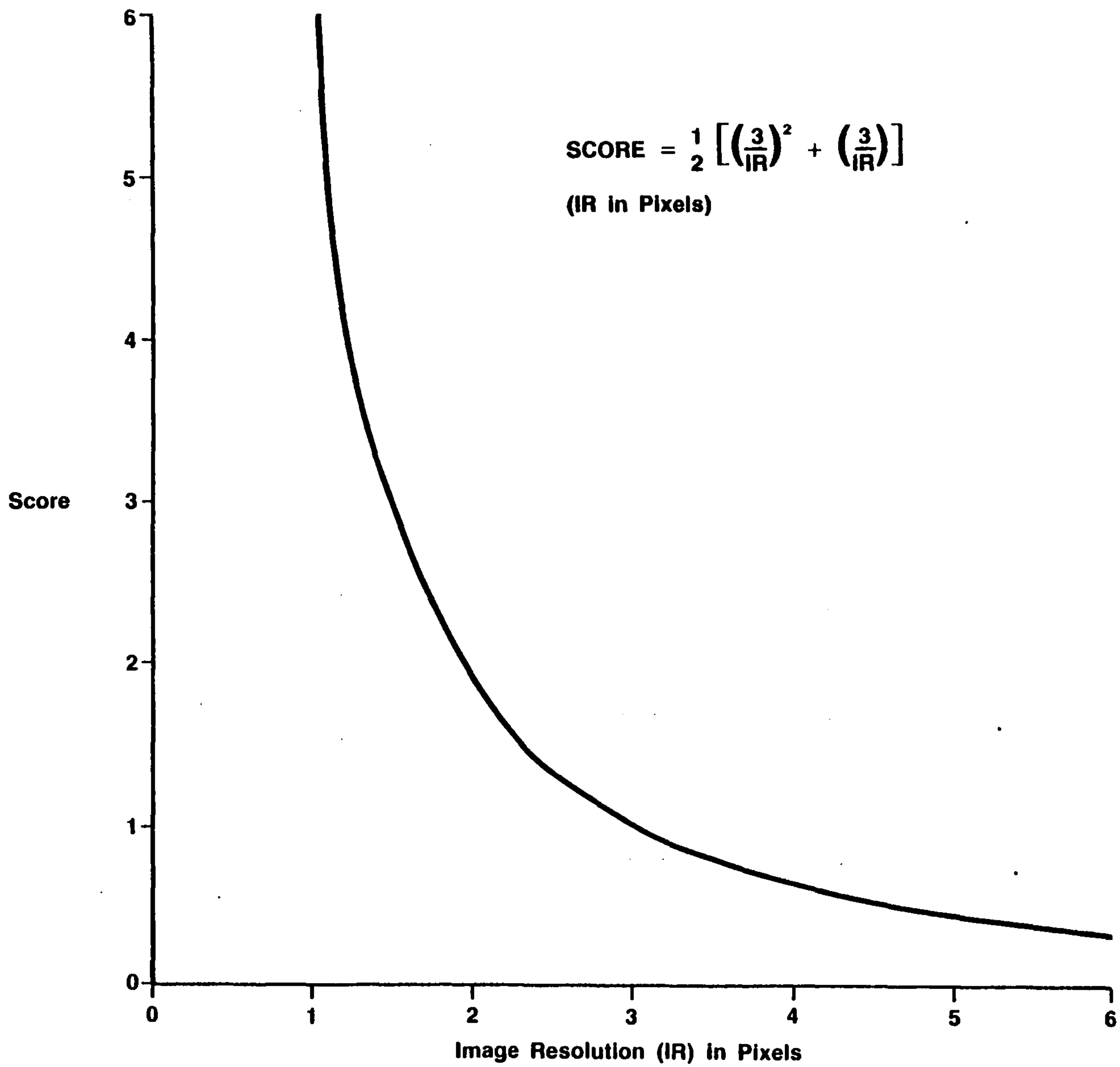


Figure 7-12: Computational Complexity Factors – IR

7.3.1.2.5 Transport Delay (T)

Basic requirement: Transport delay shall not exceed .2 seconds.

Functional goal: The score for transport delay shall be

$$\text{SCORE (T)} = 1 + .6309 \left(\cos\left(8 \pi T - 2 \tan^{-1} 4 \pi T\right) - \frac{\sqrt{2}}{2}\right) \text{(See Figure 7-14)}$$

7.3.1.2.6 Level of Detail (LOD)

Basic requirements: Level of detail control shall include consideration of:

- Object depth
- Object relevance (assigned by the modeller)
- Object location within the field of view; specifically, objects in the periphery, or in peripheral channels should be processed at a lower level of detail.

Functional goal: Score (LOD) = $1/(1 + \sqrt{1/LOD})$ (See Figure 7-15)

Thus, if only one level of detail is used, a score of .5 is given, while continuous level of detail (LOD = ∞) gives a score of one.

7.3.1.2.7 Image Breakup (IB)

Basic requirement: Regardless of image generator design, the resulting image shall not break up at any combination of angular velocities up to two radians per second or translational velocities up to 500 knots.

Functional goal: SCORE (IB) = $1 + (W_B - 2)/200 + (T_B - 500)/50000$ limited to 1.2, where W_B is the angular breakup velocity in radians per second, and T_B is the translational breakup velocity in knots.

7.3.1.2.8 Dynamic Light/Shadow (L/S)

Basic requirement: The contractor shall provide simulation of the rotorcraft landing lights.

Functional goal: Additional capability will be given as follows: SCORE (L/S) = 1 + ratio of field of view of objects computed for dynamic light and shadow to the instantaneous field of view per moving light source, limited to two.

Thus, if the entire field of view is computed for moving light/shadow effects, a score of two is obtained.

7.3.1.2.9 Curved Surface Shading (CSS)

The contractor need not provide the capability for curved surface shading. In the event curved surface shading is provided, it will be scored as follows:

SCORE (CSS) = .95 for no curved surface shading
1.00 for standard linear (Gouraud) shading
1.10 for normal interpolation (Phong) shading

Although the proposed system need not provide curved surface shading, growth to include such a capability at a later date must be provided.

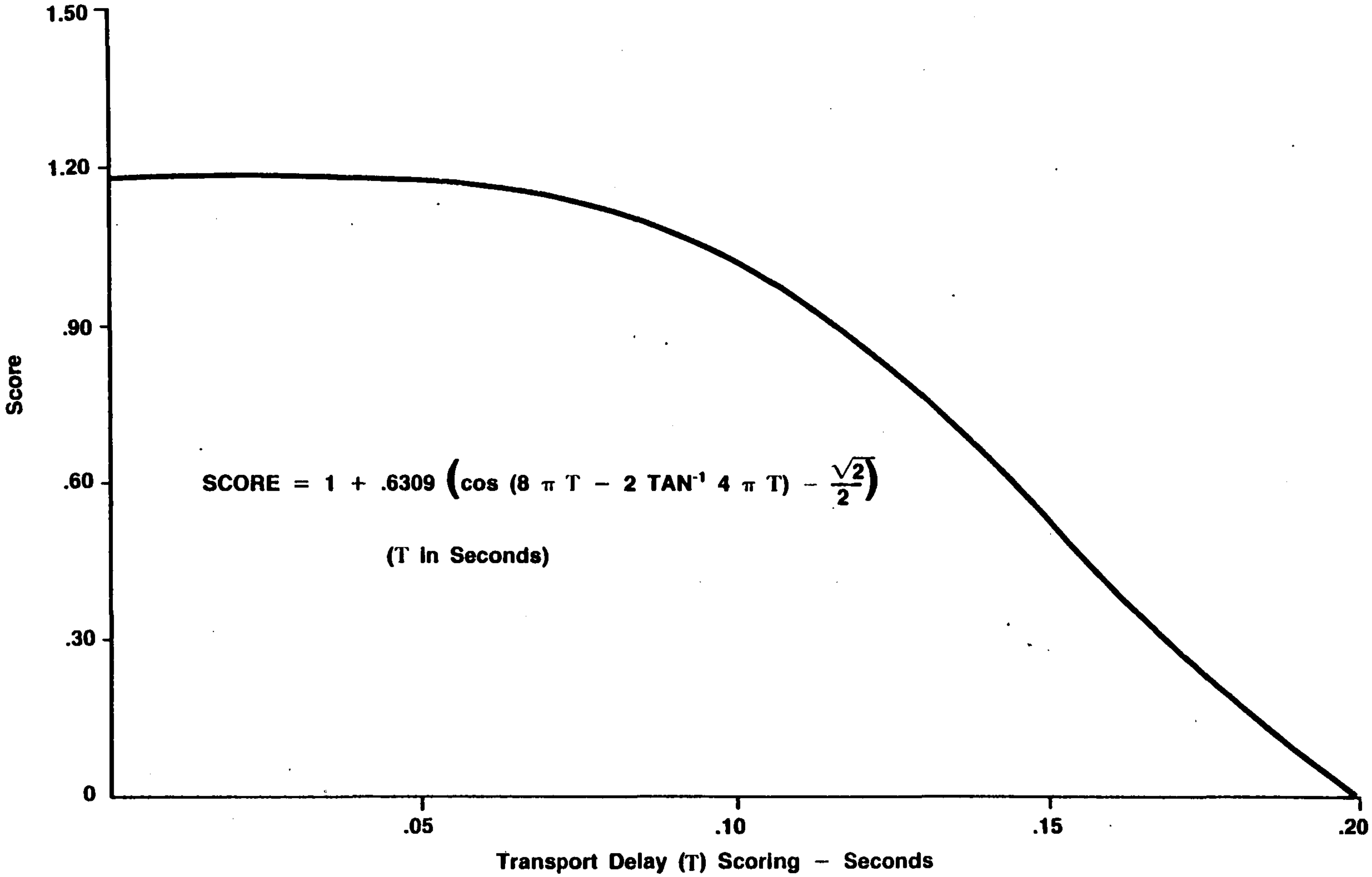


Figure 7-13: Computational Complexity Factors − T Scoring

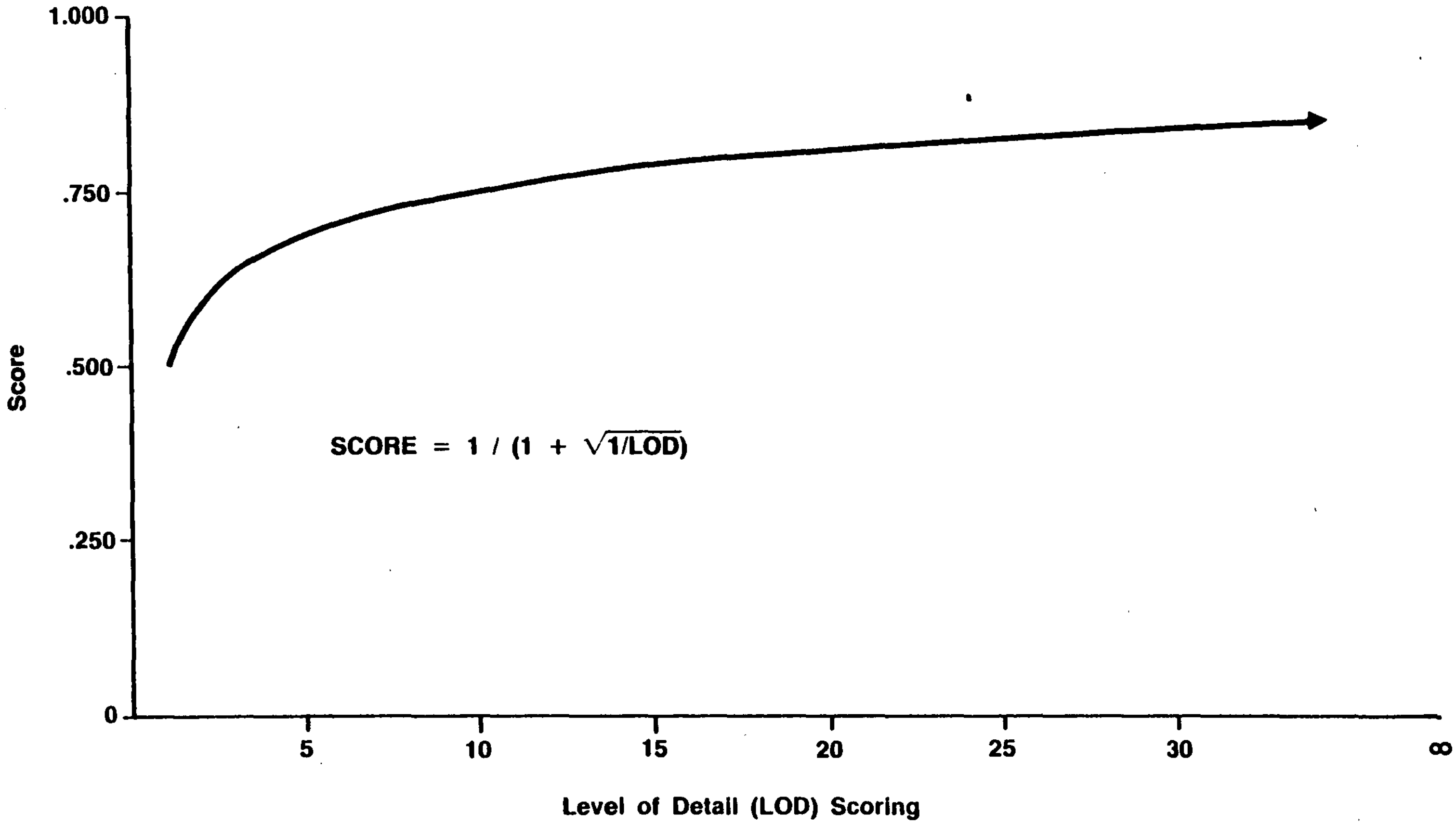


Figure 7-14: Computational Complexity Factors – LOD Scoring

7.3.1.2.10 Data Base Development System (DDS)

The data base development system, described in Section 3.5.4 of the Technical Specification, is regarded as one of the single most important CGI subsystems. Each contractor will be free to specify the development system as desired, subject to the following restrictions:

- The DDS cost shall not exceed 10 percent of the total visual system (CGI system, including displays and integration) costs.
- The DDS shall be a separate, standalone facility for the real-time image generator, but will be capable of producing data bases for use on the real-time system.

Contractors will be evaluated in terms of the overall capability, flexibility, and growth potential of the DDS. The ability of the DDS to use existing data bases, such as the Defense Mapping Agency (DMA) data, will be given strong consideration. Additionally, the number, size, and complexity of data bases proposed by the contractor to be delivered as part of the DDS will contribute significantly to this score. Scoring will be the subjective evaluation of the ACAVS technical review team such that $.9 \leq$ SCORE (DDS) ≤ 1.1.

7.3.1.2.11 Special Image Generation Effects (SE)

It is recognized that many special effects require special purpose hardware, complex software, or both, and are difficult, if not impossible to model directly. Desirable special effects include (but are not limited to):

- Rotor lighting effects
- Blowing dust, or sand, upon landing or low hover
- Target destruction or partial destruction
- Smoke
- Missile trail (exhaust plume)
- Patch fog in low lying areas
- Cloud simulation

Each contractor's approach will be subjectively scored such that $.98 \leq$ SCORE (SE) ≤ 1.02.

7.3.1.2.12 Technical Risk Assessment (TRA)

The assignment of a confidence factor to each proposed subsystem of the CGI system. This confidence factor considered a function between 0 and 1.

7.3.1.2.13 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 images plane or frequency domain statistical properties, as maps or change functions, or as procedural functions. 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. 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. The general considerations are these:

- At the very least, texture must maintain image plane coherency. By this we mean that it should be capable of restriction to the image of functional objects. This will, assuming the functional object's edge boundary is perspectively correct, provide parallax cues.

- Moveover, the texture should be spatially coherent. Together with this requirement is the requirement to be perspectively correct. The lack of spatial coherency and perspective makes the estimation of object size and aircraft velocity more difficult.

- Finally, the texture should be capable of three-dimensional superposition. This allows the user to combine object and texture types to achieve greater realism.

The scoring is as follows:

Spatial Coherency:	Take 50% off relative weighting for image plane coherency only
Object Superposition:	Take 50% off relative weighting for a nonobject superposition capacity

Weight (T) is 31/32 plus the ratio of the sum of the average horizontal (H) and vertical (V) run lengths without texture to the sum of the average horizontal (H_T) and vertical (V_T) run lengths with texture, divided by 32:

$$T = \frac{31}{32} + \left(\frac{H + V}{H_T + V_T}\right)\left(\frac{1}{32}\right)$$

7.3.1.2.14 Antialiasing

Antialiasing refers to any method of minimizing the adverse visual effects of discrete spatial sampling on CGI images, including scintillation, moire patterns, and the breakup of small objects.

Basic requirement: All proposed CGI systems will provide an antialiasing capability required to pass the test described below.

Test description: Each contractor will provide three static images centered at screen center composed of unit pixel width circular rings with spacing two, four and six pixel widths. The criterion of performance for each image will be a fixed comparison between the test images and an image generated by a three-by-three binary weight filter with 2x sampling per period. The test images must meet or better the minimal requirements.

7.3.1.2.15 Atmospheric Effects

Basic requirements:

1. At least three light levels of the sky and ground (day, dusk, night) shall be simulated, with colors of all models displayed being adjusted based on the time of day.

2. Aerial perspective shall be simulated with colors of objects being faded towards a haze color based on the distance of the objects from the viewpoint.

3. At least one layer of fog or haze shall be simulated with the top elevation, bottom elevation, and the visibility inside the fog being operator definable. Object colors shall be further faded towards a defined fog or haze color when the viewpoint is located in the fog.

4. A horizon glow shall be simulated for dusk and night scenes.

7.3.1.3 CGI Scoring Breakdown

The CGI score (S_{CGI}) is the product of four scoring factors:

- Score Content Factors (S_C)
- Score Bandwidth Factors (S_B)
- Computational Complexity Factors (S_D)
- Special Technical Factors (S_T)

That is,

$$S_{CGI} = [S_C]\,[S_B]\,[S_D]\,[S_T]$$

7.3.1.3.1 Scene Content Scoring Factors (S_C)

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 (F_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)

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

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. If the number of "potentially visible" faces or surfaces is not known, but only that for the total, then use two-thirds of the above, as approximately one-third of the faces (surfaces) will be removed by a hidden face test (sometimes called a back face cull).

7.3.1.3.2 Scene Bandwidth Scoring Factors (S_B)

Scene bandwidth factors are Field of View (FOV), Image Resolution (IR), Color (C), Frame Rate (F), and Transport Delay (T). The score is given by the formula:

$$S_B = (6\,FOV)\left\{1/2\left[\left(\frac{3}{IR}\right)^2 + \left(\frac{3}{IR}\right)\right]\right\}\left(\frac{C+72}{80}\right)\left(\frac{F}{30}\right)\left\{1 + .6309\left[\cos\left(8\pi T - 2\,TAN^{-1}\,4\pi T\right) - \frac{\sqrt{2}}{2}\right]\right\}$$

as long as all variables meet the minimal requirements. Otherwise, the score is zero.

7.3.1.3.3 Computational Complexity Factor Scoring (S_D)

The computational complexity factors are Level of Detail (LOD), Image Breakup (IB), Dynamic Light/Shadow (L/S), and Curved Surface Shading (CSS) as defined below. These factors combine as follows:

$$S_D = (1/(1 + \sqrt{1/LOD})) [IB] [L/S] [CSS]$$

7.3.1.3.4 Special Technical Factor Scoring (S_T)

This factor represents the subjective evaluation of the proposed data base development system and the special visual data base.

Not all important system design variables can be quantified on an objective basis. These factors represent a subjective evaluation of the contractor's effort in a given area or an assessment of a global property of the system, such as risk. The ACAVS program recognizes three special technical factors:

- Data Base Development System (DDS) – The combination of hardware and software used to generate new or modify existing data bases. This includes special data bases delivered by the contract.
- Special Image Generation Effects (SE) – There are several special visual effects considered important to the ACAVS mission. These include such items as rotor blade effects, blowing sand and dust, weapons effects.
- Technical Risk Assessment (TRA) – The assignment of a confidence factor to each proposed subsystem of the CGI system. This confidence factor considered a function between 0 and 1.

$$S_T = [DDS] [SE] [TRA]$$

7.3.1.4 CGI Scoring Example

The hypothetical CGI system is scored below as an example of some portions of the method described in Paragraph 7.3.1.3.

Table 7-1 is a chart of some hypothetical system scoring parameters for purposes of illustrating the scoring approach.

The score becomes:

$$S_{CGI} = [S_C] [S_B] [S_D] [S_T] = 9878$$

where

$$S_C = 19{,}500$$

$$S_B = .914$$

$$S_D = .739$$

and

$$S_T = .75$$

7.3.2 Model Board

Model board techniques were considered in only two areas: one, is that the existing NASA camera/model board technology could be utilized for the generation of HUD-type displays. The generation of a new map model section for the existing facility would be required if the CGI data base did not agree with the CGI visual scene area. NASA Ames' existing 525 TV line rate system would result in lower resolution than merely used in HUD hardware and would thus require some modification of HUD hardware equipment (since most HUD systems run at a higher TV line rate) to be compatible.

The other model board technique considered is the laser camera/model board technology. Since the laser display has such high potential to produce high detail imagery there is the possibility of trades being made. One could utilize the laser display/laser camera model board approach and thus eliminate the need for six channels of CGI and utilize the cost savings on fabricating the laser camera/model board and housing facility. Then at a later date, when CGI technology is more adoptive to NOE, integrate it into the laser system. One drawback to this approach is that the laser camera has problems with very close approaches to the terrain model board. These problems currently are hot spots, the need for good focus control at close distances, and the physical problems of map clobber.

Special effects as moving targets, clouds, dust, etc., are also difficult to generate using models although some advancements have been made in this area (see Paragraph 5.2.2).

7.4 Evaluation Summary and Conclusions

A comparison of the various ACAVS display concepts with the display rank is shown in Table 7-2. Summary comparisons of the total systems concepts are given in Table 7-3.

The rankings of the ACAVS concepts are based on the weighting discussed in Section 6 and Appendix E. These are combined with CGI scoring based on the hypothetical model to produce the total ACAVS systems ranking.

No ACAVS candidate concept is outstandingly better than the other. Each has its unique advantages and disadvantages and is a viable candidate for the RSIS program. Helmet-mounted display technology is developing rapidly with considerable interest shown by several companies and government agencies.

Table 7-1: CGI Hypothetical Scoring Values

Parameters	Values	
• Field of View (FOV)	1/6 Full Field (120°H × 60°V)	
• Image Resolution (IR)	6 Arc Min Line Pair	
• Color (C)	12 Bits	
• Frame Rate (F)	30 Hz	
• Score (T)	.914	
Transport Delay (T)	.120 Sec	
• Level of Detail (LOD)	8	
• Image Breakup (IB)	1	
Angular Breakup WB)	2 Radians/Sec	
Translational Breakup (T_B)	500 Knots	
• Dynamic Light/Shadow Effects (L/S)	1	
• Curved Surface Shading (CSS)	1 (Linear)	
• Texture (T)	1	
Ratio of Run Lengths	1	
Texture	32/1 Run Length Reduction	
• Scene Content (SC)	19,500	
Points Static (PS)	1000	
Points Moving (PM)	200	
Edges Static (ES)	0	
Edges Moving (EM)	0	
Faces Static (FS)	7000	
Faces Moving (FM)	500	
Vertices Per Face (VF)	4	
Curved Surfaces Static (CS_S)	100	
Curved Surfaces Moving (CS_M)	300	
• Scene Bandwidth (SB)	.914	
• Computational Complexity (S_D)	.739	
• Special Technical Factors (S_T)	.75	
Data Base Development System (DDS)	1	
Special Image Generation Effects (SE)	1	
Technical Risk Assessment (TRA)	.75	
• Number of Active Pixels (Hor) × (Vert)	1000 × 1000	
• Sum of 2-D & 3-D Curved Surface Patchs	18.2% of Total Edge Capacity	
• Average Edge Utilization/Model	20% of Total Edge Capacity	
• Parameter Percent of Total Capacity	Static	Moving Model
Number of Points (2 Points/Edge)	2.6%	1.2%
Number of Edges	0	0
Number of Faces	71.8%	6.2%
Number of Curved Surfaces	4.6%	13.6%

Table 7-2: ACAVS Display System Comparison

Configuration	FOV Degree	Inst* %FF	Total %FF	Resolution Arc Min/LP Foveal	Resolution Arc Min/LP Peripheral	Rank
1. Light Valves/Peri/Dome						
1.1 (GE)	55X120	15.4	36.2	7.0	7.0	10
1.2 (Sodern)	55X165	21.2	41.7	8.0	8.0	6
2. Fiber Optic Coupled Projector, Servoed/Dome						
2.1 (GE)	70X186	29.6	46.8	7.5	13.2	9
2.2 (Sodern)	70X140	22.3	42.8	6.5	11.5	7
3. Fiber Optic Coupled Projector, Fixed/Dome						
3.1 (GE)	70X233	37.1	37.1	6.5	13.0	4
3.2 (Sodern)	70X175	27.9	27.9	5.5	11.5	8
4. Laser Projector/Dome	60X175	24.3	43.2	6.0	6.0	5
5. Helmet-Mounted Display						
5.1 (GE)	55X120	15.4	62.2	7.5	7.5	3
5.2 (GE)	70X186	29.6	62.2	7.5	13.2	1
5.3 (Cyclops)	55X120	15.4	62.2	7.5	7.5	2

*Instantaneous

Table 7-3: Total Systems Concept Comparison Summary

Concept	Ranking	Comments
1.1 Schlieren Light Valves/ Peri/Dome	10	Low RSM Score. Technology Somewhat Mature
1.2 Titus Light Valve/ Peri/Dome	6	Same as Above
2.1 Schlieren Light Valve, Servo Fiber Optics	9	Lowest Light Output
2.2 Titus Light Valve Servo Fiber Optics	7	Low Light Level
3.1 Schlieren Light Valve Fixed Fiber Optics	4	Lowest Light Output, High RSM, Horizontal Display Junction
3.2 Titus Light Valve Fixed Fiber Optics	8	Low Light Level, High RSM Horizontal Display Junction
4.0 Scanned Laser with Dome	5	Highest CGI Score and High Visual Score, No Display Junctions, Lowest RSM and Visual/CGI Compatibility
5.1 Schlieren Light Valve Head Mounted Display, Lower FOV	3	Very High Flexibility, Good Brightness, New Technology Application
5.2 Schlieren Light Valve Head Mounted Display, Higher FOV	2	Very High Flexibility, Good Brightness, New Technology Application
5.3 CRT Projector Head Mounted Display	1	Very High Flexibility, Good Brightness, New Technology Application

APPENDIX A

STATEMENT OF WORK

FOR

DESIGN AND CONSTRUCTION

OF AN

ADVANCED CAB AND VISUAL SYSTEM

This Page Intentionally Left Blank

1.0 INTRODUCTION

1.1 Purpose

The purpose of this Statement of Work (SOW) is to describe the effort required to acquire an Advanced Cab and Visual System (ACAVS) which will become a part of a rotorcraft research and development simulator hereafter called the Rotorcraft Systems Integration Simulator (RSIS) which will be designed to support rotorcraft development.

1.2 Overall Project Description

Under a joint agreement, a NASA/Army project team has committed to acquiring the RSIS to be installed at the NASA Ames Research Center within the next four years (1981-1985). The RSIS complex will consist of a cockpit, visual, motion and computer components which, when integrated, form 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 the acquisition of a motion base known as the Rotorcraft Simulator Motion Generator (RSMG) to be delivered in 1982. This is an ongoing NASA Ames action. The second procurement was a study which describes the effort required for procurement of a Rotorcraft Simulator Cab, a Rotorcraft Simulator Development Station and an Advanced Visual System. These three components will hereafter be known as the Advanced Cab and Visual System (ACAVS). The third procurement is the subject of this SOW which addresses the obtaining of the ACAVS. Later, the ACAVS will be integrated into the RSMG and interfaced to the Ames simulation computer facility.

After ACAVS integration is accomplished, the whole assembly will be further integrated with the existing Ames Vertical Motion Simulator (VMS) to form a sophisticated six-degree-of-freedom moving-base rotorcraft simulator known as RSIS. This final integration effort is not currently part of the ACAVS project.

1.3 Definitions

- Advanced Rotorcraft Visual System – The visual simulation subsystem of RSIS consisting of the electronic, electro-optical and mechanical devices that can generate the image of a scene and display it to the pilot.

- Advanced Cab and Visual System (ACAVS) – A term describing the three RSIS components covered in this procurement. 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 and signal processors that can produce pictures when connected to the appropriate display device.

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

- Motion Base – A generic term for a servo-actuated platform with usually six or fewer degrees of freedom.

- Rotorcraft Systems Integration Simulator (RSIS) – A sophisticated moving-base rotorcraft simulator with a motion base (RSMG), a 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 eight actuators for six degrees of freedom. A large bridge structure which is actuated vertically carries a lateral track and carriage assembly which, in turn, carries a synergistic six-post motion platform. The six-post device is normally used to generate rotational motions only, but will be replaced by the RSMG when the RSIS is implemented.

2.0 SCOPE OF WORK

The Statement of Work defines the effort to be undertaken by the contractor in support of Government acquisition of an Advanced Cab and Visual System (ACAVS). This effort includes the design, construction, installation, integration and test of this system and support of its operation at the NASA-Ames Research Center facility.

3.0 TASKS

3.1 Design, Development and Test

The contractor shall design, develop and test an Advanced Cab and Visual System as specified in NASA Specification Number (TBD).

3.2 Project Management

The contractor shall designate a management organization with responsibilities delineated that are applicable to the ACAVS program. A Contract Work Breakdown Structure (CWBS) shall be used for management control and reporting. A proposed CWBS shall be prepared and submitted for NASA approval within 30 days of contract award using the suggested Preliminary CWBS as a guide (See Appendix C).

3.3 Systems Engineering and Integration

3.3.1 Systems Interface

Because of the complex nature of the required interfaces, a NASA-chaired Interface Control Working Group (ICWG) will be formed. The contractor shall provide an Interface Control Document (ICD) in which all hardware and software interface functions are identified and defined. A proposed format of the ICD shall be submitted to NASA for approval within 30 days of contract award. The contractor shall provide 10 status copies of the ICD to NASA one week prior to each ICWG meeting. There will be an ICWG meeting in conjunction with each design review at a minimum.

3.3.2 Systems Integration

The contractor shall perform and submit results of an ACAVS systems analysis that assesses the overall integrated system design. This analysis shall address as a minimum the following areas:

- Compatibility between the image generation and display systems
- Display system/cab interactions including image occlusion
- Disassembly, transfer and installation to and from the VMS and the ACAVS development station

These results shall be submitted for presentation at the Critical Design Review (CDR).

3.4 System Support

3.4.1 Technical and Maintenance Support

The contractor shall provide on-site technical and maintenance support during NASA acceptance testing and initial system operation at NASA. This support shall include:

- Hands-on operation of contractor-supplied equipment

- Operation of equipment during acceptance tests
- Preventive and corrective maintenance of contractor-supplied systems
- Spare assemblies and components as required to maintain contractor-supplied equipment including repair of failed assemblies
- Peculiar support equipment required for supplied systems
- Calibration of supplied equipment as required

The level of effort shall be based on a maximum of (TBD) hours of operation per day at (TBD) days per week for a period of (TBD).

3.4.2 Spares

The contractor shall supply spares for all contractor-supplied components during NASA acceptance testing and initial system operation. Spares for all critical items shall be available on site. Spares shall be those that appear on the approved spares list. A critical item is an Equipment Replaceable Unit (ERU) whose failure would seriously degrade simulator operation. A recommended spares list shall be submitted at CDR for NASA approval.

4.0 DELIVERABLES

The following items shall be delivered to NASA as part of the ACAVS procurement contract. The paragraph references are from NASA Specification Number (TBD) except as noted.

4.1 Rotorcraft Simulator

- Rotorcraft Simulator Cab – As described in Paragraph 3.3 and subordinate paragraphs
- Rotorcraft Simulator Development Station – As described in Paragraph 3.4 and subordinate paragraphs
- Rotorcraft Simulator Visual Image Generator and Data Base Development Station Hardware – As described in Paragraphs 3.5.3 through 3.5.3.1.2 and Paragraph 3.5.3.3
- Software – All software generated during the ACAVS development or purchased with computer subsystems. This includes the following:
  - Executives
  - Assemblers
  - Resident operating system
  - Compilers
  - Loaders and linkers
  - Mathematical libraries

  A data base shall be delivered as described in Paragraph 3.5.3.1.3
- Support Equipment – All support equipment required for assembly, operation, maintenance and calibration of the ACAVS
- Spares – All spares as described in SOW Paragraph 3.4.2

4.2 Documentation

- Drawings – All drawings developed as part of ACAVS design and development and test. These shall include a drawing tree that identifies and shows the relationships between all drawings
- Operational manuals
- Software manuals – These are descriptive texts that explain the operation of all delivered software programs such that a computer analyst with an experience level of (TBD) years can perform the intended program function
- Training manuals – All manuals required to become proficient in the operation of the ACAVS system hardware and software

4.3 Development Station Facility Modifications

- Development Station Cab Area Floor Mounting Hardware – As described in Paragraph 3.4.4
- RSMG Mounting Adapter – As described in Paragraph 3.4.4.3
- Transport devices – Such as bridge crane (Paragraph 3.4.4.1) and dollies (Paragraph 3.3.4.19) required to move the ACAVS hardware

5.0 SPECIAL CONSIDERATIONS

5.1 Risk Assessment

The schedule of the development of ACAVS is of particular concern. The contractor is encouraged to use those subsystem components and approaches which will, with a high degree of confidence, result in an operational system early in 1985. Evaluation of the contractor's proposal will include the following factors:

- Technological Base – Each contractor will be evaluated in terms of his organization's experience with real-time aircraft simulators, visual displays, computer graphics and (in particular) real-time CGI.
- Personnel Base – Each organization will be evaluated in terms of the quality and quantity of personnel available to work on the ACAVS program.
- Research Facilities – The extent and quality of the contractor's research facilities is considered very important for the rapid, economical solution of technical problems as they arise.
- Documentation – High quality documentation is required. The contractor's planned documentation and track record for past delivery will be evaluated closely.
- Configuration Control – Each contractor's hardware and software configuration control procedures will be carefully evaluated. The configuration control system proposed shall provide a safe, systematic and thorough mechanism for tracking configuration growth, problem areas and documentation.

5.2 High Risk Technologies

The helmet-mounted display technology is recognized as an area of high potential, but also as one of high risk. In the event that concepts involving this approach or other high risk technologies are proposed, the contractor shall also provide as part of his offering, a proposed prototype development and test of the high risk subsystem component early in the ACAVS development program.

APPENDIX B

SPECIFICATIONS

FOR

DESIGN AND CONSTRUCTION

OF AN

ADVANCED CAB AND VISUAL SYSTEM

This Page Intentionally Left Blank

APPENDIX B

SPECIFICATIONS

1.0 SCOPE OF WORK

This specification establishes the performance, design, construction and testing requirements, as defined in the Statement of Work, to be undertaken by the contractor in developing an Advanced Cab and Visual System (ACAVS). The contractor shall, in accordance with the conditions hereinafter set forth, furnish all personnel, facilities, services, equipment, and materials (other than those furnished by the Government) necessary for the integrated design and construction of an Advanced Cab and Visual System as specified by the attached NASA Statement of Work (TBD) dated (TBD).

2.0 APPLICABLE DOCUMENTS

The following documents of the exact issue shown, form a part of this specification to the extent specified herein. In the event of a conflict between this specification and any documents referenced herein, this specification shall govern. When a revision letter or date is not shown, the issue in effect on the date of invitation for proposal applies.

2.1 Government Documents

2.1.1 Standards, Military

MIL-STD-143B 12 November 1969	Standards and Specifications, Order of Precedence for the Selection of
MIL-STD-454G 5 March 1980	Standard General Requirements for Electronic Equipment
MIL-STD-461A Notice 3 [illegible] July 173	Electromagnetic Interference Character Requirements for Equipment
MIL-STD-470 26 March 1966	Maintainability Program Requirements (for Systems and Equipment)
MIL-STD-785A 28 March 1969	Requirements for Reliability Program for Systems and Equipment
MIL-STD-882 5 July 1969	System Safety Program for Systems and Associated Subsystems and Equipments; Requirements for
MIL-STD-1472B [illegible]1 December 1974	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
MIL-STD-471A Notice 1	Maintainability Verification/Demonstration/ Evaluation
MIL- -STD-781B Notice 1 28 July 1969	Reliability Tests: Exponential Distribution

MIL-STD-883 15 November 1974	Test Methods and Procedures for Microelectronics
MIL-W-16878D 16 January 1961	Wire, Electrical, Insulated, High Temperature
MIL- -I-45208A 16 December 1963	Inspection System Requirements

2.1.2 Federal

Volume 40, Number 148 July 31, 1975	Federal Register, HEW, Food and Drug Administration – Laser Products – Performance Standards
HEW, Food and Drug Administration (BRH) Report OMB NO. 57R0068, July 1976	Guide for Submission of Information on Lasers and Products Containing Lasers Pursuant to 21 CFR 1002.10 and 1002.12

2.2 Industry

USAS-Y14.15 – 1966 December 2, 1966	Electrical and Electronic Diagrams
ANSI-Y32.2 – 1975 October 31, 1975	Graphic Symbols for Electrical and Electronic Diagrams
ANSI-2136.1 – 1976 March 8, 1976	"American National Standard for the Safe Use of Lasers"

2.3 Other Publications

AFSC DH 1-3	Design Handbook – Personnel Subsystems
AFSC DH 1-6 20July 1974	Design Handbook – System Safety
ASD Exhibit Rev. C ENCT 75-2	Design and Construction Exhibit for Air Force Training Devices; General Requirements
DODISS	Department of Defense Index of Specifications and Standards
D3-9798 11 September 1975	Reliability Design Criteria for Electronic
ASPR 14-001.7	

2.4 NASA

TBD

3.0 REQUIREMENTS

3.1 General Requirements

The Rotorcraft System Integration Simulator (RSIS), composed of the Advanced Cab and Visual System (ACAVS) and the Rotorcraft System Motion Generator (RSMG), will become part of an existing simulation facility at NASA Ames Research Center and shall be designed to integrate smoothly into the existing facility and be maintained and operated by existing support groups. An understanding must therefore be acquired of the physical plan and operation of existing systems with which RSIS must interface. User's applications for ACAVS will include rotorcraft design development, product improvement, threat assessment and accident investigation.

3.1.1 Management Structure

NASA facility operational management structure and support groups and their relationships are shown in Figure B3-1.

3.1.2 Facility Constraints

Because ACAVS will be integrated into an existing facility there are physical constraints which the contractor shall consider such as weight, clearance, center of gravity, and inertia of the motion base-mounted hardware. In addition, consideration shall be given to the following areas:

- Available or existing space
- Computer, electrical and grounding interface
- Safety requirements and man-rating
- Expansion and growth

General system requirements for ACAVS require the use of new ideas, stressing innovation and originality to meet design goals. It is expected that existing and advanced technology will be employed to develop a system which could, with a high degree of confidence, be procured in the 1982-84 time frame.

3.2 Major System Components

3.2.1 Rotorcraft Simulator Cab

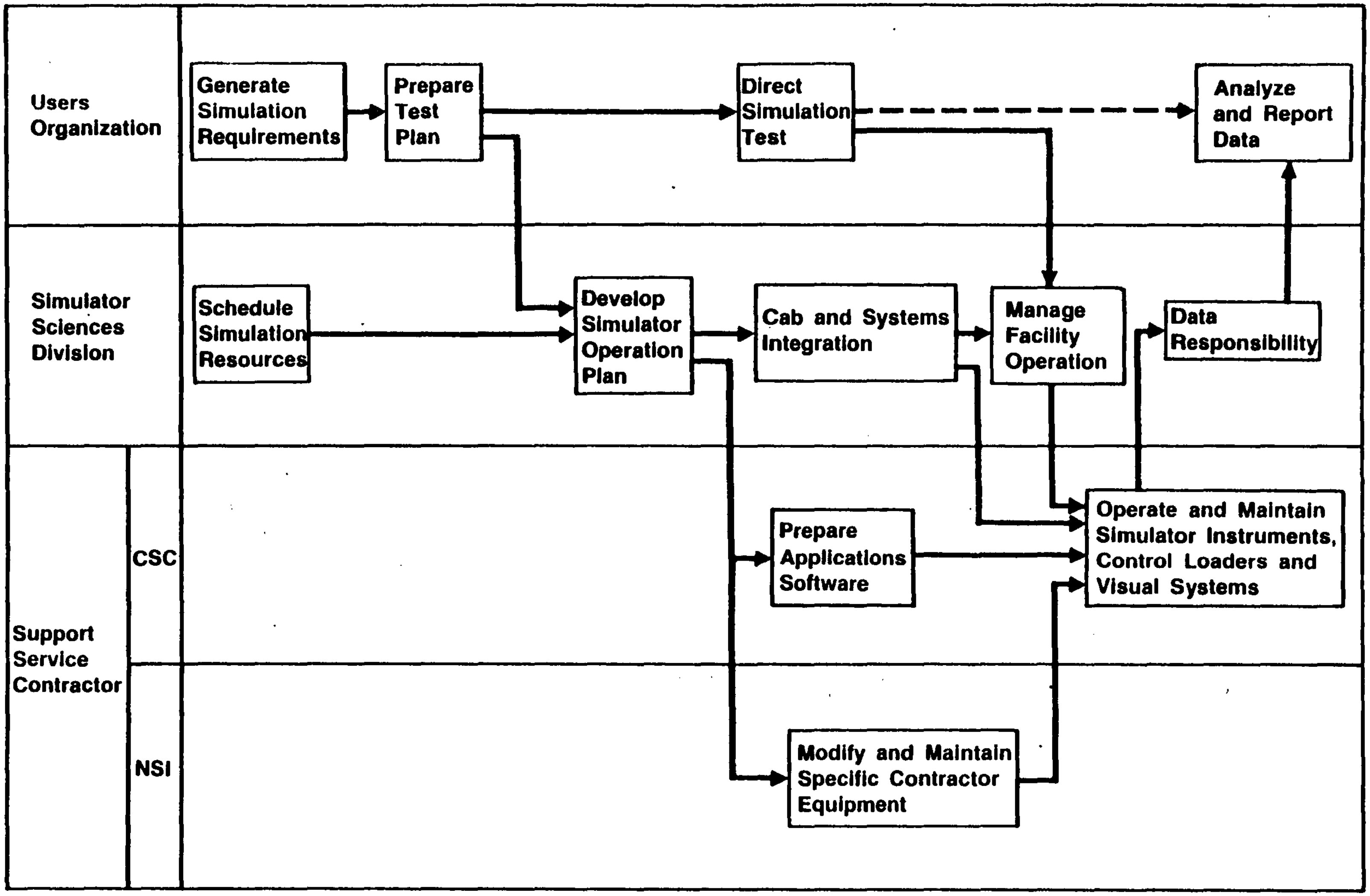
The rotorcraft simulator cab is a component of the RSIS complex. It is a generic cab with the features of rotorcraft that contains crew stations for use in rotorcraft simulation studies.

3.2.2 Rotorcraft Simulator Development Station

The Rotorcraft Simulator Development Station is an area containing power, operating consoles and floor pads that can support the development or operation of the rotorcraft simulator cab, and the advanced rotorcraft visual system on the RSMG or a floor mounting adaptor, either separately or as an integrated unit.

3.2.3 Advanced Rotorcraft Visual System

The visual simulation subsystem of the RSIS is designed for rotorcraft operations and consists of electronic, electro-optical and mechanical devices that can generate the image of a scene and display it.



CSC – **Computer Science Corp**

NSI – **Northrop Sciences Inc.**

Figure B3-1: Simulation Program Operational Relationships

3.3 Rotorcraft Simulator Cab Requirements

3.3.1 Rotorcraft Simulator Cab Item Description

The rotorcraft simulator cab will be a generic cab with the features of a rotorcraft and constructed such that it can be easily modified to accurately simulate a wide variety of current and future rotorcraft. It will accommodate at best two crew members and an observer in various seating arrangements. The cab shall be removable from within the visual systems image presentation hardware without any modifications to either. The cab must also be mountable on either the RSMG or in the rotorcraft simulator development station.

3.3.2 Rotorcraft Simulator Cab Characteristics

The rotorcraft simulator cab shall be designed within the payload limits and clearance envelope specified below and in Figure B3-2. The design shall allow easy access to and servicing of the structural attachments at the payload/motion platform interface.

- Clearance envelope (cab and visual system) 6.25m (20.5 ft) diameter sphere
- Gross weight 8,000 lbs maximum
- Moments of Inertia (limits, including RSMG upper platform)
  - I_{xx} 26,000 lb-ft sec^2
  - I_{yy} 31,000 lb-ft sec^2
  - I_{zz} 31,000 lb-ft sec^2

The moments of inertia are referenced .61m (2 ft) below the sphere center. Although cab weight minimization is not a critical factor, low weight is desirable.

3.3.2.1 Rotorcraft Simulator Cab Reorientation

After the integration of the RSMG on the VMS, some simulator research may require a reorientation of the cab/visual system. This reorientation would consist of rotating the cab/visual/RSMG system 1.57 rad (90°). This would limit the lateral position capability but expand the longitudinal capability for such specific programs as rotorcraft autorotation simulations. Such simulations would require an expanded longitudinal (fore and aft) motion capability. The contractor shall consider compatibility with such a reorientation in their design.

3.3.2.2 Motions

The rotorcraft simulator cab shall be capable of operation within the motion environment and designed to withstand the dynamic loads shown in Table B3-1 and Figures B3-3 thru B3-6.

Each degree of freedom is defined individually with respect to a nonmoving coordinate system centered .61m (2 feet) below the sphere center in its neutral position. The displacements shown in Table B3-1 are simultaneous.

3.3.2.3 Natural Frequencies

The lowest natural frequency of the motion system structure will be greater than 50.2 rad/sec (8.0 hertz). Design provisions for the rotorcraft simulator cab hardware, especially the force feel system and vibration generation system, shall be made to avoid excitation of any natural frequency greater than 50.2 rad/sec (8.0 hertz).

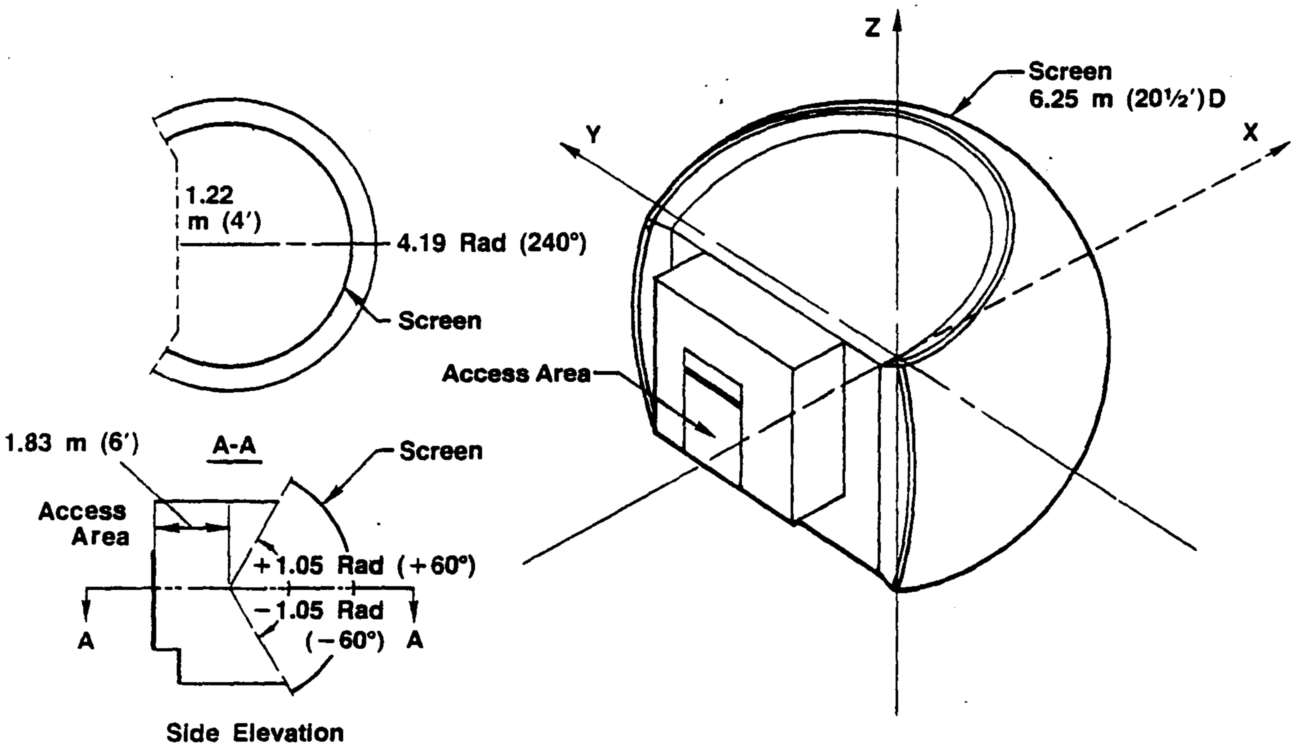


Figure B3-2: Cab/Visual System Envelope

Table B3-1: Combined Motion Base Characteristics (VMS & RSMG)

Mode	Displacement	Velocity	Acceleration
Vertical (Z)	± 30 ft.	± 20 ft/sec	± 32.2 ft/sec^2
Lateral (Y)	± 20 ft.	± 10 ft/sec	± 24 ft/sec^2
Longitudinal (X)	± 4 ft.	± 4 ft/sec	± 10 ft/sec^2
Roll	± 78°	± 40°/sec	± 115°/sec^2
Pitch	± 18°	± 40°/sec	± 115°/sec^2
Yaw	± 24°	± 46°/sec	± 115°/sec^2

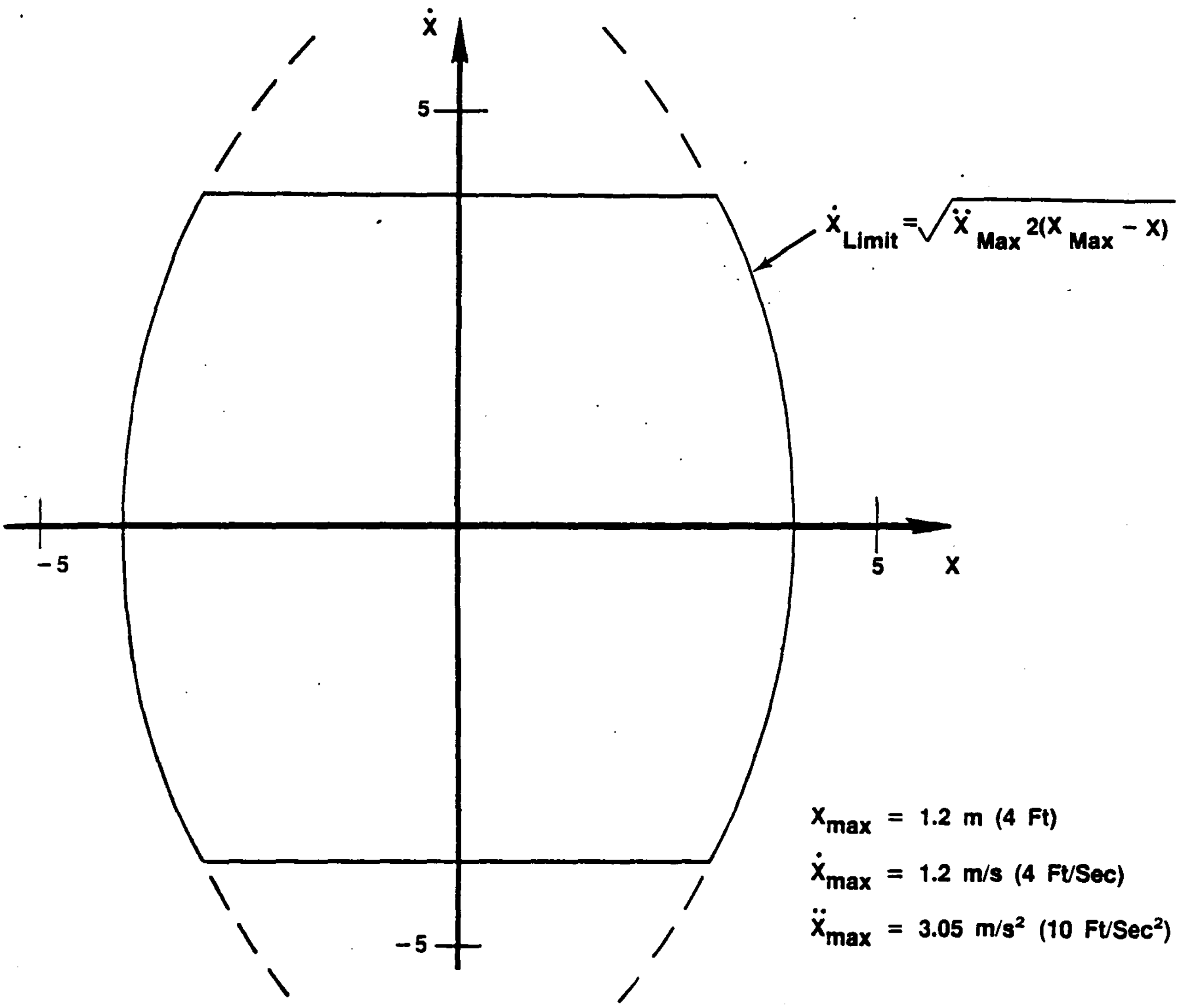


Figure B3-3: Logitudinal Position – Rate – Acceleration Envelope

Maximum Rotational Performance Acceration, Deceleration = 2.0 Rad/Sec² = α

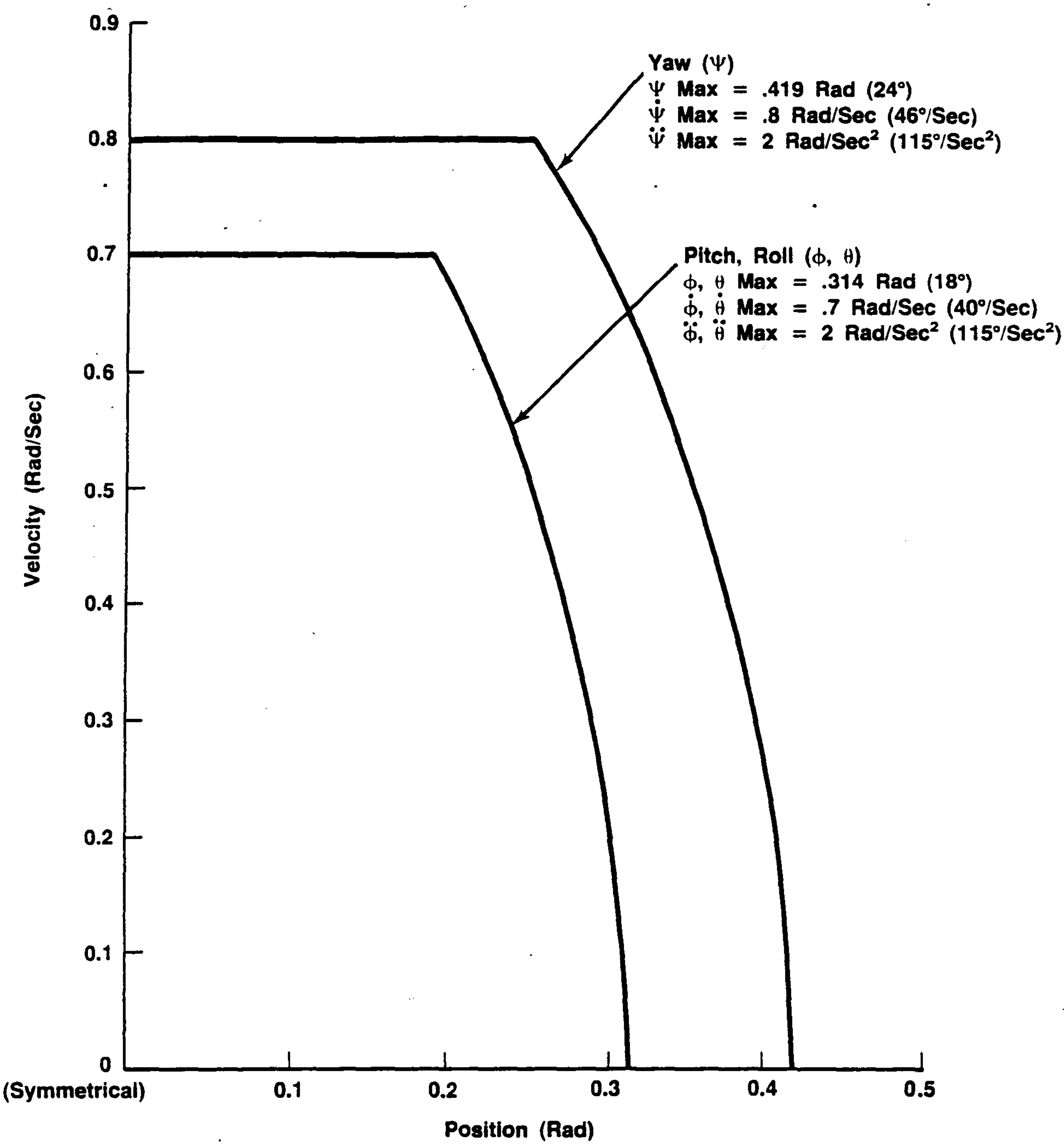


Figure B3-4: Rotational Position – Rate – Acceleration Envelopes

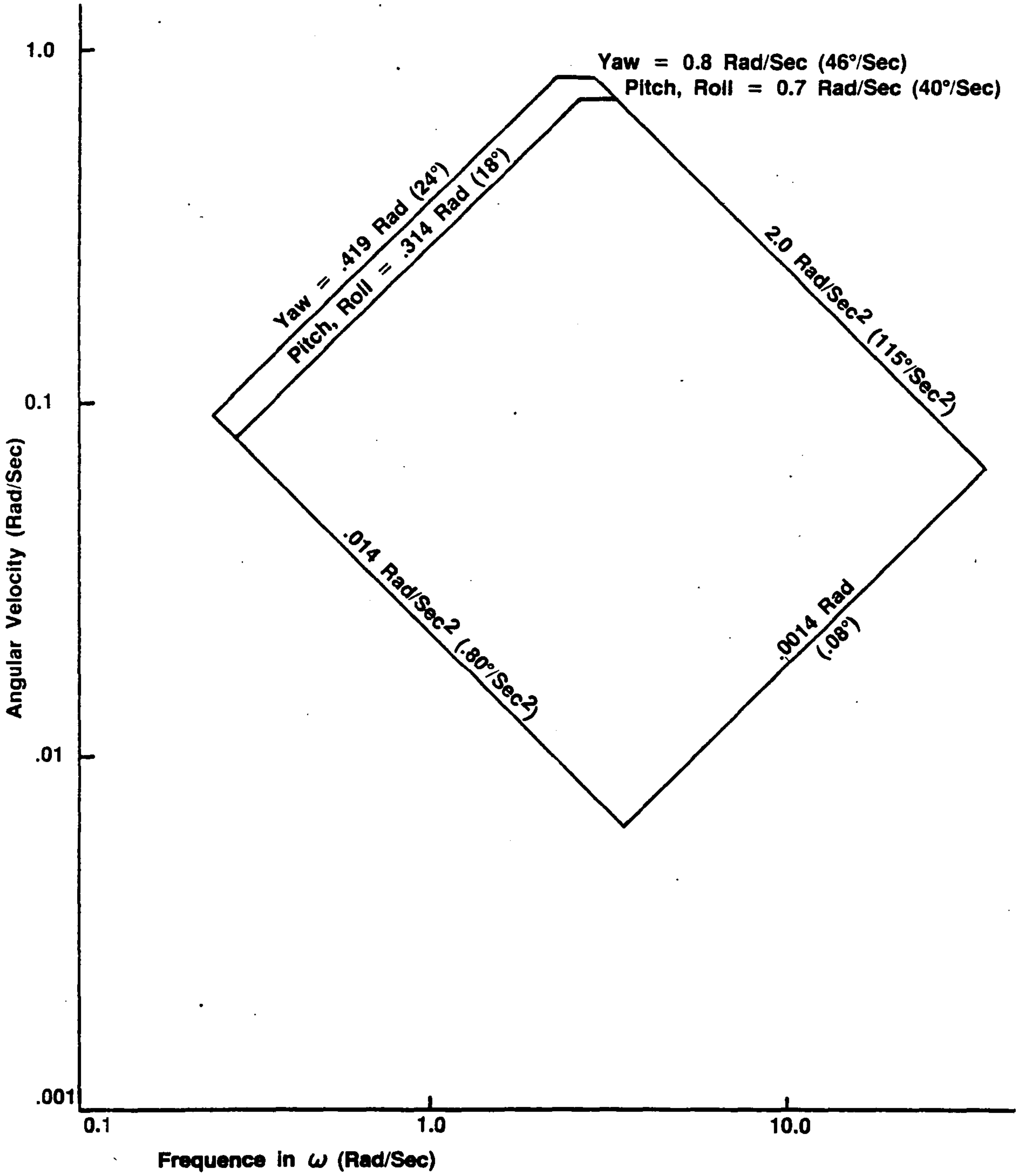


Figure B3-5: RSMG Angular Performances

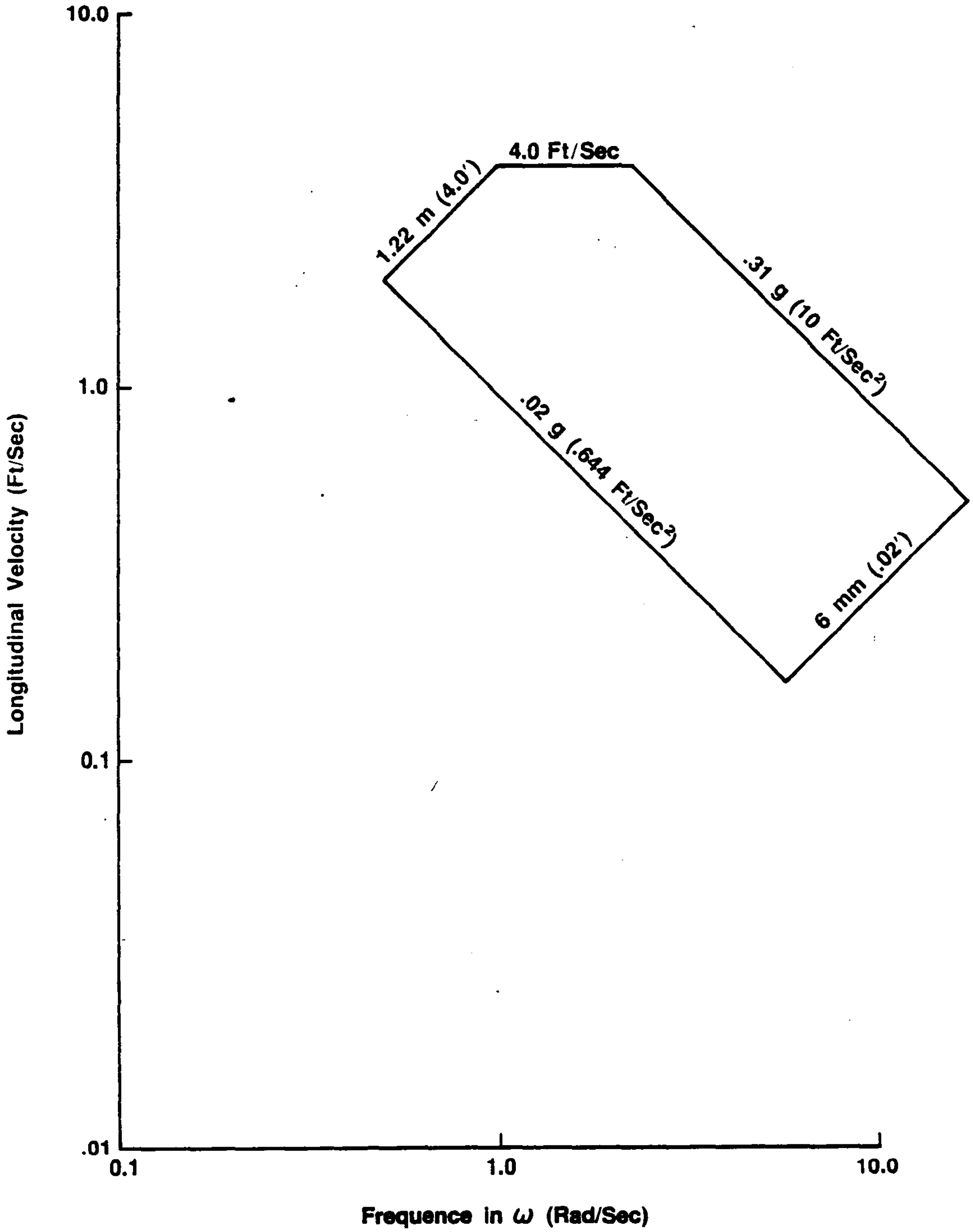


Figure B3-6: RSMG Longitudinal Performance

3.3.3 Rotorcraft Simulator Cab Interface

The rotorcraft cab/visual system will be used in two locations; on the VMS and in the development station. Hence, the structural interface must be compatible with both locations and shall be designed to allow simple and efficient changeover as well as adequate strength because the RSMG must also accept the interchangeable cab without modifications, the cab structural interface shall be compatible with the corresponding hardware and other provisions of the interchangeable cab.

Depending on the final design of the visual system structure, there may be a structural interface between it and the cab. If such is the case, any connections shall be nonpermanent so that the cab and visual system can be operated separately and independently.

3.3.4 Rotorcraft Simulator Cab Design and Construction

3.3.4.1 Cab Structure

The rotorcraft simulator cab structure shall be capable of supporting and housing all of the equipment mounted to and within it. In addition, it shall provide proper blanking, as required, of the visual display. As blanking requirements will change from configuration to configuration, permanent structure will not be appropriate. Provisions therefore shall be made such that the cab can accept specific blanking structure (or other suitable provisions) which will change with simulation requirements.

Use of lightweight material of standard structural shapes and sheet shall be considered. Design consideration shall also be given to the location of heavy equipment, such as scavenge pumps or accumulators, as low as possible within the cab structure. The cab floor shall be constructed such that it contains bays or similar provisions to accept force-feel system components and the routing of cables and hoses as required. Such bays shall provide an oil-tight sump for hydraulic spills if hydraulic devices and hoses are present.

Interchangeable cab technology should be used wherever reasonable to insure compatibility; specifically, the mounting points and methods of attachment to the RSMG. Captive cab mounting bolts are used which can be engaged or disengaged by applying a half-inch drive wrench to sockets at the cab floor. The cab mounting bolts will be safety-wired (see Figure B3-7).

Hard points shall be provided for lifting the cab on and off the VMS and for movement within the development station.

Access panels and large clearance holes shall be provided through frame members for wire and hose routing. Access panels and adequate clearance shall also be provided wherever required for ease of maintenance and changeover of cab configuration.

The rear portion of the cab shall provide a rigid structure for: the support of permanent on-board equipment; a large passenger loading door; recessed junctions for cable connectors and hose couplings; and provisions for entry and exit via the existing passenger boarding ramp. Figure B3-8 shows the similar structure for the interchangeable cab.

3.3.4.2 Crew Stations

The contractor shall provide for a variety of crew orientations with simple changeover from one arrangement to another. Such arrangements include two crew stations located side by side with the primary pilot on either the right or left, two crew stations located in tandem with the primary pilot in the front or rear, and a single crew station. In each configuration an observer's station shall be considered. Depending upon the visual presentation system, it may be necessary to change the location of the cab relative to the visual display when crew configuration changes to meet the requirements of Paragraph 3.5. Seats and restraint systems shall be representative of actual rotorcraft equipment and suitable for use in a moving-base simulator.

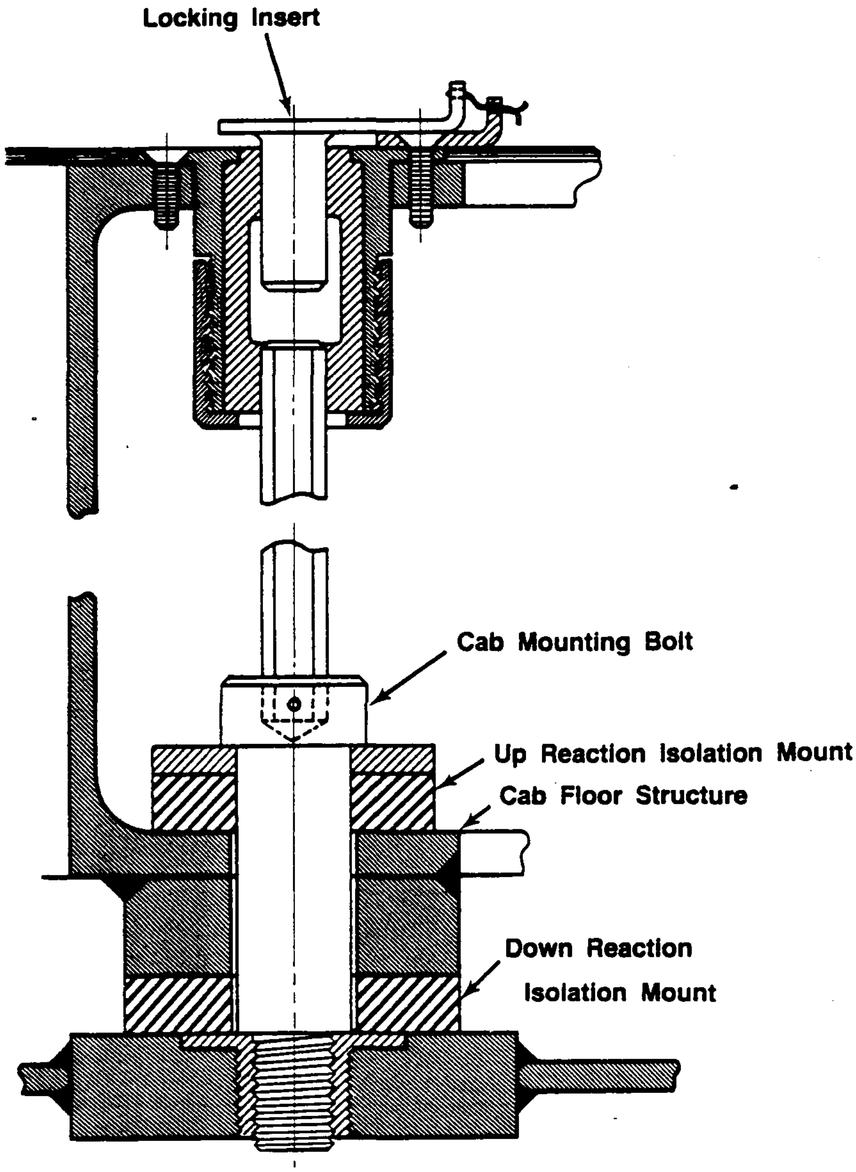


Figure B3-7: Interchangeable Cab Isolation Mount Detail

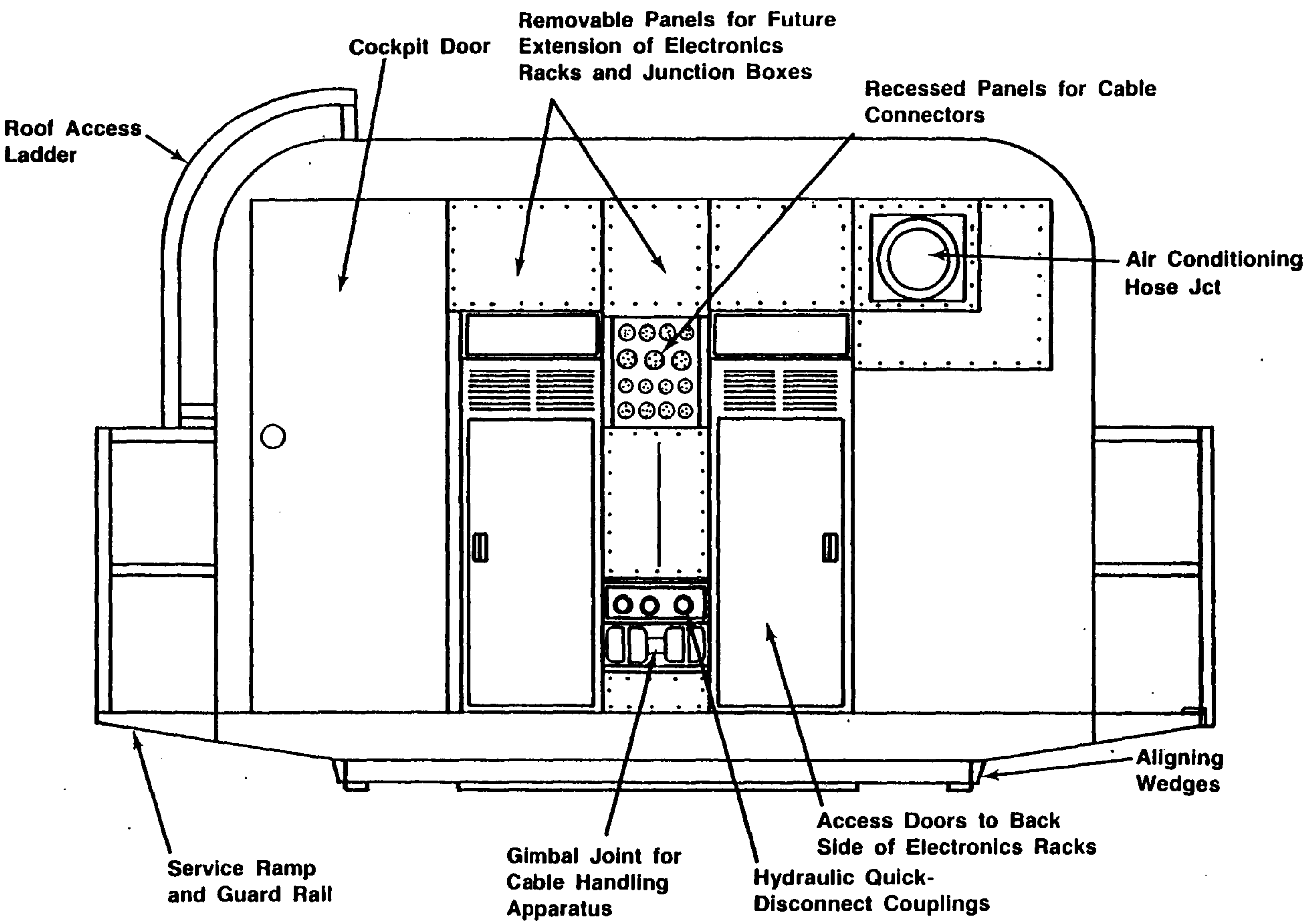


Figure B3-8: Interchangeable Cab Rear-View

3.3.4.3 Instruments

General purpose, electrically-driven simulator instruments rather than actual or modified flight hardware shall be incorporated wherever possible. Instruments shall include all basic flight instruments plus a radar altimeter and torque meter as a minimum; those instruments listed in Table B3-2 shall be included.

3.3.4.4 Instrument Panels/Consoles

User requirements for the primary instrument panel and secondary panels and consoles will be especially varied since these items depend not only on rotorcraft type but also on the particular crew stations simulated. The primary panel shall be modular, permitting easy modification and replacement, and shall require minimum time for changeover. Panels and consoles should be movable/removable to accommodate various crew station arrangements. Mounting structure shall be designed to optimize accessibility and simple changeover and to insure there is no interference with the visual display presentation system.

3.3.4.5 Primary Flight Controls

The rotorcraft simulator cab shall include appropriate basic flight controls (stick, pedals, collective, power control, and multi-axis or sidearm controller) for each crew station. Control force-feel characteristics shall be programmable and controllable by a digital computer. As a minimum, these programmable characteristics shall include nonlinear force gradients, coulomb friction, breakout (preload), viscous damping and displacement limits (stops). Control force and displacement ranges shall be representative of rotorcraft.

3.3.4.6 Additional Controls

In addition to primary flight controls the contractor shall make provisions in the simulator cab for additional controls such as separate throttles, weapons, and guidance/navigation controls.

3.3.4.7 Cab-Mounted Displays

The simulator cab shall have a programmable heads-up display for each forward facing crew station. Provisions shall also be made to accommodate other types of displays as required, such as guidance, navigation, radar and weapons system displays.

3.3.4.8 Sound Generator System

The rotorcraft simulator cab shall include a programmable sound generator system capable of simulating the cockpit aural environment of rotorcraft. Programmable sounds shall include those sounds required as flight cues; in addition, the sound of weapon fire is a goal.

3.3.4.9 Noise Suppression

Provisions shall be made to suppress unwanted sounds at the crew stations to a level no greater than 75 db. Unwanted noise includes sounds from both outside and inside the cab structure. Noise inside the cab includes sounds from servos, hydraulic lines, and moving parts. These sources provide unwanted cues to crew members and must be suppressed to acceptable levels.

3.3.4.10 Vibration Generation System

The rotorcraft simulator cab shall include a programmable vibration generator system. As a minimum the seats, controls, and instrument panels shall be vibrated. The primary requirement for vibration is in the vertical axis with the lateral axis secondary. Maximum level of vibration shall be at least 15 Hz at .5g. Programmable vibration shall include those required as primarily flight cues (see Figure B3-9).

Instrument	Communications	Navigation & Warning	Visionics
Required	**Required**	**Required**	**Required**
– Altimeter – Airspeed – HSI, Horizontal Situation (heading and ID 249) – ADI, Attitude Director (Attitude Indicator) – Turn and slip – Rotor RPM – Torquemeter (possibly dual engines) – Gas generator RPM (NI and possibly dual engines) – Accellerometer – Control position indicators – Vertical speed – Ground speed (or inertial velocity) – Clock – Flight quality (such as cruise guide)	– Internal communication system – ICS (helmet-type)	– TACAN and VOR (ID 249 with 2 needle card)	– Helmet mounted sights/trackers (as associated with IR systems) – Panel displays (1 CRT of aircraft size)
Ancillary		**Ancillary**	**Ancillary**
– Turbine inlet temperature – Annunciators for warnings/cautions – Automatic hold/hover controls		– Radar warning set – Doppler nav system – Loran	– Keyboard consoles

Table B3-2: Required Instruments and Avionics

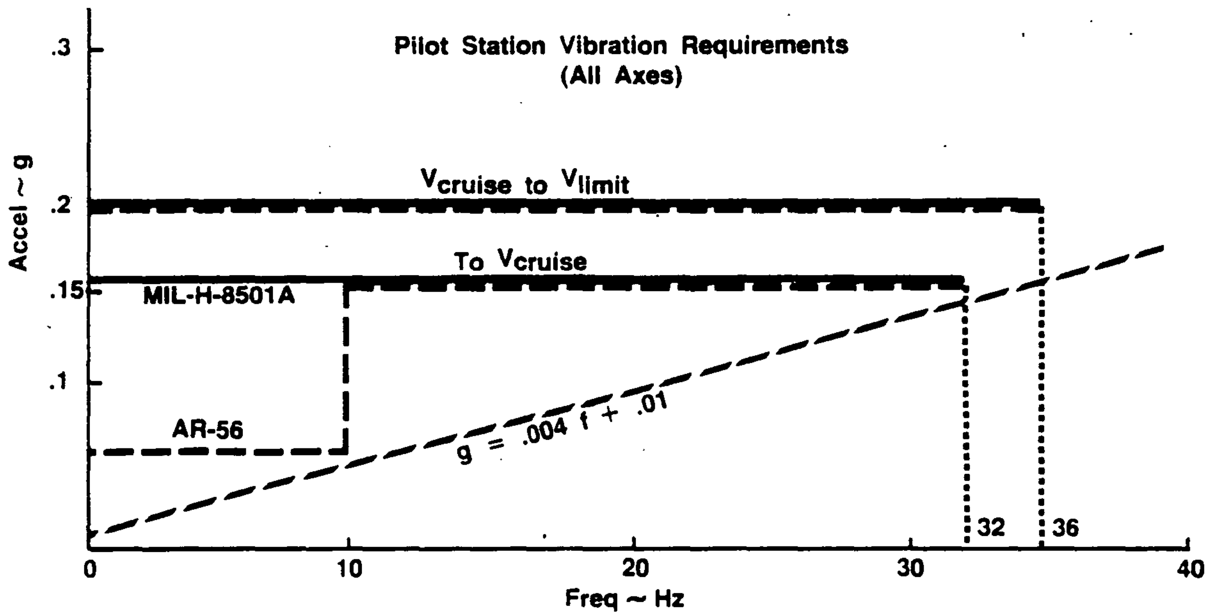


Figure B3-9: Compilation of Level Flight Vibration Specifications

3.3.4.11 Communications System

The rotorcraft simulator shall include a system to provide audio communication between crew members and external operating personnel. It shall also include the capability of simulating external air-to-air and ground-to-air communications through normal frequency and volume set/select functions.

3.3.4.12 Internal Lighting

Crew members shall be provided with lighting systems which allow them to accomplish normal day or night tasks, such as map reading, but which do not interfere in any way with the visual display presentation. The cab shall also include internal lighting to provide operations and maintenance personnel with sufficient illumination to conduct setup and modifications with the visual system in place but not operating.

3.3.4.13 Air Conditioning

Temperature and humidity within the simulator cab shall be controllable to insure normal operating conditions for crew members and support personnel and electronic equipments. Air conditioning must be supplied at both the development station and on the VMS. The VMS room is not currently air conditioned. If a heat exchanger utilizing liquid as a cooling medium is used it shall be a regenerative, closed-cycle system. Air-cooled heat exchangers shall be designed to operate with a maximum inlet air temperature of 43.3°C (110°F). Commonality with the interchangeable cab should be considered.

3.3.4.14 Electrical Interface

The rotorcraft simulator cab shall include electrical interfaces through which electrical power and signals can be transmitted to and from the cab. The electrical interface shall be readily accessible to speed coupling and decoupling and shall be as compact as possible. The electrical interface shall be compatible with the rotorcraft simulator development station, the interchangeable cab fixed-base station and the VMS. A designed-in growth potential must be considered.

3.3.4.15 Hydraulic Interface

The rotorcraft simulator cab shall include, if necessary, a hydraulic interface through which hydraulic power can be transmitted to the cab. The hydraulic interface shall be readily accessible and designed for efficient coupling/decoupling and it shall be compatible with both the development station and the VMS. Drip pans or oil-tight sumps shall be provided as necessary to collect leaking hydraulic fluid. Electrical components, cabling and hydraulic components shall be positioned to prevent any damage as a result of fluid leaks. The number of leaks and flow rate of leaking fluid shall be minimized; NASA Ames Research Center shall judge the acceptability of the tightness of the system.

3.3.4.16 Intra Signal and Power Transmission

The rotorcraft simulator cab shall include systems to transmit electrical and hydraulic power and electrical signals between the hydraulic power and electrical signals between the respective interfaces and the appropriate termination points. The signal transmission shall be designed to minimize or eliminate cross talk. The hydraulic power transmission system shall be designed to minimize aural noise.

3.3.4.17 Power Requirements

Electrical and hydraulic power requirements for the rotorcraft and simulator cab shall be determined. Compatibility with existing capabilities shall be considered, but not considered a restriction. Electrical and hydraulic power requirements in excess of or not compatible with existing capabilities must be specified.

3.3.4.18 Compatibility with Special Purpose Equipment

The rotorcraft simulator cab shall be designed to accommodate and be compatible with special purpose equipment such as helmet-mounted displays and head or eye trackers.

3.3.4.19 Transportability

The rotorcraft simulator cab shall be capable of being transported back and forth between the development station and the VMS motion platform. Depending on the design of the cab and visual system, fabrication of special transport devices may be necessary. This transportation requires movement through at least two doors, one of which has a minimum width of 3.66m (12 ft) and a minimum height of 4.27m (14 ft).

3.4 Rotorcraft Simulator Development Station

3.4.1 Development Station Item Description

The rotorcraft simulator development station involves an area where technology now exists. There is no need to develop new techniques, procedures or equipment to support it. NASA Ames Research Center has a fixed-base station for the interchangeable cab project and it is the intent to expand and improve on the concepts and technology that have already been developed.

The development station will be used to reduce the motion base down time by permitting cockpit/cab configuration changes prior to occupying the VMS. To achieve this goal, the development station must facilitate 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.

3.4.2 Development Station Characteristics

The development station consists of a control room, cab area, and RSMG area, and shall be capable of checking out and calibrating the following systems:

- Signal trunking between the cab and the control computer
- Power and electrical grounding
- Computer interface
- Primary controls (pilot's force-feel system)
- Instruments (scaling and biasing)
- Throttles and other secondary controls
- Visual display and sound generation system
- Signal interface between the RSMG and the control computer
- Vibration generator for instruments, panels, and seats
- Signal interface between the adanced visual system and the control computer

The development station shall also be capable of use for dynamic simulation without motion and interim operation of the RSMG.

The control room shall contain as a minimum the following:

- Computer input/output unit
- General purpose minicomputer
- Communications interface controller
- Remote input/output units
- Peripheral hardware
- Simulation engineer's console
- Project engineer's console
- Support hardware

Figure B3-10 shows a block diagram of required hardware.

3.4.2.1 Computer Input/Output Unit (CIOU)

The Computer Input/Output Unit is a NASA Ames designed custom interface that is used to connect the general purpose minicomputer to the host computer over a 10 megabit/sec serial data link.

3.4.2.2 General Purpose Minicomputer

A general purpose minicomputer shall be provided to serve as a communication control during a host computer controlled simulation and off-line as a diagnostic computer to control cab checkout and calibration.

3.4.2.3 Communications Interface Controller (CIC)

The minicomputer shall be interfaced to the simulation hardware through a communications interface controller. NASA Ames is currently using an in-house design which interfaces one to 16 remote input/output units.

3.4.2.4 Remote Input/Output Units (RIOU)

Remote Input/Output Units shall be used to interface control room hardware. NASA Ames is currently using an in-house design. Each RIOU will provide a general purpose interface that performs digital to analog, analog to digital, digital to synchro conversions and provides for discrete digital inputs and outputs. They will be intelligent controllers whose activities are directed by a microprocessor.

Remote input/output units will be used to interface the general purpose minicomputer to the simulation engineer's console, project engineer's console, peripheral hardware, control loader system, EADI, and the cab sound system.

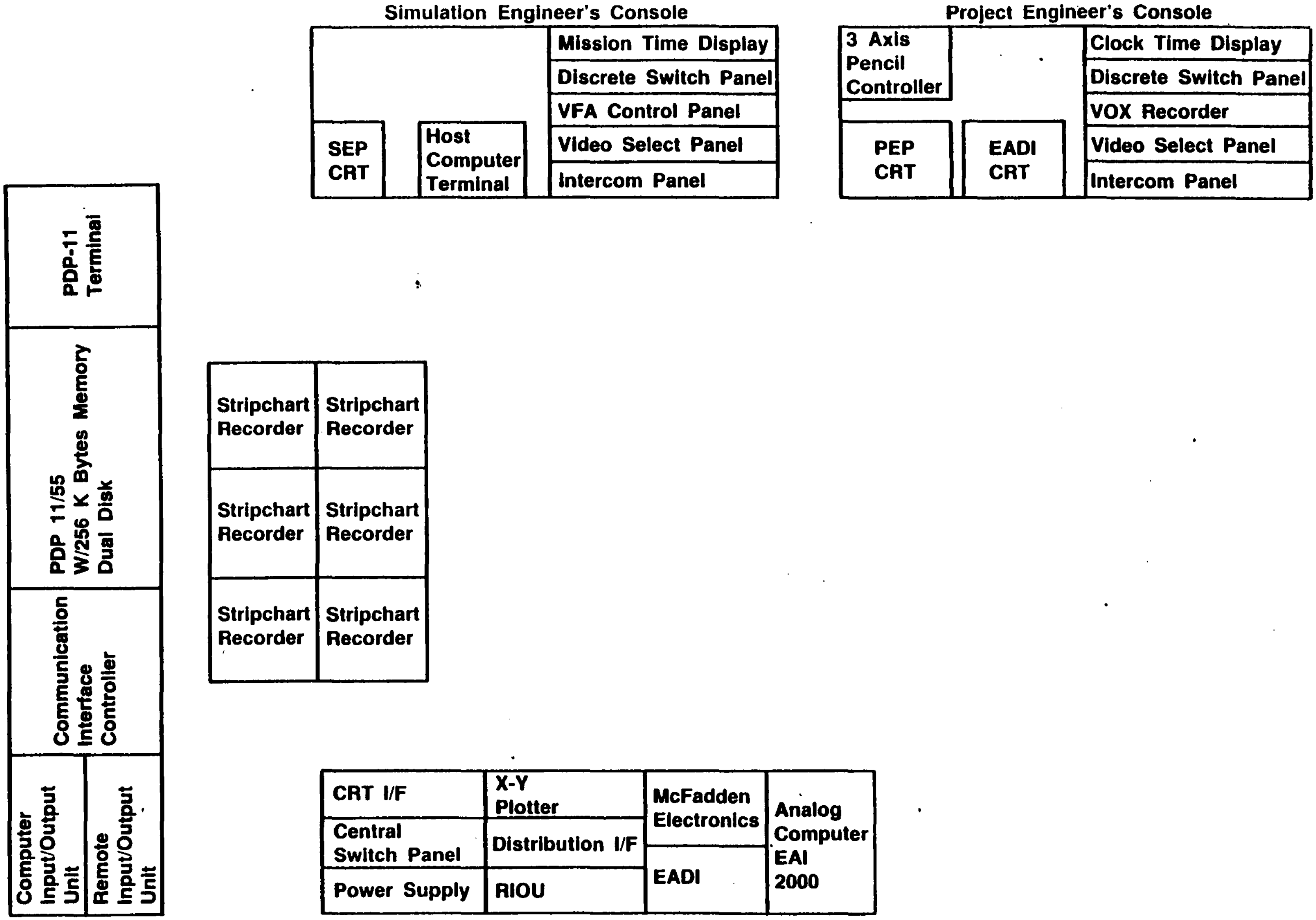


Figure B3-10: Development Station Control Room

3.4.2.5 Development Station Peripheral Hardware

As a minimum, the following periperal hardware shall be provided:

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

3.4.2.6 Simulation Engineer's Console

A simulation engineer's console shall be provided that allows for the monitoring, control and checkout of the cab/visual/RSMG at the development station. It shall contain the following items as a minimum:

- 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

3.4.2.7 Project Engineer's Console

A project engineer's console shall be provided that allows for the monitoring, control and checkout of the cab/visual/RSMG at the development station. It shall contain the following items as a minimum:

- Project Engineer's Control Panel (PEP)
- Clock time display
- Discrete simulation control panel
- VOX recorder
- Video select panel
- Intercom panel

- PEP CRT
- EADI CRT
- 3-axis pencil controller

3.4.2.8 Support Hardware

The contractor shall provide the following support hardware along with appropriate racks and connectors to provide a workable, integrated system:

- Force-feel system electronics
- EADI electronics power supplies
- Video electronics
- Sound system electronics
- CRT interface and power supplies
- Central switch panel
- RIOU racks

3.4.3 Rotorcraft Development Station Interface

The rotorcraft development station shall integrate into the existing NASA Ames research facility. Basic interface relationships required are shown in Figures B3-11 and B3-12. An existing NASA Ames host computer interfaces several simulation areas of which RSIS will be one. Interface with the host computer requires the use of a computer input/output unit design at NASA Ames. All interfaces between the development station and the cab/visual/RSMG system shall be compatible with existing interfaces and must connect with the VMS control room when the cab/visual/RSMG is mounted on the VMS.

3.4.4 Development Station Design and Construction

The contractor shall, subject to NASA Ames approval, select a site for the rotorcraft simulator cab development station and control room. The proposed site for the development station is room 153, building 243. Candidate areas for the control room include: part of room 153; an adjacent room below the mezzanine, room 231; the interchangeable cab control room; or a room (not currently existing) above the interchangeable cab control room. Figure B3-13 shows the floor plan of building N-243 and the proposed location of the development station.

3.4.4.1 Cab Area

The cab area shall be located alongside the RSMG in the development station. Ideally the cab and the visual system should be mounted separately, side by side, on a raised floor or platform with the cab floor at the same level as the platform; however, depending upon the visual system selected, available space may not allow this arrangement. All power and instrumentation cables shall be routed in a cable tray under the floor from the control room to the cab interface connections. An overhead crane shall be installed to move the cab/visual equipment within the development station. Access to room 153 is restricted by door size, the smallest opening width being 12 feet. The door could be enlarged to accommodate the cab/visual system, but such an enlargement would involve considerable expense and facility modification. Therefore, consideration should be given to designing the cab/visual system in such a manner as to facilitate movement through existing doors.

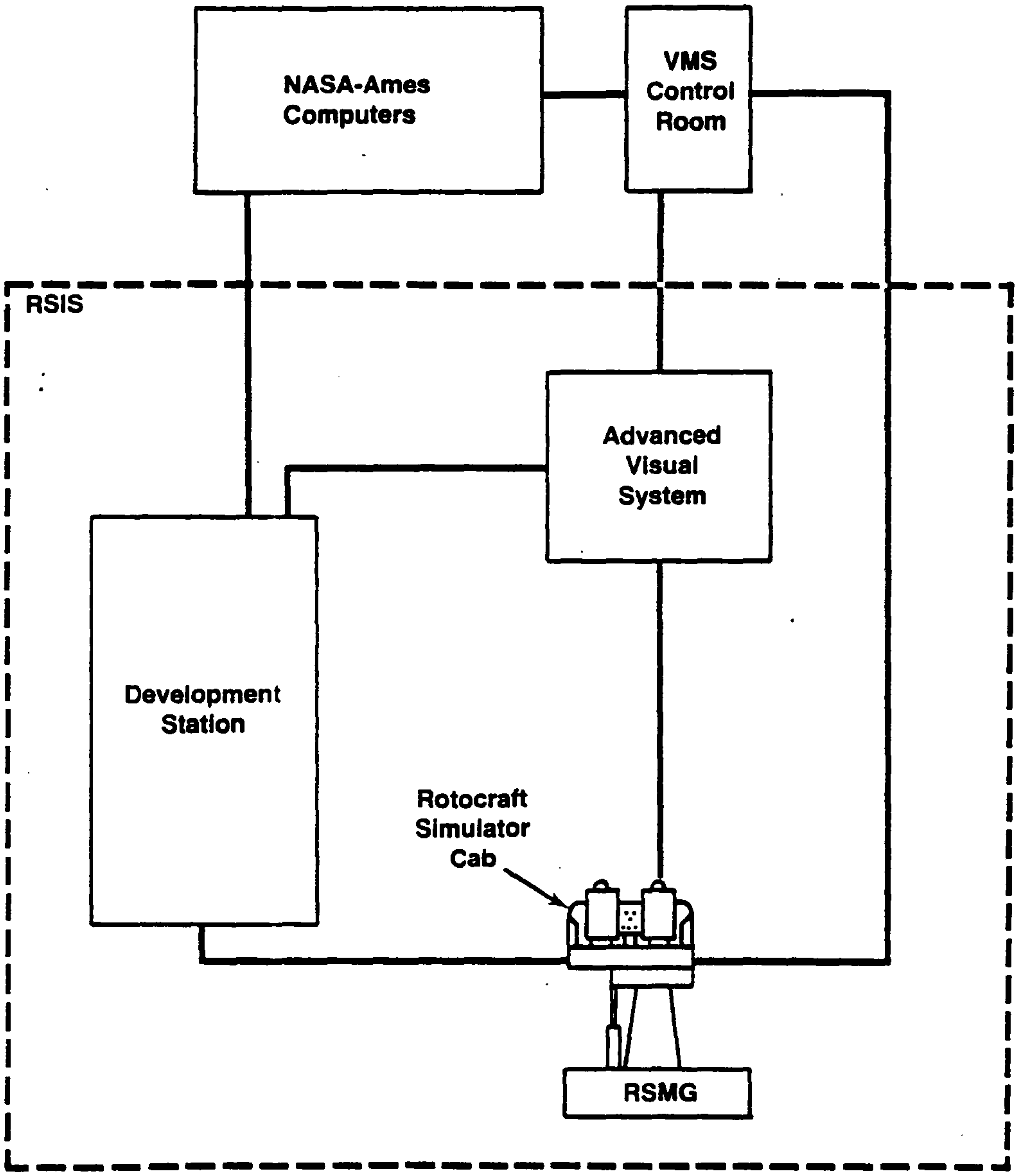


Figure B3-11: Overall System Interfaces

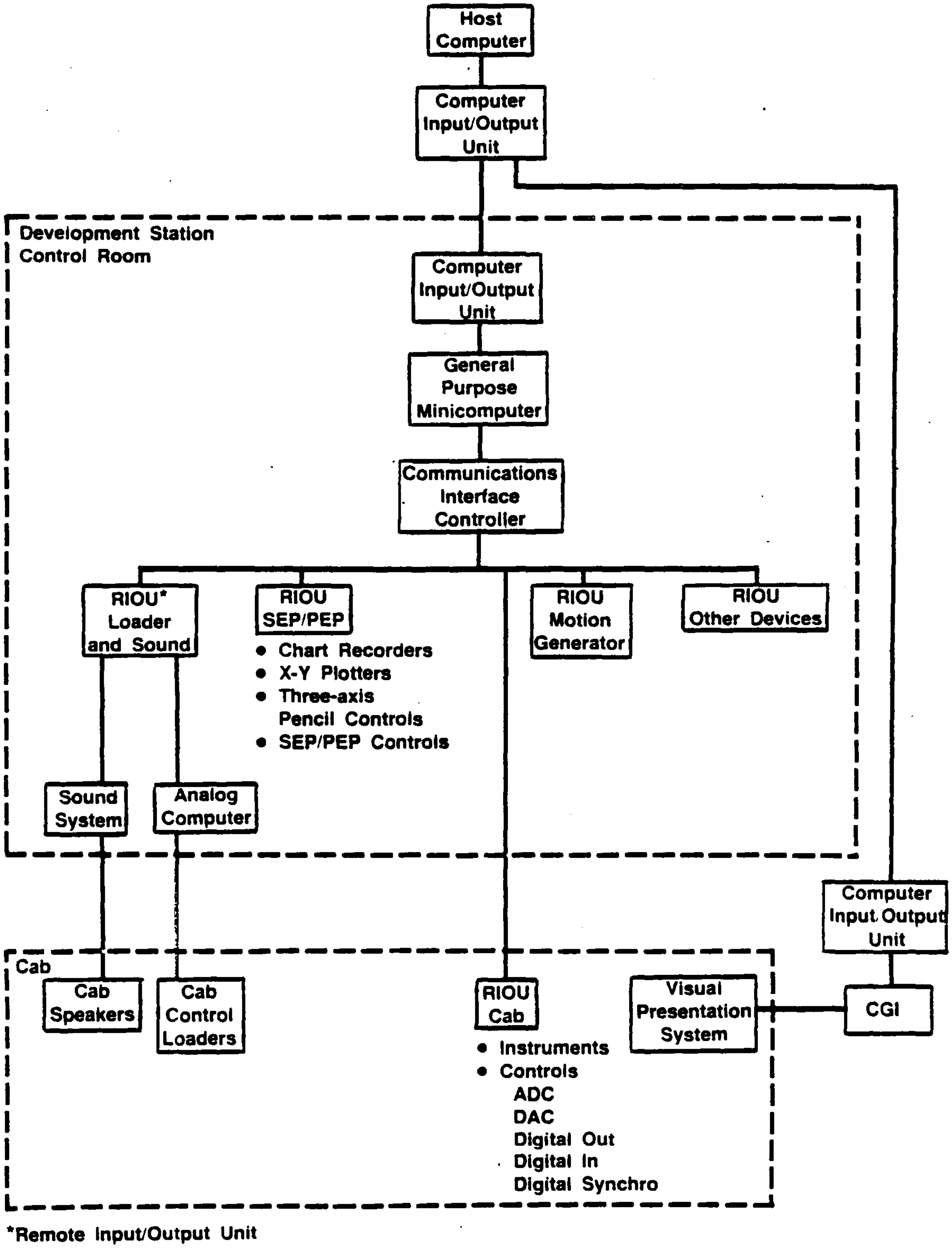


Figure B3-12: Development Station Control Room Simulation Computer Interface

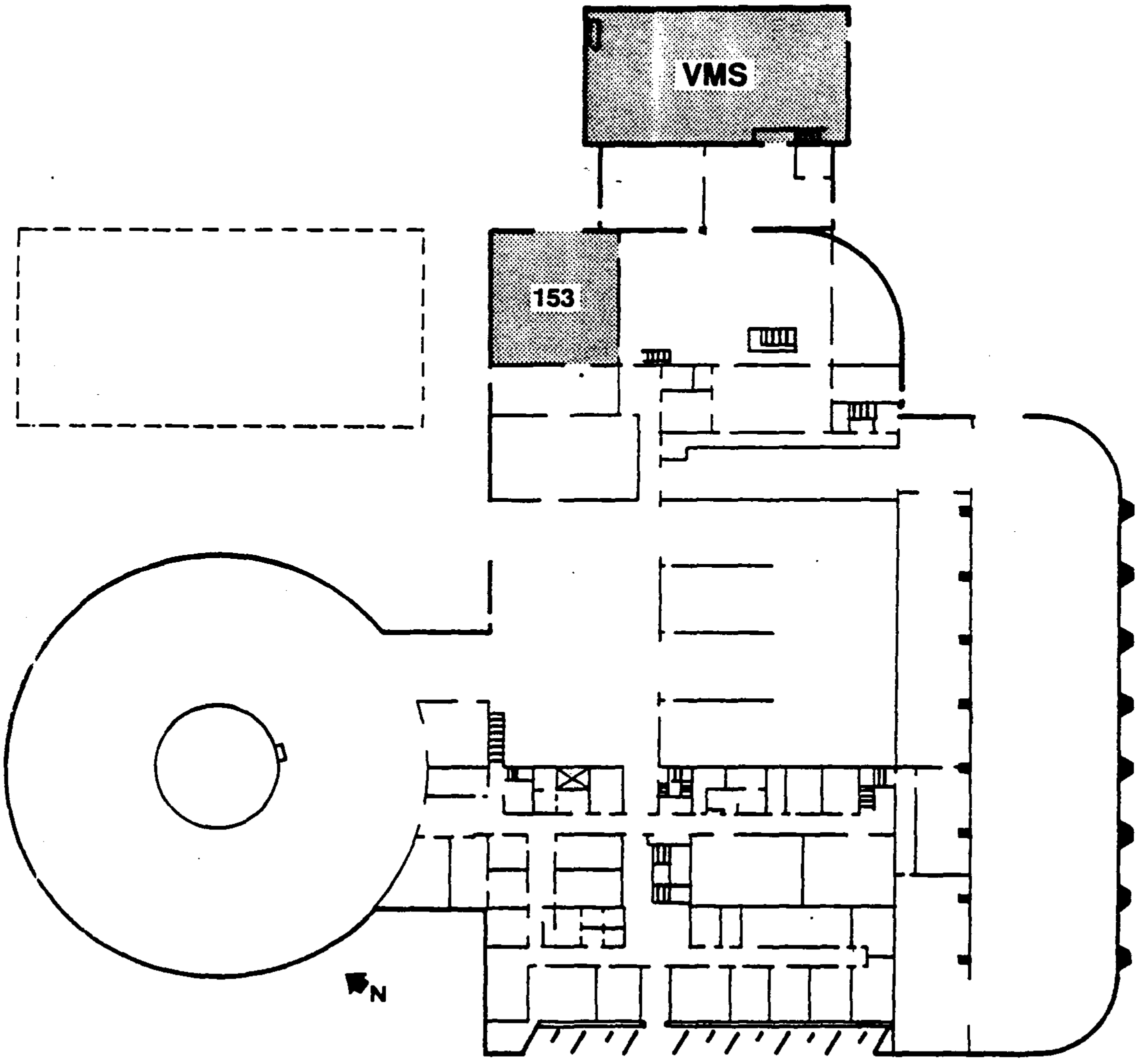


Figure B3-13: Flight and Guidance Simulation Laboratory – First Floor (N-243)

3.4.4.2 Control Room

The control room should not necessitate development of new technology as the existing NASA design could be duplicated. Whatever the final design, it shall be compatible with existing NASA Ames hardware and software. The control room shall be totally enclosed with two separate access doors. The wall facing the cab area shall have windows and a double door. The entire control room should be elevated to the same height as the cab floor and have a computer-type floor. Air conditioning to cool the electronic equipment shall be ducted below the floor. Sound insulation shall be used to control noise.

3.4.4.3 Rotorcraft Simulator Motion Generator

The development station is expected to be the test area for the RSMG. Provisions shall be made to allow the integration of the cab, motion system and development station for simulation studies. Being an area where fixed-base simulation studies may be conducted or the cab/visual system developed, the development station must provide a mounting interface that can accept the rotorcraft simulator cab and the advanced rotorcraft visual system either individually or as a cab/visual unit. This is the most likely long-term way in which this station will be used. In the short term, the area will also be used to check out and integrate the rotorcraft simulator motion generator. Therefore, provisions shall be made for mounting the RSMG and cab/visual system within the development station.

At a later time the whole assembly will be mounted on the lateral carriage of the VMS forming the complete RSIS complex. After this, the rotorcraft cab/visual unit will be transferred back and forth between the rotorcraft simulator development station and the VMS, depending on the program needs, but the RSMG will, in all likelihood, remain permanently atop the VMS lateral carriage.

3.4.4.4 Utilities

Requirements for utilities must be considered, including 400 cycle power, 60 cycle power, lighting plans for cab and control room areas and telephones.

3.4.4.5 Hydraulic Power

Provision for hydraulic power shall be considered, if required by the cab/visual system design. The hydraulic power source shall not produce excessive noise.

3.4.4.6 Air Conditioning

Air conditioning and humidity control shall be supplied to the development station. In the control room, air conditioning shall be supplied through a raised floor to the electronic equipment racks. Air conditioning shall also be supplied to the cab area. In addition, provisions shall be made to supply air conditioning to the rotorcraft simulation cab if it is designed without a self-contained air conditioning unit.

3.4.4.7 Noise Suppression

Unwanted noise in the development station shall be suppressed to a level such that it does not interfere with the cab/visual system checkout or operation.

3.5 Visual System

3.5.1 Paragraph Blank

3.5.2 Visual Display System Item Description

The advanced rotorcraft visual system shall be designed for rotorcraft simulations and shall consist of electronic, electro-optical and mechanical devices. The presentation system may consist of more common display devices such as cathode-ray tubes or use advanced electro-optical innovations such as lasers, or it may use a mix of these. Whatever its configuration, it shall be compatible with RSMG and operable with the cab while both units are mounted in the development station or on the lateral carriage of the VMS.

3.5.2.1 Visual Display System Characteristics

3.5.2.1.1 Resolution

A minimum detection angle of 1.7 mrad (six arc minutes) or less is required with a goal of .87 mrad (three arc minutes) for the background and .29 mrad to .87 mrad (one to three arc minutes) for targets. Resolution, as used here, is defined in terms of optical line pairs as seen at the displayed image.

3.5.2.1.2 Field of View

A minimum field of view of 2.09 rad (120°) horizontally by 1.05 rad (60°) vertically is required with a large field of view of approximately 70 percent of full field, 4.19 rad (240°) horizontally by +2.09 rad, −1.05 rad (+120°, −60°) vertically as a goal.

A larger total field of view could be achieved by slaving an area of interest. In such cases the instantaneous field of view must be at least 2.09 rad (120°) horizontal by 1.05 rad (60°) vertical, with 3.14 rad (180°) horizontal and 1.40 rad (80°) vertical the goal. Consideration could also be given to raster rotation.

Distortion of overall scene shall be <3 percent of picture height.

3.5.2.1.3 Luminance

An illumination range of .10 to 103 cd/m^2 (.03 −30 foot-lamberts) is required, with 171 cd/m^2 (50 foot-lamberts) as a goal. Brightness range under normal operating conditions shall be from the lower limit to the maximum level without white light or color saturation. Flatness of field shall be such that for a uniform illumination input, brightness of the scene shall not vary more than 50 percent across the full field of view.

3.5.2.1.4 Contrast

A contrast ratio range of .03 −30 is required as measured in a 2/3 of picture height circle of interest in the main field of view when the image source is from a standard test pattern of gray scale electronically generated and the display adjusted with black at cutoff, and white at saturation. At least ten gray scales shall be detectable and shall be observed under normal operating cab illumination.

3.5.2.1.5 Color

A color capability of two basic colors is required, with full color as a goal. CIE color coordinates at the display shall not deviate more than ± 2 percent from the theoretical values..

3.5.2.1.6 Viewing Volume

A high-quality viewing volume is required for the primary crew member with reduced quality visual images for a nearby second crew member in a variety of relative seating arrangements, including side-by-side and tandem.

3.5.2.2 Visual Display System Interface

Standard electrical signal communication format (3-channel video), if appropriate, shall be used between the scene generation and presentation system. The visual system shall also be mechanically and optically compatible with head-up devices.

Provisions must be made to ensure compatibility of the motion system, cab and visual system.

A common host computer system is expected to operate, on a time sharing basis, a number of NASA Ames simulation actives. The architecture and capabilities, data communication devices and operational aspects of the computer system must be considered in the design of the visual system to permit operation in an efficient manner.

3.5.2.3 Visual Display System Design and Construction

3.5.2.3.1 Sling-Load Visuals

The visual system shall include the capability of a downward direct-view image to be used by the pilot in long-cable external load work by leaning out the door or into a "bubble" window. The sling-load field of view shall be at least .52 x .52 rad (30° by 30°).

The sling-load visual system shall be designed to provide an image that can be matched in color, hue, contrast, resolution and brightness levels to the overall display. Such matching shall be acceptable to an operator under operational flight conditions when looking between the displays.

3.5.2.3.2 Stand-Alone Capability

The visual system shall be capable of operating separately from the cab as a stand-alone unit and within specifications.

3.5.2.3.3 Physical Considerations

Consideration shall be given to the cab and visual system design for ease of assembly/disassembly and to ensure adequate structural strength. In addition, the dynamic loading, vibration levels and other operational aspects must be considered in the performance characteristics of the cab and visual components when operated in conjunction with the VMS. Image resolution specifications shall not be degraded because of vibration from any source, electrical or mechanical, or by visual positioning devices.

Visual display hardware shall not obstruct aisles of cab, present a safety hazard to crew members or operating personnel or noticeably encumber crew members by special equipment. Visual equipment shall be designed to be as modular as possible for normal maintenance in its operational environment and to enhance ease of removal from the cab base structure. Upon reassembly either on or off the cab base, it shall meet its original visual and mechanical specifications. The visual display equipment shall be fabricated such that no damage can occur under normal system operation or maintenance. Full system routine maintenance shall be possible at the VMS area or the development station with all equipment in place and shall be possible to be performed by NASA Ames/contract personnel.

3.5.2.3.4 Image Mosaicking

If one or more images are combined in a mosaic, all joints must be aligned such as to not detract from the total composite image. Images shall be blended in the overlap with registration within one raster line. Color hue and intensity shall not change noticeably across mosaic joints under operational scene conditions. Contractor shall submit hue and intensity limits to NASA Ames for approval.

3.5.2.3.5 Image Occulting

Image occulting, whether structural or electro-optical, shall be done in such a manner that it is not annoying to the operator and does not interfere with normal rotorcraft handling.

3.5.2.3.6 Image Swim

Parallax errors causing image swim during operator head motion shall be minimized to less than 1% and not be objectionable to the viewer.

3.5.2.3.7 Setup Controls

Visual maintenance controls for visual system setup (contrast, brightness, hue, color tracking, linearity, etc.) shall be located such that the maintenance operator can visually see the displayed scene while making adjustments.

3.5.3 Visual Image Generation System Item Description

- Maintenance station
- General purpose computational system
- System software

3.5.3.1 Visual Image Generation System Characteristics

3.5.3.1.1 Maintenance Station and Control

The CGI maintenance station shall serve as a control center of the CGI system, where system initialization, control, monitoring, and debugging shall occur. From the maintenance station an operator shall be able to load from the CGI system general purpose computer mass storage all necessary software and data bases into both the CGI system general purpose computer memories and the CGI special purpose processor memories and thus initialize the CGI system. An operator shall be able to test any newly developed general purpose computer software or environment data base or run diagnostic software to troubleshoot special purpose processors and memories from the maintenance station. Consequently, the operator must be able to fly through an environment and view maintenance station monitors displaying the scenes being generated by the CGI system. An operator shall be able to monitor as well as alter various CGI related parameters via lights, switches (dedicated and nondedicated), and LED displays from the maintenance station. At least 20% of the switches shall be provided for growth and have dedicated and programmable function capability. The maintenance station should be located close to the special purpose CGI hardware. A summary of maintenance station components follows:

- TV Monitors and Channel Select Switches

  At least two monitors shall be provided on the maintenance console. For each monitor, a channel select switch shall allow any of the CGI system channels or windows to be displayed. At least one portable monitor shall be easily interfaced to the maintenance console. The display monitor shall be of high resolution (30 MHz bandwidth), high brightness color CRT compatible to the visual system line and field/frame ratio and shall include standard adjustments with front accessibility for contrast, brightness and independent control for selection of each RGB input. The monitors shall be constructed to provide ease of setup and maintenance.

- Joystick Control

  The viewpoint shall be controlled from the maintenance station via a joystick and speed control. Operators shall be able to fly through the environment at any attitude, altitude, and at variable speeds (including hovering) and directions.

- Parameters Panel

  The parameters panel shall be a duplicate of the panel related to the CGI system located on the simulator master control station. Switches, lights, and LED displays shall be placed on the parameters panel to allow an operator to quickly alter or monitor various CGI related parameters, including but not limited to: display status lights, fog altitude and visibility digiswitches, day/dusk/night switches, edges or faces processed readout (LED) and at least 20 spare lights and switches of which some shall be designated special switches and not be dedicated to any particular parameter.

- Computer Terminal

  A CRT terminal interfaced to the CGI general purpose computer system shall be provided at the maintenance station. An operator shall be able to load the CGI system software and data bases and interact with the diagnostic software during troubleshooting periods via commands through the computer terminal.

- Hard Copy

  A hard copy device such as a line printer shall be physically close to the maintenance station to print results of diagnostic tests during preventive and corrective maintenance periods.

3.5.3.1.2 Computer Generated Imagery Hardware

The Computer Generated Imagery (CGI) subsystem, using a numerically stored model and simulator flight data, shall generate video signals for display to the two simulator pilots. These video signals, when displayed to the pilot, shall provide the necessary visual cues to permit the pilot to perform helicopter nap-of-the-earth flying tasks. Perceptual complexity shall be provided, especially in the area of targets or navigational references, to represent real world scene complexity to visually task load the pilot for more realistic simulation. Thus, the pilot may "fly" in any direction or any attitude within the visual model and view the proper visual cues.

- Scene Construction

  The CGI shall compute the visual scene by transforming the three-dimensional terrain model into two-dimensional display scenes for single-point viewing by the pilots. This transformation shall include aircraft position and attitude within the visual data base. The result of this computation shall be signals which are generated by D/A conversion and fed directly to the display. The CGI shall compute a new aircraft position in the visual data base each 1/30 of a second or faster and output the visual scene at 30 frames per second or faster.

- Elimination of Distracting Visual Effects

  The CGI shall eliminate all distracting visual effects that occur during the computation and processing of the image. These distracting effects include:

  1. Scintillation of small faces or lights
  2. Quantization due to the computation of picture elements
  3. Abrupt addition or deletion of scene detail
  4. Repetitive or periodic motion of the visual scene not computed in the simulator flight equations

- Surface Elevation

  The CGI system shall correlate the elevation of the visually simulated surface and the surface elevation used in the simulator computations for the following situations:

  1. Takeoff and landing
  2. Air-to-surface weapon delivery
  3. Terrain crash

  The rate of change of the surface elevation shall be continuous and abrupt changes in elevation shall not be discernible to the pilot as he flies from one area of the visual data base to another.

- Performance Envelope

  The CGI shall possess the following minimum processing capabilities:

  1. A 10 × 10 nautical mile area of coverage
  2. Simulated altitude range of sea level to 20,000 feet
  3. A translation rate of at least 500 knots
  4. An angular rotational rate around any of these axes of two radians per second
  5. At least 8,000 edge equivalents per channel
  6. At least 600 edge crossings per raster line per channel if a scan line oriented system is proposed
  7. Tranport delay of less than 200 milliseconds
  8. 256 simultaneously displayable colors

- Moving Objects

  The CGI shall be capable of generating a sufficient number of moving objects to simulate at least two independently moving vehicles for simultaneous display in addition to required nonvehicle simulation, such as bomb ground impact indications, tracers, etc.

- Simulated Position

  The CGI shall generate an image positioned within the ten nm by ten nm environment that contains at least 20 bits of accurate information for all degrees of freedom (translational and rotational).

- Crash Detection

  The CGI shall detect and inform the simulator computer when a visual crash occurs. A visual crash shall occur whenever the pilot flies below the surface or into solid objects.

- Atmospheric Effects

  Basic requirements:

  1. At least three light levels of the sky and ground (day, dusk, night) shall be simulated, with colors of all models displayed being adjusted based on the time of day.

  2. Aerial perspective shall be simulated with colors of objects being faded towards a haze color based on the distance of the objects from the viewpoint.

  3. At least one layer of fog or haze shall be simulated with the top elevation, bottom elevation, and the visibility inside the fog being operator definable. Object colors shall be further faded towards a defined fog or haze color when the viewpoint is located in the fog.

  4. A horizon glow shall be simulated for dusk and night scenes.

- Special Purpose Computer

  The special purpose computer shall accept the general purpose computer outputs, and perform the high-speed data processing to generate the output video and synchronizing signals for display to the pilot in accordance with Paragraph 3.5.3.1.2 parameters. The special purpose computer system shall consist of parallel and pipelined processors designed in a modular fashion. To facilitate channel expansion and provide ease of fault isolation, viewpoint associated processing should be separate from channel associated processing.

  The special purpose computer system shall perform the following CGI operations: field of view or channel assignment processing, back face elimination, vertex or face transformation from environment coordinates to screen coordinates, face clipping, and occultation of hidden surfaces.

  A maintenance structure shall be designed into each unit of the hardware, permitting the general purpose computer to access and test hardware at the register level (utilizing the maintenance software), as well as monitor the load and capacity parameters such as potentially visible edges and edge crossings per raster line.

3.5.3.1.3 Image Generation Software

General purpose computer software shall be developed and documented to (1) provide the real-time visual system processing functions required to generate image data output to the special purpose computer system; (2) provide for transmitting data to and from the simulator computer system and the data base development system; and (3) provide diagnostic and test software for maintaining the special purpose hardware.

In addition, the following standard computer manufacturer's support programs for contractor written programs shall be provided with the CGI system if they were used in the development, operation, or testing of the CGI system equipment or programs:

- Resident operating system
- Assemblers
- Compilers

- Loaders and linkers
- Mathematical library

These programs shall be delivered in a form and medium which is suitable for direct loading and execution by the CGI computer equipment.

- Data Base Manipulation Software

  The real-time software executing in the general purpose computer will retrieve the data base from mass storage and perform the necessary bookkeeping operations to ensure that the special purpose computer system receives the proper subset of the entire data base for processing. This software shall sample the operator station consoles and take appropriate action (e.g., change CGI parameters being transmitted to the special purpose computer system) based on operator inputs.

- Maintenance and Test Programs

  Programs shall be provided to fully test the operation of the CGI system including computer equipment, special purpose equipment, flight computer interface, and special purpose interface. Diagnostics shall also be provided for all peripherals, controllers, and devices in which data transfers occur within the general purpose computer. If a malfunction occurs in the CGI special purpose computer system, these programs shall provide sufficient information to the operator to identify and locate the malfunction. They shall be capable of running with a minimum amount of operator intervention.

3.5.3.2 Interface Software

Software shall be developed to support the transmission of data (e.g., attitude matrices and position data) to and from the simulator computer. Included shall be software to compute the predicted aircraft position and attitude data for transport delay compensation.

Software shall be developed to support the transmission of data bases from the Data Base Development System (DDS) to the general purpose computer system via a 50 K baud transmission line and to store the data base onto the mass storage device.

3.5.3.3 Design and Construction – General Purpose Computational System

A general purpose commercially available digital computational system shall be incorporated into the CGI system and shall consist of a commercially available, off the shelf, general purpose digital computer with peripheral equipment, as specified herein, and associated programs to activate and support the CGI system. All equipment and computer programs shall be provided as specified herein. The digital computer system shall accept flight simulator inputs, perform real-time processing of these inputs, and provide outputs necessary for special purpose computation within the tolerances and performance criteria specified herein.

- Computer System Equipment

  The configuration of the selected computer equipment including mainframe, memory, input/output processors, interface buffers, signal conversion equipment, and peripherals shall be tailored to the real-time computer image generation processing requirements. Multicomputer and multiprocessor configurations may be incorporated. In this case, the configuration shall consist of common digital computers; i.e., same manufacturer and series designation. Multicomputer and multiprocessor configurations shall include common core, and operation shall be controlled from a single supervisor/executive computer program.

- Computer Mainframe Characteristics

  Each computer in the system shall be capable of real-time computation with adequate speed, addressable memory range and input/output processor capacity to efficiently process the outputs necessary for special purpose computations.

- Input/Output Terminal

  An input/output terminal shall be provided to allow operator intervention and communication with the CGI system. As a minimum the input/output terminal shall consist of a keyboard, CRT, and a hard copy capability with a minimum of 30 characters per second output.

- Magnetic Disc System

  A magnetic disc system shall be the primary system for on-line storage of all CGI programs and visual data base scenes, as well as the primary system for loading computer memory with the operational CGI CPS. Maintenance and test programs, with the exception of self-test, checksum, and daily readiness tests, may reside on a separate disc pack. Organization of the programs and data bases on disc shall provide access within time constraints to support mission profiles.

- Magnetic Tape System

  A magnetic tape system shall provide an on-line real-time magnetic storage and access capability. The magnetic tape system shall provide CGI CPS storage backup to the CGI disc system. A capability to copy information from magnetic tape onto the disc and to load a new disc shall be provided.

- Expansion Capability

  The CGI computer system shall be designed and configured to permit expansion of the computational capacity without significant design changes to existing hardware and without obsoleting the existing equipment. The following equipment and processing capability shall be expandable.

  (a) Computer processing time

  (b) Direct addressable memory

  (c) Input/output capability

  (d) Data base storage

3.5.4 Data Base Development System (DDS) Item Description

The Data Base Development System is considered an integral component of the computer image generation system. The DDS shall be compatible with, but separate from, the real-time image generation hardware. The DDS shall be a stand-alone system, requiring no special air conditioning facilities. Offerors will be evaluated in terms of the (a) overall capability of the proposed DDS, (b) interactive software development tools, (c) documentation, (d) ease of use, (e) future growth potential.

3.5.4.1 Data Base Functional Characteristics

- To the maximum extent possible, DDS software shall be written in a higher-level language, such as ANSI FORTRAN 77.

- The DDS will support translation of Defense Mapping Agency (DMA) data into a format suitable for implementation on the CGI system.
- Data base environments shall be a minimum of ten nautical miles square, and contain at least 2,000 edges per nautical mile square, average, exclusive of any moving models.
- The DDS shall contain a data base analysis program to evaluate the CGI parameter densities of the environment and detect overloaded areas.
- The data base shall be compatible with the existing NASA Ames Singer-Link Visual System in the sense that each can, with some manipulation, use the others' data base.

3.5.4.2 Design and Construction

3.5.4.2.1 Computational System

The computational system shall consist of a 32-bit, general purpose computer with such memory support, support software, and additional special purpose hardware as required to generate and display in nonreal-time visual scenes appropriate for display on the real-time hardware at not less than 500 edges per second per standard television frame (480V by 640H), exclusive of antialiasing. Thus, a 10,000 edge scene should require no more than 20 seconds to produce.

3.5.4.2.2 Display System

The display system shall be independent of the real-time image generation hardware, and shall consist of:

- A high (30 MHz) resolution color CRT with 8-bit RGB (each) input
- Assuming color mapping is used, at least 12-bit color map capability with the choice of the color-space programmable
- A minimum refresh rate of 30 Hz per frame

3.5.4.2.3 Computational Support Peripherals

The contractor shall provide, at a minimum, the following additional equipment interfaced to the computational system:

- A digitizing system, whose origin and scale are selectable, and radar software control, with at least a 22-inch square area and a resolution of .001 inch.
- Electrostatic printer/plotter capable of 1,000 LPM printing and one-inch/sec plotting.
- A 9-track, 1,600 bpi, 75 IPS tape drive.
- Two interactive terminals with software support system and full text editing capability. One terminal may double as a console controller.
- 300-megabyte disk drive, fully compatible with the real-time image generation disk drive.

4.0 TEST REQUIREMENTS

To be specified by NASA.

5.0 FABRICATION AND QUALITY STANDARDS

5.1 General

All parts shall be fabricated and installed in accordance with the best practices in the trade or industry.

5.2 Mechanical Fasteners

Self-locking or safety-wired NAS or MS equivalent fasteners shall be used where loss of the fasteners could cause damage to the system or injury to personnel.

5.3 Welding

Welded joints shall be free of cracks, porosity, undercuts, voids, burn-through and gaps. Fillets shall be uniform and smooth. There shall be no damage to adjacent parts resulting from the welding operation.

5.4 Electrical

5.4.1 Amplifiers

Solid-state electronic products shall be used throughout. Properly identified test points shall be provided on the front of the amplifier cards or chassis front panels for measuring all primary inputs, feedback voltages and amplifier outputs. System ground in the amplifiers and power supplies shall be insulated from chassis ground and brought through separate connector pins or terminals. All amplifier input and output wires shall be shielded. Multiple grounds on shields are prohibited.

5.4.2 Power Supplies

Power supplies shall provide at least 25 percent extra capacity and their outputs shall be metered with ammeters and voltmeters.

5.4.3 Batteries

No batteries of any type shall be used.

5.4.4 Wire Terminations

5.4.4.1 Terminal Strip Identification

A terminal strip or connector shall be furnished at each electrical device on the simulator with each wire suitably and uniquely identified by number to correspond to those marked on the simulator wiring diagram.

5.4.4.2 Connectors

Connectors shall be used on all outgoing wires from simulator to facilitate removal when necessary. Connectors shall also be used on all outgoing wires from racks and control consoles.

5.4.4.3 Insulation Lugs

Crimped insulation lugs shall be used on all screw terminals. The lugs shall be designed for the size of wire and screw terminals with which they are used. These lugs shall be applied with a tool so designed that once crimping action is started, the tool cannot be removed until the jaws "bottom."

5.4.5 Wiring Practices

5.4.5.1 AC Power Isolation

Care shall be taken to run conductors carrying AC power away from electronic signal wires whenever practicable. All AC leads shall be twisted pairs whenever practicable.

5.4.5.2 Wiring Protection

Wiring on the simulator structure shall be suitably protected from mechanical and environmental hazards.

5.4.5.3 Splicing

Splicing of conductors, unless otherwise authorized, is prohibited.

5.4.5.4 Shielding

All signal wires longer than one inch shall be shielded.

5.4.5.5 Heat-Shrinkable Tubing

Heat-shrinkable tubing shall be applied on all wires soldered or crimped to connectors. A heat gun recommended by the tubing manufacturer shall be used to shrink the tubing. The tubing shall be long enough to cover the terminal completely and least 1/2 inch of insulation. The tubing shall be the size recommended by the manufacturer for the particular wire size. After shrinking with the heat gun, there shall be no cracks or splits in the tubing. If cracks or splits appear, the tubing shall be replaced.

5.4.6 Shielded Wires

Shielded wires or cables, single or multiple conductors shall consist of stranded tinned copper not less than No. 22 AWG with thermoplastic insulation, metallic shields and oil, moisture and abrasion resistant jackets suitably rated for the application environment.

5.4.6.1 Coverage

Shields on all shielded wire shall have at least 90 percent coverage.

5.4.6.2 Ground Isolation

Each shield shall be isolated from ground except at one end where it shall be connected to a system-ground bus, not to the chassis.

5.4.6.3 Ends of Shielded Wires

The end of a shielded wire which is not grounded shall have the cut shield covered with heat shrinkable tubing. The tubing shall extend 1/4 inch beyond the cut shield and 1/2 inch back over the uncut shield insulation. The shield shall not be exposed at either end of a shielded wire.

5.4.6.4 Shields Soldered

The shields of shielded wires shall be soldered.

5.4.6.5 Shields Insulation

All shielded wires shall have the shields insulated. If a shield jacket is nicked, cut or burnt, the wire shall be replaced.

5.4.7 Unshielded Conductors

Unshielded conductors shall be copper, insulated for 600 volts and shall conform to MIL-16878. Minimum conductor size shall be No. 20 AWG.

5.4.8 Component and Wire Identification

Wires within the electronic assemblies shall be color coded using any suitable code which utilizes at least seven colors. Interconnecting cable wiring shall be identified using wire numbers affixed to the wires at each termination point.

5.4.8.1 Components Identified

All major components such as amplifiers, switches, transformers, meters, potentiometers, relays, test points, adjustable impedances, etc., shall be identified. The reference designation of each component shall appear adjacent to the component. If available space does not permit appearance of such identification adjacent to the components, a diagram or photograph showing their location and their proper identification shall be furnished with the electronic equipment.

5.4.9 Drawings

The electrical and electronics drawings shall be per USAS-STD-Y14.15 and ANSI-STD-Y32.2.

6.0 RELIABILITY AND QUALITY ASSURANCE

6.1 General

This system shall be designed and fabricated in accordance with professionally recognized standards for man-rated electronic systems. Safety, soldering, workmanship, wiring and interconnect cabling shall be in accordance with Requirements 1, 5, 9, 69 and 71, respectively, of MIL-STD-454G. MIL-STD-454G requirements are not required for off-the-shelf equipment that is acceptable to NASA, and the contractor's standards may be used in lieu of MIL-STD-454G if they are determined acceptable by NASA.

It is intended that the contractor's in-house reliability and quality assurance program be utilized to the maximum extent possible. If the contractor deems it appropriate to use his own specification, procedures, standards, etc., in lieu of those specified herein, he may propose such a substitution. The substituted provisions shall accompany the proposal.

6.2 Reliability Assurance

Design reviews shall be held as set forth in Section 8.0, and a Failure Mode, Effects, and Criticality Analysis (FMECA) shall be conducted as set forth in Section 4.0.

6.3 Quality Assurance

The contractor shall implement and maintain an effective inspection system that satisfies the requirements of specification MIL-I-45208A, Inspection System Requirements.

7.0 REPORTING

Monthly Technical Progress Reports, in letter format, shall be submitted. These reports shall include schedule status, a quantitative description of overall progress, an indication of current or expected problems which may impede performance, a solution(s) to the problems, and a discussion of work to be performed during the next month. The reports shall be in narrative form, and brief and informal in content. Four copies of each report shall be required.

7.1 Final Technical Report

A final technical report shall summarize the results of the entire detail design phase of this contract, including recommendations and conclusions based on the experience and results obtained. It shall include tables, graphs, diagrams, sketches, photographs and drawings in sufficient detail to comprehensively explain the results achieved. Further, it shall include all analyses performed by hand and computer in pursuit of the detail design in meeting the requirements specified in Section 3.0 and, in particular, those results necessary to verify safety, performance, and structural integrity. (Analyses refers here to all calculations performed and method used including computer models, etc.). A complete set of detail drawings shall also be included in this final technical report.

A draft copy of the final report shall be submitted for review and approved by NASA Ames Research Center (NARC) prior to its final printing. Ten copies and a camera-ready original of the approved final report shall be submitted in the format described in NARC Form C115. Also delivered shall be one set of reproducible copies of the detail design drawings.

7.2 Oral Presentation

The contractor shall conduct an oral presentation of the final report at the end of the contract period at NASA-Ames Research Center.

8.0 DESIGN REVIEWS

At least four design reviews shall be held during the course of the detail design phase of this contract. These reviews will be held at the contractor's facility.

- The first to be held within the first 15 percent to 20 percent of the design effort. This is to insure that the detail design is commencing and proceeding in an acceptable manner and that specifications and requirements are being met.
- A minimum of three reviews will be held during the remaining detail design phase.

An independent safety review is not planned. However, it is to be understood that a safety review will be a part of every design review. The review may be attended by NASA or its representatives. NASA reserves the right to employ independent contractors to function as technical advisors during the design reviews.

9.0 INSPECTIONS

During the fabrication stage of the contract, the Government will exercise the right of conducting unscheduled and short notice reviews and inspections of the hardware fabrication and assembly.

10.0 TESTING

A full operational test demonstrating adherence to the requirements set forth in this specification shall be performed at the contractor's facility prior to disassembly and shipment to NASA Ames Research Center as set forth in Section 4.0. This test shall be attended by the Government and/or its representatives. A test plan shall be submitted for review a minimum of 120 days prior to the scheduled test. A test procedure shall be submitted a minimum of 60 days prior to the scheduled test. Four copies of each are required.

A full operational test demonstrating adherence to the requirements set forth in this specification shall be performed after final assembly of the system at NASA Ames Research Center (Reference Section 4.0). This test shall be attended by the Government and/or its representatives. A test plan shall be submitted for review a minimum of 90 days prior to the scheduled test. A test procedure shall be submitted a minimum of 45 days prior to the scheduled test. Four copies of each are required.

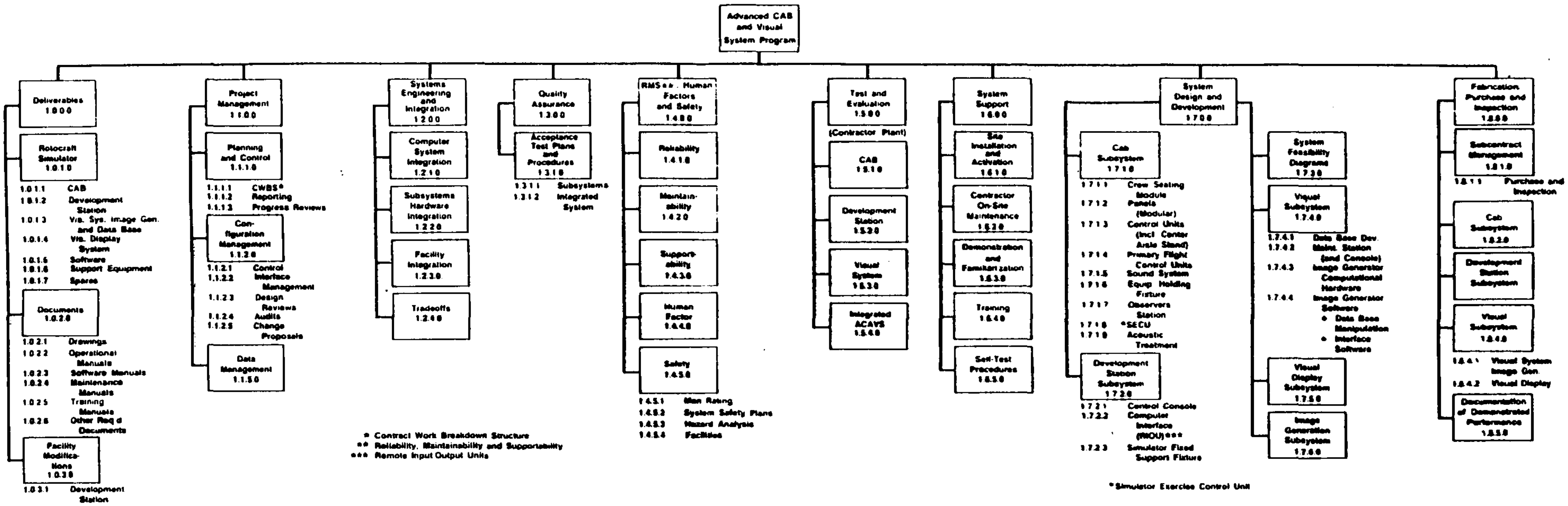
11.0 CONTRACTOR CONDUCTED ORIENTATIONS

Prior to or during the testing phases described in Section 10.0 the contractor will conduct an orientation of operation procedures of the simulator to the Government personnel who will have this responsibility after the delivery and assembly/checkout testing of the hardware at NASA Ames Research Center. During the final assembly and checkout/testing of the simulator at NASA Ames Research Center, the contractor shall conduct an orientation on maintenance procedures to the Government personnel.

APPENDIX C

CONTRACT WORK BREAKDOWN STRUCTURE

This Page Intentionally Left Blank



Appendix C: Contract Work Breakdown Structure

APPENDIX D

FACILITY MODIFICATION DEFINITION

This Page Intentionally Left Blank

APPENDIX D

FACILITY MODIFICATION DEFINITION

1.0 FACILITY MODIFICATION DEFINITION

Facility modifications should be confined to the development station area. It is recommended that all ACAVS hardware be designed to pass through existing doors and passageways as required to move equipment from the VMS to the development station. In addition, modifications within the development station should be held to a minimum. The following areas require modifications:

- Development station
  - Install raised floor
  - Install cab buildup area support hardware
  - Construction of storage facilities
  - Install overhead crane
  - Install required utilities and power
  - Construct stairs, walkway and boarding ramp
- Control room
  - Construct control room
  - Install raised floor
  - Install required utilities

Sound suppression should be considered in the development station area to control unwanted sound.

1.1 Development Station Modifications

1.1.1 Development Station Raised Floor

A computer-type raised floor should be installed over the entire development station floor (Room 153). A step down would be required at the entrance/exit door and a ramp at the roll up door (see Figure D-1). A ramp is required to allow transportation dollies into the development station. All utilities, power and air conditioning supplies should be routed under the floor.

1.1.2 Cab Buildup Area Support Hardware

Floor mounts to support the simulator cab should be installed. Depending on the visual system used, a floor mount may be required for the visual presentation equipment. All utilities and air lines should be supplied to the cab buildup area to support mechanical and electrical work on the cab. Work areas and benches should also be considered in the buildup area.

1.1.3 Storage Facilities

Storage facilities should be built to house all ACAVS support equipment and spare parts.

1.1.4 Overhead Crane

An overhead crane should be installed to move the cab/visual system within the development station. The crane could also be utilized to lift hardware up to the control room level. Dual controls should be considered such that the crane could be operated from both the floor and control room levels.

1.1.5 Required Utilities and Power for Development Station

Utilities supplied to the development station (including cab buildup area) should include as a minimum the following:

- Electrical power
  - 110V 1Ø 60 Hz
  - 110V 3Ø 60 Hz
  - 220V 1Ø 60 Hz
  - 220V 3Ø 60 Hz
  - 110V 3Ø 400 Hz
  - 28 VDC
- Hydraulic power (could possibly be a self-contained floor unit)
- Computer interface trunking
- Utility lighting
- Air supply
- Telephones
- Intercoms

An air conditioning interface with the cab/visual system should be provided to supply air conditioning to the cab and the RSMG/adapter.

1.1.6 Stairway, Walkway and Boarding Ramp

A stairway should be constructed which would allow access to the control room level and a walkway along the control room/development station wall (see Figure D-1). Access could possibly be provided to the landing outside of Room 231. A boarding ramp should be constructed from the walkway to the simulation cab for access to the cab/visual system on the RSMG or adapter. The control room walkway would not only provide access to the control room and the cab/visual system, but would provide an observation area which would not interfere with activity in the cab buildup area or simulation checkout.

1.2 Control Room

1.2.1 Control Room Construction

It is recommended that an ACAVS control room be constructed on top of the existing interchangeable cab control room. Construction should be similar to interchangeable cab control room construction. Adequate strength must be considered to support control room hardware. Large double windows should be installed along the development station wall of the control room to provide visual contact with the cab/visual system and the development station. Double doors should also be installed to allow movement of equipment.

1.2.2 Control Room Raised Floor

A computer-type raised floor should be installed in the control room with all utility power and air condition supplies should be routed under the floor.

1.2.3 Required Utilities and Power for Control Room

Utilities supplied to the control room should include the following:

- Electrical power
  - 110V 1Ø 60 Hz
  - 220V 1Ø 60 Hz
- Computer interface trunking
- Utility lighting
- Telephones
- Intercoms
- Air conditioning ducts

Air conditioning ducts should be supplied to the bottom of all electrical racks and computers.

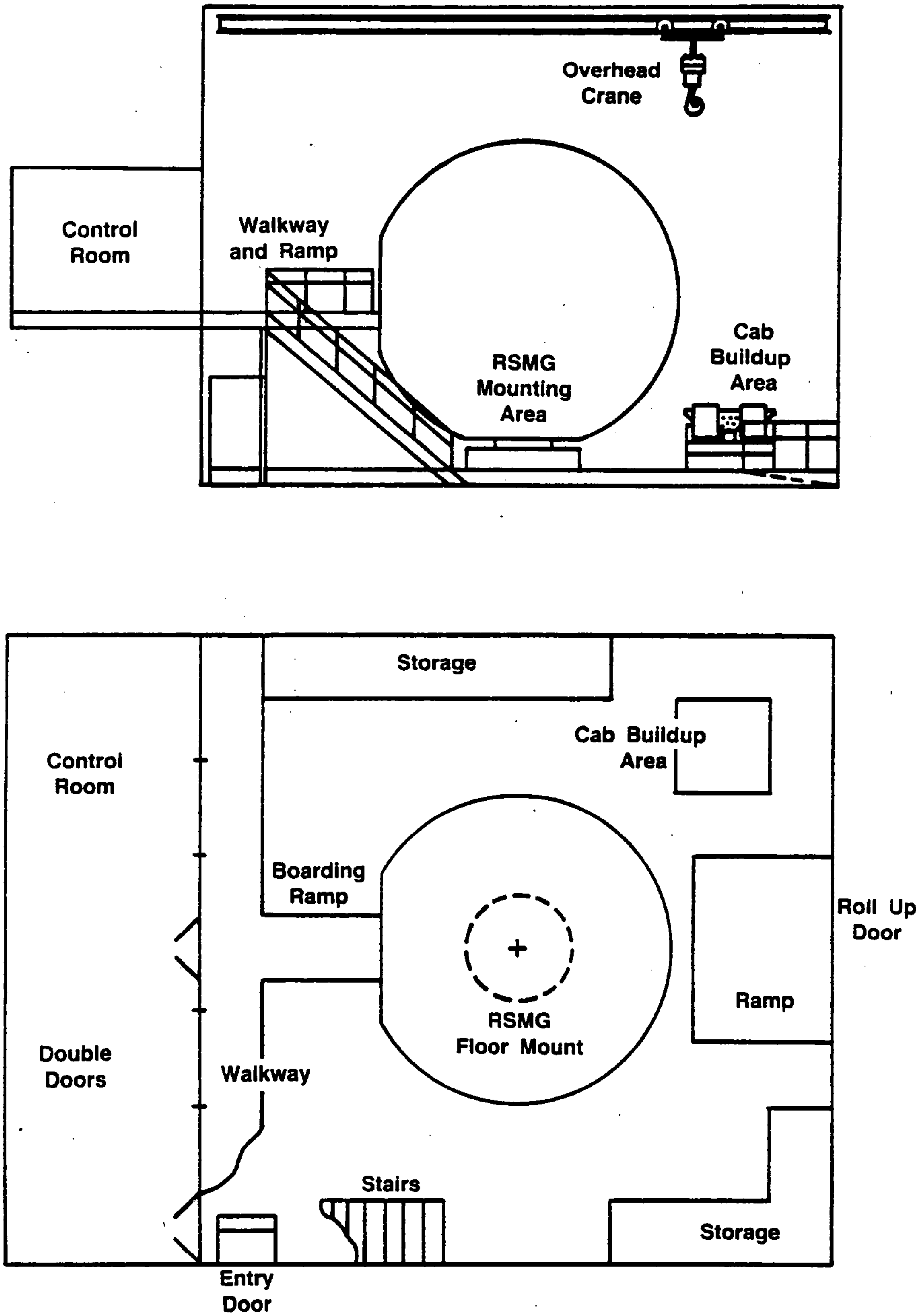


Figure D-1: Development Station Layout

APPENDIX E

CANDIDATE SYSTEM SCORING RESULTS

This Page Intentionally Left Blank

APPENDIX E

CANDIDATE SYSTEM SCORING RESULTS

1.0 VISUAL SYSTEMS

The candidate configurations for evaluation of an advanced visual system were:

No. 1.1	Light Valve (G.E.) with Periscope and Dome
No. 1.2	Light Valve (Sodern) with Periscope and Dome
No. 2.1	Light Valve (G.E.) with Fiber Optics (Servoed) and Dome
No. 2.2	Light Valve (Sodern) with Fiber Optics (Servoed) and Dome
No. 3.1	Light Valve (G.E.) with Fiber Optics (Fixed) and Dome
No. 3.2	Light Valve (Sodern) with Fiber Optics (Fixed) and Dome
No. 4.1	Laser Projector (Redifon) with Dome
No. 4.2	Laser Projector (Singer-Link) with Dome
No. 5.1	Light Valve (G.E.) with Helmet-Mounted Display
No. 5.2	Light Valve (G.E.) with HMD and High Resolution Inset
No. 5.3	CRT Projector (Cyclops) with HMD and High Resolution Inset
No. 6	Interchangeable Type CAB with CRTs and HMD

These configurations have their scoring summarized in tabular form on the following pages. The technical parameters which were scored are shown below:

Resolution	–	128 points
Field of View	–	128 points
Luminance	–	60 points
Contrast	–	60 points
Color	–	24 points
		400 points total

The qualifying assumptions of the scoring methodology are shown in the following list:

- Dome screen gain = 1
- Periscopes and fiber optic lens over pilot's head centered on the dome
- Light valve luminance at operational minimum
- Screen brightness computed on flat screen area, B = F/A rather than spherical screen area, therefore brightness value is conservative
- All projectors/CRTs three-color
- HUD usage only possible with Sodern projectors in dome which provide adequate screen brightness
- HUD may be integrated into a Helmet-Mounted Display
- Exit pupil of a single display at center of sphere
- Multiple exit pupils of display focus and edge of field compensated for slewing movements
- Occlusion by cabin structure
- Entrance/egress into cab, seating and normal work volumes
- Periscopes configuration only slewed in pitch due to need to keep gimbal configuration small
- Pilot will wear the HMD when considering the combined ICAB/HMD type configuration (No. 6)
- Copilot will have degraded visuals in this proportion:

  20 percent nominal factor for copilot's resolution x 100 percent HMD

  80 percent laser

  60 percent fixed/dome

  40 percent slaved/dome

  20 percent ICAB type

- Copilot will have degraded visuals in the proportion of 20 percent nominal factor x .75 or 75 percent for all field of view considerations:

  a) loss of field and occulted field of copilot

  b) occulted field of pilot

The visual system scoring information is displayed in Tables E-1 through E-3. A plot of the field of view ranking and resolution ranking versus configuration score is shown in Figure E-1.

Table E1-1: Visual Display Summary

Configu-ration	Instantaneous Viewed Area In Feet Sq. †	Area Rank	Best Field Resolution In Arc Min.	Resolution Rank
1.1	193	8	7	4
1.2	266	7	8	6
2.1	372	2	7.5	5
2.2	280	6	6.5	3
3.1	466	1	6.5	3
3.2	351	4	5.5	1
4.1	305	5	6	2
4.2	359	3	9.4	7
5.1	193	8	7.5	5
5.2	372	2	7.5	5
5.3	193	8	7.5	5
6	100	9	5.5	1

† 10-Foot Radius Spherical Screen or Equivalent Field

Table E1-2: Visual Display Summary

Configuration	Score, Raw	Score, % of 400 Points	Score, Rank
1.1	182	45.5	12
1.2	229	57.3	6
2.1	206	51.5	10
2.2	213	53.3	8
3.1	238	59.5	4
3.2	208	52	9
4.1	234	58.5	5
4.2	214	53.5	7
5.1	268	67	3
5.2	306	76.5	1
5.3	274	68.5	2
6	189	47.3	11

Table E1-3: Visual Display Summary

Configuration	Normalized Score	Rank
1.1	238	12
1.2	299	6
2.1	269	10
2.2	278	8
3.1	311	4
3.2	272	9
4.1	306	5
4.2	280	7
5.1	350	3
5.2	400	1
5.3	358	2
6	247	11

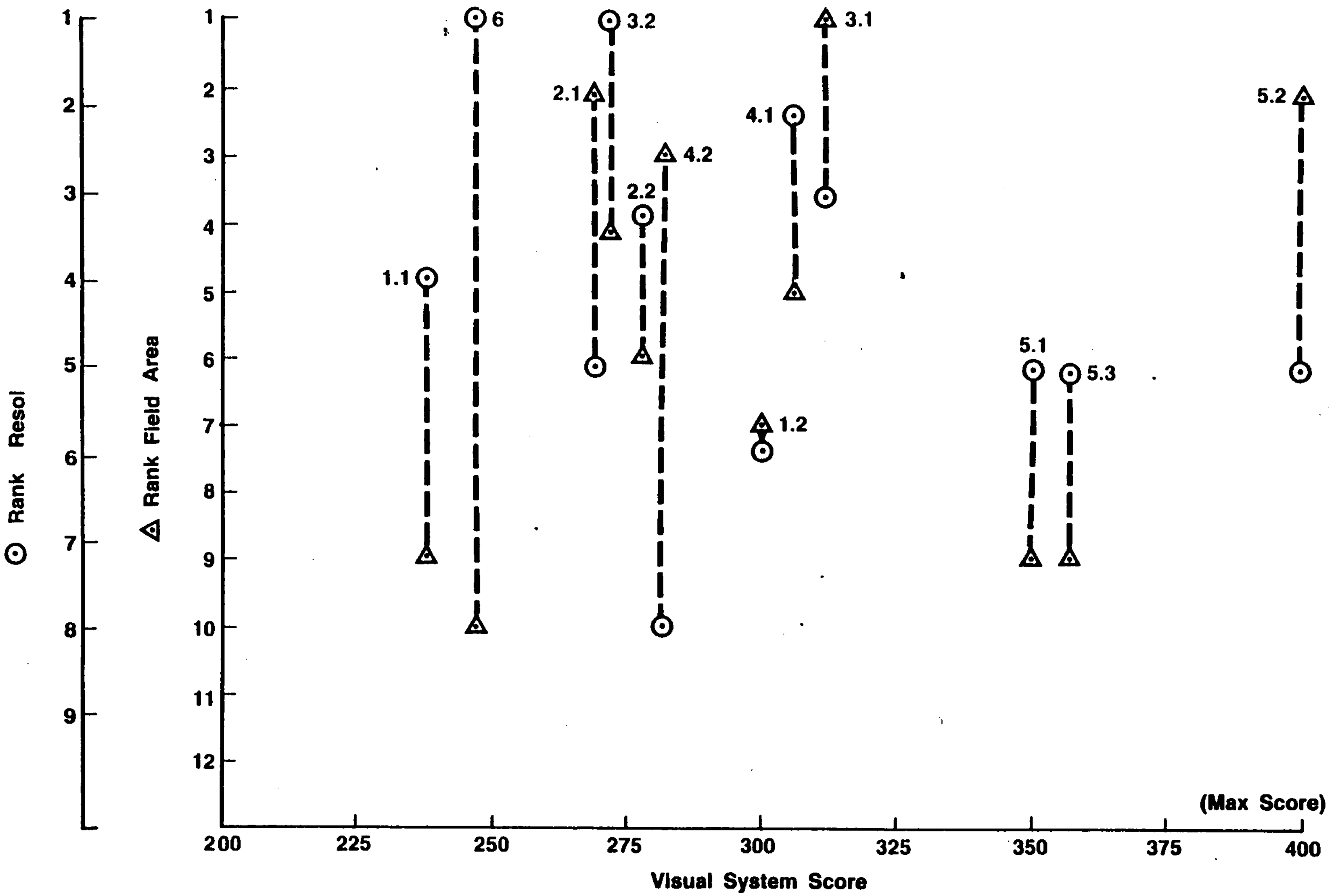


Figure E1-1: ACAVS Visual Score, Versus Resolution and Field of View Ranking

2.0 CGI SYSTEM

2.1 Evaluation

Six Computer Generation Image (CGI) manufacturers and five additional computer graphics research centers were evaluated as part of this study effort.

Each organization was ranked from one (low) to eleven (high) 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 such as Singer-Link does not score as highly as a research house, such as NYIT. 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 capability 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, we believe only five possess the overall experience, technical base, financial strength, and manufacturing capacity required to accomplish the ACAVS program. They are: (1) Redifon/Evans and Sutherland, (2) General Electric, (3) Singer-Link, (4) Marconi, and (5) ATS. McDonnell Douglas does not construct competitive raster scan visual systems, and Information International, while extremely promising, is not yet a real time visuals supplier on a production basis and is unlikely to be so before 1982. Table E2-1 presents the CGI scoring 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.
- Subject to condition (1), the CGI system should be modular and expandable.
- The procured system should be compatible with the existing Singer-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.

The technology assessment produced the following conclusions per company:

- Redifon/Evans and Sutherland (E & S)

  Boeing regards this teaming relationship between Redifon and E&S as an overall, outstanding capability. It is not likely that E&S will deviate significantly from its planned product line for the ACAVS program. A variant of the CT-5, a current E&S product for the U.S. Army, will probably be proposed. The CT-5 will be a fully capable, proven, production technology by 1982. Additionally, the CT-5 architecture, while not possessing extraordinary imaging capacity, is modular, expandable, and relatively inexpensive. E&S is one of the strongest research and development oriented CGI manufacturers, with a described reputation for high image quality. Their documentation is good to excellent in depth and easy to read. Reliability of E&S products is high. Disadvantages include the fact that E&S has never tackled any visual simulation problem remotely as complex as the ACAVS program (and therefore has no experience in this area) and, in Boeing's view, tends to emphasize image quality at the expense of image complexity.

Table E2-1: Computer Image Generation – Competitive Capability Assessment

Organization	Current Status	Technology Base		Economic Base			Total Overall	
		Theoretical	Actual	Business	R&D	Hardware	Theory	Actual
1. Redifon/Evans and Sutherland	10	(6) Strong (Rapidly Improving)	(10) Strong	9	10	10	35	39
2. General Electric	11	(3) Moderate	(11) Very Strong	11	9	9	32	40
3. Link	9	(4) Moderate	(7) Moderate	8	6	6	24	27
4. Marconi	8	(5) Strong	(9) Moderate	6	7	7	25	29
5. ATS	7	(7) Strong	(8) Moderate	7	8	8	30	31
6. McDonnell † Douglas	6	(1) Moderate	(6) Moderate	5	5	5	16	21
7. Magi ††	5	(2) Moderate	(1) Poor	4	1	4	11	10
8. NYIT ††	3	(10) Very Strong	(3) Moderate	2	3	2	17	10
9. Animation †† Systems	2	(11) Very Strong	(4) Moderate	3	4	3	21	14
10. Cal Tech/ JPL††	1	(9) Very Strong	(2) Fair	1	2	1	13	6
11. Information International ††	4	(8) Very Strong	(5) Moderate	10	11	11	40	37

† Non-raster-scan technology, inapplicable to the ACAVS Program
†† Non-real-time technology, inapplicable to the ACAVS Program

- **General Electric (G.E.)**

  G.E. is the unquestioned leader in proven production CGI system technology. G.E. draws on a wide range of experience in both the commercial and military markets; and while their approach is neither flexible nor expandable, they are the only competitor to have successfully constructed high complexity, wide field-of-view visual systems. G.E. is or has been involved in four programs with technology spinoffs applicable to ACAVS: Project 2360 (Tactical Combat Trainer), Project 2363 (Advanced Tactical Air Combat Simulation), the B-52 Weapon System Trainer, and the Compuscene Systems. It is likely that G.E. will propose a system combining some of the best features developed for each of the above mentioned programs, and can be expected to deliver on time and within budget. General Electric has not been known for its technological innovation, and, until very recently, appeared to finance only minimal, product related research and development. The loss of the B-52 WST to Singer-Link, as well as market pressure from the powerful Redifon/Evans and Sutherland team will probably force a management reappraisal in the basic research area. However, this research is not expected to benefit the ACAVS program in the 1982 time frame – G.E. provides documentation of generally good (but variable) quality, depending on the degree of product line evolution. G.E. has been severely criticized in the past for lack of responsiveness to customer requirements once a system is in the field.

- **Link**

  Until recently, Singer-Link has been considered a carbon copy of General Electric, in terms of its basic approach, and behind in its overall ability to deliver solid production equipment. Through an intensive, multiyear research and development program, Singer-Link is now, in Boeing's view, roughly equivalent to General Electric and a serious competitor. Singer-Link has spent a great deal of time and money analyzing Defense Mapping Agency (DMA) data structures and should possess an excellent data base construction capability. After winning the B-52 WST, we expect Singer-Link production technology to solidify. A modification to its B-52 WST/Project 2360 CGI technology may be expected in the 1982 time frame. Singer-Link is an excellent all-around simulation manufacturer with extensive in-house experience. Singer-Link's field support teams are considered excellent, although Singer-Link documentation is not widely held in high regard. Singer-Link is by far the most compatible of all potential visual system contractors with current NASA-Ames equipment.

- **Marconi**

  Marconi Radar Systems Ltd., of Leicester, England, offers an alternative CGI system for consideration. Very little published data exists regarding the Marconi system, and we were unable to observe any operational Marconi visual systems, although we did visit their research and development facilities in Leicester. The Marconi system is apparently a first-stage, pipelined polygon processor using a list priority algorithm, making it similar in many respects to the G.E. architecture. Marconi provided, however, superior texture generation capability, a capacity required for the ACAVS program. The Marconi system represented the most promising approach we were able to observe while conducting our competitive technology assessment. We were especially impressed with Marconi's research and development program relative to Singer-Link and G.E. Marconi documentation is well organized. Flexibility and expandability could not be assessed.

- **Advanced Technology Systems (ATS)**

  ATS, a division of the Austin Company, is by far the most underated potential competition for the ACAVS program. It is our view that the current low opinion of ATS in the commercial and military marketplace is technically unfounded and due principally to over-zealous marketing. A newcomer to CGI, ATS has not yet perfected its Computrol system. A review of their patent applications and available technical reports convinces us that the ATS approach should work, and work well. In our opinion, Computrol will be operationally sound by 1982. Formal ATS documentation was not available for review.

A distinct advantage possessed by both ATS and Marconi is the lack of an existing product line, which increases the likelihood that they can "customize" their systems to NASA's requirements.

2.2 Summary

Assessing the direction of CGI was much more difficult than assessing individual companies capabilities. There is considerable controversy within the computer graphics community concerning the development of real-time architectures, and particularly the impact of VLSI design methods. Current structures are dominated by the polygon processing/list priority methods and are likely to remain so for the foreseeable future (fives years or more). It is Boeing's view that in the mid- to late-1980s simulation visual systems will return to pixel-based rather than polygon-based systems; however, none of the projected changes can have much impact on the ACAVS program. It is our current opinion that the most modular, expandable and flexible approach belongs to Evans and Sutherland.

2.3 CGI Scoring Equations Definition

Summary:

The CGI score (S_{CGI}) is the product of four scoring factors: Score Content Factors (S_C), Score Bandwidth Factors (S_B), Computational Complexity Factors (S_D), and Special Technical Factors (S_T). That is,

$$S_{CGI} \cdot S_C \cdot S_B \cdot S_D \cdot S_T$$

- Scene Content Factors (S_C)

  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:

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

  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. If the number of "potentially visible" faces or surfaces is not known, but only that for the total, then use 2/3 of the above, as approximately 1/3 of the faces (surfaces) will be removed by a hidden face test (sometimes called a back face cull).

- Scene Bandwidth Factors (S_B)

  Scene bandwidth factors include Field of View (FOV), Image Resolution (IR), Color (C), Frame Rate (f), and Transport Delay (T). The score is:

$$S_B = (6\ FOV) \left\{ 1/2 \left[\left(\frac{3}{IR} \right)^2 + \left(\frac{3}{IR} \right) \right] \right\} \left(\frac{C+72}{80} \right) \left(\frac{f}{30} \right) \left\{ 1 + .6309 \left[\cos (8\pi T - 2\ TAN^{-1}\ 4\pi T) - \frac{\sqrt{2}}{2} \right] \right\}$$

  as long as all variables meet the minimal requirements. Otherwise, the score is zero.

- Computational Complexity Factor (S_D)

  The computational complexity factors are Level of Detail (LOD), Image Breakup (IB), Dynamic Light/Shadow (L/S), and Curved Surface Shading (CSS). These factors combine as follows:

  $$S_D = (1/(1 + \sqrt{1/LOD})) [IB] [L/S] [CSS]$$

  (See Paragraph 7.3.1 of the report for description and graphs).

- Special Technical Factor (S_T)

  This factor represents the subjective evaluation of the proposed data base development system and the special visual data base.

APPENDIX F

COST AND AVAILABILITY

This Page Intentionally Left Blank

APPENDIX F

COST AND AVAILABILITY

This appendix is an estimate of the costs and availability of each of the candidate systems. Costing values shown in Figure F1-1 are representative of the equipment values and facility construction values for the simulator cab and development station. Visual generation/display hardware costs shown are representative of the various visual system hardware costs for each major component that is utilized in the candidate concepts described in the main report, Section 6.0. These values are used in the generation of the cost breakdown summary by concept system as shown in Figure F1-2. Again the values shown are representative of total concept system costs minus the total system integration cost which includes manpower and system integration equipments for special interface system checkout. These integration and checkout costs are expected to be at least 1.5 times the system hardware costs. Should the image generation system be a laser camera/model board technique those CGI costs will need to be replaced by the laser camera model board costs plus the cost of a NASA Ames facility to house this equipment.

Simulator Cab	Cost in Dollars
Cab Structure & Misc Hardware	75K
Sound System	50K
Force-Feel System	200K
Vibration System	75K
Instruments and Panels	100K
HUD	60K
	500K

Development Station	
Overhead Crane	10K
Control Room Construction (500 sq ft @ $35/sq ft)	18K
Walkway and Stairs (Steel)	7K
Ramp & Hydraulic Cylinders	5K
Computer Floor	20K
Electronic Hardware	440K
	500K

Visual System Hardware	
Projector - GE	100K
Sodern	500K
Cyclops w/lens	37K
Laser	3000K
Helmet-Mounted Display	300K
Head Tracker	175K
*CGI/Channel	1000K
*Laser Camera	3000K
*Model Board (Detailed 200:1 Scale)	200K

*Image Generation Equipment

Figure F1-1: Cost Breakdown by Major Components

Concept	1.1	1.2	2.1	2.2	3.1	3.2	4.0	5.1	5.2	5.3	6.0 *
Control & Dev	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50	.50
Cab	.50	.50	.50	.50	.50	.50	.50	.55	.55	.55	.55
HUD	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06	.06
Dome/Enclosure	.05	.05	.05	.05	.05	.05	.05	—	—	—	—
Projection Sys	.30	1.50	.30	1.50	.40	2.00	3.00	.60	.60	.048	.6**
Servo Sys	.20	.20	.10	.10	—	—	.025	—	—	—	—
Head Track	.15	.15	.15	.15	—	—	.15	.10	.10	.10	.10
Sling CRT	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05
Periscope/ Helmet	.06	.06	—	—	—	—	—	.60	.60	.60	.30
Fiber Optics/ Lens	—	—	.06	.06	.05	.05	—	—	—	.062	—
Visual Sys CGI	3.00	3.00	3.00	3.00	4.00	4.00	6.00	6.00	6.00	6.00	4.00
HUD CGI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total ▲	5.87	7.07	5.77	6.97	6.61	8.21	11.34	9.46	9.46	8.97	7.16

▲ Cost In Millions
***6.0 This Configuration is a HMD for the Pilot with a CRT Window for a Second Crew Member**
*** * Includes CRT for Second Pilot**

Figure F1-2: Cost Breakdown Summary by Concept System

Table F1-1 shows the availability of the different concept systems. Assuming that the RFP is delivered in early 1981, it is anticipated that it will require at least three and one-half years lead time before the system equipment could be installed at the NASA Ames facility. Two factors influencing this long lead time are the CGI system and the TITUS light valve projector (if this projector is used). These factors, since they are the driving functions in system availability, are the reason there is not a wider spread in system availability. Detailed scheduling is not possible at this period of time because of the many variations in concepts reported on and because the final vendor concept may be some mixture of existing projector and CGI technology with potential for growth to ultimately meet ACAVS visual goals.

Table F1-1: Projected Availability of Proposed Systems

Concept	Config-uration	1981	1982	1983	1984	1985	
TV Projector/Periscope with Dome (Servoed)	1.1 1.2					▲ ▲	
TV Projector/Fiber Optics with Dome (Servoed)	2.1 2.2					▲ ▲	
TV Projector/Fiber Optics with Dome (Fixed)	3.1 3.2					▲ ▲	
Laser Projector	4.0						▲
Helmet-Mounted	5.1 5.2 5.3					▲ ▲ ▲	
Estimated NASA Procurment Milestones		▲ RFP	▲ Contract Award				

APPENDIX G

BIBLIOGRAPHY

This Page Intentionally Left Blank

APPENDIX G

BIBLIOGRAPHY

Appel, A. The notion of quantitative invisibility and the machine rendering of solids. *Proceedings of the 22nd Association of Computing Machines National Conference,* 1967, 387-93.

Appel, A. Modeling in 3-D. *IBM Systems Journal,* 1968, *7,* #3 and 4, 310-21.

Appel, A., and Stein, A. Program for the interactive design of polyhedra. *IBM Technical Disclosure Bulletin,* 1971, *14,* 2037-45.

Archuleta, M. *Hidden surface processing.* Livermore, California: California University, March 1973.

Armit, A. A multipatch design system for coons' patches. IEEE International Conference on Computer Aided Design, Southhampton, New Jersey, Conference Publication 51, April 1969.

ASD. Air Force aircrew training devices master plan. Wright-Patterson AFB,Ohio: Aeronautical Systems Division, Deputy for Development Planning, Technical Report, ASD-7R-78-16, March 1978.

Atherton, Peter, Greenburg, Donald, and Weiler, Kevin. Polygon shadow generation. SIGGRAPH-ACM Publication, *Computer Graphics,* August 1978, *12,* #3.

Badler, N., and Bajcsy, R. 3-D representations for computer graphics and computer vision. SIGGRAPH-ACM Publication, *Computer Graphics,* August 1978, *12,* #3, 153-60.

Barnhill, R. E., Brown, J. H., and Klucewicz, I. M. A new twist in computer aided geometric design. *Proceedings of Computer Graphics Image Processing,* August 1978, *8,* #1, 78-91.

Baron, P. C., Charles, E. R., Sprothery, D. E., and Jorgensen, D. B. High resolution, high brightness color television projector, analysis, investigations, design, performance of baseline projector. Final Report. Wright-Patterson AFB, Ohio: Air Force Human Resources Laboratory, Technical Report, AFHRL-TR-77-33(1), September 1977.

Batson, R. M., Edwards, E., and Eliason, E. M. Computer generated shaded relief images. *Journal of Research, U.S. Geographic Survey,* July-August 1975, *3,* #4, 401-8.

Bibermann, L. M. (ed.) *Perception of displayed information.* New York: Plenum Press, 1973.

Blinn, J. F. A scan line algorithm for displaying parametrically defined surfaces. *Proceedings of the Fifth Conference of Computer Graphics and Interactive Techniques,* 1978.

Blinn, J. F. Simulation of wrinkled surfaces. SIGGRAPH-ACM Publication, *Computer Graphics,* August 1978, *12,* #3, 286-92.

Blinn, J. F., and Newell, M. E. Texture and reflection in computer generated images. *Communications of ACM,* October 1976, *19,* #10, 542-47.

Bouknight, W. J., and Kelley, K. C. An algorithm for producing half-tone computer graphics presentations with shadows and movable light sources. *Proceedings of the AFIPS-SJCC,* 1970, *36,* 1-10.

Brown, J. L. Visual elements in flight simulation. Alexandria, Virginia: Defense Documentation Center, Defense Logistics Agency, Report No. AD-A037 388, July 1975.

Bunker, W. M. Visual scene simulation with computer generated images. *Progress in simulation.* New York: Gordon and Breach, 1972, *2,* 91-114.

Carlbom, I., and Paciorek, J. Geometric projection and viewing transformations. *Computer Surveys,* 1978, *10,* 4.

Cariucci, L. A formal system for texture languages. *Pattern Recognition,* 1972, *4,* 53-72.

Carpenter, C. Computer rendering of fractal curves and surfaces. Seattle, Washington: Special Interest Group for Graphics, SIGGRAPH'80, 1980.

Carton, E. J., Rosenfield, A., and Westka, J. S. Some basic texture analysis technology. Publication of Maryland University, TR-288, June 1974.

Casasent, D. Special light modulators and their use in optical data processing. Pittsburgh, Pennsylvania: Carnegie-Mellon University, September 1977.

Catmul, E. Computer display of curved surfaces. *IEEE Transactions on Computers,* 1975, 11-17.

Clark, B. A. J. Optical aids for pilot-controlled hovering of light helicopters (u). Australian Dod, April 1977.

Clark, J. H. Designing surfaces in 3-D. *Communications of ACM,* August 1976, *19,* #8, 454-60.

Clark, J. H. Hierarchical geometric models for visible surface algorithms. *Communications of ACM,* October 1976, *19,* E10.

Conners, R. W., and Harlow, C. A. A theoretical comparison of texture algorithms. *IEEE Transactions on Pattern Analysis and Machine Intelligence,* May 1980, *PAMI-2,* 3, 204-22.

Cooper, F. R., Harris, W. T., Sharkey, V. J. The effect of delay in the presentation of visual information on pilot performance. Final Report. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-IH-250, December 1975.

Corrick, G. E., and Scanlan, L. A. Human performance evaluation of matrix displays. Aerospace Medical Research Lab, Technical Report, AMRL-TR-78-110, December 1978.

Crow, F. C. Shadow algorighms for computer graphics. SIGGRAPH-ACM Publication, *Computer Graphics,* 1977, *11,* #2.

Crow,F. C., and Phong, B. T. Improved rendition of polygonal models of curved surfaces. *Proceedings of the Second USA-Japan Computer Conference,* August 1975, 475.

Cyrus, M. L. Method of compensating transport lags in computer image generation visual displays for flight simulation. Final Report. Brooks AFB, Texas: Air Force Human Resources Laboratory, Technical Report, AFHRL-TR-77-6, March 1977.

Deutsch, E. S., and Belknap, N. J. Texture descriptions using neighborhood information. Publication of Maryland University, Technical Report, TR-184, April 1972.

Forbus, K. D. Light source effect. *Proceedings of the Society of Photo-Optical Instrumentation Engineers,* 1978, *155,* 50-53.

Forrest, A. R. Coons surfaces and multivariable interpolation. Cambridge, Massachusetts: Cambridge University, CAD Group Document, December 1971.

Forrest, A. R. Mathematical principals for curve and surface representation. In I. J. Brown (ed.), *Curved surfaces in engineering.* Guildford, Surrey, England: FPC Science and Technology Press Ltd., 1972, 5.

Fu, K. S., and Lu, S. Y. Computer generation of texture using a syntactic approach. *Proceedings of SIGGRAPH-ACM, Computer Graphics,* 1978, *12,* #3, 147-49.

Galloway, M. M. Texture analysis using gray level run lengths. Publication of Maryland University, Technical Report, TR-314, July 1974.

Gouraud, H. Computer display of curved surfaces. Publication of the University of Utah, Technical Report, UTEC-Csc-71-113, June 1971.

Gouraud, H. Continuous shading of curved surfaces. *IEEE Transactions,* June 1971, *C-20,* 623-29.

Griffiths, G. A surface display algorithm. *Computer Aided Design,* January 1978, *10,* #1, 65-73.

Hanson, T. G. Research on visual display integration for advanced fighter aircraft. Dayton, Ohio: Air Force Aerospace Medical Research Laboratory, Technical Report, AMRL-TR-78-118, January 1979.

Haralick, R. M., Shanmugam, K., and Dinstein, E. Textural features for image classification. *IEEE Transactions on Systems, Man and Cybernetics,* November 1973, *SMC-3,* 6, 610-21.

Hayes, K. C., Rosenfield, A., and Shah, A. N. Visual texture analysis 4. Publication of Maryland University, Technical Report, TR-230, February 1973.

Heintzman, R. J., and Shumway, D. A. A systematic approach to visual system requirements and development. *Proceedings of the AIAA Visual and Motion Simulation Conference,* Dayton, Ohio, April 1976.

Honeywell, Avionics Division. An introduction to Honeywell helmet mounted displays. Minneapolis, Minnesota: Honeywell Inc., April 1977.

Hooks, J. T., Butler, E. A., Cullen, R. K., and Peterson, R. J. Design study for an auto-adaptive landing signal officer (LSO) training system. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-77-C-0109-1, December 1978.

Horn, B. K. P. Shape from shading. Cambridge, Massachusetts: MIT, Project MAL Report, TR-791, November 1970.

Horn, B. K. P. Obtaining shape from shading information. In Winston, P. H. (ed.), *The psychology of computer vision.* New York: McGraw-Hill, 1975, 115-55.

Jolesz, B. Visual pattern discrimination. *Proceedings of IRE Transactions on Information Theory,* February 1962, *IT-8,* #1, 84-92.

Jolesz, B. Inability of humans to discriminate between visual textures that agree in second order statictics—revisited. *Perception,* 1973, *2,* 391-405.

Jolesz, B. Experiments in the visual perception of texture. *Scientific American,* April 1975, *232,* #4, 2-11.

Klucewicz, I. M. A piecewise C^1 interpolant to arbitrarily spaced data. *Proceedings of the CGIP,* August 1978, *8,* 1, 91-112.

Knuth, D. E. *Sorting and searching.* Massachusetts: Addison-Wesley, 1973.

Lane, Jeff, and Carpenter, Loren. A scan line algorithm for the computer display of parametrically defined surfaces. Seattle, Washington: Boeing Commercial Airplane Co., Advanced Systems R&D Document, A SRD-2, June 1978.

Lyons, R. Aviation wide-angle visual system (AWAVS), trainer design report, subsystem design report. Final Report. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-75-C-0009, May 1977.

McLain, D. H. Computer construction of surfaces through arbitrary points. *Proceedings of the IFIP,* North Holland, Amsterdam, 1974, 717.

McRuer, D. T. Mathematical models of human pilot behavior. January 1974.

Mahl, R. Visible surface algorithms for quadratic patches. *Proceedings of IEEE Transactions on Computers,* January 1972, *C-20,* 1-4.

Martin, W. L., and Task, H. L. Matrix element display devices and their application to airborne weapons systems. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, Visual Display System Branch, Human Engineering Division.

Mills, G. S. Research on visual display integration for advanced fighter aircraft. Wright-Patterson AFB, Ohio: Research Laboratory, Technical Report, AMRL-TR-78-97, November 1978.

Morrill, C. D. Parallel processing applied to computer image generation. Akron, Ohio: Publication of the Goodyear Aerospace Corporation.

Myers, A. J. An efficient visible surface algorithm. PhD dissertation. Columbus, Ohio: Ohio State University, Computer and Information Science Department, 1977.

NADC. Investigation of motion base drive techniques. Alexandria, Virginia: Defense Documentation Center, Defense Logistics Agency, Technical Report, AD-A053830, March 1978.

Newman, W. M., and Sproull, R. F. *Principles of interactive computer graphics* (2nd ed.). New York: McGraw-Hill, 1979.

NTEC. *Proceedings of the 11th NTEC-Industry Conference.* Orlando, Florida: Naval Training Equipment Center, November 1978.

Parent, R. E. A system for generating three-dimensional data for computer graphics. PhD dissertation. Columbus, Ohio: Ohio State University, Computer and Information Science Department, December 1977.

Phong, B. T. Illumination for computer generated images. *Communications of ACM,* June 1975, 18, 311-15.

Pratt, K. K. *Digital image processing.* New York: John Wiley and Sons, January 1978.

Prenter, P. M. *Splines and variational methods.* New York: John Wiley and Sons, 1975.

Purks, S. R., and Richards, W. Visual texture discrimination using random-dot patterns. *Journal of the Optical Society of America,* June 1971, *17,* #6, 765-71.

Redifon Simulation, Ltd. American Airlines development program and results for the scanned laser visual system research and breadboard development. Volume I, Final Report. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-77-C-0001, September 1979.

Redifon Simulation, Ltd. American Airlines scanned laser. Final Report. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-77-C-0001, December 1979.

Reeves, W. H., and Stinson, J. L. Software design for a visually-coupled airborne systems simulator (VCASS). Master's thesis. Wright-Patterson AFB, Ohio: Air Force Institute of Technology, School of Engineering, Technical Report, AFIT/GCS/EE/-78-6, March 1978.

Rhinehart, R. M. Wide-angle, multiviewer infinity display design. Final Report. Wright-Patterson AFB, Ohio: Air Force Human Resources Laboratory, Technical Report, AFHRL-ER-77-71, December 1977.

Richard, G. L., and Puig, J. A. Delay of visual feedback in aircraft simulators. Final Technical Note. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-IN-56, March 1977.

Richard, G. L., Cyprus, M. L., Cox, D. C., Templeton, T. K., and Thompson, L. C. Compensation for transport delays produced by computer image generation systems. Final Report. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-IH-297, June 1978.

Rochester University. Visual elements in flight simulation. Alexandria, Virginia: Defense Documentation Center, Defense Logistics Agency, Technical Report, AD-772 586, December 1973.

Rodemann, A. H., Breglia, D. R., and Mohon, W. N. Holographic heads-up display for naval aviation training. Final Report. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-3713-03, May 1975.

Rogers, D. F., and Adams, J. A. *Mathematical elements for computer graphics*. New York: McGraw-Hill, 1976.

Schacter, B., and Narendra, A. Random pattern generation process. *Proceedings of the CGIP*, 1979, *8*, 95-114.

Schindler, R. A. Optical power spectrum analysis of display imagery. Final Report. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, Technical Report, AMRL-TR-76-96, November 1976.

Schindler, R. A., and Martin, W. L. Optical power spectrum analysis of display imagery. Final Report. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, Technical Report, AMRL-78-50, June 1978.

Semple, C. A., Vruels, D., Cotton, J. C., Durfee, D. R., and Hooks, J. T. Functional design of an automated instructional support system for operational flight trainers. Final Report. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-76-C-0096-1.

Singer Company, Link Division. Project 1183, Engineering Technical Report. Alexandria, Virginia: Defence Documentation Center, Defense Logistics Agency, Technical Report, AD-A058 055, June 1978.

Singer Company, Simulation Products Division. Aviation wide-angle visual system (AWACS) design, analysis report. Final Report. Orlando, Florida: Naval Training Equipment Center, Technical Report, NAVTRAEQUIPCEN-75-C-009-1, April 1975.

Staudhammer, J. Computer generation of real-time colored three-dimensional objects. *Proceedings of the Seventh Hawaii Conference of Information Science*, January 1974.

Staudhammer, J. Software for real-time image generation. *Proceedings of the Computer Software Applications Conference*, November 1977, 372-76.

Sutherland, I. E. Computer graphics: Ten unsolved problems. *Datamation*, May 1966, *12*, #5, 22-27.

Sutherland, I. E. Sproull, R. F., and Schumacker, R. A. Sorting and the hidden surface problem. *Proceedings of the AFIPS 1973 Computing Conference*, 685-93.

Sutherland, I. E., Sproull, R. F., and Schumacker, R. A. A characterization of ten hidden surface algorithms. *Proceedings of the ACM on the Computing Surveys*, March 1974, *6*, #1, 1-55.

Swallow, R. J. CHARGE – Interactive graphics system terminal: Theory of operation. Alexandria, Virginia: Human Resources Research Organization, Technical Report, HUMRRO-TR-74-26.

Szabo, N. Real-time digital image generation. *Proceedings of SIGGRAPH-ACM on Computer Graphics*, July 1977, *11*, #2, 35.

Tactical Air Command. Simulator comparative evaluation. Final Report. Eglin AFB, Florida: November 1977.

Tanimoto, S. L. A graphic-theoretic real-time visible surface editing technique. *Proceedings of SIGGRAPH-ACM on Computer Graphics*, Summer 1977, *11*, #2, 223-26.

Thomas, G. T., and Jones, L. Design of an off-axis wide field-of-view visual display system for flight simulators. Final Report. Warminster, Pennsylvania: Naval Air Development Center, Systems Directorate, Technical Report, NADC-79023-20, January 1979.

Warnock, J. E. A hidden surface algorithm for computer generated half-tone pictures. Rome, New York: Rome Air Developmental Center, Technical Report, RADC-TR-69-249.

Watkins, G. S. A hardware compatible algorithm for generating visible surfaces from 3-D data. *Proceedings of the Eighth Annual UAIDE Meeting*, 1969, 389-401.

Watkins, G. S. A real-time visible surface algorithm. Salt Lake City, Utah: University of Utah, Technical Report, UTEC-Csc-70-101, June 1970.

Wechsler, H., and Masatsuga, K. A new edge detection technique and its implementation. *Transactions of the IEEE on SMC*, December 1977, *SMC-7*, #12, 827-36.

Weiler, Kevin, and Atherton, Peter. Hidden surface removal using polygon area sorting. *Proceedings of the Fourth Annual Conference on Computer Graphics, Interactive Techniques and Image Processing*, 1977.

Weszka, J. S., Dyer, C. R., and Rosenfield, A. A comparative study of texture measures for terrain classifications. *Proceedings of the IEEE on SMC*, April 1976, *SMC-6*, #4.

Whitman, R. Experiments in texture perception. Final Report. Cambridge, Massachusetts: MIT, Contract F44620-74-C-0076, January 1978.

Williams, D. A. Video generation and control system. Final Report. Wright-Patterson AFB, Ohio: Air Force Avionics Laboratory, Technical Report, AFAL-TR-76-164, August 1976.

Williams, L. Casting curved shadows on curved surfaces. *Proceedings of the SIGGRAPH-ACM, Computer Graphics*, August 1978, *12*, #3, 271-74.

Yeend, R., and Carico, D. A program for determining flight simulator field-of-view requirements. Patuxent River, Maryland: Naval Air Test Center, Technical Memo, NATC-TM-78-1-RW, September 1978.

Zucker, S. W. On the foundations of texture: A transformational approach. Baltimore, Maryland: Maryland University, Technical Report, TR-331, September 1974.

Zucker, S. W. Toward a model of texture. *Proceedings of the CGIP,* 1976, *5,* 190-202.

APPENDIX H

VISUAL SYSTEM RESOLUTION DEFINITION

This Page Intentionally Left Blank

APPENDIX H
VISUAL SYSTEM RESOLUTION DEFINITION

The definition of photo-optical resolution in scanning electronic systems was obtained from Reference I-1. This source defined the resolution in a spatial frequency pattern by the equation:

$$R \doteq \frac{n_b + n_w}{2d} \qquad (1)$$

R = resolution in "lines" or line pairs

n_b = number of black bars in the distance d

n_w = number of white bars in the distance d

d = the reference, normalizing, or unit dimension taken between convenient points

Since the minimum resolution is $n_b = 1$ and $n_w \doteq 1$, and the continued increase in these white and black bars in a space d would be paired, the resolution of raster scanned images is given by

$$R_s = \frac{n_b + n_w}{d} \qquad (2)$$

The quotation marks around lines implies that "lines" is equivalent to line pairs in some technical areas. A quote from Reference H-2 is appropriate here.

> Note that in optical work the convention is to consider a "line" to consist of one light bar and one dark bar, that is, one cycle. In television parlance, both light and dark lines are counted. Thus, ten "optical" lines indicate ten light and ten dark lines, whereas ten "television" lines indicate five light and five dark lines. To avoid confusion "optical" lines are frequently referred to as line pairs, e.g., ten line pairs per milimeter.

A numerical example for a raster scanned CRT (Equation 2) would be:

$$R_s = \frac{(200 + 200)}{127 \text{ mm, height of display}} \qquad R_s = \frac{(200 + 200)}{5 \text{ in., height of display}}$$

$$= 3.15 \text{ lines/mm} \qquad = 80 \text{ lines/in.}$$

An example of an enlarging lens .200 × .254m format (8" × 10") (Equation 1) would be:

$$R = \frac{(2100 + 2100)}{2 \times (337) \text{ mm image diameter @ f/16 and infinity}}$$

$$= 6.25 \text{ line pairs/mm}$$

A concise definition of the picture resolution element is found in Reference H-3, Section 8-22. It is stated in this reference that no television signal can contain as many resolution elements as it does picture elements. This reference defines the Kell factor, which relates picture resolution elements to television resolution elements.

It is also a common practice to define optical resolution relative to the extent of the optical field of view, and in such cases the units are normally expressed in line pairs/milliradian.

VOLUME II REFERENCES

H-1 RCA Corporation. *Electro-optics handbook*. Technical Series EOH-11. Harrison, New Jersey: RCA Corporation, 1974.

H-2 Smith, W. J. *Modern optical engineering*. New York: McGraw-Hill, 1966.

H-3 Fink, D. G. *Television engineering handbook*. New York: McGraw-Hill, 1957.

APPENDIX I

SUPPORTING COMPUTATIONS AND COMPUTER PROGRAMS

This Page Intentionally Left Blank

APPENDIX I

SUPPORTING COMPUTATIONS AND COMPUTER PROGRAMS

1.0 VIEWPOINT DISTORTION WITHIN A SPHERE

Distortion is a general term referring to the situation in which an image is not an accurate, scaled reproduction of an object. There are many types of distortion; tangential distortion and perspective distortion occur predominately in spherical screen viewing.

A viewpoint error calculation for the projected scene distortion on a spherical screen was made. Briefly, the description of the computation is as follows:

1. A sphere radius R is defined (inches).

2. A projector pupil point P1 is defined (x, y, z inches).

3. An eyepoint P2 is defined (x, y, z inches).

4. An elevation angle ϕ is defined (constant or variable) from the origin.

5. An azimuth angle ψ is defined (constant or variable) from a dropped (or elevated) perpendicular from the eyepoint to the horizontal plane defined by the elevation angle (see Figure I-1).

6. The distances between the eyepoint and the sphere point (P3) and the projector and the sphere point are computed.

7. With direction cosines, the angle between these two distances is calculated; this is the error angle, θ.

8. Also the elevation angle ϕ, from the eye point to the sphere point, is calculated.

10. The error angle is plotted versus the azimuth angle with the elevation angle normally being held constant.

Case I

R = 3.05m (120 inches)

P1 – x = 0, y = 2.54 mm (0.1 inch), z = 0

P2 – x = 0, y = 0, z = –.13m (–5 inches)

ϕ = –.52 rad (–30°)

θ ≐ .04 rad (2.1°) constant

ϕ' = –.49 rad (–27.9°)

Case II

$R = 3.05m$ (120 inches)

P1 – $x = -.25m$ (–10 inches), $Y = 0$, $z = .30m$ (12 inches)

P2 – $x = 0$, $y = 0$, $z = -.13m$ (–5 inches)

$\phi = -.52$ rad (–30°)

θ = [see Figure I-2]

$\phi' = -.49$ rad (–27.9°)

θ, the error angle, varies from approximately .08 rad (4.5 degrees) directly in front of the viewer to .17 rad (9.5 degrees) for a larger area behind the viewer.

Case III

$R = 3.05m$ (120 inches)

P1 – $x = -.25m$ (–10 inches), $y = 0$, $z = .30m$ (12 inches)

P2 – $x = 0$, $y = 0$, $z = -.13m$ (–5 inches)

$\phi = .52$ rad (30°)

θ = [see Figure I-3]

$\theta' = .56$ rad (32°)

θ, the error angle, varies from approximately .16 rad (9.25) degrees over an angular volume of ±1.40 rad (±80) degrees in front of the viewer to a minimum of .09 rad (5 degrees) directly behind the viewer.

Case IV

$R = 3.05m$ (120 inches)

P1 – $x = -.25m$ (–10 inches), $y = 0$, $z = .30m$ (12 inches)

P2 – $x = 0$, $y = 0$, $z = -.13m$ (–5 inches)

$\phi = 1.05$ rad (60°)

θ = [see Figure I-4]

$\phi' = 1.06$ rad (61°)

θ, the error angle, varies from approximately .14 rad (8.3 degrees) over a volume of ±.61 rad (±35 degrees) in front of the viewer to a sharp minimum of 4.36 mrad (1/4 degree) directly behind the viewer.

The listing of the computer program for viewpoint distortion is given in Table I-1.

P1 – Projection Point
P2 – Eye Point
P3 – Look Point (Variable)

$\angle F = \angle \phi$ Phi
$\angle S = \angle \psi$ Psi
$\angle T = \angle \theta$ Theta
$\angle V = \angle \phi'$ Phi Prime

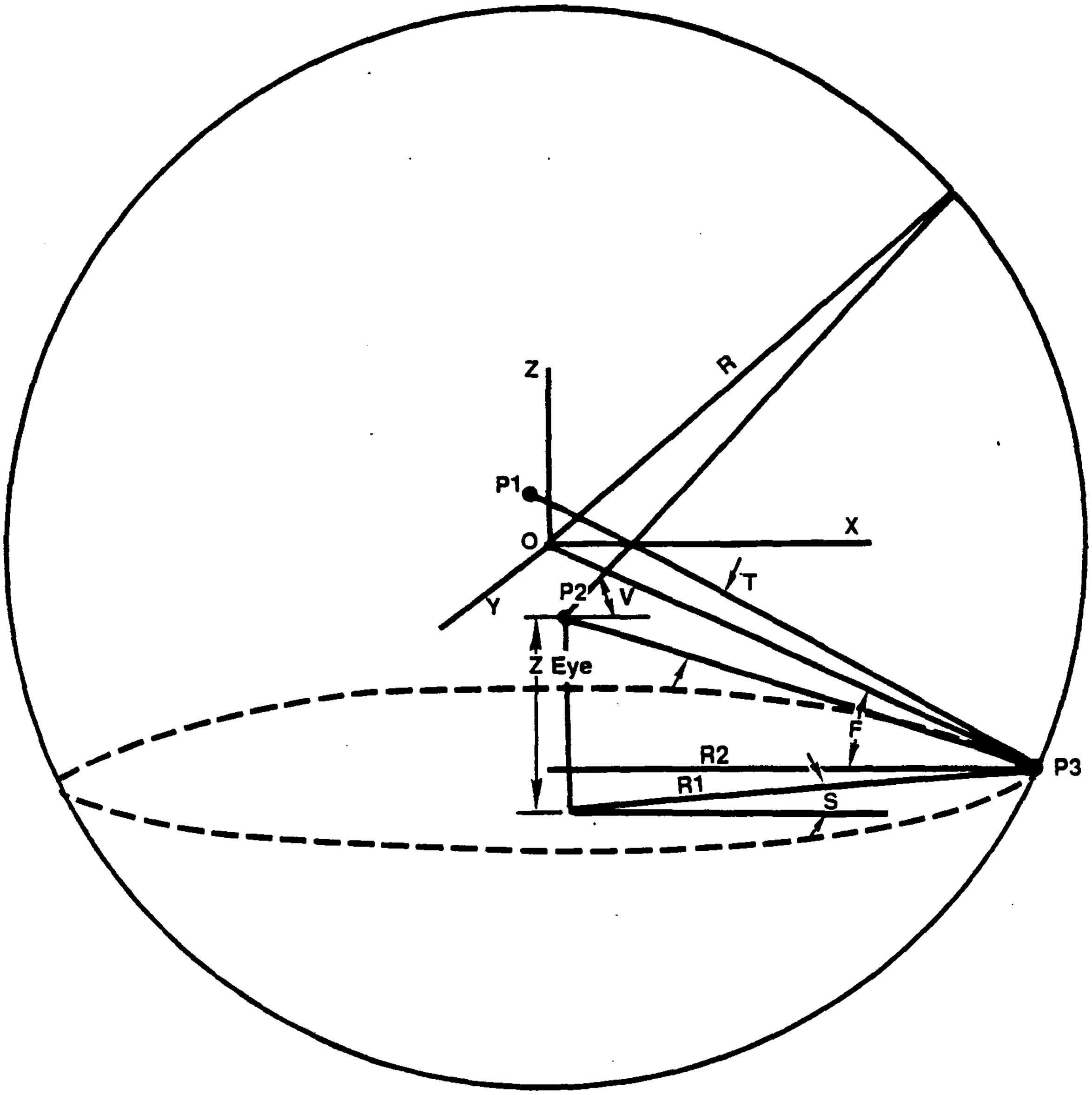


Figure I-1: Sphere Geometry

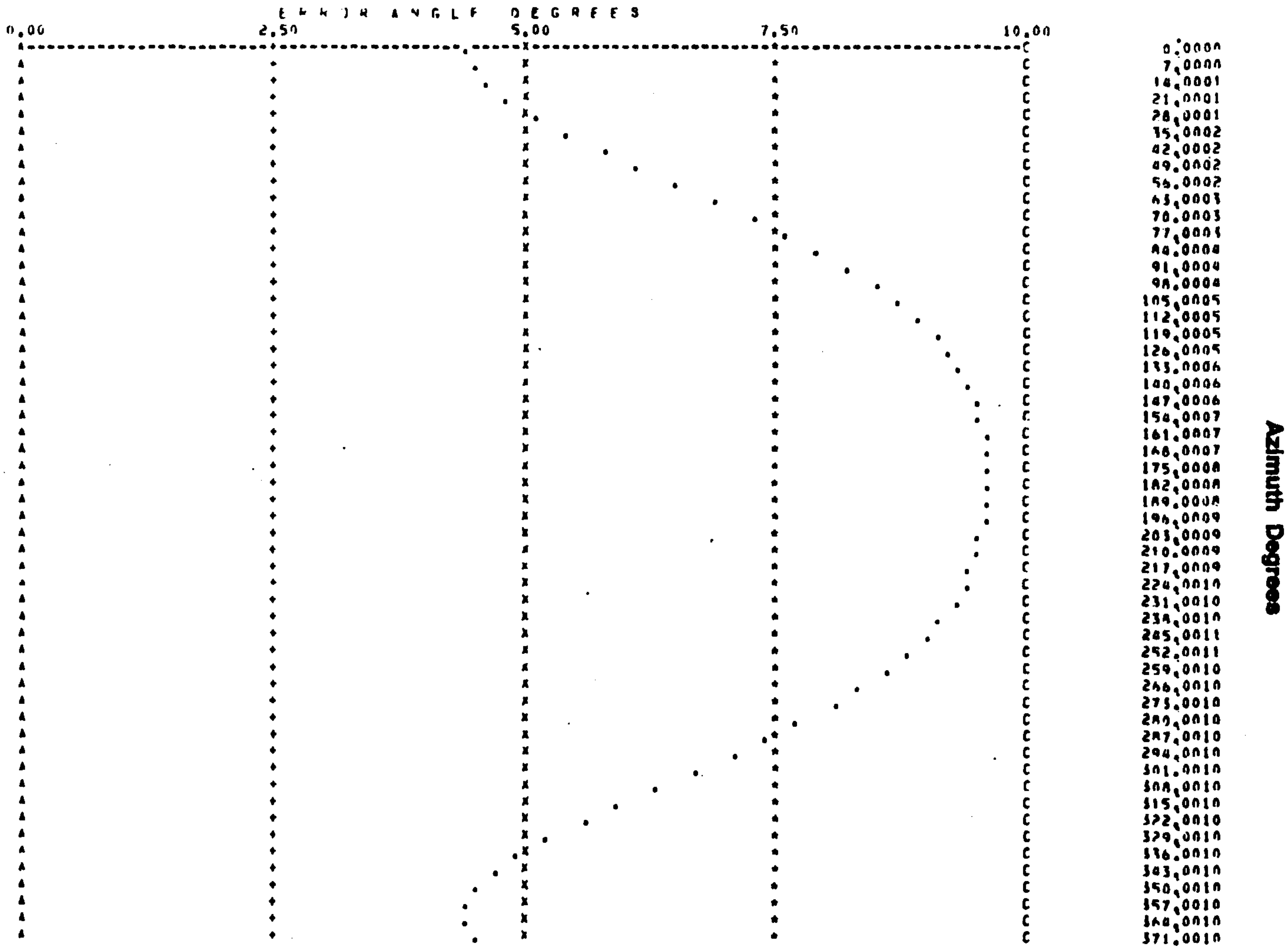


Figure I-2: Viewpoint Distortion on a Spherical Screen (ϕ = −30°)

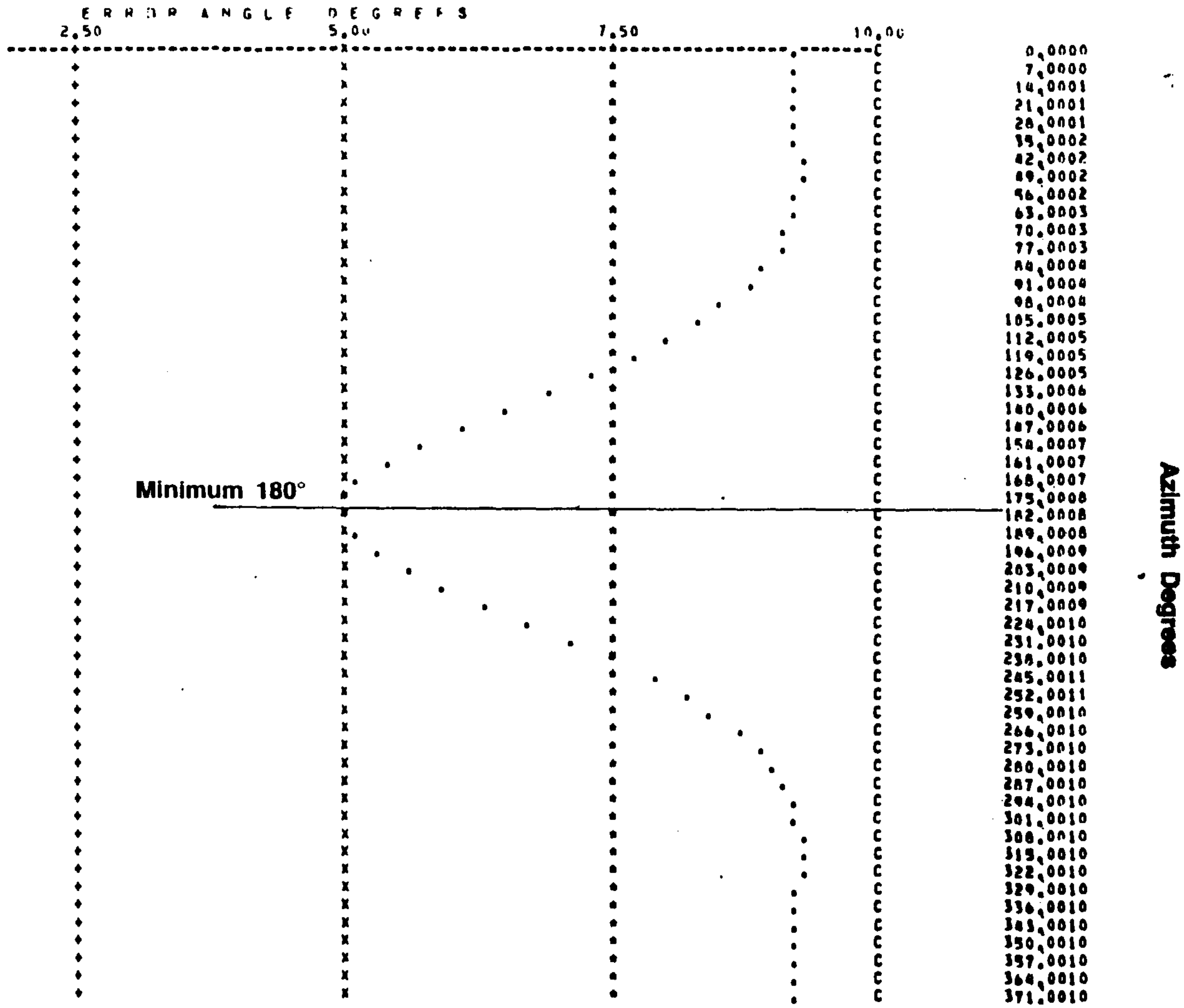


Figure I-3: Viewpoint Distortion on a Spherical Screen (ϕ = 30°)

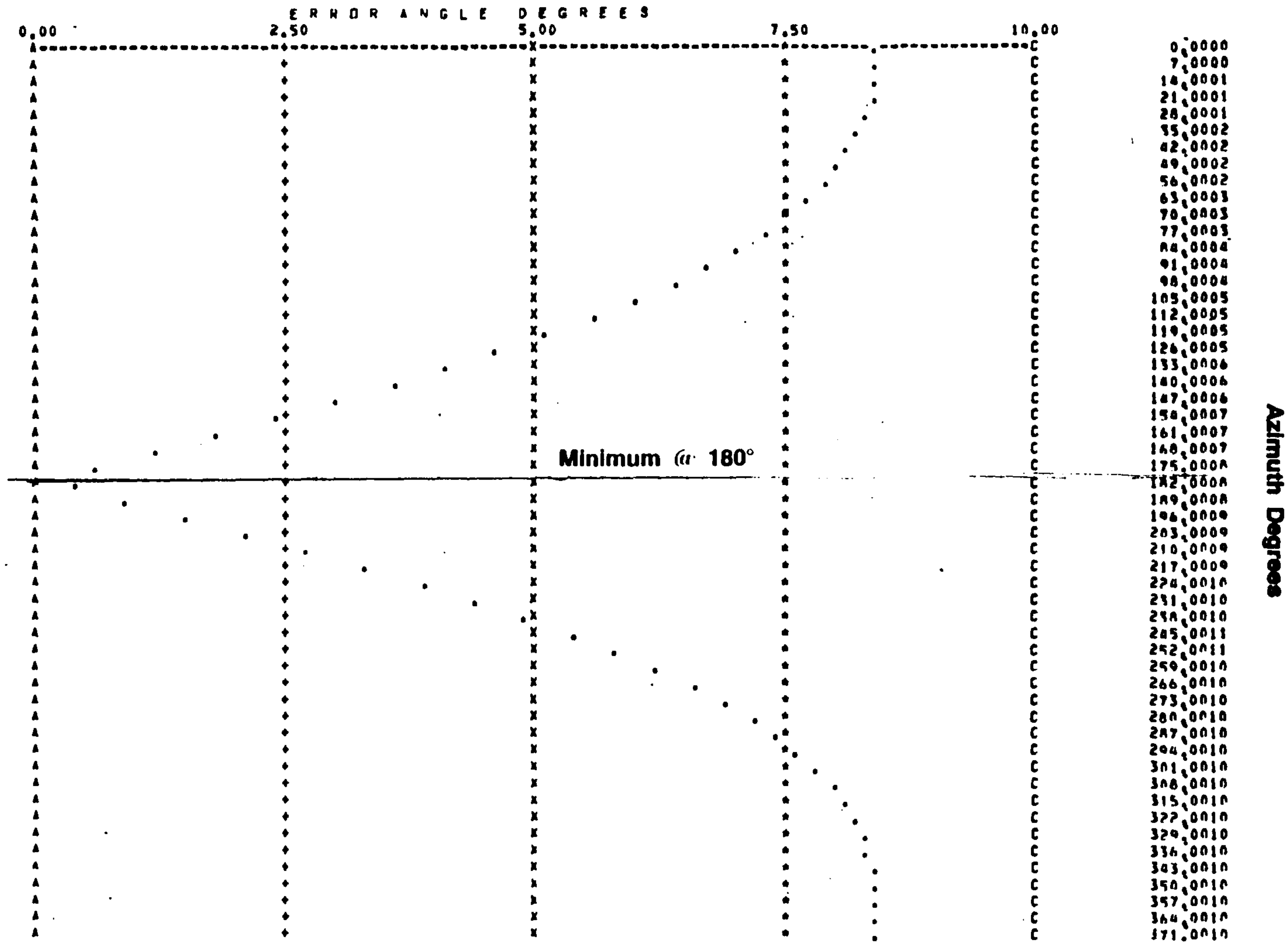


Figure I-4: Viewpoint Distortion on a Spherical Screen (ϕ = 60°)

Table I-1: Distortion Computer Program Listing

```
      SUBROUTINE PLOT(DATA, NS, KURVS, XSTRT, XSTEP, XMAX, ISYM, MAN,
     C                XDATA, MV, NPTS, INCRMT)
      DIMENSION ALINE(101), BLINE(101), DATA(KURVS, NS), SYMBL(12),
     C          ISYM(12), IY(12), XDATA(MV)
      DATA BLANK/' '/,DOT/'I'/,SYMBL/'C','*','X','+','.','A','O',
     C          '#','Q','S','*',' '/,ABAR/'I'/
      DATA CENTR1/1.5/,CENTR2/51.5/,BLINE/101*'-'/
      AMAX = 0.
      AMIN = 0.
      XVAL = XSTRT
      NO = 1
      IN = INCRMT+1
      WRITE(6,9)
      DO 6 N=1,12
    6 IY(N) =0
      BLINE(1) = ABAR
      BLINE(26) = ABAR
      BLINE(51) = ABAR
      BLINE(76) = ABAR
      BLINE(101) = ABAR
      DO 10 I=1,101
   10 ALINE(I) = BLANK
      NSTEPS = 1. + ((XMAX - XSTRT)/XSTEP)
      IF (MAN.EQ.1) NSTEPS = NPTS
      DO 20 I=1,KURVS
      DO 20 K=1,NSTEPS
      IF (DATA(I,K).GT.AMAX)  AMAX=DATA(I,K)
      IF (DATA(I,K).LT.AMIN)  AMIN=DATA(I,K)
   20 CONTINUE
      IF (AMIN.LT.0.) GO TO 30
      SCALE = 100/AMAX
      CENTR = CENTR1
      T1 = AMAX
      T2 = 0.75*AMAX
      T3 = 0.5 *AMAX
      T4 = 0.25*AMAX
      T5 = 0.
      GO TO 60
   30 AIMIN = -AMIN
      IF (AMAX.GT.AIMIN) GO TO 40
      IF (AMAX.EQ.0.)  GO TO 35
      SCALE = 50/AIMIN
      T1 = AIMIN
      T2 = 0.5*AIMIN
      T3 = 0.
      T4 = 0.5*AMIN
      T5 = AMIN
      GO TO 50
   35 SCALE = 100/AIMIN
      CENTR = 101.5
      T1 = 0.
      T2 = 0.25*AMIN
      T3 = 0.5 *AMIN
      T4 = 0.75*AMIN
      T5 = AMIN
      GO TO 60
   40 SCALE = 50/AMAX
```

Table I-2: Distortion Computer Program Listing (Cont'd)

```
      T1 = AMAX
      T2 = 0.5*AMAX
      T3 = 0.
      T4 = 0.5*(-AMAX)
      T5 = -AMAX
   50 CENTR = CENTR2
   60 VARX = XSTRT
      ICNTR = CENTR
      DO 110 J=1,NSTEPS
      IF (MAN.EQ.1) VARX = XDATA(J)
      ALINE(ICNTR) = DOT
      Y = - XSTEP
      IF ((VARX.GT.(XSTEP*0.25)).OR.(VARX.LT.(Y*0.25))) GO TO 80
      WRITE (6,5) T5, T4, T3, T2, T1
    5 FORMAT  ('+',T4,F10.2,T29,F10.2,T54,F10.2,T79,F10.2,T104,F10.2)
      DO 70 M=1,101
   70 ALINE(M) = BLINE(M)
   80 DO 81 L=1,KURVS
      IY(L) = (DATA(L,J) * SCALE) + CENTR
      ALINE(IY(L)) = SYMBL(ISYM(L))
   81 CONTINUE
      DO 83 M=1,KURVS
      DO 82 N=1,KURVS
      IF (((IY(M).EQ.IY(N)).AND.(M.NE.N)).AND.(.NOT.((ISYM(N).EQ.12)
     C      .OR.(ISYM(M).EQ.12)))) ALINE(IY(M)) = SYMBL(11)
   82 CONTINUE
   83 CONTINUE
      IF (NO.EQ.1)  GO TO 95
   85 WRITE(6,4)  ALINE
    4 FORMAT (T11,101A1,T116,F15.4)
   95 IF(MAN.EQ.1) XVAL = XDATA(J)
      IF(MAN.NE.1)  VARX = VARX + XSTEP
      IF(NO.NE.1)  GO TO 105
      WRITE(6,4) ALINE, XVAL
  105 NO = NO + 1
      IF (NO.EQ.IN)  NO = 1
      IF (MAN.NE.1) XVAL = XVAL + XSTEP
      DO 106 M = 1,101
  106 ALINE(M) = BLANK
    9 FORMAT('1',35X,'E R R O R  A N G L E   D E G R E E S',/)
  110 CONTINUE
  130 RETURN
      END
C
C
C           VIEWPOINT ERROR CALCULATION WITHIN A SPHERE FOR SCENE DISTORTION.
C
C
```

```
      DIMENSION  S(55),F(55),Z3(55),ZEYE(55),R2(55),R1(55),X3(55),Y3(55)
     C    ,T(55),DATA(55),PSI(55), PHI(55), E(55),EEQ(55),SEQ(55) , V(55)
      DIMENSION NSYM(12), XRAY(60), XDUM(1), NYS(10), FEQ(55)
     C ,EEYE(55),EPLOT(8,60)
      DATAPSI/0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,16.,
     C17.,18.,19.,20.,21.,22.,23.,24.,25.,26.,27.,28.,29.,30.,31.,32.,
     C  33.,34.,35.,36.,37.,38.,39.,40.,41.,42.,43.,44.,45.,46.,
     C  47.,48.,49.,50.,51.,52.,53.,54./
      XDUM(1) = 0.
      DO 59 N2 = 1,8
   59 NSYM(N2) = N2
      DO 61 K2 = 1,60
      EPLOT(1,K2) = 10.
      EPLOT(2,K2) = 7.5
      EPLOT(3,K2) = 5.
      EPLOT(4,K2) = 2.5
   61 EPLOT(6,K2) = 0.
    1 CONTINUE
      READ (5,10)  R
      READ (5,10)  X1, Y1, Z1
      READ (5,10)  X2, Y2, Z2
   10 FORMAT (6F12.3)
      DO 32 I = 1,55
      PHI(I) = 0.5235987
   32 CONTINUE
      DO 33 I = 1,55
      S(I) = .122173 * PSI(I)
      SEQ(I) = S(I)/.0174532
      F(I) = PHI(I)
      FEQ(I) = F(I)/0.0174532
      Z3(I) = R * SIN(F(I))
      ZEYE(I) = Z3(I) - Z2
      R2(I) = R * COS(F(I))
      B = X2 * COS(S(I)) -Y2*SIN(S(I))
      BSQ = B*B
      C = X2**2. + Y2**2. - R2(I)**2.
      IF ((BSQ - C).GE.0.)  GO TO 23
      GO TO 90
   23 CONTINUE
      R1(I) = -B + SQRT(BSQ   - C)
      X3(I) = X2 + R1(I) * COS(S(I))
      PRINT, ZEYE(I), R2(I), B, C, R1(I), X3(I)
C
C
C        COORDINATES  &  DISTANCES  ARE  IN  INCHES
C
C               PICK  A  PLANE  P  WITH EACH  S   AND   F
C
C    S = PSI        F = PHI        V = SIN (PHI PRIME(ANGLE FROM VIEWPOINT) )
C
C               R2  IS  RADIUS  OF  PLANE  P     S, F, AND E ARE IN RADIANS
C
C               R1  IS  DISTANCE  IN  PLANE P  FROM  PERP.  FROM  P2  TO  P3
C
C               T  =  COS THETA            E  =  THETA  =  ARCCOS (T)
C
C               V = SIN PHI PRIME        EEYE = PHI PRIME = ARCSIN (V)
C
```

Table I-4: Distortion Computer Program Listing (Cont'd)

```
C
      Y3(I) = Y2 - R1(I) * SIN(S(I))
      D1 = SQRT((X3(I)-X1)**2  + (Y3(I)-Y1)**2  + (Z3(I)-Z1)**2 )
      D2 = SQRT((X3(I)-X2)**2  + (Y3(I)-Y2)**2  + (Z3(I)-Z2)**2 )
      V(I) = ZEYE(I)/D2
      EEYE(I) = ARSIN(V(I))/.0174533
      D8 = D1*D2
      T(I) =((X1-X3(I))*(X2-X3(I)) + (Y1-Y3(I))*(Y2-Y3(I)) + (Z1-Z3(I))*
     C        (Z2-Z3(I)))/D8
      PRINT, Y3(I), D1, D2, D8, T(I)
      E(I) = ARCOS(T(I))
      EEQ(I) = E(I)/.0174532
      EPLOT(5,I) = EEQ(I)
   33 CONTINUE
      WRITE (6,11)  R, X1, Y1, Z1, X2, Y2, Z2
   11 FORMAT ('1',8X,'I N P U T   D A T A',//,9X,'SPHERE RADIUS, INCHES'
     C,F10.3,3X,'P1 COORD, S',3F10.3,//,10X,'P2 COORD, S',3F10.3)
      WRITE (6,15)
   15 FORMAT ('1',      9X,'D E R I V E D   C O O R D, S',/, 12X,'X3',10X
     C    ,'Y3'10X'Z3')
      WRITE (6,16)  (X3(I), Y3(I), Z3(I), I =1,55)
   16 FORMAT (3X,/,55(' ',4X,3F12.3/))
      CALL PLOT(EPLOT, 55, 6, SEQ(1), SEQ(2), SEQ(55), NSYM,0, SEQ, 55,
     C 55, 1)
      WRITE (6,12)
   12 FORMAT ('1',17X,'O U T P U T   D A T A',/ ,6X,'S(RAD)'4X'S(DEGR.)'
     C  ,3X,'FEQ(DEGR.)'
     C     2X'E(RADIANS)'2X'EEQ(DEGR.)'2X'EEYE(DEG.)')
      WRITE (6,13) (S(I),SEQ(I),FEQ(I), E(I), EEQ(I),EEYE(I), I=1,55)
   13 FORMAT (3X,/ ,55(' ',6E12.4/))
      GO TO 1
   90 WRITE (6,14)
   14 FORMAT (' ',5X,' I M A G I N A R Y   R O O T S ')
   99 STOP
      END
```

APPENDIX J

TYPICAL ROTORCRAFT PILOT STATION EQUIPMENTS

This Page Intentionally Left Blank

APPENDIX J

TYPICAL ROTORCRAFT PILOT STATION EQUIPMENTS

FACILITY	NOMEN-CLATURE	USE	CONTROL LOCATION
Intercommunication	Interphone Control C-6533/ARC	Intercommunication between crewmembers and control of navigation and communication radio	Cockpit lower console, crew-chief/gunner's stations, and troop commander's station at center of cabin overhead with handset
FM communications	Radio Set AN/ARC-114A VHF-FM No. 1	Two-way voice communications; FM and continuous-wave homing frequency range 30 through 75.95 MHz	Lower console
FM communications	Radio Set AN/ARC-114A VHF-FM No. 2	Same as No. 1 VHF-FM, except no homing is provided	Lower console
VHF communications	Radio Set AN/ARC-115A VHF-AM	Two-way voice communications in the frequency range of 116.000 through 149.975 MHz	Lower console
UHF communications	Radio-Transmitter Radio, RT-1167/ARC-164(V) UHF AM	Two-way voice communications in the frequency range of 225 to 399.95 MHz	Lower console
Voice security system	TSEC/KY28 C-8157/ARC	Secure communications	Lower console

Figure J-1: Communication/Navigation Equipment – Sikorsky UH-60A

TYPICAL ROTORCRAFT PILOT STATION EQUIPMENTS (CONT'D)

FACILITY	NOMEN-CLATURE	USE	CONTROL LOCATION
Automatic direction finding	Direction Finder Set AN/ARN-89	Radio range and broadcast reception; automatic direction finding and homing in the frequency range of 100 to 3000 kHz	Lower console
VOR/LOC/ GS/MB receiving set	Radio Receiving Set AN/ARN-123(V)	VHF navigational aid, VHF audio reception in the frequency range of 108 to 117.95 MHz and marker beacon receiver operating at 75 MHz	Lower console
Doppler navigation set	Doppler Navigation Set AN/ASN-128	Provides present position or destination navigation information in latitude and longitude (degrees and minutes) or Universal Transverse Mercator (UTM) coordinates	Lower console
Radar signal detecting set	Detecting Set Radar Signal AN/APR-39V	Detects threat radar signals	Lower console
Infrared countermeasure set	Countermeasures Set AN/ALQ-144( )(V)	Provides IR countermeasure	Instrument panel
Magnetic heading indications	Gyro Magnetic Compass AN/ ASN-43	Navigational aid	Lower console

Figure J-2: Communication/Navigation Equipment – Sikorsky UH-60A Cont'd

TYPICAL ROTORCRAFT PILOT STATION EQUIPMENTS (CONT'D)

FACILITY	NOMEN-CLATURE	USE	CONTROL LOCATION
Chaff dispenser	Dispenser Set XM-130	Dispenses chaff	Lower console
Identification friend or foe	Transponder Set AN/APX-100(V)	Transmits a specially coded reply to a ground-based IFF radar interrogator system	Lower console
Absolute altimeter	Radar Altimeter AN/APN-209	Measures absolute altitude	Instrument panel

Figure J-3: Communication/Navigation Equipment – Sikorsky UH-60A Cont'd

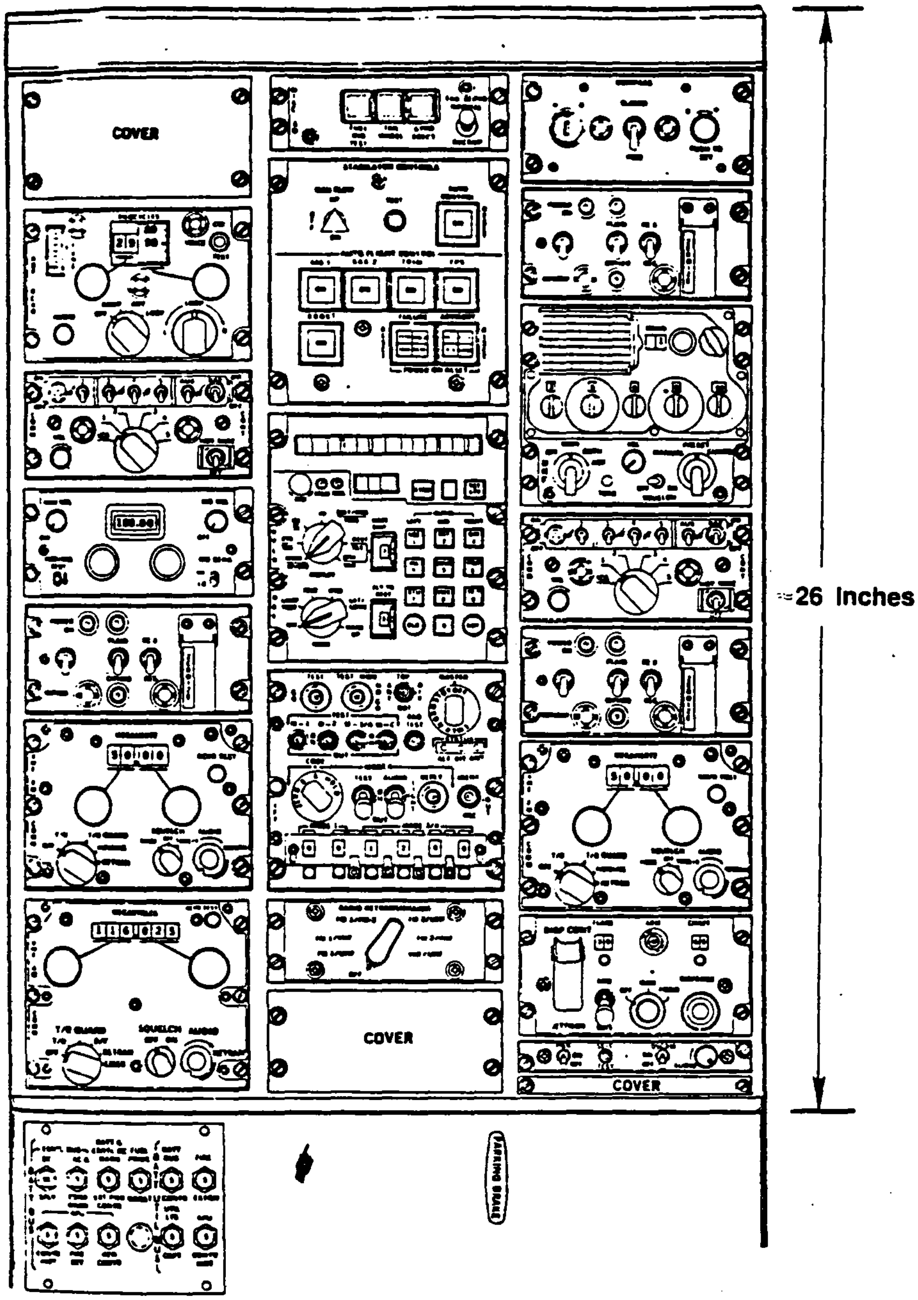


Figure J-4: Lower Console, Sikorsky UH-60A

Modes of Operation.

The radar detector AN/APR-39V-1 may be operated in either the discriminator off or discriminator on mode.

CONTROL	FUNCTION
BRIL Control	Varies brilliance of cathode ray tube (CRT) display.
Filter Control	Varies density of red polarized faceplate filter (used for day or night operation) by moving a tang right or left.

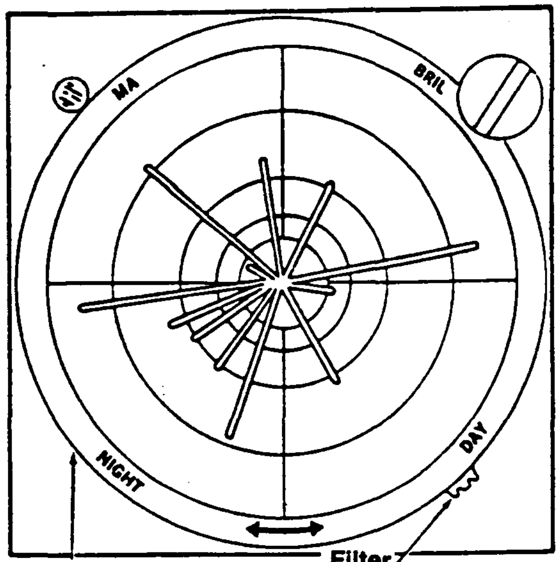


Figure J-5: Radar Detector/Display, Sikorsky UH-60A

a. Discriminator Off Mode. When operated in the discriminator off mode, the DSCRM switch is placed OFF. In this mode all high band received signals with an amplitude greater than the predetermined threshold level are displayed on the CRT and an audio signal, representative of the combined amplitudes and Pulse Repetition Frequencies (PRFs), is present at the headset. The displays indicate the total radar environment in which the helicopter is operating. Each radial strobe on the CRT is a line of bearing to an active emitter. When a SAM radar complex becomes a threat to the helicopter (low band signals correlated with high band signals), the unique alarm audio is superimposed on the PRF audio signal and the MA lamp and associated strobe start flashing. Lengths of strobes and audio levels depend on the relative strength of the intercepted signals. A typical display when operating in the discriminator off mode is shown in Figure J-5.

b. Discriminator On Mode. When operating in the discriminator on mode, the DSCRM switch is placed ON. In this mode, signals are processed to determine their conformance to certain threat-associated criteria.

(1) The signal level must be greater than the minimum threshold level.

(2) Pulse width must be less than the maximum pulse width.

(3) PRF must be greater than the minimum pulses per second (PPS).

(4) The pulse train must exist with not less than minimum pulse train persistence.

(5) The CRT display is divided into eight sectors. Strobes are displayed only in those sectors in which signals meeting all threat criteria are present. This reduces display clutter by eliminating low-level and wide-pulse width signals and by selective sector display. Intercepts which meet these requirements are displayed as described in "a." above.

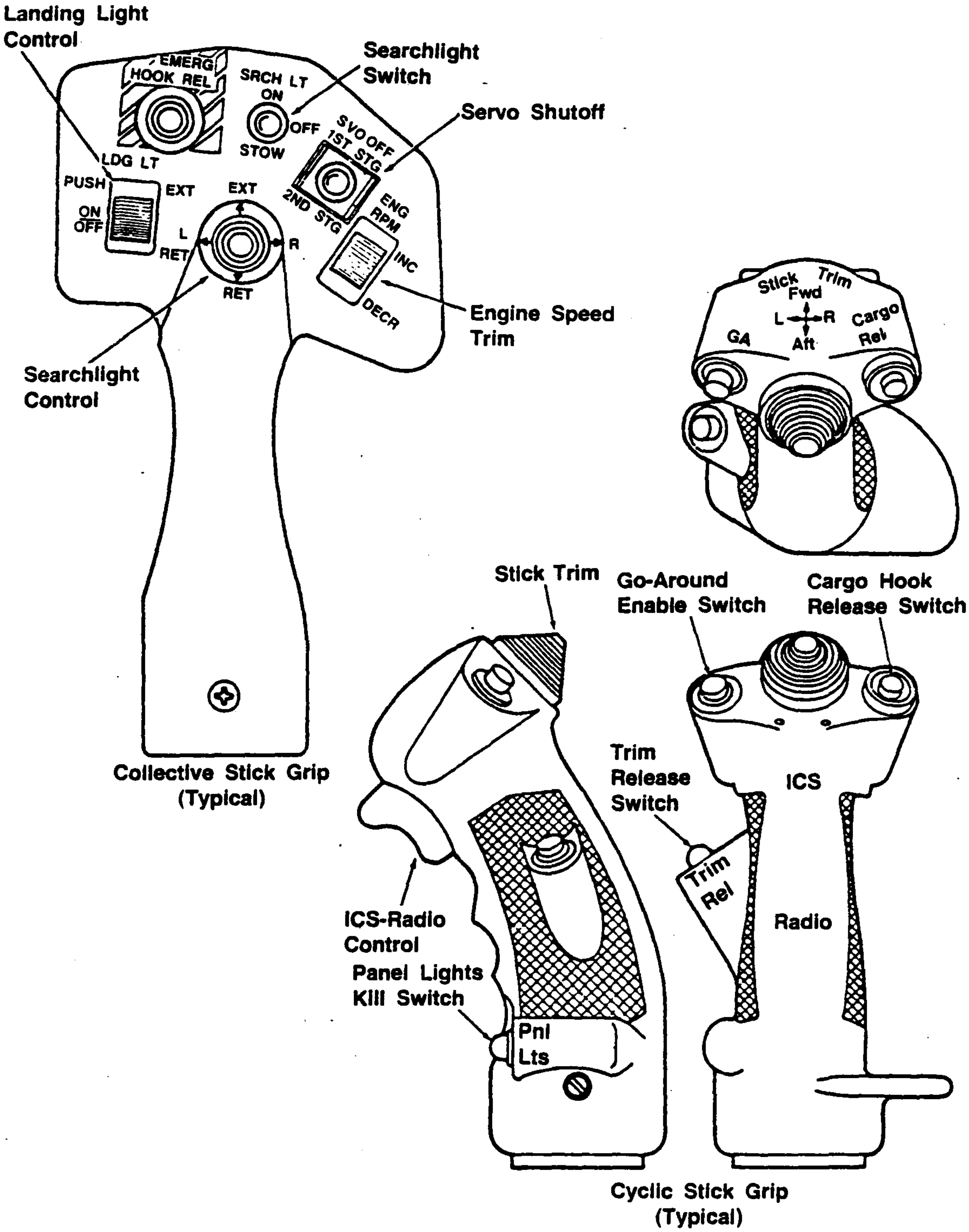


Figure J-6: Collective and Cyclic Grips, Sikorsky UH-60A

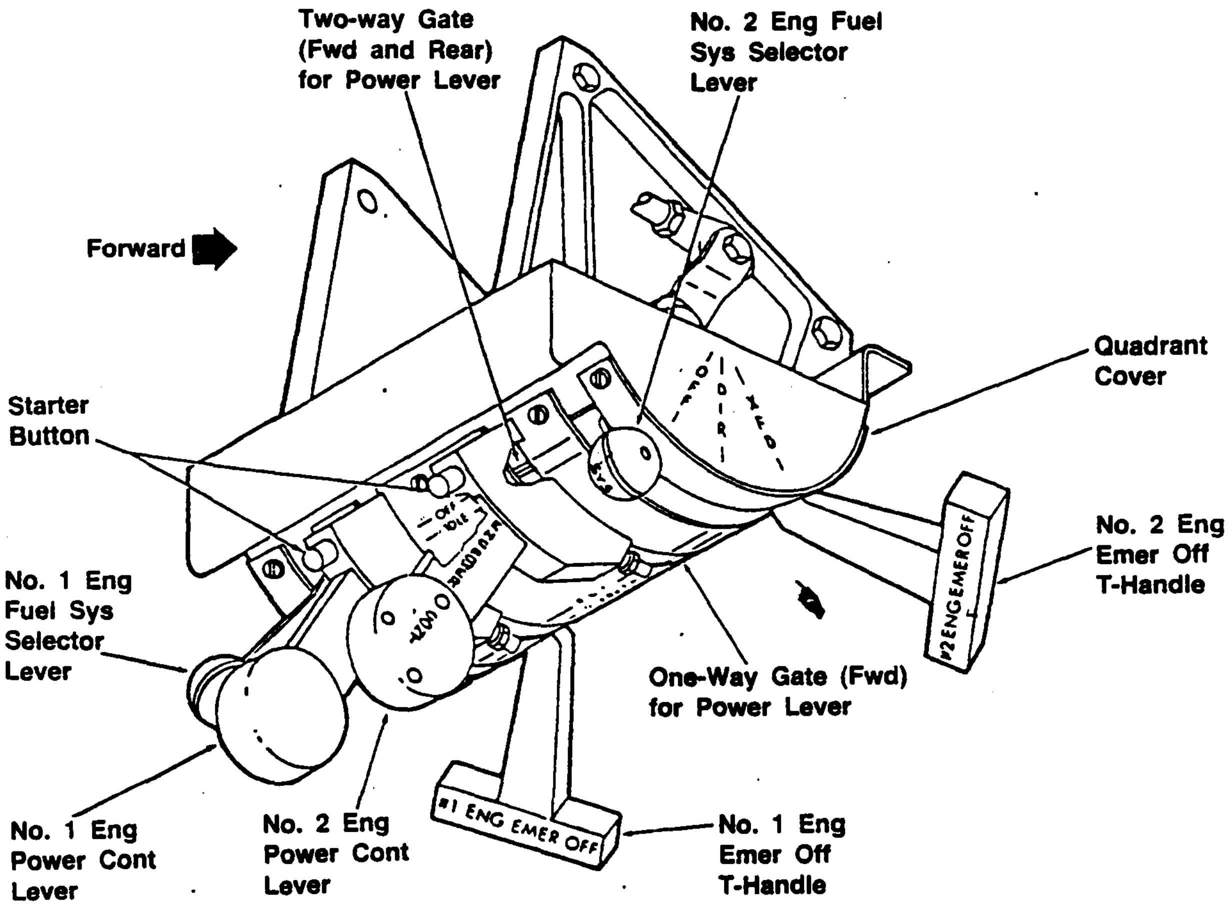
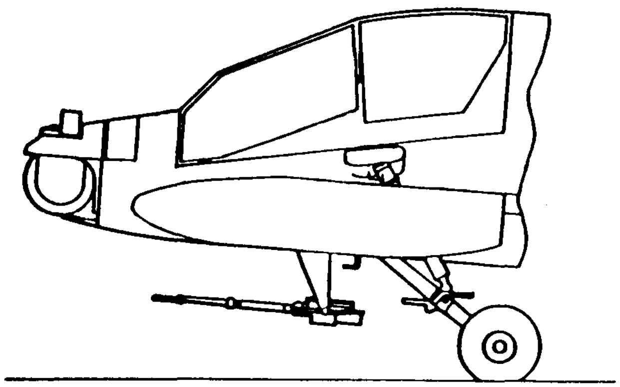


Figure J-7: Engine Control Quadrant, Sikorsky UH-60A (Overhead)

This Page Intentionally Left Blank



PILOT STATION

1. Fire Extinguisher Bottle Select Switch
2. Engine Fire Control Handles
3. Master Caution/Warning Panel
4. Engine Turbine Gas Temperature (TGT) Indicator
5. Engine Torque Indicator
6. Airspeed Indicator
7. Electronic Attitude Director Indicator (EADI)
8. Turn and Slip Indicator
9. Radar Altimeter
10. Accelerometer
11. Standby Attitude Indicator
12. Pressure Altimeter
13. Clock
14. Magnetic Compass Correction Card
15. Magnetic Compass
16. Emergency Canopy Jettison Handle
17. Fuel Quantity Indicator
18. Engine Oil Temperature Indicator
19. Engine Oil Pressure Indicator
20. Engine Gas Generator Speed (N_G) Indicator
21. Engine Power Turbine Speed (N_P) and Main Rotor Speed (N_R) Indicator
22. Conditioned Air Outlets
23. Fire Control Panel
24. Radar Warning Display
25. Horizontal Situation Indicator (HSI)
26. Rapid Response Vertical Speed Indicator (VSI)
27. Emergency Hydraulic Control Panel

27a. Emergency Hydraulic Pressure Indicator

28. Hydraulic Pressure Indicator
29. Deleted
30. Deleted
31. Tail Wheel Lock Control Panel
32. Caution Panel
33. Radio Placard

33a. Remote Transmitter Selector Display

33b. Intercom Failure Override Control Switch

34. Communications System Control Panel
35. Parking Brake Lock Handle
36. Fire Detector Test Control Panel
37. VHF-FM Radio Control Panel (AN/ARC-114)
38. Secure Voice Control Panel (TSEC/KY-28)
39. Directional Control Pedal Adjustment Control
40. Outside Air Temperature (OAT) Indicator
41. Instrument Test Panel
42. Missile Control Panel
43. Automatic Stabilization Equipment (ASE) Control Panel
44. Rocket Control Panel
45. Cabin Air Control Panel
46. Selective Stores Jettison Control Panel
47. Electrical Power Control Panel
48. Engine Overspeed Test Control Panel
49. Power lever Quadrant
50. Fuel Control Panel
51. Lighting Controls
52. Anti-ice Control Panel
53. Collective Switch Panel
54. Radar Warning Control Panel
55. Countermeasure Control Panels
56. Laser Warning Panel
57. UHF-AM Radio Control Panel (RT 1167/ARC-164)
58. TSEC/DY-58 (SWP) Secure Voice Control Panel
59. IFF Transponder Control Panel (AN/APX-100)
60. Automatic Direction Finder (ADF) Control Panel (ARN-89)
61. Auxiliary Power Unit (APU) Control Panel
62. Circuit Breaker Panels
63. Heading and Attitude Reference System (HARS) Control
64. Advisory Light Assy-Arm/Safe-F/C
65. Stabilator Position Indicator
66. Stabilator/Airspeed Placard
67. Icing Severity Indicator

Figure J-8: Pilot Flight Control Instrument Layout – Hughes AH-64 (Cont'd)

This Page Intentionally Left Blank

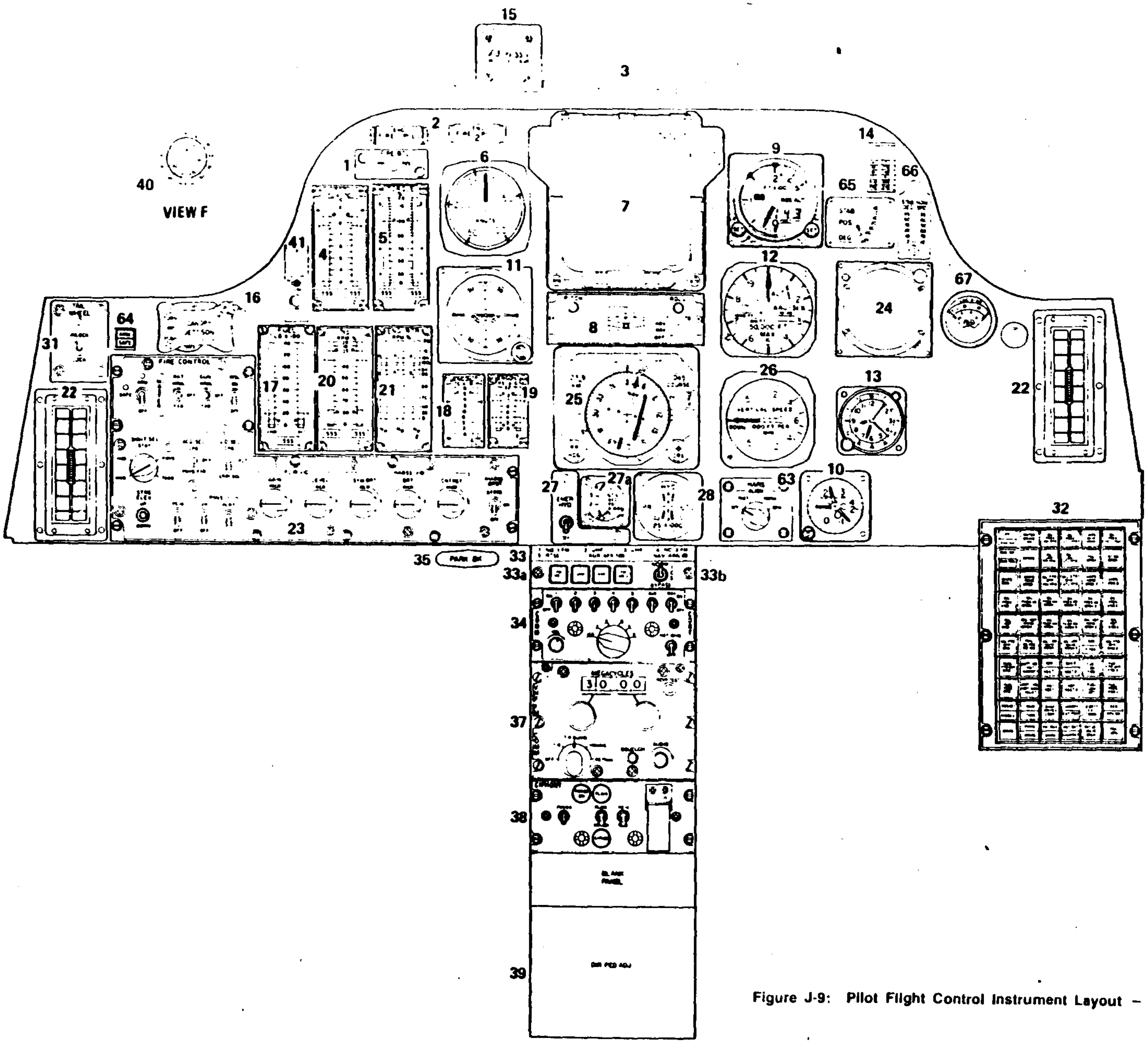


Figure J-9: Pilot Flight Control Instrument Layout – Hughes AH-64 (Cont'd)

This Page Intentionally Left Blank

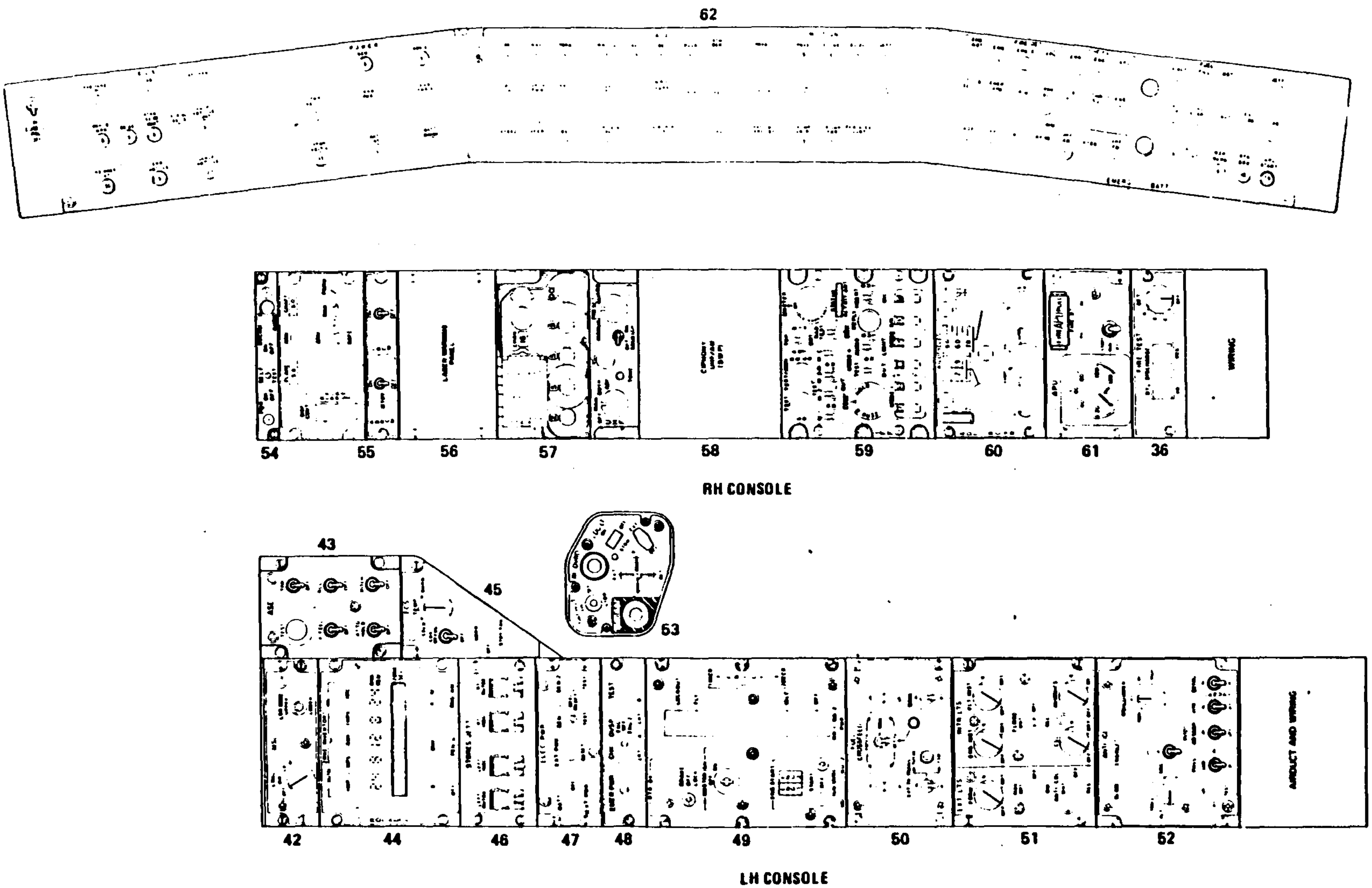
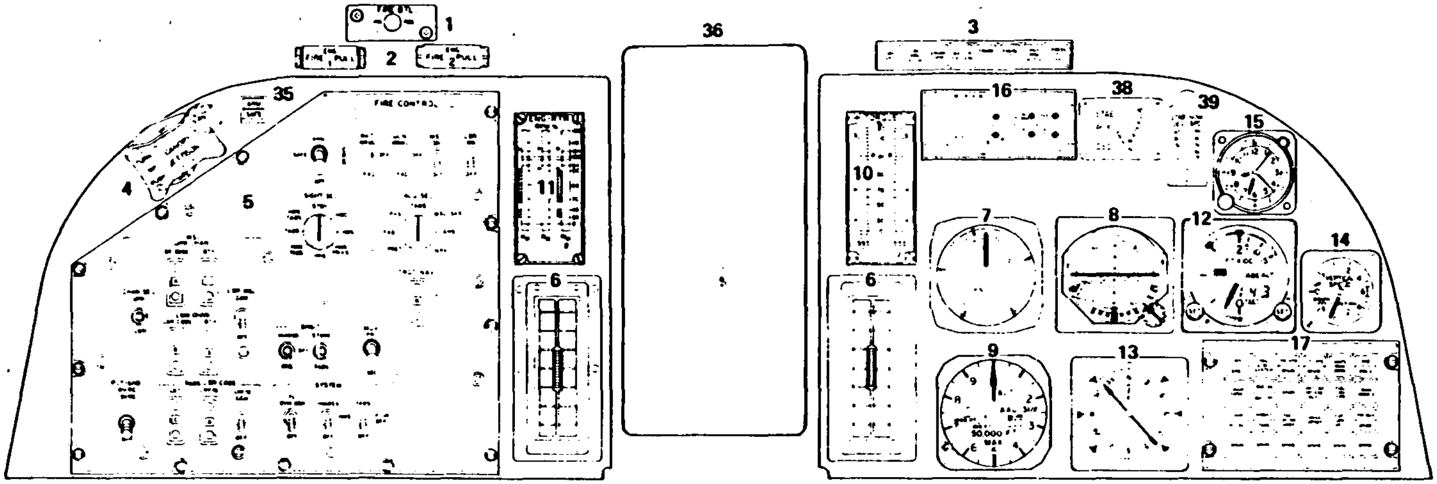


Figure J-10: Pilot Flight Control Instrument Layout – Hughes AH-64 (Cont'd)

This Page Intentionally Left Blank

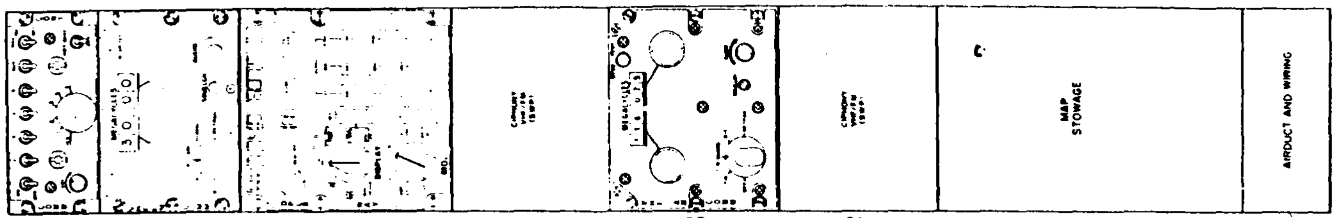


COPILOT/GUNNER

1. Fire Extinguisher Bottle Select Switch
2. Engine Fire Control Handle
3. Master Caution/Warning Panel
4. Emergency Canopy Jettison Handle
5. Fire Control Panel
6. Conditioned Air Outlets
7. Airspeed Indicator
8. Attitude Indicator
9. Pressure Altimeter
10. Engine Torque Indicator
11. Engine Power Turbine Speed (Np) and Main Rotor Speed (N_R) Indicator
12. Radar Altimeter
13. Radio Magnetic Indicator (RMI)
14. Rapid Response Vertical Speed Indicator (VSI)
15. Clock
16. Selectable Digital Display
17. Caution Panel
18. Radio Placard
19. Data Entry Keyboard
20. Missile Control Panel
21. Recorder Control Panel
22. Auxiliary Control Panel
23. Anti-ice Control Panel
24. Power Lever Quadrant
25. Emergency Fuel Control Panel
26. Interior Lighting Control Panel
27. No. 1 Circuit Breaker Panel
27a. No. 2 Circuit Breaker Panel
28. Communications System Control Panel
29. VHF-FM Radio Control Panel (AN/ARC-114)
30. Doppler Control Panel
31. TSEC/KY-58 Secure Voice Control Panel
32. VHF-AM Radio Control Panel (AN/ARC-115)
33. Map Stowage
34. Collective Switch Panel
35. Advisory Light Assy-Arm/Safe-F/C
36. Optical Relay Tube
37. Flare Release
38. Stabilator Position Indicator
39. Stabilator/Airspeed Placard

Figure J-11: Copilot/Gunner Control Instrument Layout – Hughes AH-64

This Page Intentionally Left Blank



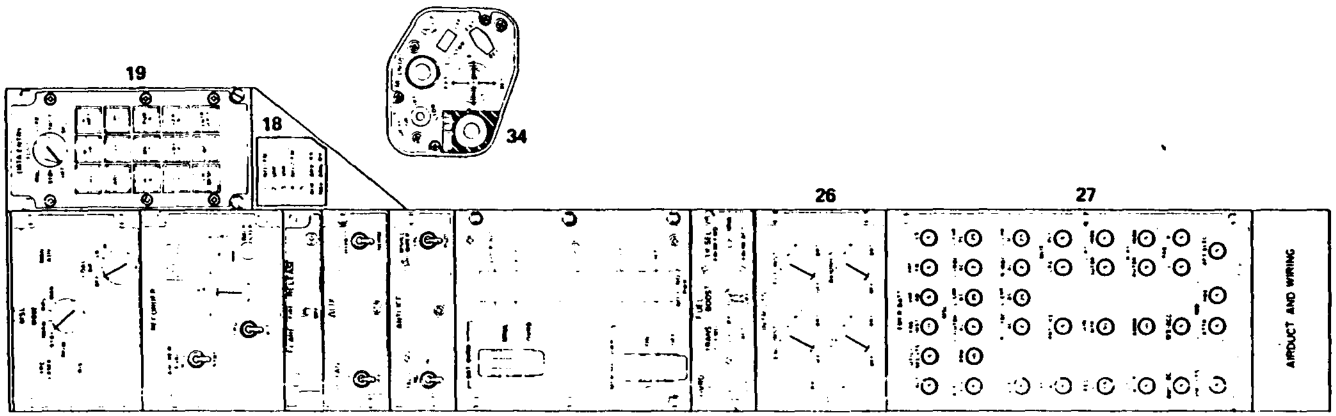


Figure J-12: Copilot/Gunner Control Instrument Layout – Hughes AH-64 (Cont'd)

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-166236		

4. Title and Subtitle	5. Report Date
Conceptual Design Study for an Advanced Cab and Visual System: Volume II	July 1980
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
R. J. Rue, M. L. Cyrus, T. A. Garnett, J. W. Nachbor, J. A. Seery, and R. L. Starr	
9. Performing Organization Name and Address	10. Work Unit No.
Boeing Military Airplane Company Wichita, Kansas	11. Contract or Grant No. NAS2-10464
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
National Aeronautics and Space Administration Washington, DC 20546 Army Aeromechanics Laboratory (AVRADCOM)	Contractor Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

Technical Monitor: Arlin Deel, Mail Stop 215-1, NASA Ames Research Center, Moffett Field, CA 94035 (415) 965-5891 or FTS 448-5891

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. Scope of Work, Applicable Documents, Requirements, Test Requirements, Fabrication and Quality Standards, Reliability and Quality Assurance, Design Reviews, Inspections, Testing, Contractor Conducted Orientations Appendices A through J are contained in Volume II.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Visual system NASA RSIS Program Advanced Cab Display system	Unclassified - Unlimited STAR Category - 05

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
UNCLASSIFIED	UNCLASSIFIED		

*For sale by the National Technical Information Service, Springfield, Virginia 22161

End of Document