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Raster Graphic Helmet-Mounted Display Study

William S. Beamon and Susanna I. Moran
General Electric Company
Daytona Beach, Florida

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CHAPTER 1
STUDY REPORT EXECUTIVE SUMMARY

1 OVERVIEW

General Electric Simulation and Controls System Department (GE/SCSD) is pleased to submit this technical report to NASA Langley Research Center in fulfillment of the Statement of Work (SOW), NAS1–18711, of May, 1988.

This report addresses the derivation of requirements for a full color, binocular high resolution, wide field of view raster graphics helmet–mounted stereo–capable display suitable for application to advanced rotorcraft pilot display interface research. Particular emphasis was given to the means by which full color and high resolution could be obtained. Three approaches for the physical implementation of the display device were presented to NASA LaRC during the conduct of the study, and two of these approaches have been selected for possible development. The initial approach selected for long–range development was a laser scanned, high resolution system which has been in the initial phases of development at General Electric for three years. The second approach chosen seems feasible for more near–term implementation on a helmet mounted display (HMD) currently being delivered to NASA LaRC. This second approach involves a novel method for deriving full color from a subminiature CRT and a patent application has been filed and assigned to NASA LaRC as part of this contract. The specifications for the Color Raster Generator Using a Subminiature Cathode Ray Tube have been delivered to NASA LaRC as a separate document.

This report is organized as five chapters and two appendices. Chapter One is this report overview and summary.

Chapter Two presents the derivation of research oriented display requirements, which were derived from task–related pilot requirements as an initial basis and design goal. This initial set was then compared with an absolute minimum requirement set known to be employed with current rotorcraft sensor suites, and a research related set was then derived which represents a current near–term limit in the state of the art.

Chapter Three presents an organization and review of the current technology suitable for use in producing full color, high resolution display capability required by the HMD.

Chapter Four presents the three design approaches chosen for presentation to NASA LaRC for further development. These included the laser scanned approach, a Thin–Film Transistor Liquid Crystal Display approach, and the subminiature color CRT approach.

Chapter five presents the summary and conclusions of the study.

Appendix A states a Development Plan for the Laser Scanned system.

Appendix B states the Specifications for the Laser Scanned HMD system.

CHAPTER 2

2 DISPLAY REQUIREMENTS ANALYSIS

2.1 OVERVIEW

Task related observer requirements were devised to determine an initial goal set of maximum display requirements. It was found that out–the–window target acquisition requirements appropriate for air combat maneuvering called for display field–of–view, resolution, scene luminance and contrast levels far beyond what would be useful and affordable for rotorcraft research. These initial requirements were compared with a set of minimum requirements known to be used in worst–case conditions by AH–64 test pilots.An achievable set of research requirements was then derived which would exceed minimum requirements handily and provide the field–of–view, resolution and full color capability necessary to investigate the utility of color and stereo viewing with various display formats.

2.2 DISPLAY REQUIREMENTS DERIVATION

Display requirements were derived to suit the intended use of the Helmet Mounted Display (HMD) system and as directed in the Statement of work (SOW). The stated usage is for research in rotorcraft advanced cockpit applications, where full color, high resolution and adjustable wide field of view will permit examining stereopsis, eye dominance, possible display format conflicts with out–the–window (OTW) scene content and other factors for which insufficient color HMD display performance data exists. Indeed, there are fundamental questions as to how best to use full color beyond the usual categorical coding applications for displayed data. Ultimately, the display is to be developed into a flight–rated device, but the initial requirements are for a research device which will be driven by a small visual system which will present various reticles, maps, weapons and systems status symbology, but which is not intended to present full out–the–window imagery.

This chapter presents the findings of Task 1.The objective of that task was the derivation of the requirements for a helmet–mounted display (HMD), specifically the identification of the advanced cockpit environment in which that display will interface, the determination of task–related activities as these will affect the display requirements, and the link between those and the total system requirements.

Display requirements for the helmet display were derived from rotorcraft flight task and observer requirements, which are beyond required display capabilities, and from empirically determined minimum flight–related sensor operating requirements, which are the very minimum to be of any use. From these, a set of research requirements was derived which are achievable and which call for sufficient field of view and resolution to allow various data display formats to be evaluated. The resulting display requirements are more stringent than minimum (sensor derived) requirements and less stringent than the eye–limited observer related requirements for target acquisition. The user display requirements in a rotorcraft operational setting ideally would ideally mimic the field of view and resolution characteristics of the (good) observer. ACM target acquisition task requirements drive this.

On the other hand, operational sensor display usage in IFR/night conditions has been shown to be effective with as little as 30 by 40 degree fields of view, although this requires the pilot to slew his head over a wide area to obtain situation awareness. Clearly, the helmet display research requirements should be larger than this in order to investigate improved display formats and less than the ultimate hemispherical coverage with one arcminute resolution, since this is not concurrently achievable with helmet visor optics or the raster generator.

2.3 RESEARCH METHODOLOGY FOR FLIGHT RELATED REQUIREMENTS

The preliminary step in determining the observer display requirements is a cockpit configuration analysis based on extensive literature review and pilot interviews. (1) The focus of that analysis is a chronology of cockpit configurations, from the traditional knobs and dials, to 2–D and 3–D visual representations.

The next step in the determination of display requirements follows a top–down design (Figure 2.3–1). Task–related observer requirements are identified by mission type. Visual cues with display content and scene characteristics necessary for each mission are identified, with missions further broken down into phases with subtasks. That yields required information, which identifies the needed visual information cues and the rules that govern displays. Visual information cues, plus rules, determine display representation, which, in turn, drives the display requirements.

2.4. COCKPIT CONFIGURATION ANALYSIS

The changing nature of warfare and the concomitant complexity of modern aircraft have had profound impacts on cockpit design considerations. The crux of the matter is the study of the "human factors equation, finding what it is about human needs and wants, and man's physical and emotional capabilities and limitations, that, when taken into account in cockpit design and development, actually improve pilot and aircraft performance." (2)

While there is a multitude of issues in cockpit design (3), this study focuses only on in–cockpit representation of information with particular emphasis on advanced imagery and man–machine interfaces as they relate to helmet–mounted display requirements. The discussion that follows is drawn from three primary sources of information: avionics literature (4); past experience with in–cockpit imagery design; and pilot interviews.

2.5. FROM CONVENTIONAL TOOLS TO ADVANCED IMAGERY

The traditional representation of in–cockpit information for aircraft and rotorcraft has consisted of discrete dials and knobs. As airborne conditions have become more intense, particularly in the military arena, those discrete tools have proliferated by a factor of ten in the past thirty years. A World War I fighter had 10 to 15 gauges, controls and instruments; and there were about 35 in a P–51 Mustang of World War II vintage. By the 1960s, the F–111 carried some 200 instruments, with the F–15 carrying over 300. (5) The human factors issue is task overload for the pilot: the discrete representation of information places the total burden of interpretation on the pilot, who needs to filter out a large amount of information in a very short time. Early human engineering efforts focused on properly grouping and arranging the instruments according to system and function and on making the markings legible. Display integration was very limited and selective display was just not possible with the hardware involved.

The use of video instruments and the evolution of electronics in the cockpit, primarily in the form of the conventional instrumentation replaced by multi–function CRT displays, has not entirely alleviated the problems of pilot workload. According to one researcher:

> "Data or symbols presented on these displays are highly codified, requiring their meaning to be learned and responses trained at higher cognitive levels. Although [the cockpit] presents more DATA to the pilot, it does not necessarily provide more INFORMATION, as the human is not able to assimilate all that is presented to him simultaneously." (6)

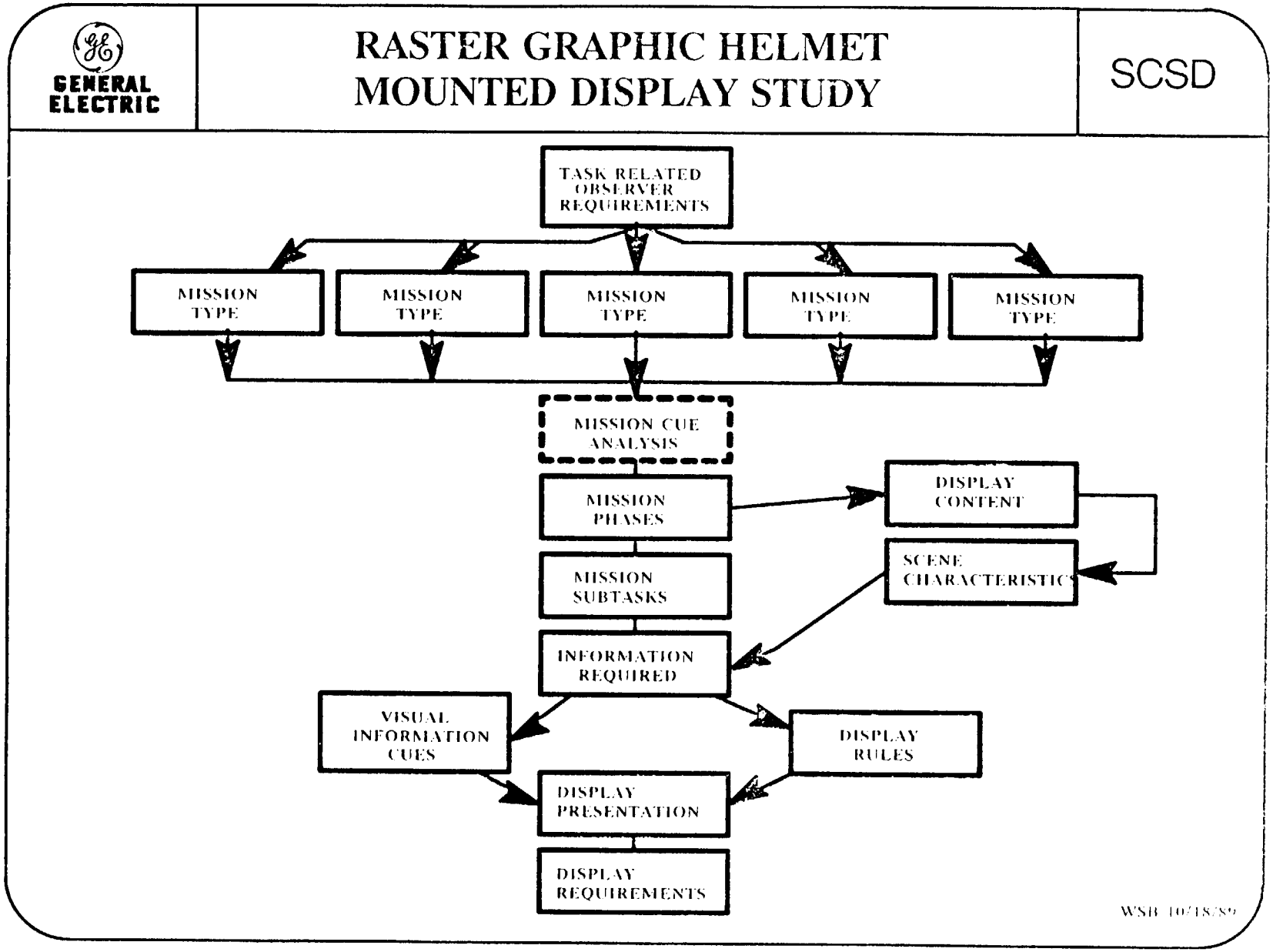

Figure 2.3–1. Requirements Derivation Sequence

Additionally, two–dimensional video presentations have failed to address the nature of human sensors. Human senses operate in 3–D, hence, traditional 2–D can provide only a "peephole" into the actual 3–D world. For pilots, this results in "sensor/mismatch information/overload",(7) that is particularly acute in times of stress.

As illustrated in Table 2.5–1, a "giant leap" forward in a qualitative direction has not occurred in the current cockpit configuration. For example, instrument numbers, location and Field–of–View (FOV) are fixed, data are observer selected and exceeds the observer's bandwidth.

Table 2.5–1. EVOLUTION OF COCKPIT INSTRUMENTATION

Old	Current	Future
Fixed Number	Fixed Number	Variable Number
Fixed Location	Fixed Location	Head/Eye Directed
All Data Present	Selective Data	Selective, Integrated Data
Single Function	Single/Multi–Function	Multi–Function
Fixed FOV	Fixed FOV	Variable FOV
Fixed Format	Fixed Format	Variable Format
No Smarts	Some Smarts	Expert Assist/Advice
Some Redundancy	Some Redundancy	Full Redundancy
Circular,Tape	Circular,Tape,CRT	HMD, CRT Backup
Observer Selection	Observer Selection	System Selection
Beyond Bandwidth	Beyond Bandwidth	Matches Bandwidth

Research and development on advanced avionics design for future fixed– and rotor–wing aircraft are incorporating the human factors– based impetus for a technological break from conventional and 2–D representation to 3–D, integrated and virtual display formats. The trend in advanced avionics design is following what the Air Force Systems Command calls "mindware", (8) defined as follows:

Symbolic information and display knowledge representations;
Multi–sensory and perceptual organization of presented data;
Interface control structure(s); and
Wholistic design principles of human–system interface design.

2.4.2. SYMBOLIC INFORMATION AND DISPLAY KNOWLEDGE REPRESENTATION

The research and development in this area centers primarily on finding the most optimum display representation for the pilot. A primary element of this research is the movement toward 3–D representation of information, projected on a wide FOV on innovative types of displays, and moving toward a "virtual" world in the cockpit. While specific findings are beyond the scope of the present study, the challenge is to find that optimum human–system interface design, which, in essence, needs a match between types of human organizational elements and saliency. The sub–components of these include:

Sensory Organization	Object Saliency
Intensity	
Contrast	
Color	
Legibility	
Perceptual Organization	Pattern Saliency
Spatial Arrangement	
Temporal Arrangement	
Cognitive Organization	Decision Saliency
Problem Framing	
Semantics Structure	
Interface Control Structure	

2.4.3. MULTI–SENSORY AND PERCEPTUAL ORGANIZATION OF PRESENTED DATA

Along with increasing 3–D visual representation of information, advanced avionics incorporate control by new methods, such as voice and eye contact. Sound is generated in 3–D, which not only allows increased sensory capability, but also positional hearing; sound acts as a pointer for a radius of 3–5 degrees. The future development of Super Cockpits includes an ultra–high–fidelity sound system that will act as the pointer for objects and targets, and also serve as a voice–operated weapon–system command. Coupled with this, research is now ongoing for a mechanism that will allow the pilot to move objects on the screen with simple movement of the eyes.

2.4.4. INTERFACE CONTROL STRUCTURE(S)

One aspect of interface control is rapid reconfiguration of controls and displays, with easy conversion between air–to–air and air–to–ground combats. Advanced aircraft and rotorcraft will have on–board display libraries from which the pilot can choose the display format he needs, as well as change it. Map inserts and video–mixing are currently being incorporated in some flight simulators. Rapid reconfiguration has direct relevance to helmet–mounted displays. Certain status monitor information displays, such as fuel gauges and altitude will be presented to the pilot with symbology: characters; and icons. However, terrain mapping for mission status and tactical information will be displayed with imagery in helmet displays. Since these are essentially TV images, imagery is readily adaptable to reconfigurable controls.

2.4.4.1. WHOLISTIC DESIGN PRINCIPLES OF HUMAN–SYSTEM INTERFACE

If the pilot needs a "virtual" world presented to him, there also needs to be an integration of sensor imagery and Heads–up–Display (HUD) symbology with HMDs, or total projection of imagery through the HMD. With some variation between developers of Super Cockpits, the HUD is generally the primary display, with the HMD providing the visual imagery, including terrain, targeting information, weapons information and threat data. However, there is increasing research on "stand–alone" helmets that will give the pilot a wide FOV with projection of "the world as it is really organized so he can orient his eye to something in space and interact with it." (9)

2.5. TASK RELATED VISUAL INFORMATION AND DISPLAY REQUIREMENTS

2.5.1. MISSION TASK ANALYSIS

Missions may be categorized by type. Each mission may, in turn, be broken into a sequence of tasks, each of which may be trained separately. Tasks, in turn, may be further subdivided into subtasks, each requiring information from within (via instruments) or from outside the cockpit, via the visual scene. Radar and Forward–Looking–Infra–Red (FLIR) indications, of course, are generated by displays within the cockpit on the instrument panel, on HMD devices, or on a HUD.

2.5.2. MISSION TYPES

Mission types vary greatly in their requirements for Out–the–Window (OTW) visual scenes and fidelity or richness of visual cues. Instrument flight, in fact, requires no visual cues, except for the initial phases of taxi and takeoff and the final phases of approach and landing. In the visual presentation for rotorcraft, nap–of–the–earth (NOE) flight, poses the most stringent requirements for visual cue presence, with the pilot spending a minimum of time "head down" looking at instruments.

To find the maximum requirements for displays, four mission types have been isolated: Nap–of–the–Earth (NOE); Search and Rescue (SAR); Air–to–Ground (A/G) Combat; and Air–to–Air (A/A) Intercept. These are discussed below.

2.5.2.1. NAP–OF–THE–EARTH

The most stringent requirement for rotorcraft, and the most critical, is terrain following and terrain avoidance (TF/TA). Because of the necessary tradeoff between masked time and speed, identification of objects relevant to the progress of the flight is crucial. In terms of synthetic imagery for OTW, the pilot needs cues with high object detail for distance perspective relative to motion. One such motion perspective can be provided with a 3–D "time–to–impact" depth map of the visual fields. Additionally, the Area–of–Interest (AOI) needs to be head–directed with a relatively small FOV.

2.5.2.2. SEARCH AND RESCUE

In a typical SAR mission, the pilot relies heavily on on–board navigational information systems and displays, and on radio contact with ground stations. Aircraft flight symbology and enhanced navigational display features provide important information, with synthetic imagery generated in–cockpit needing high detail object identification. Sensor systems, including LLLTV, FLIR or radar could be configured to provide a limited set of cues on a helmet display to aid visual acquisition as an alternate format.

2.5.2.3. AIR–TO–GROUND COMBAT

A/G Combat requires extensive flight operations at low altitude. Terrain following and terrain avoidance for low level flight demand highly detailed visual scenes, and navigation to and from targets, which is highly task–intensive, requires an electronic tactical map. The pilot needs continuously updated situational awareness information with threat locations. A 3–D (top perspective) target map with range, location, distance from ownship, capability, and representation of moving ownship will provide important visual cue information for that situational awareness. For threat information, a tactical display of the ground order of battle is important for updating information on the dynamic movement of enemy ground targets. FLIR imagery of weapons deployment results is also critical for A/G flight. Where out–the–window scene information is present, synthetic or sensor derived video should be distorted and scaled to match the perspective of the observed scene, as seen through the visor. This reduces visual data conflicts.

2.5.2.4. AIR–TO–AIR INTERCEPT

In an air–to–air intercept scenario, the pilot relies heavily on ground controlled intercept instructions and uses the on–board air–to–air radar extensively. The intercept usually involves flight in clouds and instrument conditions. The pilot needs target identification of Friend–or–Foe (IFF) before engagement, and situational assessment for Probability of kill (Pk) of ownship and target, maneuverability and location of target, and coordination of sensors and missiles. As in A/G, weapons deployment results are critical.

2.5.3. INFORMATION REQUIREMENTS

2.5.3.1. MISSION PHASES AND SUBTASKS

Each mission type has a set of phases with subtasks and required information necessary to complete those subtasks. Table 2.5.3.1–1 illustrates the relationship between mission phases, subtasks and information requirements for air–to–air intercept.

2.5.3.2. DISPLAY CONTENT

From the visual cue analysis and the mission–related information requirements, it is possible to categorize the minimum display contents that the system must provide:

a. Generation and Presentation of Ownship Information;
b. Generation and Representation of Flight Information;
c. Imaging Sensors;
d. Sensor Integration;
e. 3–D Synthetic Terrain Display (On–Board Decision–Aid);
f. 3–D Moving Maps;
g. Radar Information;
h. Terrain Following/Avoidance;

Table 2.5.3.1–1. Mission Phases, Subtasks and Information Requirement

Phase	Subtasks	Required Information
Pre–Flight, Launch and Departure	Reticle Alignment On–Board Systems Check Flight Control Check Monitor/Control Heading Monitor/Control Attitude Monitor/Control Altitude Monitor/Control Speed	Systems Status Heading Attitude Altitude/Speed Time Distance–to–Go
Navigation	Terrain Following/ Avoidance Correlation of Ownship Position Airspace Monitoring	Terrain Profile Identifiable Objects Obstacle Positions Navigational Info
En Route Maneuvers	Interpret Terrain Navigate Course Monitor Airspace Revise/Modify/Update Flight Plan Call Up Tactical Map Communicate With Ground Activate Weapons Sensors	Terrain Profile Attitude Heading Weapons Status Tactical Map Formation Status Ownship Location Distance–to–Go
Altitude Transit	Monitor Instrument Monitor Airspace Check System Status	Altitude/Speed Ownship Location Formation Status
Search and Identification of Enemy Aircraft	Acquire Targets Identify Targets	Tactical Maps Target Maps Sensors
Monitoring System Status	Monitor Ownship and Weapons Status	System Status Caution and Warning Weapons Status
Communications	Conduct and Receive Ground Communications Monitor Sensors Monitor Radar	Aural Communiques Needed for Mission Radio Frequency All Sensor and Radar

Table 2.5.3.1–1. MISSION PHASES, SUBTASKS AND INFORMATION REQUIREMENTS (Continued)

Phase	Subtasks	Required Information
Threat Encounter and Weapons Delivery	Acquire Targets Attack Targets Receive Enemy Detection Receive Hit/Assess Damage	Target Maps Tactical Maps Sensors Weapons Status Weapons Directionals Weapons Effects Damage Assessment Safe Zones/No Safe Zones Safe "Path Home"
Damage Assessment Ownship	Monitor Ownship Status Assess Damage Threshold	Hydraulic Electrical Pneumatic Engine Rotor
Return to Base	Monitor/Control Heading Monitor/Control Altitude Monitor/Control Attitude Monitor/Control Speed Complete Landing Checklist	Heading Altitude Attitude/Speed Position of Ownship

i. Tactical maps
j. Display of Lethality Information;
k. Weapons Status Information;
l. Display of Safe and No–Safe Zones; and
m. Display of "Safe Paths Home".

2.5.4. SCENE CHARACTERISTICS

From the mission types, and coupled with the more general display contents, type and quantity of scene characteristics with display resolution and FOV can be derived, as illustrated in Table 2.5.4–1.

Table 2.5.4–1. TASK–RELATED OBSERVER REQUIREMENTS

Mission type	Resolution	FOV	Scene Characteristics
NOE	Medium/High	30 X 40	Synthetic Terrain 3–D Depth Map 40 Moving Models 100 Symbol Units 50 Graphics Units/25 Moving Color
SAR	Medium	80 X 180	Synthetic Terrain Radar Display 40 Moving Models 50 Symbol Units 50 Graphics Units/25 Moving Color
A/G Combat	High	80 X 180	Synthetic Terrain 3–D Target Map Radar Map 3–D Tactical Situation Map 2–D Weapons Information 60 Moving Models 150 Symbol Units 50 Graphics Units/25 Moving Color
A/A Intercept	High	80 X 180	Synthetic Terrain 3–D Target Map Radar Map 3–D Tactical Situation Map 2–D Weapons Information 60 Moving Models 100 Symbol Units 50 Graphics Units/25 Moving Color

2.5.5. VISUAL INFORMATION CUES

The specific information requirements are presented to the pilot with visual cues. These are listed below, organized by type.

Flight Control Cues

Alignment Reticle
Artificial Horizon
Field–of–View (FOV) Center
Ground Speed
Airspeed
Error Speed
Roll/Pitch
Bank
Acceleration (G)
Vertical Velocity
Tachometer
Torquemeter
Barometric Altimeter
Bearing to Waypoint
Hover Indicator
Heading
Lubber Line
True Magnetic Heading Indicator
Terrain Following – Terrain Avoidance (TF/TA)

Communications Cues

System
Channel
Frequency
Mode
Target Assignment
Mission Updates

Terrain Mapping Cues

Terrain
Trees
Railroad
Road
Town/Cities
Isolated Structures
Power Lines
Power Poles

Lakes
Towers
Rivers
Ownship

Navigation Cues

Time
Time–to–Go
Range
Ground Speed
Airspeed
Speed Error
Bearing to Waypoint
Hover Indicator
Heading
Altitude
Altitude Above Ground (AGL)
Altitude Above Sea Level (MSL)
Acceleration (G)
Gross Weight
Designation of Aircraft Position
Barometric Pressure
Outside Air Temperature (OAT)
Wind Velocity
Wind Direction
Turbulence Level
Storms/Lightning

Configuration Cues

Designation of Armament Load
Quantity of Armaments
Types of Armaments
Fuel Quantity
Fuel Weight
Engine Status
Fuel Flow
Wind Velocity
Wind Speed
Turbulence Level
Attitude
Damage Assessment

Friend/Foe Identification Cues

Friendly Aircraft
Unknown Aircraft
Hostile Aircraft
Ownship
Friendly Troops
Unknown Troops
Enemy/Hostile Troops
Enemy Radar
Tanks
Vehicles

Ground Target

Tactical Mapping Cues

Threats
Threat Envelope
Friendly Aircraft
Unknown Aircraft
Hostile Aircraft
Enemy/Hostile Troops
Unknown Troops
Friendly Troops
Enemy Radar
Ground Target
Armament Load – Ownship
Armament Load – Enemy
Ownship Position

Weapons Delivery Cues

Target Data
Search
Damage Assessment
Tactics
Strike Point
Acquisition Cursor, Air–to–Air
Target Designator/Radar Lock–on, Air–to–Air
Target Lock–On, Air–to–Air
Target Designator
Breakaway
A/G Targeting
Time–to–Go
Timing

Sensor Communications Cues
FLIR Elevation
FLIR Azimuth
FLIR Symbology Status
LLLTV Status
Radar – Identification Friend or Foe (IFF)
Radar Altimeter
Radar Warning Set (RWS)
Radar Warning Device (RWD)
Doppler Navigation
Radar and IR Jammer
Chaff and Flare Dispenser

Aircraft State Cues

Fuel

Fuel Flow
Engine
Engine Parameter
Power Turbine RPM
Rotor RPM
Torque
Oil Pressure
Oil Temperature
Hydraulics
Electrical
Pneumatics
Environmental
Flight Control
Automatic Stabilization
Fault Detection/Location

Caution and Warning Cues

Master Caution/Warning
Electrical Failure
Engine Out Of Limit
Degraded Control Surface
Hydraulic Failure
Hydraulic Out Of Limit
Hydraulic Inoperative
Hydraulic System Off Line
Generator Inoperative
Engine Fire
Engine Inoperative
Engine Vibration
Radar Overheat
Electronic Counter Measure (ECM) Failure
Fuel Valve Inoperative
Fuel Problem
Rotor Damage/Failure

2.5.6. RULES FOR DISPLAY

The shift from conventional through current to advanced in–cockpit imagery, or display format representation, has not eliminated some fundamental man–machine design questions. In fact, we have more questions than answers, so far. For example:

b. In what format should information be presented?
c. What simultaneous information does the pilot need to see?
d. How much simultaneous imagery is needed?
e. Should all types of information presented to the pilot be color? And if so, how much color is enough (too much)?
f. What is the proper mix of symbology and imagery?
g. What methods will be used for "de–cluttering" the screen?
h. Where should information be presented?
i. What is the optimum physical configuration of the displays?

j. How is a focal point of interest generated for the pilot?
k. How is tactical information communicated to or from the pilot?
l. Should information be completely integrated?
m. Is there a need for separate display of particular transitory features?
o. How is critical (or any) information prioritized?
p. How is the pilot to select which data and formats to use?
q. How much of the data display sequence should be automated?
r. How can data best be combined to present information?

It is possible, however, to delineate some rules for information display heuristics. The recommended format for the visual cues is listed in Table 2.5.6–1. Use those rules as a point of departure. Listed below are some of the rules, far from exhaustive, that relate directly to representation of in–cockpit information.

a. Every control and display should be logical, accessible and readable.
b. Cockpit design should be consistent in the use of displays and functions.
c. As far as possible, displays should be standardized, both in terms of symbology and color.
d. When possible, pictorial representation should take priority over any other display
format.
e. Alphanumerics without accompanying symbols should be used sparingly.
f. Displays and controls for like functions should be grouped together and encourage
viewing and operation from left to right, top to bottom, or back to front. (10)
g. Information should only be displayed at the needed time.
h. To reduce the amount of information displayed, especially at critical times, a declutter option should be provided to the pilot.
i. Zoom capabilities should be available to reduce clutter.

Table 2.5.6–1. Visual Cues with Recommended Format and Display Device

Visual cue	Update Rate	Recommended Format Display	Display Device
Alignment Reticle	10	Icon	Helmet
Artificial Horizon	60	Line	
Field–of–View (FOV) Center	60	Icon	
Ground Speed	10	Symbol + Alphanumerics	
Airspeed	10	Symbol + Alphanumerics	
Error Speed	10	Symbol + Alphanumerics	
Roll/Pitch	60	Symbol + Alphanumerics	
Bank	60	Symbol + Alphanumerics	
Vertical Velocity	60	Polygon	
Tachometer	60	Symbol + Alphanumerics	
Torquemeter	60	Symbol + Alphanumerics	
Barometric Altimeter	30	Symbol + Alphanumerics	
Bearing to Waypoint	30	Icon	
Hover Indicator	30	Icon	
Heading	30	Icon + Alphanumerics	
Lubber Line	30	Icon	
True Magnetic Heading	1	Alphanumerics	
Terrain Follow/Avoid	30	Icon	
Deceleration	1	Alphanumerics	
Time	1	Alphanumerics	
Time of Day	1	Alphanumerics	
Time–to–Go	1	Alphanumerics	
Range	1	Alphanumerics	
Bearing to Waypoint	30	Icon	
Altitude	60	Icon	
Altitude Above Ground	60	Alphanumerics	
Altitude Above Sea Level	60	Alphanumerics	
Gross Weigh	10	Alphanumerics	
Designation of Aircraft	60	Icon	
Sound Level	1	Symbol + Alphanumerics	
Combined Terrain/Culture	60	Icons/Polygons	Helmet
Terrain			
Trees			
Railroad			
Road			
Town/Cities			

Table 2.5.6–1. Visual Cues with Recommended Format and Display Device (Continued)

Visual Cue	Update Rate	Recommended Format Display	Display Device
Isolated Structures			
Power Poles			
Power Lines			
Lakes			
Towers			
Rivers			
Ownship			
Combined Weather Map	60	Polygons + Alphanumerics	Helmet
Barometric Pressure			
Outside Air Temperature (OAT)			
Wind Velocity			
Wind Direction			
Turbulence Level			
Combined Stores Display	10	Icons + Alphanumerics	Helmet
Designation of Armament Load			
Quantity of Armaments			
Types of Armaments			
Threats/Targets			Helmet
Target Assignments	10	Alphanumerics	
Mission Updates	60	Alphanumerics	
Damage Assessment	30	Icon or Alphanumerics	
Friendly Aircraft	30	Icon	
Unknown Aircraft	30	Icon	
Hostile Aircraft	30	Icon	
Ownship	30	Icon	
Friendly Troops	30	Icon	
Unknown Troops	30	Icon	
Enemy/Hostile Troops	30	Icon	
Enemy Radar	30	Icon	
Tanks	30	Icon	
Vehicles Icon	30	Icon	30
Ground Target	10	Symbol	10
Threats	60	Icon/Polygon	60
Threat Envelope	60	Polygon	60
Flight Envelope	60	Polygon	60

Table 2.5.6–1. Visual Cues with Recommended Format and Display Device (Continued)

Visual Cue	Update Rate	Recommended Format Display	Display Device
Armament Load – Ownship	10	Icon	
Armament Load – Enemy	10	Icon	
Target Data	30	Symbol + Alphanumerics	
Search	60	Symbol	
Tactics	60	Symbol	
Strike Point	30	Symbol	
Acquisition Cursor, A/A	30	Symbol	
Target Designator/	30	Symbol	
Radar Lock–on, A/A	30	Symbol	
Target Lock–On, A/A	30	Symbol	
Target Designator	10	Symbol	
Breakaway	10	Symbol	
A/G Targeting	10	Symbol	
Timing	10	Alphanumerics	
System Status/CAW			Helmet
Fuel Quantity	10	Icon + Alphanumerics	
Fuel Weight	10	Icon + Alphanumerics	
Fuel Flow	10	Icon + Alphanumerics	
Fuel	10	Symbol	
Fuel Flow	10	Symbol	
Engine	10	Symbol	
Engine Status	10	Icon	
Engine Parameter	10	Symbol	
Power Turbine RPM	10	Symbol + Alphanumerics	
Rotor RPM	10	Symbol + Alphanumerics	
Torque	10	Symbol	
Oil Pressure	10	Symbol + Alphanumerics	
Oil Temperature	10	Symbol + Alphanumerics	
Hydraulics	10	Symbol + Alphanumerics	
Electrical	10	Symbol + Alphanumerics	
Pneumatics	10	Symbol + Alphanumerics	
Environmental	10	Symbol + Alphanumerics	
Flight Control	10	Symbol + Alphanumerics	
Automatic Stabilization	10	Symbol + Alphanumerics	

Table 2.5.6–1. Visual Cues with Recommended Format and Display Device (Continued)

Visual Cue	Update Rate	Recommended Format Display	Display Device
Fault Detection/Location	10	Symbol + Alphanumerics	
Master Caution/Warning	10	Symbol + Alphanumerics	
Electrical Failure	10	Symbol + Alphanumerics	
Engine Out Of Limit	10	Symbol + Alphanumerics	
Degraded Control Surface	10	Symbol + Alphanumerics	
Hydraulic Failure	10	Symbol + Alphanumerics	
Hydraulic Out Of Limit	10	Symbol + Alphanumerics	
Hydraulic Inoperative	10	Symbol + Alphanumerics	
Hydraulic System Off Line	10	Symbol + Alphanumerics	
Generator Inoperative	10	Symbol + Alphanumerics	
Engine Fire	10	Alphanumerics	
Engine Inoperative	10	Symbol + Alphanumerics	
Engine Vibration	10	Symbol + Alphanumerics	
Radar Overheat	10	Symbol + Alphanumerics	
Electronic Counter Measure (ECM) Failure	10	Symbol + Alphanumerics	
Fuel Valve Inoperative	10	Symbol + Alphanumerics	
Fuel Problem	10	Symbol + Alphanumerics	
Rotor Damage/Failure	10	Symbol + Alphanumerics	
Sensor			Helmet
FLIR Elevation	60	Polygon	
FLIR Azimuth	60	Polygon	
FLIR Symbology Status	60	Icon/Polygon	
LLLTV Status	60	Icon/Polygon	
Radar – Identification Friend or Foe (IFF)	30	Icon	
Radar Altimeter	30	Icon	
Radar Warning Set (RWS)	30	Icon	
Radar Warning Device (RWD)	30	Icon	
Doppler Navigation	30	Icon	
Radar and IR Jammer	30	Icon	
Chaff and Flare Dispenser	30	Icon	

2.5.7. EMPIRICALLY DERIVED MINIMUM DISPLAY REQUIREMENTS

Interviews with AH–64 test pilots determined that pilots can use sensor sights at night for nap–of–the earth flight, even with their limited fields of view. The pilot instinctively alters his normal daylight viewing behavior by sweeping the sight (PNVS) left and right to view the terrain on either side of the flight path, thereby obtaining enough scene information to provide "situation awareness" and avoid terrain contact. No doubt clearance altitude is increased and airspeed is reduced, compared to daytime conditions. While tasks can be performed under these conditions, the field of view is marginal at best and only serves to peg the minimum instantaneous field of view a helmet display should be capable of. The depicted scene is in monochrome, but luminance levels, contrast, resolution, update rates and other factors are comparable to what one would require for the research HMD, field of view being the primary detractor. This situation represents a "worst case" requirement context.

2.5.8. RESEARCH RELATED REQUIREMENTS

Research requirements were derived to obtain the maximum performance available with current technology. The traditional "big three" display factors of field of view, resolution and perceived luminance were juggled to provide a set of requirements which greatly exceed the worst case sensor derived requirements and are less than the best case, but currently unobtainable, instantaneous field of view and resolution demanded by an observer's air–to–air target acquisition task. Image quality and stereo factors were also included.

The following factors were among those considered:

1. The field of view was set by the widest available visor choice which still permitted reasonable resolution to be displayed. The image generator is not required to provide full out–the–window scenes, but the wide format is required to investigate how data and information may best be presented within and around the OTW scene observed through the visor.

2. The resulting resolution available is approximately 3 arc–minutes per pixel, which is sufficient for the symbology and data formats likely to be investigated, but insufficient for long range target acquisition, which is not required.

3. Luminance levels and contrasts afforded by the laser scanned system are excellent. Visor optical characteristics permit good ambient scene throughput (>50%) and good display throughput so that relative luminance levels of the display with respect to the ambient scene may be varied over a wide range.

4. Scan parameters of line and field rates are sufficiently high as to be adequate for the presentation of flicker–free imagery of good image quality. These factors should not confound the measurement of observer performance data for the formats chosen to be investigated.

5. Provisions for adjusting the center of the display to each eye is provided to allow a full range of stereopsis (0 to 40 degrees) to be investigated and to allow for anthropometric variance in interocular distance over 5th to 95th percentiles. The exact mechanical arrangement for doing this will be implemented during the development and integration of the scanner subsystem with the visor optic subsystem.

2.5.9. REQUIREMENTS SUMMARY

Figures 2.5.9–1 through 2.5.9–6 depict the requirements for the helmet display system, as are required for the intended use of the HMD as a research tool.

2.5.10. SUMMARY

From the foregoing analysis, it is possible to set display requirements for the rotorcraft HMD. While specific technologies will be analyzed and reported as part of Task 2, a brief summary of findings is presented here to conclude Task 1.

The information requirements and representation analysis has yielded some boundaries for the HMD. The FOV ranges from 30 by 40 to 80 by 180 degrees with high resolution. Update rates range from 1 to 60 Hz (Table 2.5.6–1). Except for sensor information, projected imagery will need to be in full color with translucency.

Following trends in advanced avionics, the rotorcraft HMD will need to project 3–D imagery, situational awareness data, maps, a relatively large number of moving models, symbols, and graphics. The helmet will also have to integrate HUD and sensor information by overlay or by separate channels. Based on the task–related information cue analyses, the most stringent requirement for the system will come from NOE flight, where high–detail object identification and synthetic terrain are needed. A/G combat and A/A intercept pose the most stringent requirements on moving models, and 3–D threat and target information.

References

1. Two GE/SCSD ongoing projects, the Pilot's Associate (PA) Program and the Rapidly Reconfigurable Crewstation (RRC) Project, have entailed in–cockpit imagery design. Pilots from the Center for Advanced Airmanship (CAA) and on–site at Daytona Beach were interviewed on several occasions to determine pilot preferences for display format and location. These interviews were conducted over a year span and includes round–table "brainstorming sessions", open–ended questionnaires, and closed (quantitative) questionnaires.
2. Marvin Leibstone, "Human Factors and Cockpit Technology", Military Technology, July 1988, p. 69.
3. For example, such physical considerations in cockpit design as the possible trade–off between the "best" seat adjustment for the pilot and allowable weight of the aircraft.
4. The literature includes: government specifications for several aircraft, fixed– and rotor–wing; research papers; conference papers; journal articles; and books.
5. "Military Avionics", Avionics, May 1986.
6. "Super Cockpit", Flight International, 7 March 1987, reprint of T. Furness and D. Kocian, Putting Humans Into Virtual Space.
7. Steven L. Thompson, "The Big Picture", Air and Space, April/May 1987.
8. Super Cockpit Industry Days, Armstrong Aerospace Medical Research Laboratory, Wright–Patterson AFB, Ohio, 31 March – 1 April, 1987
9. "Military Avionics", op it.
10. Cary R. Spitzer, "Matching Avionics to the Aircraft", Avionics, November 1988, p. 30.

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY

DISPLAY REQUIREMENTS

SCSD

	MAXIMUM (WITH OTW VISUALS)	MINIMUM (SENSOR + SYMBOLOGY)	RECOMMENDED FOR RESEARCH
FIELD OF VIEW (TOTAL)	80V/180H	30V/40H	60V/110H
EACH EYE	80V/110H	30V/40H	60V/75H
BINOCULAR OVERLAP	40	(NR)	40 DEG
RESOLUTION (PIXEL SIZE)	1 ARCMIN	2–3	2–3.5
AT EYE LUMINANCE	6 FT–L	3–4	3–8
COLOR GAMUT	CONTIN.	8 BIT (LIMITED)	8 BIT CONTIN.
GREY SCALE LEVELS	12–BIT	8 BIT (256)	8 BIT (256) RBB
TRANSMISSIVITY	100%	10–25%	20% MINIMUM
EXIT PUPIL SIZE	25MM	10–15MM	>15MM
INTEROCULAR ADJUSTMENT	58–72MM	58–72MM	58–72MM
OVERLAP ADJUSTMENT	0–40 DEG	0–40 DEG	0–40 DEG
LUMINANCE/COLOR MATCH	YES	YES	YES
COLLIMATION	1 FT–INF.	2FT–INF.	2FT–INF.
EYE RELIEF	15MM	15MM	15MM

Figure 2.5.9–1. Display Requirements

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY
RASTER FORMAT

SCSD

LINE RATE	=	1024
INTERLACE	=	NON
PIXELS/LINE	=	1280
ASPECT RATIO	=	3:4
UPDATE RATE	=	60
FRAME RATE	=	60
DISTORTION	=	< 1%
GAMMA	=	ADJUSTABLE, 1.5 –3
SMEAR/LAG	=	INDISCERNIBLE
STABILITY	=	LESS THAN 1/2 %
JITTER	=	<.05 %
FLICKER	=	INDISCERNIBLE

Figure 2.5.9–2. Raster Format

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY
HELMET MECHANICAL / CONFIGURATION

SCSD

- WEIGHT < 5 LBS.
- CENTER OF GRAVITY – MINIMIZE DIFFERENCE FROM NORMAL HEAD C/G
- FOV INTRUSION – MINIMIZE
- FITMENT, COMFORT ADJUSTMENT – PAD INSERTS OR INFLATABLE BLADDER
- UMBILICAL – QUICK DISCONNECT, FLEXIBLE, NORMAL HEAD MOTION RANGE
- SHARP PROTRUSIONS – NONE
- HEADSET, MICROPHONE PROVISIONS – YES
- SHOCK PROTECTION, ELECTRICAL – YES
- DURABLE CONSTRUCTION – YES

Figure 2.5.9–3. Helmet Mechanical Configuration

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY

HEADTRACKER REQUIREMENTS

SCSD

● TRACKING ANGLES	=	FULL HORIZONTAL: +/–120 DEGREES VERTICAL: +60/–30 DEGREES
● ACCURACY	=	1% ANGULAR
● TRANSLATION VOLUME	=	20" CUBE
● TRANSPORT DELAY	=	<75 MS (TOTAL SYSTEM)
● UPDATE RATE	=	60 HZ
● LINEARITY COMPENSATION	=	ADJUSTABLE
● DATA SIG/NOISE RATIO	=	>30 db
● EMI SUSCEPTIBILITY	=	NO
● BORESIGHT	=	SIMPLIFIED PROCEDURE
● CALIBRATION		SIMPLIFIED PROCEDURE
● SIZE		<1.5 " CUBE
● WEIGHT		< 6 OZ
● UMBILICAL MOUNTING		FLEXIBLE WITH DISCONNECT

Figure 2.5.9–4. Headtracker Requirements

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY
EYETRACKER FACTORS

SCSD

- USED FOR CONTROL POINTING
- 1/2 DEGREE ACCURACY
- > 60 HZ UPDATE
- SIMPLIFIED CALIBRATION PROCEDURES
- +/– 20 DEGREES ACCEPTANCE ANGLE
- LOW DATA NOISE

Figure 2.5.9–5. Eyetracker Factors

GENERAL ELECTRIC

RASTER GRAPHIC HELMET
MOUNTED DISPLAY STUDY
HELMET DISPLAY PHYSICAL DESIDERATA

SCSD

The all–up weight of the helmet plus display shall be less than five pounds.
The display components shall be conformal with projections to the top and sides minimized and covered by a protective shell for durability.
The center of gravity of the helmet plus display shall be approximately as that of the head alone.
The display assembly shall either attach to a personal helmet or have provisions for easy adjustment to fit 5th to 95th percentile head sizes snugly.
The umbilical shall be small, light, not restrict movement and have a disconnect.
Adjustments for focus, interocular variance, boresight and overlap.
Materials shall be durable, light, shatterproof and non–conductive.
Test fixtures and software with graphics/data shall permit rapid alignment of the optics and headtracking (and/or eyetracking) hardware.
Provisions for fitting headsets, a microphone and oxygen mask shall be made.
Eye relief should be sufficient to allow spectacles to be worn.

Figure 2.5.9–6. Helmet Display Physical Desiderata

2.6. DISPLAY REQUIREMENTS FOOTNOTES

2.7. DISPLAY REQUIREMENTS BIBLIOGRAPHY

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CHAPTER 3

3. TECHNOLOGY ASSESSMENT

3.1. PURPOSE

This chapter will serve to address the Task 2 requirements stated in the Statement of Work (SOW). In summary, the SOW requires: 1. preparation of a taxonomy matrix of technologies showing developmental risks and potential performance gains as a function of time, and, 2..an assessment of new enabling technologies and HMD media,. These key subtasks will be addressed to most quickly derive the key characterizes of all HMD approaches, determine where current technology limitations exist and what design approaches are best for both generating full color, high resolution images and overcoming limitations of current designs. From that basis, we define what enabling technologies are required and what risks are involved.

3.2. APPROACH

All HMD designs employ components both on and off–helmet as part of the overall system. It is important to minimize the weight and size of on–helmet components while providing good displayed image quality. All HMD systems must have some form of visor optics and eye and/or head–tracking components on–helmet. In addition, a real image of the scenes to be depicted must also be available for use by the visor optics and subsequent viewing by the observer. The raster generator which forms the images and the visor optic components are the two key subsystems which characterize an HMD design and are the two areas most needing development for color HMD designs. The fundamental requirements are to allocate the heavy, bulky components of the raster generator off–helmet, minimize the size and weight of on–helmet components and provide a small, flexible umbilical between the two. (See Figure 3.2–1).

3.3. RASTER GENERATOR TAXONOMY MATRIX

A properly organized taxonomy matrix is an effective means of conveying the manner by which a color raster may be generated for HMD use. This approach may be shown to categorize existing color and monochromatic HMD display processes, and it allows the characteristics of new technologies to be weighed effectively as they would apply to a new helmet design. Such a matrix is depicted in Figure 3.3–1, where the fundamental assumption is that the image will be a raster format, suitable for use with a color image generator with traditional, or only slightly modified, video output formats. The principle characteristic is where pixel luminance is first generated: on–helmet or off–helmet and what type of scanning is used. The visor optic type is also a key discriminant. Generated off–helmet, an image pixel's luminance must be transferred to the helmet via optical fibers or fiber arrays. Scanning may be at each, either or both ends. On–helmet pixel luminance generation requires electronic video data transfer to the helmet via coaxial cables for scanning processes on–helmet.

The organization of the matrix in this particular form seemed to most clearly delineate where available and near term technology could be used for providing a color image. It is also based on an overview of existing helmet designs.

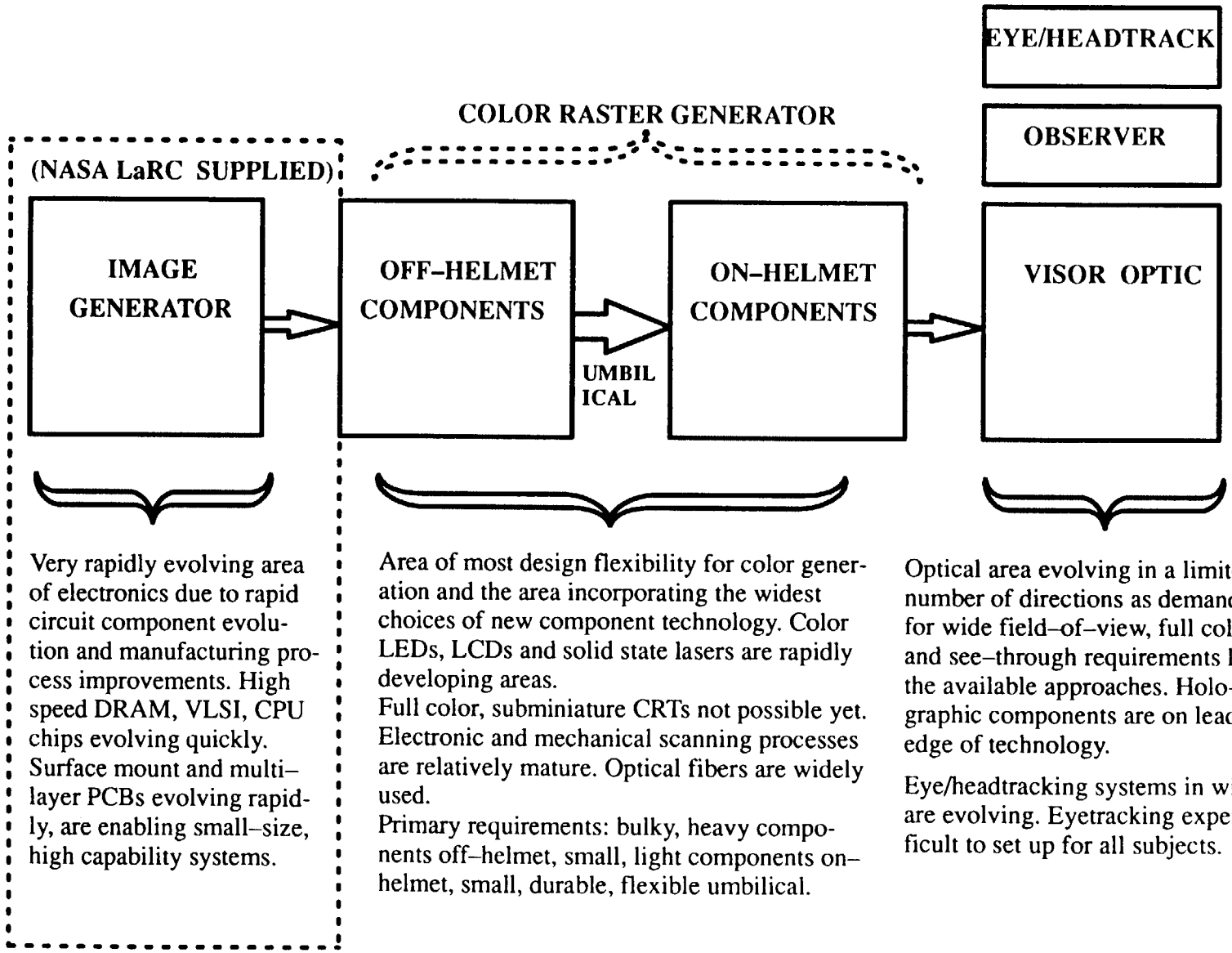

Figure 3.2–1. Technology Application Areas

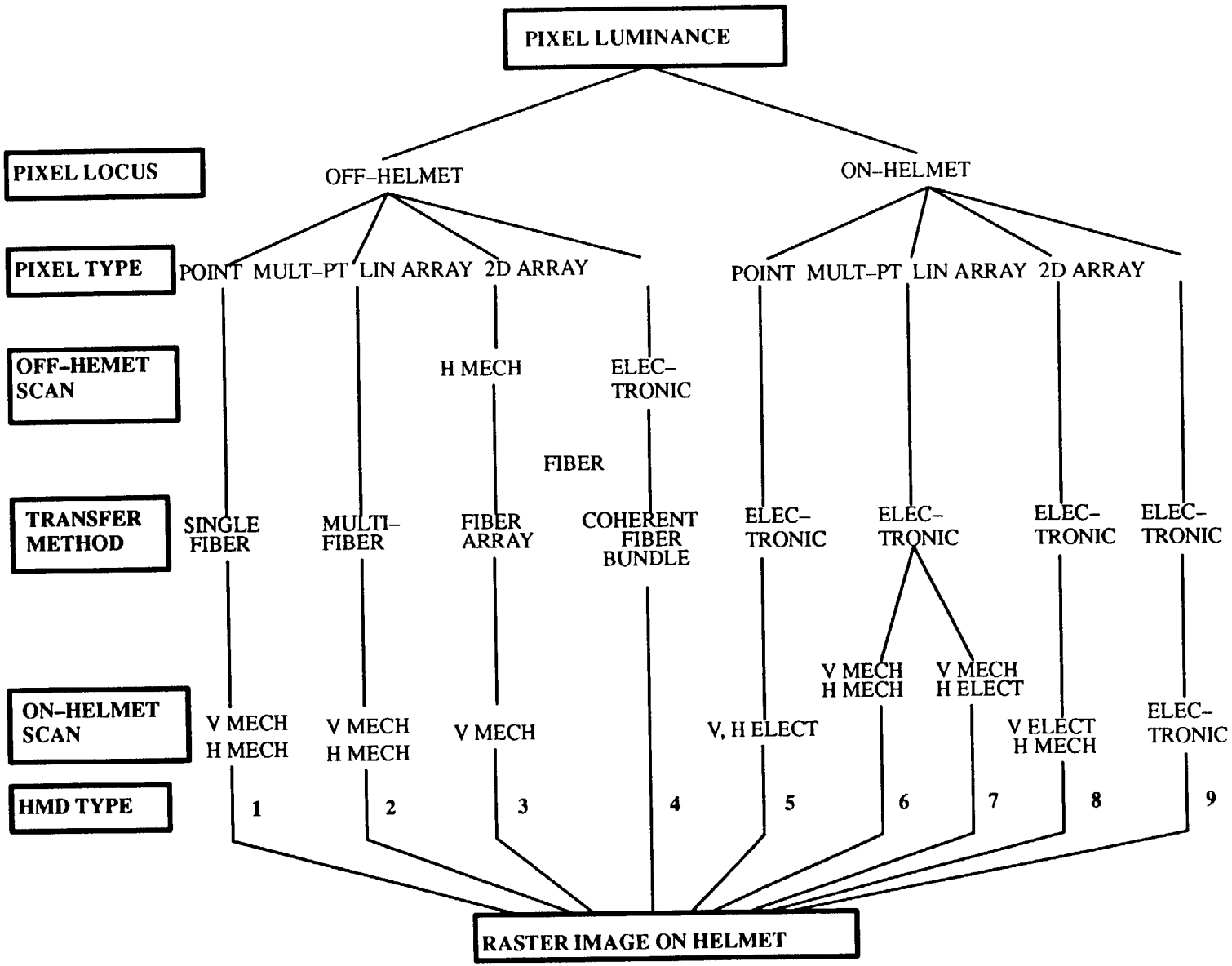

Figure 3.3–1. Taxonomy Matrix of Raster Generation Processes

Table 3.3–1. Taxonomy Matrix Examples of Helmet Display Systems

HMD TYPE	NAME	NOTES
Off–Helmet Pixel Luminance Processes		
1.	None Known	The scan rates required to mechanically scan a single pixel on–helmet are excessive. Acousto–optic scanning is possible at the required rates, but multiple wavelength (color) deflection is an issue with A–O scanners.
2.	GE IR&D	Painting multiple (eight or more) scan lines simultaneously allows scan rates to be reduced to where galvonometer mirror scanners are possible. Under development. Laser sources used for high luminance and are off–helmet.
3.	VDRT (NTSC)	The VDRT system has been under development for several years. Lasers provide luminance which is scanned horizontally to form a scan line which is then sent to the helmet via a coherent optic fiber strip. Vertical scanning, projection on a dome then follows. Limited image quality.
4.	FOHMD (CAE)	The CAE HMD system enjoys some success and is currently the only wide FOV, good resolution, full color HMD design in use. Four GE light valves provide complete rasters for two background and two movable inset rasters. The primary deficit is the coherent fiber optic bundle required to convey the images is bulky and inflexible as an umbilical.
On–Helmet Pixel Luminance Processes		
5.	Many CRT HMDs	All monochrome HMD designs which employ sub–miniature CRTs as raster generators use this approach. Color is possible with field sequential color filters (rotating wheel), but image edge artifacts occur with motion. Beam penetration phosphors provide a limited color selection suitable for use as reticle/status displays. Multiple CRT (RGB) approaches are possible with weight and size penalties. LCD panels are typed here as 3–D arrays, rather than two–axis scanned point pixels.

Table 3.3–1 lists examples of existing HMD designs which may be categorized by the taxonomy matrix of raster generation processes. For each process, there is a limited set of technology which may be applied.

Table 3.3–1. Taxonomy Matrix Examples of Helmet Display Systems (Continued)

HMD TYPE	NAME	NOTES
Off–Helmet Pixel Luminance Processes		
6.	not known	Multipoint on–helmet pixels could be scanned mechanically to provide a high resolution, full color raster if the luminance sources can be made small and bright enough. This would be a variation of the Type 2 approach, where fibers could be replaced with RGB solid–state laser chip arrays. Visible RGB lasers are under rapid development. Currently, blue is generated by frequency doubling techniques using YAG or other crystals, which limit video modulation rates.
7.	GE/NASA	Full color may be generated on–helmet by using a special subminiature CRT to scan RGB data in the horizontal (fast) axis, while using a galvanometer mirror for vertical scanning. Fast RGB phosphors are required to prevent image smearing and special techniques must be used to provide good luminance without burning the phosphor.
8.	Private Eye	This inexpensive system employs an oscillating mirror to scan a linear array of red LEDs to form a complete image. Color is possible with an array of RGB LEDs (under development). It is currently in development and in limited use as a personal computer or terminal display. Worn on a headband, it could be adapted for HMD use if brightness, resolution, green and blue color LEDs and scan stability (one/eye) issues are resolved.
9.	All LCDs	Miniature LCD panels are widely under development, particularly in Japan. Small, thin, light and requiring little power, they offer promises of full color panels which could be used directly or as three monochrome panels, each backlit with RGB light (e.g. Kodak LC–500 projector). The requirements for small image size and high resolution are beyond current manufacturing capability, but development is rapid. The large number of interconnects demanded by high resolution require that row/column address decode circuits be incorporated on the display, increasing its size. Several non see–through HMDs are in use as research tools (NASA JSC) and improved versions are under development.

3.4. COLOR CAPABLE TECHNOLOGY FACTORS

3.4.1. LUMINANCE GENERATION COMPONENTS

Generating a raster can be done a number of ways, each requiring one or more color emitting pixels be scanned in some manner to form the raster. Off–helmet pixel luminance generation is conveyed to the helmet via optical fibers and the luminous ends are imaged directly or scanned and imaged. On–helmet luminance sources and additional scanning components, if required, must be small, light weight and not generate excessive heat. More luminance energy is available from off–helmet sources, since size and weight are not primary constraints. The choice of on–helmet luminance sources is more limited, particularly where color is required.

Off–helmet pixel luminance sources for point, multipoint , 2D–array or 3D arrays must be conveyed to the helmet via optical fibers. A single fiber would be needed for a point pixel, multiple separate fibers for multipoint, a linear fiber array for a 2D–array and a coherent fiber bundle for 3D arrays which convey a complete image. Obviously, luminance sources must be modulatable at high speed (up to 40 Mhz), be full color and be optically coupled tightly to the fibers. Being off–helmet, size, weight, heat generation and other requirements are less stringent than for on–helmet devices and more choices exist.

3.4.1.1. GAS LASERS

Gas lasers are mature technology, and as such, are obvious choices for off–helmet pixel luminance generation for several reasons. Units are available off–the–shelf which output red, green or blue wavelengths at power levels which range from < 1 mW to tens of watts, much more than is available from CRTs, light valves or other off–helmet sources. A full gamut of color is available over a broader range, saturation and purity than can be generated by other sources. Red, green and blue beams must be separately modulated at fast rates (up to 40 Mhz) by suitable devices, such as the Acousto–Optic–Modulator (AOM). These devices are also available off–the–shelf at the required speeds. The separately modulated beams must be combined and input to the optical fibers with suitable optical components, including dichroic reflective combiner elements and lenses for collimation and input to and from the modulators. These elements are also widely available.

The number of separate laser pixels required will depend on the design approach chosen and whether scanning occurs off–helmet. Multiple laser beams can be generated from a single source by using mirror/beamsplitter combinations which permit each beam to be separately modulated and combined.

Laser HMD designs are in use where line scanning occurs off–helmet and the complete scan line is conveyed to the helmet (NTSC VDRT projector) via a linear fiber array. A vertical scanner is mounted on the helmet which projects the complete image on a dome. Due to variance in transmissivity, image quality is poor ("streaky") when projected, and dome costs and size are issues.

A off–helmet laser system under research at GE and proposed for development by NASA LaRC uses eight discrete fibers per eye and scanning occurs in both axes on the helmet. Coupling efficiency is greater and variance in fiber transmissivity may be compensated for. The umbilical is expected to be small and flexible. Image quality, brightness and resolution are expected to be good.

3.4.1.2. SOLID STATE LASERS

Solid state laser diodes and diode arrays for color generation have only recently become available on the open market. Solid state lasers offer several important benefits as pixel luminance choices. First, if the laser directly emits light at the correct color, then direct modulation is possible at high video rates. This is currently not the case with blue, which is obtained by frequency doubling from infra–red wavelengths using YAG niobate compound crystals. Such crystals exhibit minimum drive level thresholds (become non–linear), have limited conversion efficiency (10–20%) and have limited modulation rates (~40 kHz), which are too slow for video. The evolution of solid state lasers is primarily an area involving molecular physics and manufacturing processes, but considerable development is in progress and it is expected that solid state lasers will supplant many gas lasers in new product designs.

Another particularly good characteristic of these devices is size. The chips themselves can be very small (< 1mm) and the emitting area can also be very small and suitable for direct imaging. Some edge–emitting IR devices used for laser printers (Kodak) have exit apertures < 10 microns in size. Such small size is perfect for mounting the pixel source on the helmet or in an array which can be scanned on the helmet. High luminance from small devices requires the use of a heat sink, but the small image required by a HMD limits the output needed if an efficient visor is used. Materials and manufacturing processes required to obtain all three colors are evolving from vendors such as Amoco. Costs are currently comparable or higher than gas lasers of equal power, but are expected to drop dramatically in the next few years as manufacturing processes improve. Processing is comparable to some phases of integrated circuit production. These lasers can be efficiently coupled to optical fibers directly by means of gradient–index (GRIN) lenses.

Eye safety is an issue with either gas or solid state laser units. The GE R&D approach uses a rear projection screen to form an image suitable for use with the visor optic relay lens, which should increase the exit pupil size and avoids the observer seeing the laser beam directly. An additional safety factor is to implement sensors which cut off the lasers if scanning fails.

3.4.1.3. LIGHT EMITTING DIODES

Light emitting diodes for IR, red, yellow and green have been on the open market for over a decade. Blue LEDs using a silicon substrate have been on the market for only about two years. These are currently produced with low yields by Siemens and recently by Cree Research, using high–purity silicon. Panasonic dropped out of the market, but continues research. The Siemens units have low luminance and low switching rates (< 1 MHz), making them unsuitable for use as single pixel luminance sources. Super bright red LEDs employing Gallium Aluminum Arsenide and phosphide compounds (GAASP) exhibit high output (>100 milicandelas) and fast switching speeds (>25 MHz). Arrays of these are use in HMDs (Private Eye). Green LEDs have moderate luminance output (~40 mcd) and moderate switching speeds (<7 MHz). They may be used in arrays, but present an unsaturated, yellow–green color. Siemens constructed and delivered several devices employing a quad array of one super red, one green and two blue LEDs for testing as color luminance sources. Switching speeds, low output and difficulty coupling it to a small fiber prevented it's use in the GE R&D HMD brassboard. It is expected that luminance output (particularly blue) and switching speeds will improve in the next few years. Cree research is investigating manufacturing processes which permit constructing improved diodes of all three wavelengths on a common high–purity silicon substrate. These devices may be directly applicable as either on–helmet pixel luminance sources in the next five years. Costs (and luminance output) are considerably lower than solid state lasers.

3.7.4.1.4. LIGHT VALVES

Light valve projectors are suitable for use off–helmet as color sources of complete images. Their output must be optically coupled to a coherent fiber optical bundle for transmission to the helmet, where it is imaged on the visor optics. Coupling of a two–dimensional, raster scanned color image to a coherent, two–dimensional array of fibers is not easily done without producing image quality problems. The luminance is carried only by the core of the optical fiber, which may have a cross–sectional area as little as one percent of the total fiber's area with it's surrounding cladding. Coupling efficiency is diminished accordingly, since only a small proportion of the image is transferred by the core, that in the cladding being lost by scattering and absorption. Further, fibers must be made as small as possible in order to have an umbilical which is not unduly stiff or large. CAE's successful FOHMD color HMD couples the images of four GE light valves, two for background imagery, two for high resolution sets, over four coherent bundles. The resulting umbilical is unduly cumbersome and somewhat inhibits natural head motion by the pilot.

The polished ends of the coherent bundle consists of a fiber array in which only the core of each fiber transmits scene luminance information. The reconstructed image on the other end exhibits a "chickenwire" appearance when viewed and resolution is limited to half the fiber pitch. The most commonly used method of dealing with the image quality and resolution issues, when a broad–band luminance source is used, is to employ a matching pair of prisms at each end of the fiber to smear an individual pixel's information across multiple fibers according to the wavelength of the pixel luminance. Constant deviation prisms are used and the process is termed "wavelength multiplexing", since a portion of each pixel's information is transmitted by multiple fibers. Artifacts, including the "black dot" appearance of broken fibers, are much reduced, although not totally eliminated, and resolution is improved by, typically, a factor of two. A similar problem exists for the NTSC VDRT laser helmet projector, which sends a complete scan line to the helmet via a coherent linear fiber array for subsequent vertical scanning and projection. The narrow bandwidth of laser light obviates the use of wavelength multiplexing techniques and image quality suffers.

3.4.1.5. CATHODE RAY TUBES

CRT projectors may be employed in the same manner as light valve projectors, but fewer lumens are available. Coupling efficiency and umbilical issues common to the light valve system remain. CRTs are a mature technology and costs are low.

3.4.1.6. SUBMINIATURE CRTS

Helmet display requirements have driven the design and development of subminiature CRTs for over two decades. Active screen sizes may be as small as 1/2 inch (Hughes), with typical CRT/deflection yoke weights as low as 800 grams (Thomas Electronics). No existing subminiature CRTs offer full color, since shadow masks cannot be manufactured for such small devices, nor can phosphor triads be deposited. Luminance output and resolution would be too low as well. Limited color is available from beam penetration CRTs at sufficient brightness to be useful as a reticle or system status HMD. Research over the last several years has addressed higher luminance output, more burn–resistant phosphors (single–crystal types), but manufacturing problems remain involving thermal expansion coefficient mismatches and transfer efficiency of the screen luminance. Additional research has significantly improved visor designs, with newer approaches (holographic elements) offering higher throughput efficiency and good ambient or outside visibility as well.

Resolution of the subminiature CRTs depends on the display spot size, which is a function of electron gun design and spot "blooming" that may occur as electron beam currents increase at the highest luminance output levels. For a CRT with a 1–inch active area, present limits are

slightly over 1000 lines, depending on the phosphor used. Single crystal phosphors have excellent spot characteristics and are used for electron gun testing. Screen luminance goals have been driven by the inefficiency of display visors with very inefficient optical transfer, such as the Farrand Pancake Window (< 7 percent), but newer holographic systems will surmount the problem with four to five times better transfer efficiency. Costs are only several thousand dollars per CRT/yoke assembly and are not expected to change appreciably in the next few years. Research continues.

Full color may be obtained from one or more subminiature monochrome CRTs by several methods. A field–sequential approach using a single, white–phosphor CRT will generate full color images if a synchronized RGB color segmented filter wheel is spun in front of the screen. At least one HMD has used this process and color imagery was sent from the moon using this approach at the camera end. Image quality problems are observed for objects which translate through the scene quickly, as would be the case with head motion. Colors are generated at detail edges due to the slow update cycle of each color in sequence. Resolution is good, since no shadow masks are involved.

A triplet of red, green and blue–phosphored subminiature CRTs could present high resolution, full color and good luminance by optically combining the images from all three. For stereopsis, six CRTs would add considerable weight and bulk to an HMD.

A mixed design employing one subminiature CRT (per eye) to produce full color has been devised for this contract. Shadow mask or grille designs are not feasible and a beam–indexed stripe approach is also not feasible yet. An alternate design using the CRT to paint the red, green and blue pixel data for one scan axis (horizontal, the fast sweep axis) and using a galvanometer to provide vertical sweep has been devised. The best approach calls for a subminiature CRT with a triple–beam, inline electron gun to sweep adjacent, parallel, red, green and blue phosphor stripes simultaneously. These color scan lines would be optically overlaid and scanned vertically by a small galvanometer–driven mirror to produce a complete image. Such a design offers low weight and employs current technology, so the design and implementation cycle may be relatively short. The unique components of this design have been incompletely researched at this point and issues remain as to whether a sufficiently fast red phosphor and subminiature 3–beam gun can be easily obtained. A single beam design with fast green and blue (slower red) phosphors can be acquired in several month's time at low cost. Chapter three will address this approach again.

3.4.1.7. LCD PANELS

Considerable progress has been made on both monochrome and color LCD panels in recent years. Most development has been by Japanese manufacturers for commercial products, such as pocket–sized TVs or laptop computer display screens. Research at GE CR&D has produced a 6–inch, full color panel suitable for avionics use. LCDS offer exciting promise as on–helmet image sources, since they are small, thin, light weight, consume very little power and are reasonably durable. Pixels are arranged in rows and columns and image data are updated in sequence. Better thin film transistor, active matrix (TFTLCD) designs exhibit good grayscale rendering and reasonably fast switching speeds (40 to 25 ms), making them suitable for helmet video. Active matrix designs differ from cheaper row/column address types by having an active component (thin film FET pixel driver) at the intersection of each row/column address. The FET is coupled with a small capacitor voltage storage element which stores luminance values between refresh cycles. Better gray scale is also possible with this approach. Ovonic Imaging Systems currently leads U.S. efforts with an 8 X 8 inch, 1,296 by 1,296 pixel active matrix, TFTLCD panel capable of color.

Color is usually produced by placing a color mask under the front surface of the LCD panel so that color subpixel triads or quads form color in a manner analogous to the action of color

triads or stripes on a CRT. LCD panels can be transmissive or reflective. More common transmissive design are illuminated from the rear by diffuse sources. Additional resolution and full color may be had by using three panels, separately illuminated with red, green and blue light, and combining the output using a combiner cube with dichroic filters. Kodak's LC–500 video/computer projector employs such an approach successfully.

Current resolution limits for small (Casio 5–inch diagonal) LCDs are 1.2 M addressable pixels per panel. Such panels exist commercially as units with color subpixel quads, which limit resolution. If the color mask were removed and three units were combined with RGB rear illumination, good color and resolution would result. Size would be more of a problem for helmet mounting. A field sequential approach using switched color for rear illumination is possible, but LCD switching speeds are not currently fast enough to reduce color movement artifacts.

Development areas exist for commercial color panels larger than 20 inches diagonal, which is the current state of the art. These larger panels are useful as product replacements for directly viewed CRTs and as computer and HDTV displays. Military systems also use displays of this type for various systems, since the LCDs can be ruggedized. Commercial markets exist for very small color TFTLCDs (video camera viewer) with good resolution, but manufacturing problems exist which make successful designs difficult. First, it is desirable to have both high resolution and a large proportion of the screen consist of active pixel areas. This means that row/column address lines and interconnects must be very small. As these transparent conductors become thinner, their resistance increases and adjacent row or column "bleedover" or "crosstalk" becomes a considerable problem. Secondly, as the active display area becomes smaller and resolution is increased, then the row/column address circuitry must be added to the periphery of the display to reduce the number of interconnect lines to manageable levels. This increases the overall size of the display around the active area.

The availability of small sized, high resolution LCD panels suitable for use as HMD color image sources is likely in the next five years and they will probably appear as low cost, commercial Japanese units.

3.4.1.8. ELECTRO–LUMINESCENT (EL) PANELS

EL panels are less difficult to manufacture, have a higher production yield and cost less than LCD panels. They are being widely developed as an option or substitute for LCDs. They are emissive, rather than reflective or transflective, offer lower luminance and have shorter lifetimes than LCDs. EL panels used for rear illumination of LCD screens for laptop computers typically experience a 50 percent drop in luminance in about 1500 hours. They also require more power than LCDs, typically 15W for a 12–in. display panel. EL panels have under development for about a decade, some of the first being developed at Westinghouse by T. P. Brody, who later spun off a new company to continue development.

Efforts to design color panels are ongoing and show promise for release within the next five years. The development of small panels with sufficient resolution and luminance output to be used as on–helmet image sources for an HMD is not currently promising, as LCD designs can be rear illuminated to provide the required image brightness.

3.5. SCANNING PROCESSES SUITABLE FOR HMDS

3.5.1. ELECTROMAGNETIC/ELECTROSTATIC DEFLECTION

Electromagnetic deflection is primarily used for CRT sweep deflection. Off–helmet video projectors which could be used to generate a complete image for transfer to the HMD by means of coherent fiber bundles would employ this process. GE light valves, in use with the CAE FOHMD system, actually use electrostatic deflection for both sweep and luminance

modulation. Modulation occurs when the electron beam in the light valve swept to either side of its scan line position at RF rates (tens of megahertz), so as to create a diffraction patttern on an oil film which causes color luminance to escape the Schlieren bars in the light valve. Changes in electron beam intensity are only used for blanking.

All on–helmet subminiature CRT HMD designs use electromagnetic deflection to generate a raster. The subminiature CRT is supplied with a conformal deflection yoke, giving the tube with yoke a cylindrical format. The combination is quite successfully employed in a wide variety of monochrome HMD designs. The proposed color stripe subminiature CRT design with either a single or the three–beam inline electron gun would also use electromagnetic deflection. The single–gun approach would use an existing deflection and gun assembly, but horizontal sweep rates would be some three times that normally used. The inline gun may require that a yoke be tailored to properly drive three beams. The cost of subminiature CRTs are relatively low, on the order of one to several thousand dollars, which is a fraction of the cost of a typical visor optics system. Deflection systems are mature technology.

3.5.2. ACOUSTO–OPTIC DEFLECTION

Acousto–optic deflection is suitable for deflecting laser beams in one axis at extremely fast (>30 MHz) rates over small angles (< 5 degrees). Similar to the acousto–optic modulator (AOM), the device is optimized for specific wavelengths. It is suitable for use as a horizontal beam scanner in high line rate laser systems and can be used with galvanometer or faceted mirror scanners for vertical sweep to form a small complete raster image. It is small and light enough to be used on an HMD and requires little power, but color and image size issues remain.

3.5.3. GALVANOMETER MIRROR SCANNERS

Galvanometer mirror scanners employ an open– or closed–loop galvanometer servo to position a small mirror to a commanded angle. Mechanical deflection angles may exceed 30 degrees, in an optical deflection angle of twice that. These small, motor–like devices can deflect mirrors at rates up to several hundred hertz, but rates depend on the mirror/armature moments of inertia, the power of the galvo and drive levels. Faster galvanometer scanners are available as open–loop, torsional pendulum types. These devices may have beryllium mirrors, which have low inertial moments and are stiff enough to resist distortion at rates up to four kilohertz. These devices are resonant scanners, and if tuned to drive waveform frequencies to within one–half percent, may be synchronized with the sweep waveform. They produce a sinusoidal sweep, and scan lines can be made reasonably linear if active video is produced over 85 percent of the angle (65 % of the waveform period). Under these conditions, pixel dwell times are approximately twice as short in the center than at each edge.

A combination of a closed–loop scanner and a sinusoidal scanner can be used to scan a complete image if multiple scan lines are painted at once. Using eight simultaneous scan lines allows an interlaced, 1000–line image format to be produced using a four kilohertz resonant scanner in the horizontal axis and a linear, closed loop scanner running at 60 Hz vertically. A 2000–line interlaced/1000–line non–interlaced format is being set up which will paint scan lines in both directions. The active line count in the raster is only limited by the mechanical flyback and settling time of the linear vertical galvo. Further, if each laser beam is equally displaced vertically, vertical sweep angle requirements are reduced by a corresponding amount. This approach is used by the GE R&D system presented in this contract. The optical layout chosen permits small mirrors to be used, so both galvo units are quite small (approximately 1 X 1 X 2 inches for each galvo), and are lightweight.

3.5.4. ROTATING POLYGON MIRROR SCANNERS

Rotating polygon mirror scanners offer two primary advantages over galvanometer–type (particularly resonant–types) scanners for optical scanning at high rates. Specifically, sweep

angles are linear with time (not sinusiodal) and flyback, or retrace, times are usually much lower and depend only on the beam size with respect to the mirror facet size. Beams must be cut off where a portion of the beam falls on two adjacent facets. Novel approaches using two switched beams at slightly different feed angles allow this retrace time to be essentially zero. But rotating polygon mirror scanners are only useful for optical scanning off–helmet. They are large, noisy, require compressed air for high speed bearings, exhibit excessive gyroscopic effects and have safety considerations (mirror wheel explosion) at the high rates employed (up to 35 000 RPM). They are in use in a number of laser scanned raster projection systems and NTSC's VDRT system employs such a device to generate horizontal scan lines, which are then transferred to the helmet via a coherent fiber strip for subsequent vertical scanning via a galvanometer. Mirror wheels are expensive, requiring high precision mirror face manufacturing for equal vertical line spacing. Mirror wheel size and particularly weight and strength are crucial for high speed operation. Drive electronics must be stable to ensure stable synchronization. Precision ball bearings may be used at rates slightly above 20,000 RPM, but air bearings must be used above that. High speeds also cause windage losses and audible noise. Materials and manufacturing processes continue to improve, but electronic processes offer better promise in the next decade.

3.5.5 PIEZO MIRROR TECHNOLOGY

Piezo mirror technology was examined for applicability and several sources were located. these devices are relatively simple, consisting of a thin slab of piezo material upon which electrodes have been plated on both sides. Deflection is accomplished by applying a voltage across the electrodes, which results in the slab bending. Mirror deflectors have been constructed using pairs of the deflectors operating out of phase and attached to opposite edges of the mirror. These devices were rejected for vertical deflection use due to the difficulty in obtaining a linear.,closed–loop stable response. Their use for the 4 kHz horizontal scanner was rejected for stability, mirror size, and deflection angle performance at the required speed. A suitable off–the–shelf device could not be located and galvonometer scanners with the required speed, small size, and linearity were chosen instead.

3.6. HEAD TRACKING TECHNOLOGY

Headtracking systems fall into three operating principle categories: electromagnetic, optical and ultrasonic. The most widely employed system is the Polhemus (now Kaiser) 3–Space system, which is electromagnetic in operation. This system employs a sensor–receiver pair of modules, each consisting of a set of miniature coils, mounted orthogonally in three axes. One set, the transmitter, is mounted atop and to the rear of the helmet. The receiving coils are mounted on the cockpit structure behind the pilot. The transmitter coils are sent a sequence of pulses which vary in received amplitude according to the difference in angles in all axes between the transmitter and receiver coils modules. The system is specified to operate within a volume measuring 20 inches on a side. In practice, ranges beyond about 15 inches result in the recovered position signal having considerable RMS position noise. Current design efforts involve increasing the effective position data rates beyond the current 60 data points per second, so that data filtering processes can be employed. Faster rates can be filtered more effectively, and position or rate prediction algorithms can be used to reduce the transport delay in scene position responses to head movement. Some current systems (ISCAN) specify data output rates as high as 240 Hz at reduced accuracy. Current head position accuracy is on the order of one–half inch, and angles are one–half to one degree. Research continues to improve data rates and accuracy. These systems have small, lightweight on–helmet components and costs are approximately 20,000 dollars per system for the hardware. The trend for the next five years will be higher performance (data rates and accuracy) and moderate cost increases.

Acoustical systems (e.g.–A. E. Gaertner) operate by timing the arrival of acoustic pulses emitted from a series of emitters (spark gap) to a series of ultrasonic microphones mounted on the cockpit structure. This is a relatively new technology, but the brassboard system under development is evolving as a 6–DOF, flight capable system which will be demonstrated to NTSC in Feb., 1990. The claimed accuracy is on the order of one arc–minute with position accuracy of perhaps 1/10 in. Current data rates are 120 Hz, but 240 Hz is expected soon. Costs of the initial unit are in the $40–50,000 range. On–helmet components are lightweight and relatively small, and the system may show promise. Some digitizing tablets employ this technology.

Several headtracking systems employing optical processes are in use. One of the best–performing systems is in use with CAE's FOHMD display. It uses a series (6) of IR–emitting diodes mounted on a small "halo" ring atop the helmet. Each of these diodes is strobed in sequence and observed by four solid–state IR–sensitive video cameras mounted above on the cockpit structure. While each camera operates at a 60–Hz field rate, phasing the video synchronization to each camera results in data acquisition at a 240–Hz rate. Data must be position normalized prior to filtering and prediction processes. Accuracy is better than with the electromagnetic systems, but it's components are larger and four cameras must be mounted so as not to obstruct the pilot's field of view. Costs are in the $15–20,000 range. This system is useful here if the raster generator system on the helmet does not conflict with mounting position requirements for the IR–emitter ring (the laser scanner does, the color CRT approach does not).

A recent Textron development, for which details are lacking, apparently employs a bi–axial optical detection device which is capable of resolving the offset of the centroid of a beam of light from the center of the sensor. The sensor has a pair of electrodes in both axes which provide resistance ratios measurable to one part in one million. Sample rates are expected to approach a kilohertz, but 1–300 Hz is more likely now. Accuracy is expected to be excellent with good weight and form factors required for on–helmet use. The brassboard system under development now has an accuracy limited by the 12–bit A/D in use. Costs are reported to be near $4–5,000, the sensor costing $1200. Several sizes of the sensor are available, the largest having an active area of 20 mm in diameter, but having lower sample rates. Textron currently uses the device for X–Y table positioning, but adaption for helmet use is possible, by adding a lens to each sensor and improved electronics. This system shows near–term promise for further development.

There are a number of other approaches, including scanning mirror/IR emitter trackers (obsolescent) and one video system which employs an eyetracker–type video camera to follow a black spot affixed to the subject's forehead which were reviewed, but are not recommended for use here.

3.7. VISOR SYSTEM TECHNOLOGY

Of the possible helmet visor choices (Figure 3.7–1) two remain after wide field of view, full color correction and low distortion are factored in as requirements. Many catadioptric and mirror/beamsplitter systems are in use, but the recent advent of color–corrected holographic optical elements (HOE) for use in visor designs is the most promising current technology. A recently devised process by the Technology Innovation Group, Inc. allows the optical relay process from the raster image to be much more efficient than that of the Pancake Window (the other choice, in use with FOHMD), which suffers from both low ambient (about 8 percent) and optical throughput. Ambient throughput from this new device is expected to be as high as 60 percent, with optical throughput efficiencies better than half that. Full details are lacking, as the design has not been fully disclosed and portions of the manufacturing process for the HOE are being refined. It will consist of a pair of relay lenses, the HOE and a visor

optic element. The weight will depend on final lens design, but should not differ much from current monochrome visors used with CRTs. The configuration will depend on the raster generator output images' format, but it expected that the laser scanner approach will require that the images be above and on the front of the helmet and relayed down to the visor. A design opportunity exists to examine whether the scanner and visor lens elements can be integrated to save size and weight. Initial costs are very high, on the order of $200–250,000 for the first systems, which no doubt includes much non–recurring design and development costs. The 80 degree FOV (per eye) Pancake Window units are also very expensive. The HOE visor shows the most promise in the next four to five years. The field–of–view requirements are challenging, however, and it remains to be seen whether an artifact–free image can be produced.

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY

SCSD

REFLECTIVE TYPE

- HIGHLY EFFICIENT
- SOME DISTORTION PROBLEMS
- SOME COLOR CORRECTION PROBLEMS
- MODERATE FIELD–OF–VIEW
- BULKY FORM FACTOR

CATADIOPTRIC TYPE

- COMBINED REFRACTION/REFLECTION, WIDELY USED
- DISTORTION, COLOR CAN BE COMPENSATED FOR
- MEDIUM OPTICAL EFFICIENCY
- MODERATE FIELD–OF–VIEW
- MORE LENSES = MORE WEIGHT

HOLOGRAPHIC IMPROVEMENTS

- SOLVES POSITION CONFLICTS OF MIRROR/BEAMSPLITTER SYSTEMS
- VERY LOW OPTICAL EFFICIENCY
- CAN BE COLOR CORRECTED
- VERY WIDE (80 – 100 DEGREE, CIRCULAR) FIELD–OF–VIEW

Figure 3.7–1. Visor Optic Approaches

CHAPTER 4
DESIGN APPROACH

4.1. PURPOSE

This chapter will serve to address the requirements for Task 3 as stated in the Statement of Work (SOW). Summarily, Task 3 consists of the following five subtasks:

–Derive two hardware approaches to meet the requirements derived in Task 1.3.

–Consider factors such as CRT, TFEL,light valve and fiber–optic technology; holographic and other optical techniques; optical or magnetic headtracking; oculometer and other eyetracking relevant technologies.

–Identify development risks, expenditures of time and resources as well as capability trade–offs.

–Present candidate approaches and a recommendation to LaRC for approval.

The simultaneous requirements for full color, high resolution and wide field of view (FOV), combined with good ambient out–the– window (OTW) visibility limit the choice of existing HMD systems to zero. The closest performance of an existing system is CAE's FOHMD. Obviously, if the design were easy to do, there would be a number of choices available. But there aren't and the color requirement is the main culprit. The visor optics must be fully color corrected and wide FOV, which puts its design at the leading edge of technology. There are no immediate choices for a small, lightweight color raster generator, either, since subminiature CRTs cannot display color in the usual manner with a shadow mask or grill. There are promising new technologies, such as TFT–LCD color matrix panels, which offer small size, low power, light weight and other attractive attributes, but the required combination of small size and adequate resolution is not likely to be available in the next three to five years, although the trends are all in the right direction.

Figure 4.1–1 depicts the area of design focus for a new approach to a color HMD. Figure 4 .1–2 depicts on overall block diagram of the HMD system required by NASA LaRC and is, in general, the block diagram of any HMD system.

The block labeled "image generator" is the system which generates high resolution RGB color video data based on an observer's line of sight, altitude, time of day, etc. Normally, this data would be sent straight to displays for observation. The output of this system is two RGB channels of video data (for stereopsis) and synchronizing signals for the displays.

The block labeled "video generator" is a video converter and is only required if the scan rates or image format is different than normal IG scan formats. Under such conditions, several scan lines or perhaps an entire field or frame of video will be stored and then read out at the rates required by the particular raster generator process chosen. It is a post processor and should have as little throughput delay as possible.

The "heart" of a HMD design lies in the design of the raster generator which paints the image on the image plane required by the relay lens of the visor optics. The design of all other subsystems is driven by the configuration of the raster generator and the visor optic. Initial desiderata for a color raster generator design are depicted in Figure 4.1–3. Portions of the raster generator may reside on–helmet or off–helmet, depending on the process chosen. An example of an off–helmet process is the CAE FOHMD design, in which complete images from four light valve projectors, located off–helmet, are sent to the helmet via coherent fiber optic bundles in order to provide a useful image to the crewman. A typical on–helmet raster generator example is any monochrome subminiature CRT HMD, which only requires that video and deflection signals be sent to the helmet. Other examples of mixed designs were discussed in chapter two and depicted by the raster generator taxonomy matrix.

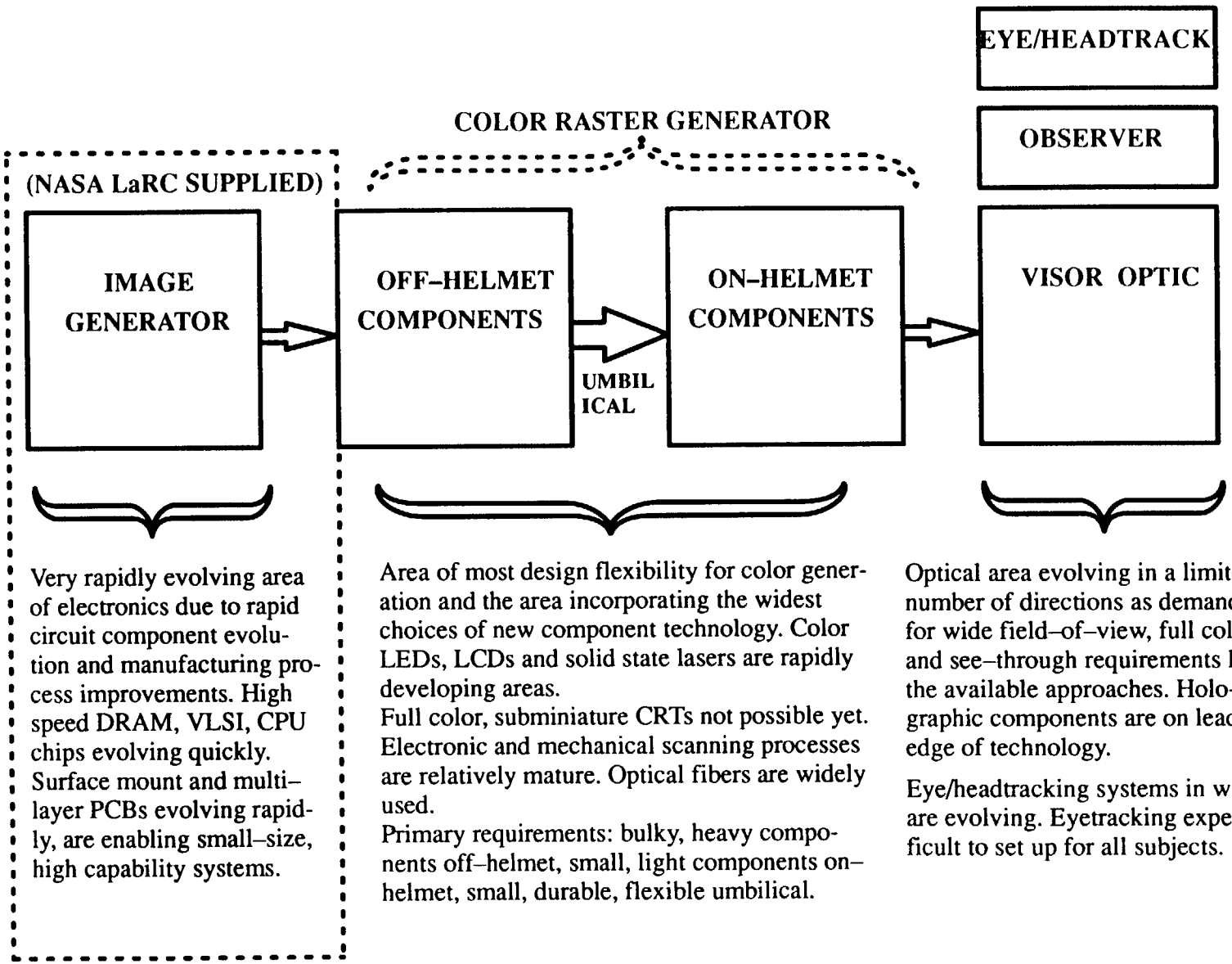

Figure 4.1–1. Technology Application Areas

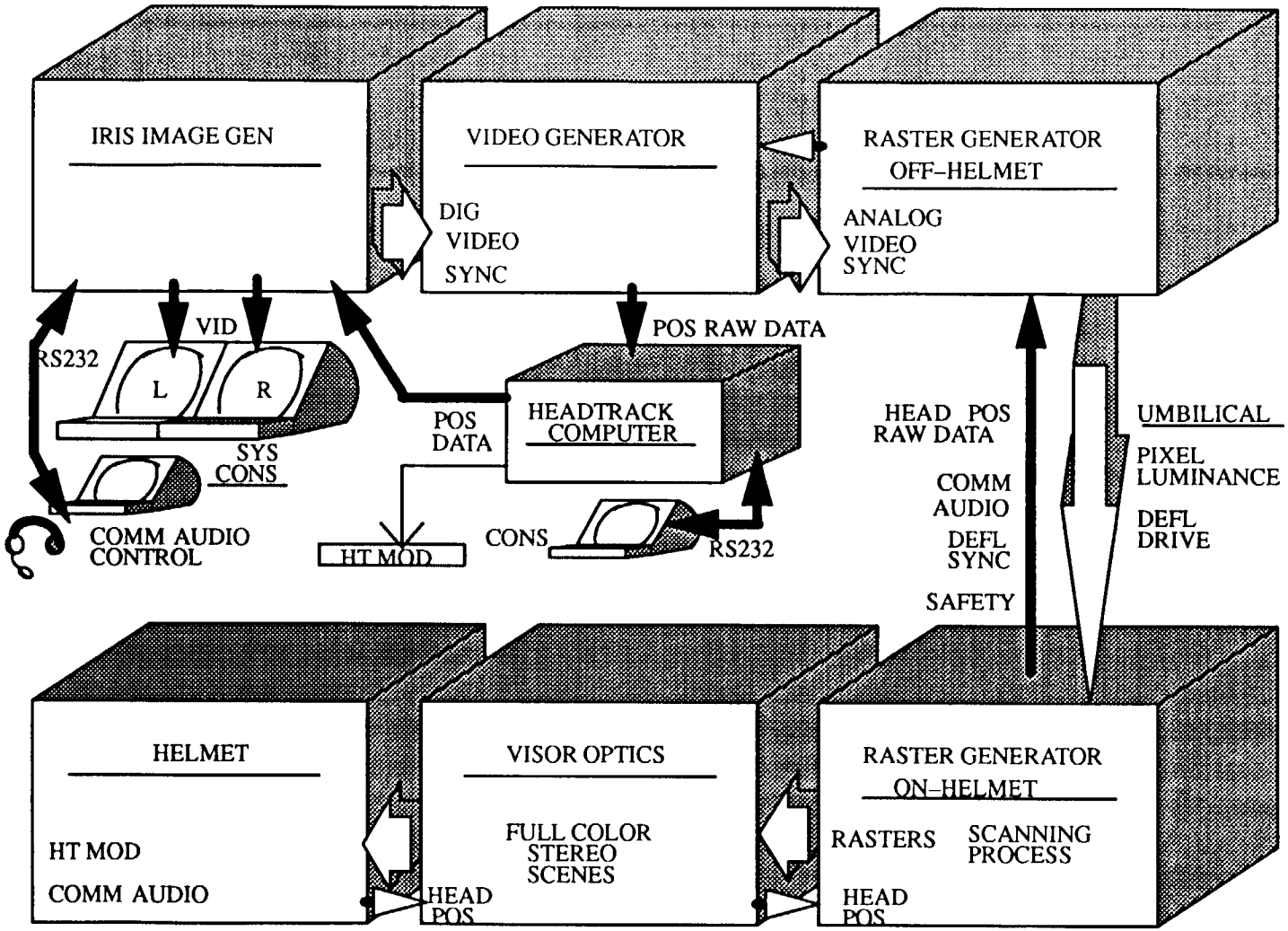

Figure 4.1–2. LS/HMD Signam Flow (Baseline System)

RASTER GENERATOR INITIAL CONSIDERATIONS

The raster generator design is the heart of the color HMD system.
Consider multiple approaches: near term implementation with existing hardware. longer term with emerging, but not yet capable hardware, and max performance.
Components used should be small, light and require low power with high luminance.
Keep the umbilical small and adopt a form which does not restrict head motion.
Learn from problems of older designs: image quality in VDRT, umbilical in CAE, etc.
Lasers offer best color range, highest luminance, but require mech. or AO scanning.
LCDs look promising, lack resolution and small size now, most development in Japan.
Color with subminiature CRTs using shadow masks won't have the resolution, but a novel approach using mixed–mode scanning and special phosphor may work and allow existing HMDs with color–corrected optics and submin CRTs to be adapted.
The highest performance visor systems (Farrand) have the lowest efficiency.
Don't expect other design vendors to provide a lot of current information.
Check into other possibilities, including single–crystal phosphors and holographics.
Design raster generator to meet format requirements of visor optics with good perf.
Low luminance image will require efficient visor, probably catadioptric design.
A laser scanned image will allow more visor choice flexibility, but have to compensate for scan rate limits of galvo or piezo scanners. Acousto–optical scanning is fast, but has low scan angles and can be large, heavy. Put heavy components off–helmet.

Figure 4.1–3. Raster Generator Initial Considerations

A suitable color image must be in the correct form and position for use by a visor optic subsystem. Of the catadioptric, mirror/beamsplitter, "pancake window" and holographic visor processes reviewed, only the very recently devised (details are still not public) holographic visor optic has the expected performance to meet the required color correction and field of view specified. The "pancake window" used by CAE's FOHMD is a fall-back choice, but lacks ambient visibility, is optically very inefficient and may not fully meet field of view requirements. The visor must have provisions for focus, interocular distance and pupil centroid location adjustment to fit 5th through 95th male pilot anthropometric data. Additional adjustments must exist to permit varying scene overlap to each eye from zero to 40 degrees and for raster alignment.

The helmet shell itself should be lightweight, fit a wide variety of head sizes and be adjustable for snug fit to prevent the scene being displaced with normal head movement (Figure 4.1–4). Inflatable air bladders or selectable pads are the usual method of adjusting the helmet fit. The helmet also serves as the mount for the visor optic subsystem, the on-helmet portion of the raster generator, the umbilical and provides mounts for the communications microphone/headset and headtracking transmitter. All of this hardware must have a weight of five pounds or less and have a composite center-of-gravity close to that of the head alone, as a design goal.

Three choices were ultimately devised. Two of the three were recommended (Figure 4.1–5) the first based upon a subminiature CRT with mixed electronic and mechanical sweep; a second using ongoing GE R&D involving a laser scanned system; and a third employing an obvious long-range TFT-LCD approach.

4.1.1. THE SUBMINIATURE COLOR CRT APPROACH

The subminiature color CRT approach was devised in an effort to "work around" the fact that normal color CRT approaches of using a shadow mask or grill cannot be applied to a subminiature tube because the extremely small and dense spacing required for mask elements and phosphor triads exceed the capabilities of any current manufacturing technology. You'd have to accurately deposit color phosphors a grain at a time. Using three CRTs (one red, one green, one blue) per side is too heavy, but would have the required performance. A single tube, indexed-beam approach won't work, either, due to the stripe density required for the stated resolution.

One approach is to use the good factors of a subminiature CRT (high electronic sweep rates, good resolution with a continuous phosphor) to provide the scan line generation process and use a galvanometer scanner to provide a linear vertical sweep needed to make a complete raster, a task to which it is perfectly suited. Three contiguous, parallel stripes of red, green and blue phosphor can be swept by individual electron beams using the usual electromagnetic deflection process. Phosphor decay times would have to be shorter than the horizontal line's sweep time. Since the RGB components of a color scan line are displaced vertically, they must be simultaneously combined optically or video data delays can be introduced for two of the three colors to provide contiguity and overlap when the raster is scanned vertically. A delay of N multiple scan lines can easily be provided by the use of line buffers in the video generator. The number of active scan lines per frame is reduced by the delay line factor, since scan lines at the very top and bottom of the raster would have incomplete color information during the delay time.

GENERAL ELECTRIC

RASTER GRAPHIC HELMET
MOUNTED DISPLAY STUDY
HELMET DISPLAY PHYSICAL DESIDERATA

SCSD

The all–up weight of the helmet plus display shall be less than five pounds.
The display components shall be conformal with projections to the top and sides minimized and covered by a protective shell for durability.
The center of gravity of the helmet plus display shall be approximately as that of the head alone.
The display assembly shall either attach to a personal helmet or have provisions for easy adjustment to fit 5th to 95th percentile head sizes snugly.
The umbilical shall be small, light, not restrict movement and have a disconnect.
Adjustments for focus, interocular variance, boresight and overlap provided.
Materials shall be durable, light, shatterproof and non–conductive.
Test fixtures and software with graphics/data shall permit rapid alignment of the optics and headtracking (and/or eyetracking) hardware.
Provisions for fitting headsets, a microphone and oxygen mask shall be made.
Eye relief should be sufficient to allow spectacles to be worn.

Figure 4.1–4. Helmet Display Physical Desiderata

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY

SCSD

- RECOMMENDED APPROACH FOR COLOR HMD

  PRIMARY: SUBMINIATURE COLOR CRT APPROACH
  - WILL ALLOW COLOR RESEARCH TO BEGIN MORE QUICKLY
  - IMAGE QUAL, LUM, RES OK FOR FORMAT & 3D RESEARCH.
  - USES EXISTING COLOR CORRECTED HMD SYSTEM
  - CAN BE IMPLEMENTED QUICKLY (SOLVE PHOSPHOR & GUN)
  - REQUIRES MODS TO CRT/RELAY LENS, MAY REQ LINE BUFFER

  SECONDARY: MULTI–LINE LASER SCANNER APPROACH
  - PROBABLE HIGHEST RESOLUTION, LUMINANCE, FOV
  - REQUIRES IG MODS FOR EIGHT LINE VIDEO
  - RECOMMEND FARRAND PANCAKE VISOR (100 DEG/EYE)
  - PROBABLY IMPLEMENT FASTER THAN LCD APPROACH
  - G–LOADING IN HELO LESS THAN FIGHTER A/C

Figure 4.1–5. Recommended Approaches for Color HMD

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Since scan lines will repeat their position on the phosphor's surface with each horizontal sweep, the phosphor could easily be burned. One way to improve phosphor life is to use an asymmetric scanning spot which is "stretched" vertically, so as to spread the electron beam's energy over a larger area of each phosphor stripe. The asymmetric spot shape can then be made smaller and symmetrical by means of an anamorphic, or "strip" lens, which has optical power in only one axis. This makes the RGB spots symmetrical and brings them closer together at the focal point, so lower video delays are involved. Color phosphors for green and blue with the required short decay times and luminous efficiency have been identified as types T45 and T46. One possible candidate for the companion red phosphor has recently been identified. Some 20 years ago, Westinghouse experimented with a calcium sulphode phosphor which exhibited most of the properties required here. The phosphor was not registered and is no longer available from Westinghouse. There is one probable Japanese source: Mitsui's Mining and Smelting Central Research Labs, in Ageo, Saitani Prefecture, Japan.

The vertical galvanometer scanner would sweep the scan lines vertically to produce a complete raster at the required image plane for the visor. Normal sweep rates are required, but multi–line video buffers must be used for two of the colors to provide the correct superimposition of RGB data to form a complete color scan line at the raster plane. Since the phosphors are continuous, horizontal resolution is only limited by electron beam spot size. Vertical resolution is a function of spot shape, determined by the anamorphic lens. Ideally, the spot shape will be symmetrical at the focal plane, thus vertical resolution (active line count) will be similar to the pixel pitch. This concept has been patented (pending) as a joint GE/NASA LaRC concept for this contract. Figure 4.1.1–1 and depicts the subminiature color CRT concept for a raster generator.

The optimum subminiature color CRT approach calls for a triple–beam, inline electron gun. Such designs exist for small color CRTs. The use of three simultaneous beams improves overall display luminance, compared to a single–beam gun, and sweep and video buffering processes are simplified. An initial search was conducted by telephone to a number of CRT specialty houses (in the U.S.), but a source for an inline gun of sufficiently small size has not been located as yet. Thomas Electronics indicated that a 15mm gun is required, but a 19mm gun is the smallest located thus far. A Japanese source (perhaps Sony) may be possible. An interim solution is to use a single–beam gun (available from Thomas Electronics and others) and to sweep all three stripes in sequence. For a 1000–line raster format, this forces horizontal sweep rates to be beyond 90 kHz, video bandwidths (and video buffer speeds) to go up by a factor of three. Dwell time per pixel is similarly reduced, providing lower luminance. This is not an optimum design, but may enable initial testing to be done while a triple–beam gun is being located or devised. Another possibility is to use a slightly larger CRT with a 19mm inline gun. A subminiature CRT with color stripes and single–beam gun can be fabricated is less than two months at a cost of 2–3,000 dollars. The single–beam alternative approach is depicted in Figure 4.1.1–2.

GE/NASA COLOR CRT CONCEPT (DISCLOSED)

* *HORIZONTAL DEFLECTION IN CRT, VERTICAL BY GALVO/MIRROR
* FAST RGB PHOSPHOR WITH TALL, THIN SCANNING SPOT
* STRIP LENS ALLOWS ASTIGMATIC SPOT, MORE LUMINANCE
  IMPROVED BURN RESISTANCE
* COULD BE APPLIED TO EXISTING CRT HMDS WITH COLOR CORRECTED OPTICS
* DEVELOPMENT NEEDS: IN–LINE GUN, FAST RED PHOSPHOR

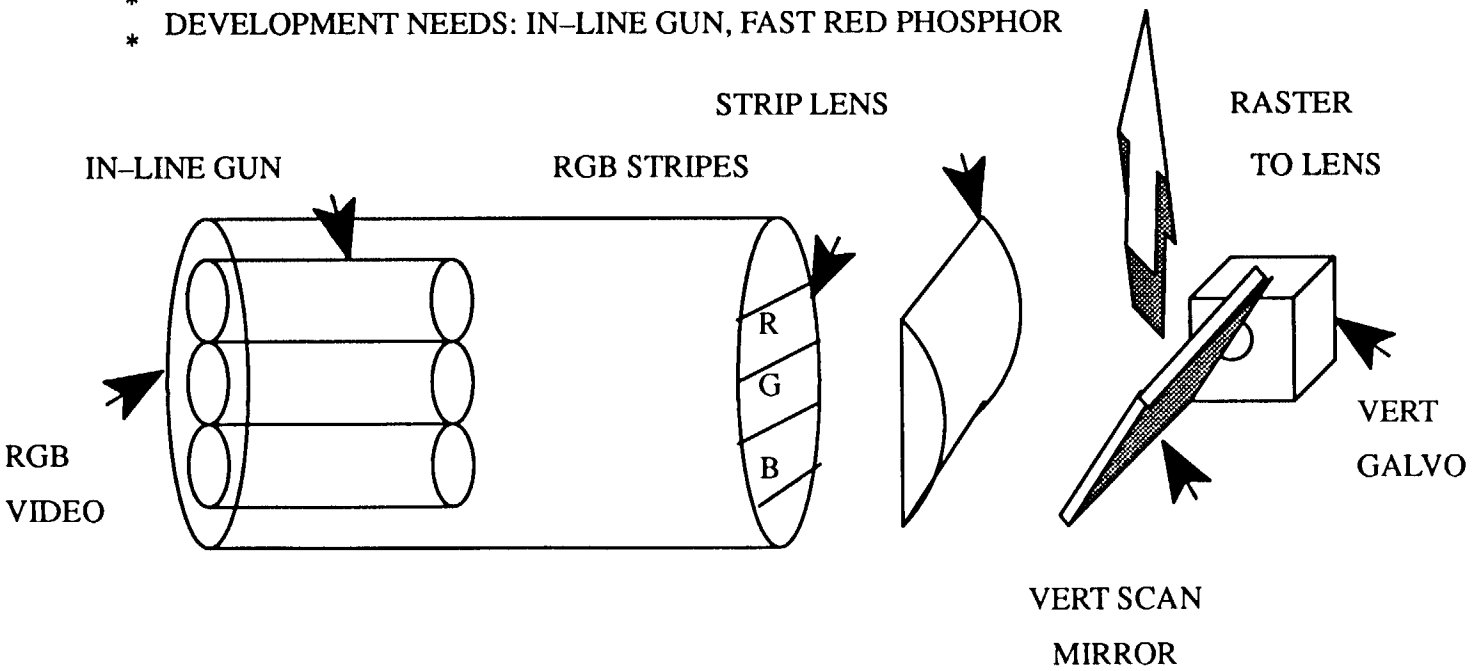

Figure 4.1.1–1. GE/Nasa Color CRT Concept

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GE/NASA COLOR CRT CONCEPT, ONE GUN

* HORIZONTAL DEFLECTION IN CRT, VERTICAL BY GALVO/MIRROR
* FAST RGB PHOSPHOR WITH TALL, THIN SCANNING SPOT
* STRIP LENS ALLOWS ASTIGMATIC SPOT, MORE LUMINANCE
  IMPROVED BURN RESISTANCE
* COULD BE APPLIED TO EXISTING CRT HMDS WITH COLOR CORRECTED OPTICS
* DEVELOPMENT NEEDS: IN-LINE GUN, FAST RED PHOSPHOR
* HAS VERY FAST SWEEP RATES, FAST PIXEL RATES
* THOMAS HAS GUN, 1 MIL SPOT

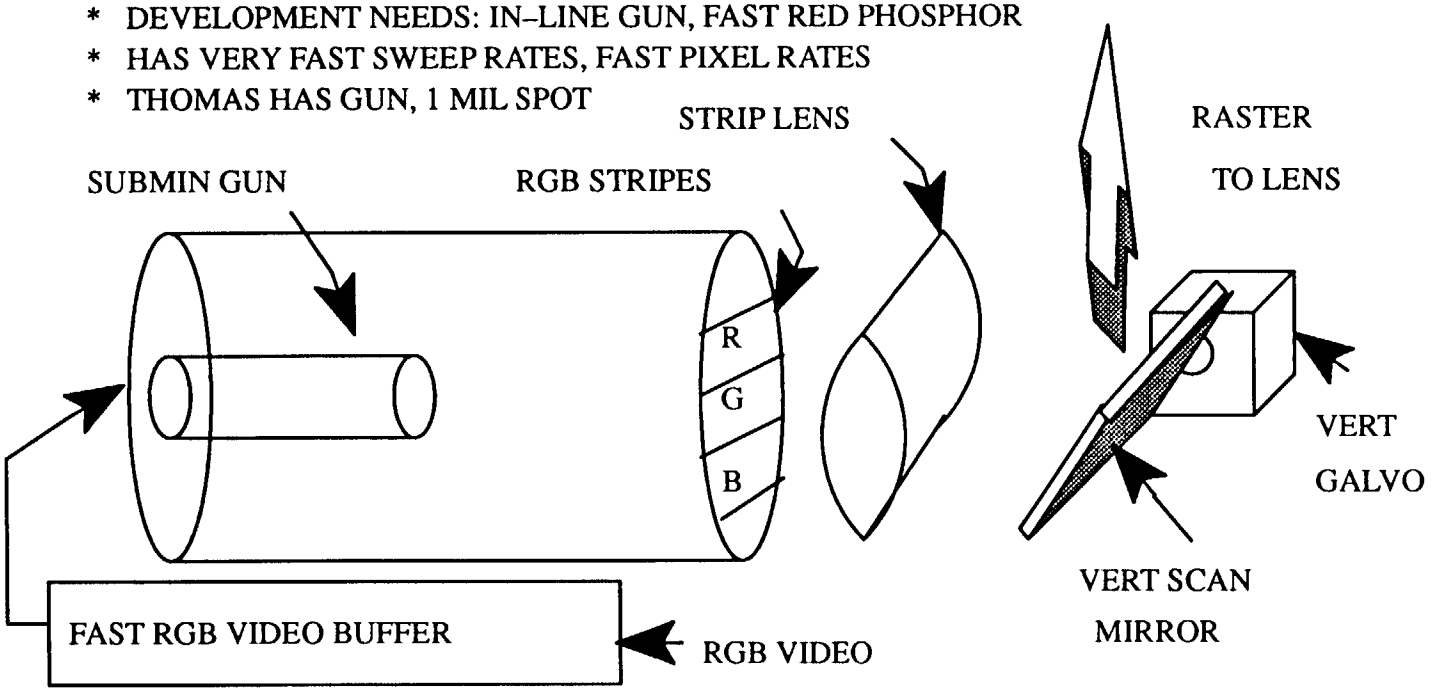

Figure 4.1.1-2. GE/Nasa One Gun Color CRT Concept

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A video generator is required to buffer the data for two adjacent colors by the number of line times it takes for the vertical scanner to translate the third color to a point where the other two overlap optically. In other words, the red phosphor may be painting video for the current line from the IG, while the adjacent green will be painting video data one or two lines old, depending on the optical displacement, as measured in scan lines. Buffer rates with the three gun approach are on the order of 30 MHz and are typical rates for current hardware. The single gun approach will require a buffer some three times faster, which will require careful design, but is not excessive. Synchronizing pulse speeds are unchanged.

It is believed that this approach may be easily applied to an existing NASA LaRC HMD design which has subminiature CRTs and color corrected visor optics. The vertical scan mirror would simply replace an existing fold mirror in the optical path from the CRT to the visor and the new CRT and yoke assembly would replace the existing monochrome assembly.

4.1.2. THE GE IR&D LASER SCANNER HMD SYSTEM

Research has been ongoing at GE SCSD for over two years on a laser scanned approach for a color raster generator which paints eight full color scan lines simultaneously. This approach exploits several unique features which enable a high resolution raster to be generated on–helmet.

The use of eight simultaneous scan lines permits 1000–line raster formats to be generated with a horizontal sweep rate of only 4 kHz. The 4 kHz rate, in turn, enables the use of small galvanometer mirror scanners for horizontal deflection. a linear galvanometer scanner is used to provide the vertical sweep required to paint a complete raster image. The horizontal scanner is a torsional pendulum type and exhibits sine–wave oscillation. Only 85 percent of the scan angle in one direction is used to paint video (34 percent of one full cycle time), resulting in a reasonably linear scan line format with only very slight droop at the edges prior to horizontal scanner scan direction reversal. Maximum video bandwidth requirements are reduced to less than 14 MHz for the 1000–line, 1000 pixel format, but for evenly spaced pixels along a line, the dwell time per pixel in the center of the raster line is half that for a pixel at each end of the line, due to velocity changes in the sine–wave sweep.

A set of simultaneous design requirements had to be solved in choosing the lenses, the scanners, the fibers and the overall layout. The raster image size (19mm diagonal, 3:4 format) was fixed by the initial visor chosen. It is the size of a typical subminiature CRT's format. For a 1000 by 1000 pixel raster, the resulting spot size is 11.4 by 15.2 microns. A fiber was chosen with a 9 micron core to allow for diffraction limits of the lenses. The use of two lenses to form a 1:1 telephoto path was chosen to provide collimated pixel luminance between the lenses. The numerical aperture of the fibers, combined with the focal length of the lens was chosen to provide collimated pixel beams of 8 to 10 mm, which was limited by the size of the horizontal scan mirror (16mm), since the mirror would be displaced slightly from the beam convergence point. The fiber chosen has the required 9 micron core size and a NA of 0.1, which provides a 10mm beam at the 50mm focal length of the lens. The scan angles required to paint the raster image's size dictated the f–number and the focal length of the lens. A high quality off–the–shelf 50mm, f1:1.2 lens for a 35mm SLR camera was chosen for the design. The initial set of fibers was cemented in a test fixture which formed the input pixel plane for the system. Fiber spacing and alignment was imprecise and the resulting image did not exhibit contiguous sectors. The latest fiber set has provisions for minor adjustment of the ends of the fibers. A single off–board laser with modulator was used to provide test pattern luminance for all eight fibers. Three more lasers have been acquired to form a brighter, more complete raster image. The block diagram for the overall laser scanned system is depicted in Figure 4.1.2–1.

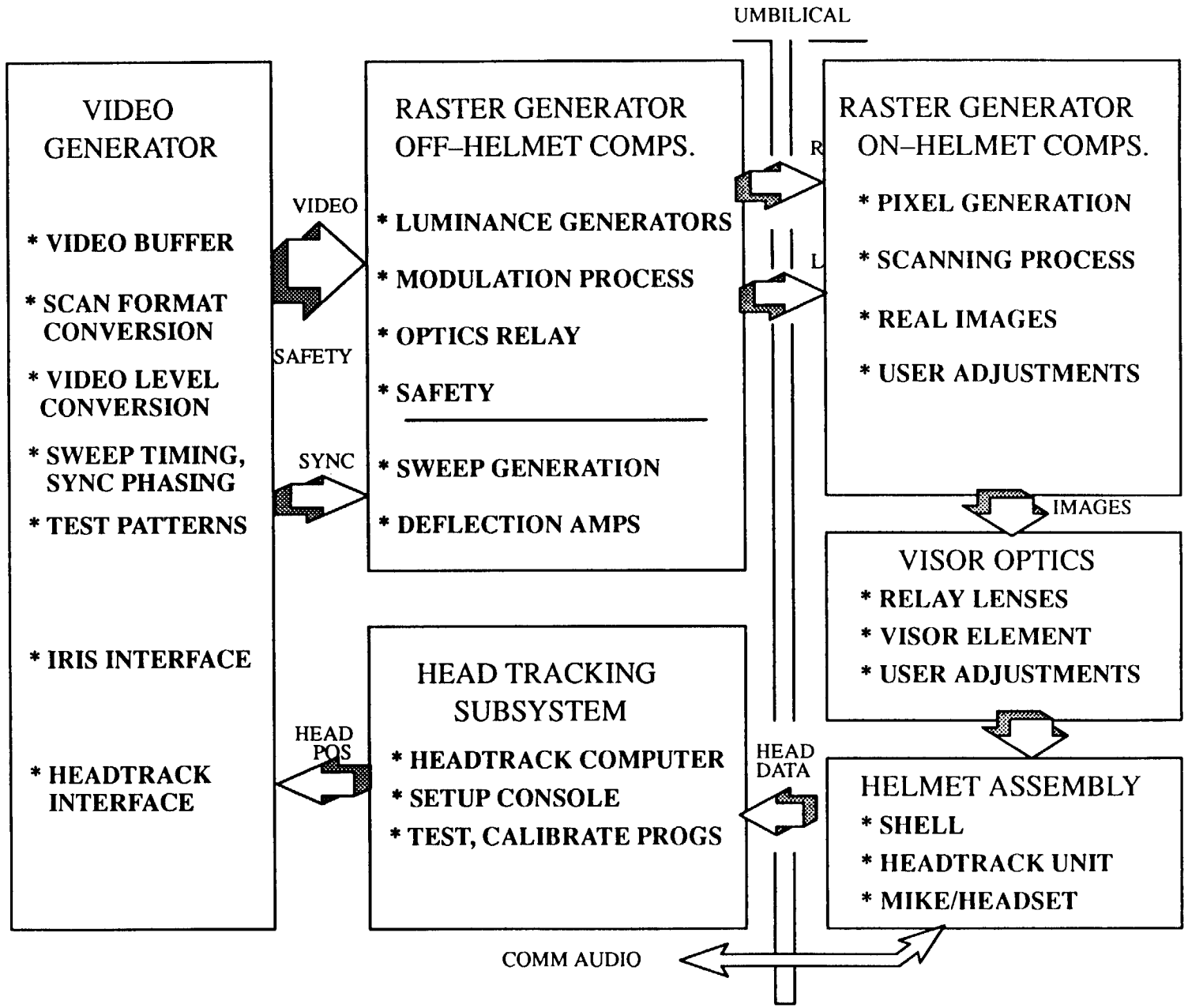

Figure 4.1.2–1. Baseline Block Diagram

By displacing the ends of the optical fibers which form a vertical array of eight beams and angling the beams outward systematically before entering the lens, collimated beams are formed which cross at the center of the path between the two lenses. The lens pair forms a 1:1 telephoto relay with image planes at the focal plane at the outer end of the each lens. This crossover point is where both scan mirror planes are located and represents the smallest optical "footprint" of the image's pixel data. Small scan mirrors can thus be used. Further, equally displacing the fibers reduces the vertical deflection angle requirements by a factor of eight and linearity can be achieved more easily. Deflection must use collimated beams in order to form a flat raster plane at the focal plane of the output lens. The current two lens configuration is symmetrical, with image luminance passing through the lens pairs in opposite directions for the left and right rasters. each lens thus acts as an input and an output lens, providing considerable size and weight reductions over the earlier approach which consisted of four lenses arranged as an "X". The new configuration simply folds the "X" in the middle, producing a "V" optical path. With both scanners operating on luminance for each eye simultaneously, scene stability and registration is ensured.

It is hoped that a 2000–line (interlaced) or 1000–line (non–interlaced) can be demonstrated next using active scanning during both directions of the horizontal sweep. Currently, the 4 kHz scanner, being a torsional pendulum type, produces a sine–wave horizontal sweep. Only some 85 percent of a half cycle (34 percent of a one–cycle period) is allocated for active pixel production. At 85 percent of the scan angle, the scan lines exhibit minimum curving upward and downward at the outer edges, prior to the scanner reversing direction. A plan to add an empirically derived, 8 kHz waveform to the vertical scanner driver will allow the vertical scanner to straighten out the less than two arc–minutes of residual curvature in the raster. This will allow scan lines to be painted in the reverse direction, resulting in a 2000–line (interlaced) format. The vertical scanner is a closed–loop type, producing a linear sawtoothed vertical sweep. Finite vertical flyback times currently limit the 1000–line raster format to about 850 active displayed lines, but a faster scanner has been procured and will be tested for reduced flyback times and response at 8 kHz. The previous scanner's tested bandwidth was limited to 3800 Hz.

The raster is a 15mm diagonal, 3:4 format suitable for input to the visor optic subsystem. This real image is painted on a super high resolution rear projection screen with a gain of 1.5 to 2 f–stops. This provides some measure of laser safety and increases the exit pupil size. Additional safety is planned by having the lasers cut off in the event of sweep failure. The optical fiber core, which is imaged through the lens system, is only nine microns in size. Diffraction limits for the lens are computed to be approximately five microns. The spot size is expected to be about 12 microns when focused. The currently used breadboard configuration is depicted in Figure 4.1.2–2, as is a schematic of the unfolded optical path demonstrating the eight splayed, displaced pixel beams.

The fundamental approach allocates all heavy, bulky components off–helmet. Lasers and modulators are off–helmet and power levels may easily be scaled to provide any display luminance desired. The umbilical to the helmet is small, consisting only of 16 optical fibers and the galvanometer and headtracker leads. The use of off–helmet lasers provides sufficient display luminance, contrast and a full color gamut. On–helmet scanner components are small and have been shown to produce a stable raster with no speckle. An improved two–lens optical arrangement should reduce weight and bulk considerably over the earlier design employing four lenses. At this juncture, a 1000–line raster (850 active lines) has been demonstrated, but with imperfect fiber alignment.

● BREADBOARD RASTER GENERATOR LAYOUT

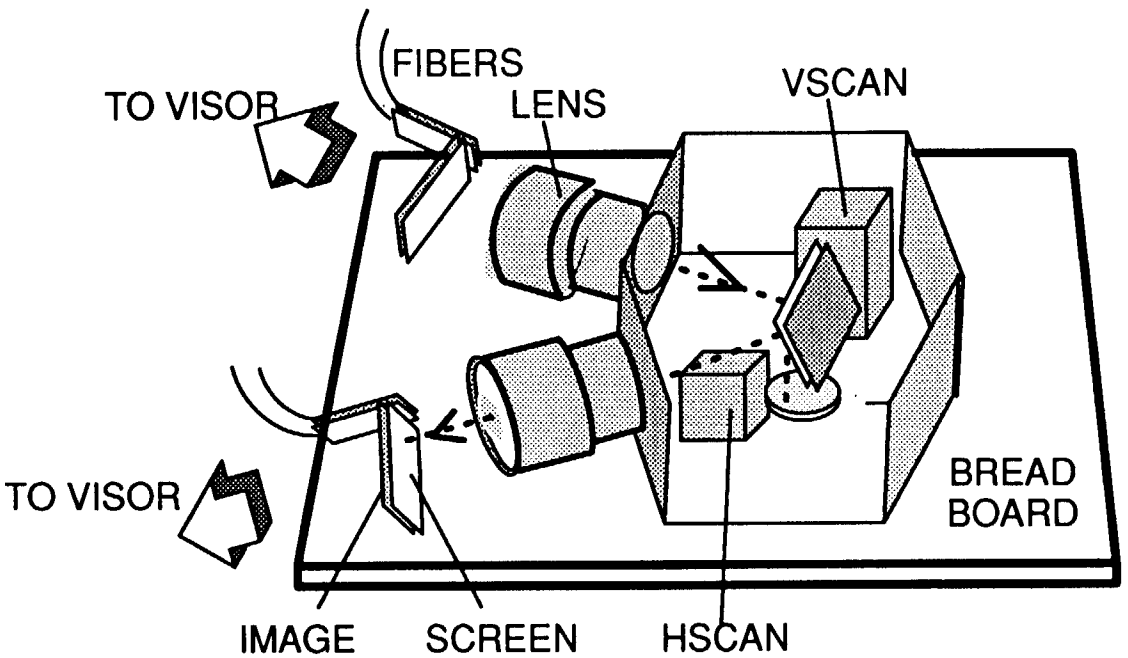

Figure 4.1.2–2. Breadboard Raster Generator Layout

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The visor of choice for this system is in development by the Technology Innovation Group, Inc. Details are not fully released at this point in time. The raster generator will be mounted atop the helmet, toward the front, and feed the visor from above. A design opportunity exists to examine the total optical requirements for the raster generators and the input relay lens of the visor, so that additional weight and size reductions can be identified for the visor plus raster generator as a system.

4.1.3. THE TFT–LCD APPROACH

A TFT–LCD approach employing active matrix liquid crystal panels was devised and presented to NASA LaRC. These devices offer the promise of light weight, small size, low cost and power requirements. They are also robust. The TFT–LCD approach is currently in widespread development, both as large color panels suitable for HDTV and "laptop" computer displays, and as small panels suitable for miniature TV use. Most of the development is being done by the Japanese for commercial applications, although GE CR&D has developed a 1000–line color display for aircraft instrument use. The projected approach would have employed a cube of three panels to produce full color at high resolution in a manner similar to video projector designs currently marketed by Sharp and Kodak (LC500). Panels with the required small size and pixel density are not currently available.

The primary development problem of very small, high density Thin–Film–Transistor (TFT), active matrix LCDs is one of manufacturing and materials technology. For a one inch diagonal display with 1024 lines and 1280 pixels, the row/column address lines, which consist of transparent conductive material, exhibit sufficient resistance that crosstalk and address speed effects arise. The active areas of for effective mask alignment tolerances during production. A high proportion of active area is desirable to improve contrast and to reduce the visibility of the residual structure. Switching speeds are a function of spacing between the panels, and present limits seem to be about 25 ms.

Interconnect issues also exist for any LCD and are worse for miniature units in the sense that the area required for decode logic is large compared to the active screen size. the best solution is to incorporate the row/column address drivers on the LCD substrate, so that far fewer interconnects are required between the LCD and video controller. These inactive areas on the periphery of the display can influence the configuration of multipanel displays, as are used for RGB color.

The small display size required for HMD use suggest three possible configurations. One choice would be to use a rear illumination of red, green, and blue in a field–sequential manner. Only one LCD panel per eye would be required and either RGB LED or laser sources or fiber optic sources could be used to provide rear illumination of the panel. Switching speeds of the panel have to be faster than is currently available, and some color fringe artifacts will be noted with scene translation due to head movement.

A second choice is to use three panels and a combiner cube, each panel having it's own red, green, or blue rear illumination. Such units are currently used by Kodak and Epson in video projection units. Current commercial resolutions are 320 pixels by 200 lines and grid structure between pixels is noticed, but color rendition is good and lag is not noticeable. Projectors with increased resolution (up to 640 x 480) are under development.

A third choice of using one panel with color subpixels is possible at reduced resolution. such panels are in wide use by Sharp and other Japanese manufacturers of miniature TV and VCR units. NASA JSC has one inexpensive HMD which utilizes two of these panels and the resolution is sufficient for the limited research they plan to conduct with it. Figures 4.1.3–1 and 4.1.3–2 list the LCD approach and development risks.

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY

SCSD

• LCD DESIGN APPROACH

The particular LCD panel configuration chosen will depend upon what has the best size, pixel density and color capability several years hence.

There are three basic approaches: a single color panel (either color subpixels or a new color pixel process), field-sequential RGB rear illumination or the use of three panels arranged around three adjacent sides of a combining cube with dichroic reflectors (e.g. Sieko/Kodak video projector).

The cube approach will be larger and somewhat heavier due to the use of three panels and three illumination sources with the cube. The single panel approach has obvious size and weight benefits. The LCD panels take minimum power and rear illumination can be shipped by fibers from off-helmet sources to reduce thermal effects. Scan sequencers should be on the helmet to reduce the umbilical size and quick-disconnect complexity. Coupling to the visor would be as with a subminiature CRT, except the single panel could require a shorter relay lens assembly and be closer to the visor, thus providing a better form factor.

THE IDEAL SOLUTION:

Use a single panel of 1.0 to 1.5 in. square, having 1200–1600 rows/columns, and full color capability per pixel. The active pixel area would be large (>90%) with respect to grid dimensions. Switching speeds would be ~15ms. Illumination would be provided by off-board sources and coupled by fiber. An incandescent or RGB solid state / LED rear illumination source would also work.

Either catadioptric or holographic color-corrected visor optics would be used.

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Figure 4.1.3–1. LCD Design Approach

GENERAL ELECTRIC

RASTER GRAPHIC HELMET MOUNTED DISPLAY STUDY

SCSD

- LCD PANEL DEVELOPMENT RISKS

SMALL SIZE, HIGH PIXEL DENSITY

While the small size and pixel circuit density of TFT LCD panels is well within the capability of manufacturing equipment used for ICs, the characteristics of the transparent row/column address lines (e.g. tin oxide's resistance) cause cross-coupling of pixel effects to adjacent rows or columns. And the active pixel area as a proportion of cell size is diminished due to the finite size of the transistor circuits in each cell. A visible "screen wire" pixel grid would reduce the image quality.

INTERCONNECT DENSITY:

With small size and high resolution, row/column address density increases. Address decoders, counters and clocks could be built into the periphery of the panel for reduced umbilical and connector complexity.

COLOR METHOD:

An ideal solution might to be to construct an LCD "sandwich", such that one layer selected the color (crystal rotation?) and the other, modulation. Or RGB subpixels could diffuse into the pixel in the layer above. Currently, the only available solutions are RGB subpixels, three-panel or field sequential illumination, that I know of.

LOCUS OF DEVELOPMENT EFFORTS:

With the most strident development occurring in Japan, linkages are difficult.

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Figure 4.1.3–2. LCD Panel Development Risks

NASA LaRC rejected the LCD approach, since the time frame for the development of panels with both small size and suitable pixel density is unlikely in the next four to five years. Efforts to spur development by the Japanese for limited markets has also resulted in limited success. The TFT–LCD approach will not be elaborated upon further in this document.

4.2. DEVELOPMENT RISK AREAS

4.2.1. SUBMINIATURE COLOR CRT APPROACH

The subminiature color CRT approach has two primary areas of risk associated with full implementation as initially devised. These are the choice of a suitable red phosphor and the choice of a three–beam inline electron gun with appropriate characteristics. Fallback choices for each areas exist. While the ultimate performance of the CRT system is not expected to be as good as the 2000–line laser scanned system, it has the advantage of being implemented more quickly and will probably easily adapt to existing visor and HMD designs which currently employ color corrected optics and subminiature CRTs.

The three–beam gun was specified because it offers higher display brightness, since three simultaneous beams emit more energy than a single beam which must be swept sequentially across the three color stripes. In addition, the design of the video line buffer and horizontal deflection circuits are simplified for the three–gun approach, since video data output rates and deflection rates are lower by a factor of three. The use of an inline gun, rather than the "delta" configuration should reduce the size and complexity of the deflection yoke and driving circuits.

Single beam electron guns are readily available at low cost which have the spot size and deflection characteristics which are required. Three beam, inline guns are in wide use in standard color CRTs which employ a shadow mask or grill. Very small (9–in. diagonal) color CRTs may employ guns which are 19mm in size. Such guns could easily be grafted to the subminiature CRT's envelope, but the performance of such an arrangement has never been tested. Issues identified involve focus range, resulting spot size, deflection linearity and the general behavior of the electron beam between the gun and the phosphor surface. Very little commercial CRT development is currently being done in the U.S. at this time, Zenith being an exception. The Japanese produce the majority of new color CRT designs, and Sony is a leader in the inline gun area.

One approach to reducing the risk of obtaining a suitable, 15mm inline gun is to graft the smallest commercially available (19mm) gun onto a slightly larger subminiature CRT's envelope with the three–stripe color phosphor and test it's performance. If the resulting performance is acceptable, the resulting weight and size increase would be minor compared to the benefits afforded by beginning research using a full–color system much earlier than would be possible with the laser scanned system.

Suitable green and blue phosphors for the three–stripe color approach have been identified as T45 and T46 types. Persistence times of 250 to 350 microseconds are desirable, since these are on the order of one line's sweep time. Burn resistance is also an important parameter, since line sweeps will occur on the same path as the previous line. One red phosphor has been identified (Thomas Electronics) which has the required decay time, but it's luminous efficiency is about 10 percent of the green and blue. The application of the phosphors as three parallel, contiguous stripes is not a problem, according to Thomas Electronics officials, who indicated that a subminiature CRT/yoke assembly with a single–beam gun with the required color stripes could be delivered in 4–8 weeks at a cost of 2–3000 dollars.

A detailed design of the subminiature CRT process has not been done. Such an effort would also address the choice and placement of the anamorphic lens, considering the input image plane requirements for the visor system, the spacing of the color stripes and the height of the astigmatic scanning spots.

The visor system's vendor has been identified and an approach has been chosen to provide the field–of–view and color correction necessary to meet specifications. Such a visor has not been produced, and questions remain as to whether one holographic optical element or two will be required for each eye. If two are required, due to the wide field of view and color ranges specified, then a slight, out–of–focus vertical edge may be discernable in the displayed image. The design of the visor system has been estimated to be from six months to one year. Fabrication will require a similar time frame. The holographic optical element's design will depend on the wavelengths and bandwidth of the phosphors or lasers chosen. These characteristics will differ for the CRT's phosphor and the laser, and must be included in the design of the holographic film. This risk factor is common to both the CRT and laser scanned approaches.

A color–corrected visor with a slightly reduced field–of–view has recently been produced for use by NASA LaRC. It is curently a monochrome stereoscopic HMD.

4.2.2. LASER SCANNED APPROACH RISK FACTORS

The laser scanned approach has the probable payoff of producing a full color image with a wider range and more saturated colors, higher resolution and higher display luminance. Risk areas involve image quality, since the image will be composed of eight juxtaposed sectors which must be carefully aligned and which require good vertical scanner linearity; speckle effects, resulting from the use of coherent laser light must be minimized, but these were not observed for the red test image, even at high luminance levels; and the overall configuration and resulting weight and CG of the raster generator and visor assembly when integrated on the helmet.

Initial research efforts have primarily addressed the design of the raster generator. It is believed that the design of the video generator (post processor) required to convert normal image generator data and scan rates to an eight simultaneous line format required by the scanner is relatively straight–forward. Variable output pixel timing, required to linearize pixel sizes along a scan line is also not a problem. Transport delays should be one field time, worst case, and will depend on the hardware design chosen.

Scanner galvanometers are off–the–shelf items, but the full 2000–line (interlaced) or 1000–line (non–interlaced) format has yet to be demonstrated. A faster vertical scanner has been implemented and it is hoped that it will exhibit the required two arc–minute response at an eight

kHz rate necessary to permit bi–directional raster scanning. This approach will double both the resolution and the scene luminance available from the display.

4.3. HMD DESIGN APPROACH SUMMARY

Three design approaches for generating high resolution and full color were identified as possible candidates for development and were presented to NASA LaRC for approval.Much of the design effort focused on the raster generator portion of the HMD, since the unique part of the development effort was the requirement for full color capability. The laser scanned approach was chosen for further definition and development. A Development Plan (Appendix A) and Design Specification (Appendix B) were prepared and constitute the latter part of this document. Specifications for the Subminiature Color CRT approach were delivered to NASA LaRC under a separate contract extension.

Summary and Conclusions

This study produced a development plan and design specifications for a full color, high resolution, wide field of view HMD suitable for use in a research environment and suitable for further development into flight rated hardware. The selected laser scanned approach was based upon an concept which has been under development at GE/SCSD. Two novel approaches which relate to the laser scanner and a color subminiature CRT concept have been reported to NASA LaRC under this contract.

The task–related requirements analysis only confirms what is already known: pilots want full eye–limited field of view and resolution capability in a full color HMD. In fact, there are relatively few tasks which demand this capability. In reality, rotorcraft pilots often make do with far less capability and compensate by altering their normal scanning behavior. This approach does have safety consequences, as NVG–related accident reports can attest to. The requirements stated for the HMD which are pertinent to a research setting press the current limits of technology and are more than adequate to investigate the benefits of color used with various system information formats.

The technology survey represents a snapshot of technology which is in a constant state of evolution. The taxonomy matrix depicted in this report provides a meaningful format against which the operation of current HMD systems may be categorized and also provides a framework by which the expected benefits of the application of emerging areas of technology may be assessed when they are allocated to on– and off–helmet portions of the raster generator subsystem. This baseline should aid future design investigations in this area.

A total of three design approaches were presented to NASA LaRC. LCD panels were presented as one approach, as they promise light weight, small size and low power, but the technology is not sufficiently mature to offer small size, high resolution and low interconnect density yet. The subminiature color CRT approach offers quick implementation to an existing NASA LaRC HMD design with color corrected optics which is in the last stages of construction. The performance of the CRT is expected to be somewhat lower in resolution than that promised by the laser scanner system, particularly if the 2000–line laser format is realized.The design approaches presented should allow NASA LaRC to proceed toward both near– and longer–term solutions for full color, high performance HMDs for rotorcraft research.

APPENDIX A
DEVELOPMENT PLAN

FOR A

LASER SCANNER
HELMET–MOUNTED DISPLAY

APRIL 13, 1990

NASA–LANGLEY RESEARCH CENTER

HAMPTON, VA

23665–5225

1.0 SCOPE

This development plan is for a generic solution to the Laser Scanned Helmet Mounted Display (LS/HMD). The plan discusses a range of possible LS/HMD configurations and subsystem components and the probable system and subsystem development risks. In addition, a list of analyses and critical tests which should be performed by the LS/HMD contractor to verify concept feasibility and performance verification is provided including a rough estimate of costs and recommended program scheduling and phasing. The recommended phasing for specific subsystems is designed to minimize the overall program risk and costs by proving the most critical elements of the LS/HMD first and evolving the prototype design from a proven base of knowledge. It is recommended that there be close liaison between the customer (NASA) and the contractor during the development of the LS/HMD in order that alternatives and technical decisions will lead to an optimum configuration which in addition satisfies the specification requirements. This development plan should be read in conjunction with the LS/HMD specification as it does not attempt to duplicate the basic requirements and background information.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this development plan to the extent stated herein. a. Specification for a Laser Scanner Helmet Mounted Display dated April 13, 1990.

3.0 SYSTEM DESIGN

System engineering methodology, including appropriate trade–off analyses, is recommended in order to achieve the specified (Specification – Laser Scanner Helmet Mounted Display) performance and recommended schedule for the development of the LS/HMD at minimum cost.

3.1 DEVELOPMENT PHASING

A three–phase plan is recommended for the development of the LS/HMD as follows:

a. **Phase I** – Phase I should consist of all of the system analyses and detail design of the overall system.

b. **Phase II** – Phase II should consist of the procurement, fabrication and testing of both the raster generator and visor subsystems.

c. **Phase III** – Phase III should consist of the procurement, fabrication and testing of the remainder of the subsystems and the integration and testing of the LS/HMD system.

Such a three phase plan will afford NASA the opportunity for incremental funding, if it so chooses, in three separate fiscal years in addition to minimizing the overall technical risk of the LS/HMD development (e.g., the most critical subsystems can be proven prior to Phase III).

3.1.1 PHASE I ANALYSES AND DESIGN SEQUENCE

The recommended analyses and design sequence within the phase I is as follows:

a. Overall Design

1. Select raster generator design, analyze displayed raster performance

2. Apportion components to on–helmet and off–helmet locations

b. Off–helmet components

1. Select and layout off–helmet components, identify and solve component performance required and design overall adjustment and alignment scheme.

2. Assess video modulation level, gamma conversion and distortion correction requirements. Identify video and scan driver electronics.

c. On–helmet components

1. Analyze color raster generation method construct timing diagrams of the scanning method conduct raytrace verification of optics verify image input requirements for the visor, verify performance of all critical components.

2. Design mounts, verify overall HMD configuration, analyze helmet weight, CG and inertia.

3.1.2 PHASE II PROCUREMENT, FABRICATION AND TESTING SEQUENCE

The recommended procurement, fabrication and testing sequence within phase II is as follows:

a. **Procurement** – It is recommended that the raster generator and visor subsystems be procured only after joint approval of the two subsystem designs. An optimum design from the point of view of both maximum performance and minimum weight will dictate that the two subsystems be designed jointly. This will necessitate that a full design disclosure will be required between each subsystem contractor if different. The procurement of either of these subsystems alone without the benefit of a joint design development may result in a reduced overall system performance or a helmet weight penalty.

b. **Fabrication** – No special sequence is recommended during the fabrication of the raster generator and visor subsystems.

c. **Testing** – It is recommended that both subsystem and integrated subsystem tests be performed for the raster generator and visor subsystems. This will enable the verification of the critical static display performances. Such data will be useful in verifying that the specified performance of all other (Phase III) subsystems is sufficient to optimally combine with these two subsystems. In regards to the helmet, the helmet contractor must know where the required attachment points are to be located if the helmet is to be designed for minimum weight. Otherwise the helmet must be designed

for a range of attachment point locations which implies a strengthened area rather than a strengthened point location which in turn translates into an increased helmet weight design.

3.1.3 PHASE III PROCUREMENT, FABRICATION AND TESTING SEQUENCE

The recommended procurement, fabrication and testing sequence within phase III is as follows:

a. **Procurement** – No special recommendations are made with regards to the phase III procurement.

b. **Fabrication** – No special recommendations are made with regards to the phase III fabrication.

c. **Testing** – It is recommended that an Government–Specified Graphics Generator workstation be made available to the prime contractor for in–plant tests in order that the entire LS/HMD can be integrated and tested. In this regards, an alternative to a Government loaned IRIS workstation will be its lease or purchase as part of the contract. However, if the system design reveals and the Government approves a modification to the IRIS in order to improve system performance (e.g., minimum transport delay, etc.) then such modifications should, of course, be done on appropriate equipment or IRIS modules which will be furnished as part of the LS/HMD program.

3.1.4 FUNCTIONAL DESIGN

The LS/HMD when integrated with two Silicon Graphics 3D work stations (Government–Specified) Graphics Generator shall be capable of displaying variable performance including real–time full color stereopsis imagery utilizing two instantaneous overlapping views. The Government–Specified Graphics Generator imagery shall be controlled in direction of view by closed loop command inputs from a tracking radiator attached to the observer's helmet and a proximity sensor. The LS/HMD baseline system is divided into six (6) major subsystems which collectively contain the basic elements necessary to provide the required functional capability. It should be noted that any specific LS/HMD configuration could deviate somewhat from that shown in terms of locating a specific hardware function in a different subsystem. For instance, the full color raster could be generated within either off–helmet or on–helmet subsystem hardware.

The six subsystems comprising the baseline LS/HMD is shown in Figure 3.1.4–1. Each of the subsystem descriptions includes (1) the assumed component/functions, (2) the analyses required, (3) a discussion of the development risks, (4) a discussion of the critical testing required and (5) the estimated cost, where low cost is approximately $50K to 100K, medium = $100K to 250k and high cost is greater than $250K.

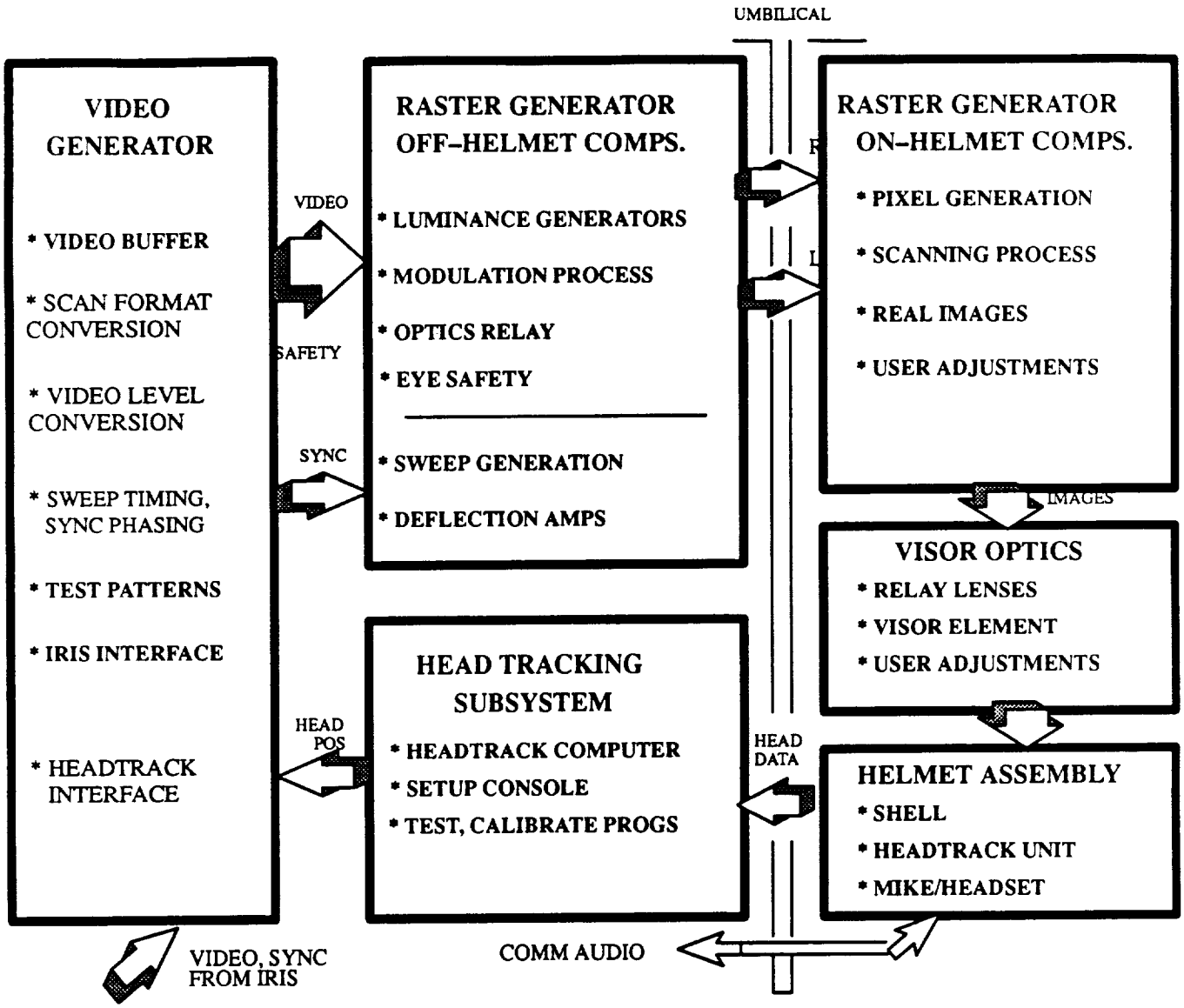

Figure 3.1.4–1. LS/HMD Baseline Subsystem Block Diagram.

3.2 TRADE–OFF ANALYSES

The design and trade–off study phase should address the known development risks which will provide support for all required subsystem procurement specifications. The trade–off analyses relative to the proposed system and subsystem designs should provide:

a. Alternative designs with resulting theoretical system and subsystem performance to assure that the proposed design is the correct and optimum choice

b. Specification compliance of the proposed design, and

c. Detail design descriptions with block and signal flow diagrams, functional descriptions, component/subsystem performance and so forth.

All trade–off analyses should be presented to NASA for approval at the Preliminary Design Review (PDR) and summarized at the Critical Design Review (CDR) for final approval prior to the procurement of any hardware. The critical issues of overall system performance and technical risk should be thoroughly reviewed prior to design freeze.

3.2.1 PERFORMANCE ANALYSES

The most critical analyses issues relative to system performance are the displayed image quality and the size, weight and inertia of the operational helmet mounted display. Any trade–off of these parameters should be done with the full knowledge and approval of NASA.

3.2.1.1 DISPLAYED IMAGE QUALITY

The proposed design should be capable of producing a displayed image whose quality reflects the specified performance for all display parameters. It should be noted that the performance of the Government–Specified Graphics Generator may introduce some image quality degradation which should be identified for purposes of judging the image quality of the LS/HMD. All competing designs should be analyzed relative to each of the following critical display parameters.

a. **Resolution** – The display resolution, especially within the stereopsis region, should be maintained over the full range of luminance and head motions.

b. **Luminance** – The display luminance should be easily controlled for the various simulated time of day and external (to the visor) scene luminance.

c. **Field–of–view** – The display field–of–view, especially within the stereopsis region, should not be traded off with any other display performance. It is desirable to achieve a HMD design which can significantly exceed the specified field–of–view in both the stereopsis and extended 2D regions.

d. **Full color** – It is desirable that the quality of the displayed image for each of the three primary colors should be comparable over the full range of luminance and head motions.

e. **See through capability** – The see through capability of the display should not degrade the quality of the displayed image.

f. **Head motion** – It is desirable that head motion not degrade the overall image quality or introduce any HMD artifacts. An analysis of the effects of head motion on image quality should be made for each specified mode of operation.

3.2.1.2 SUBSYSTEM ANALYSES

Each of the subsystems comprising the LS/HMD should be analyzed in terms of (1) their functions, (2) their interface with other subsystems, (3) the performance required to meet the subsystem specification and (4) their impact on achieving the overall system performance including the required displayed image quality.

3.2.2 TECHNICAL RISK ASSESSMENT

The proposed design should assess the technical risk associated with achieving each specified performance. In addition, all alternative designs should desirably establish the technical risk associated with achieving the specified overall performance. Table 3.2.2–1 provides a technical risk assessment for each of the critical hardware and associated interfaces relative to each of the major subsystems for the generic LS/HMD. It should be noted that all of the LS/HMD system and subsystem specific design concepts will have many, if not all, of the same key technology development risks.

3.2.3 TECHNICAL RISK REDUCTION

The proposed design should implement a technical risk reduction plan for each of the subsystems. For instance, the risk of developing an effective raster generator design may be reduced by sequencing the development to address known high risk areas in the design. For the raster generator, these areas are primarily choosing a color image generation process which permits locating the light weight, small sized components on the helmet and any large, heavy or heat producing components off–helmet. The resulting design approach should permit high resolution, high luminance and an artifact–free, stable raster of high image quality to be displayed. Image quality issues are of relatively high risk, since CRT systems may not produce the required resolution and mechanically scanned designs are more likely to have artifacts in the displayed raster.

4.0 FUNCTIONAL DESIGN

The six subsystems comprising the baseline LS/HMD is shown in Figure 3.1.4–1. Each of the subsystem descriptions includes (1) the assumed component/functions, (2) the analyses required, (3) a discussion of the development risks, (4) a discussion of the critical testing required and (5) the estimated cost, where low cost is approximately $50K to 100K, medium = $100K to 250k and high cost is greater than $250K.

4.1 VIDEO GENERATOR SUBSYSTEM

4.1.1 COMPONENTS/FUNCTIONS

The video generator functions to translate RGB digital video data generated by the image generator to a format required by the raster generator. All synchronizing waveform generation, scan line and field phasing, video data conversion, gamma compensation and video driver functions are performed within this subsystem. This may include the generation of standard or non–standard video line, pixel and sweep timing waveforms. The digital data may be stored or buffered using low transport delay processes prior to conversion to analog form with appropriate gamma and distortion correction. The preferred method for video data transfer from the IRIS to the video generator is via the system bus or in digital form from the video board, whichever provides the least transport delay.

The video generator interfaces to the image generator via shielded digital data lines in order to receive and control the flow of pixel data. It has an additional interface to the raster generator

Table 3.2.2–1. LS/HMD Subsystems and Associated Technical Risks

SUBSYSTEM/SYSTEM (COMPONENTS/PERFORMANCE)	TECHNICAL RISK ASSESSMENT		
	HIGH	MEDIUM	LOW
VIDEO GENERATOR SUBSYSTEM			
		Distortion	
RASTER GENERATOR SUBSYSTEM			
Lasers			Full color Lumens
Modulators			Bandwidth
Scanners		Frequency	
Fiber optics			Diameter Transmission
Mounting			
		Alignment	
Safety		Eye	
			Shock
VISOR SUBSYSTEM			
		Eye relief	
HELMET SUBSYSTEM			
	Weight Inertia Size		
		Fitting Transparency	
			Communications
HEAD TRACKER SUBSYSTEM			
		Transport delay	
LS/HMD SYSTEM			
Image	Artifacts		

Table 3.2.2–1. LS/HMD Subsystems and Associated Technical Risks (Continued)

	HIGH	MEDIUM	LOW
	Transport delay Quality		
		Resolution	
			Field–of–view
Interfaces			Raster gen/Fiber optics
			Raster/visor image
			All others

supplying video and blanking waveforms to the pixel luminance generator and providing synchronizing and deflection waveforms to the deflection amplifiers. All timing waveforms for the raster generator are provided by the video generator. Separate video data shall be provided for the display to each eye.

4.1.2 ANALYSIS REQUIRED

The following analysis should be required for the video generator.

a. **Raster scanning** – An analyses should be performed to determine the method of raster scanning to achieve a full 2000 scan line stereopsis field of view. In addition, the analyses should determine what impact the proposed raster scanning will have on the Government–Specified Graphics Generator in terms of raster distortion, transport delays and potential image anomalies with image and head motion.

b. **Timing requirements** – An analyses should be performed to determine the synchronization required and the timing tolerance which can be permitted in this subsystem.

c. **Distortion compensation** – An analyses should be performed to determine the correction if it is required, to compensate for any LS/HMD introduced distortion. Affects on geometric accuracy, and effects on resolution shall be addressed.

d. **Make/buy review** – An analyses should be performed to determine the design characteristics of the raster generator as they relate to the video generator output requirements and the overall required system performance. The analyses should determine the impact and benefits that would result in any modification to the Government–Specified Graphics Generator output format. Affects on transport delay shall be addressed.

4.1.3 DEVELOPMENT RISK

The key technology risks associated with the video generator subsystem as they relate to the baseline LS/HMD concept include the raster scanning, the timing requirements, transport delay and the distortion compensation. All other design requirements of the subsystem including the buffer, line drivers, gamma correction, head tracking interface and the required LS/HMD test and alignment patterns have been successfully implemented by many contractors on many devices. The primary area of design risk in the video generator is in the development of a design which has low transport delay of video data during the conversion process required by the raster generator. A Component Risk, Video Subsystem summary of the design risk associated with the video generator is provided in Figure 4.1.2–1.

	HIGH	MEDIUM	LOW
Overall design			
weight			X
configuration			X
transport delay		X	
IG interconnect			X
Video memory function			
design			X
transport delay		X	
IG interconnect			X
Video/raster timing/phasing			X
Video gamma compensation			X
Video drive			X
Built–in–test patterns			X
Detection/sync functions			
sync derivation			X
drive			X
Development sequence			
Distortion correction (if required)			X

Figure 4.1.2–1. Development Risk, Video Subsystem

4.1.4 CRITICAL TESTING REQUIRED

The critical testing associated with the video generator subsystem is as follows:

a. Synchronization. – Synchronization between the two Government–Specified Graphics Generators should be verified for the required video data rates associated with the design raster scan characteristics.

4.1.5 COST ESTIMATE

The video generator hardware has been estimated to be a low cost item.

4.2 RASTER GENERATOR SUBSYSTEM

The raster generator subsystem consists of devices which generate the color raster images with sufficient brightness, resolution and proper size for the visor optic subsystem. The raster generator and visor subsystems are the two most critical subsystems required in the full color LS/HMD design.

As depicted by Figure 4.2–1 raster generator functions may be designed either entirely on–helmet, off–helmet, or balanced between the two. All current helmet designs may be categorized by this diagram. For example, if scanning and image generation occurs entirely off–helmet (e.g., CAE FOHMD system), then the entire image must be transferred to the helmet via a coherent fiber optic bundle. On the other hand, if the image is generated entirely on–helmet (subminiature CRT and LCD designs), only an electronic umbilical is required. Mixed designs (e.g., NTSCs VDRT helmet projection system) employ one axis scanning (horizontal) off–helmet and the other (vertical) on–helmet, requiring an umbilical with both optic and electronic linkages. Other combinations are possible and indeed may be required to generate full color rasters which produce the specified image quality at the display.

4.2.1 OFF–HELMET COMPONENTS

It is desirable to have the bulky, heavy or heat producing components off–helmet and have as small and flexible an umbilical as is practical. The on–helmet components should be small, light weight, and be as physically robust as is practical. The overall location of on–helmet HMD components should allow a design which has a center of gravity approximately centered between the observer's ears, no sharp edges and few protuberances, enabling the normal range of head motion and positioning within normal cockpits to be used.

4.2.1.1 COMPONENTS

The off–helmet components, depending on the design approach chosen, have less stringent size, weight and configuration requirements than the components allotted to the on–helmet portion of the raster generator. As such, risk is reduced as compared to the on–helmet components. Risk is also lowered by the intended use of the HMD system as a research tool, rather than a flight–rated system. If pixel, line or full scene luminance data are generated off–helmet and transferred to the on–helmet portion of the HMD, then many off–the–shelf components may be employed in the design and the design risk is primarily one of configuration, mounting and setup and adjustment of the components.

All major luminance generating, beam splitting/multiplying, modulating and optical components required to produce pixel luminance and send it to the fiber umbilical are off–the shelf components of low risk. The overall configuration is low risk, since major components are off–helmet. Additional size and complexity reduction is possible with solid state lasers employed as luminance generators. Fiber coupling is a known process, but design of the quick–disconnect for the umbilical requires careful design . A baseline configuration is depicted by Figure 4.2.1.1–1.

HMD IMAGE GENERATION APPROACHES
PIXEL TYPE–SCANNING–TRANSFER–RASTER IMAGE CHOICES

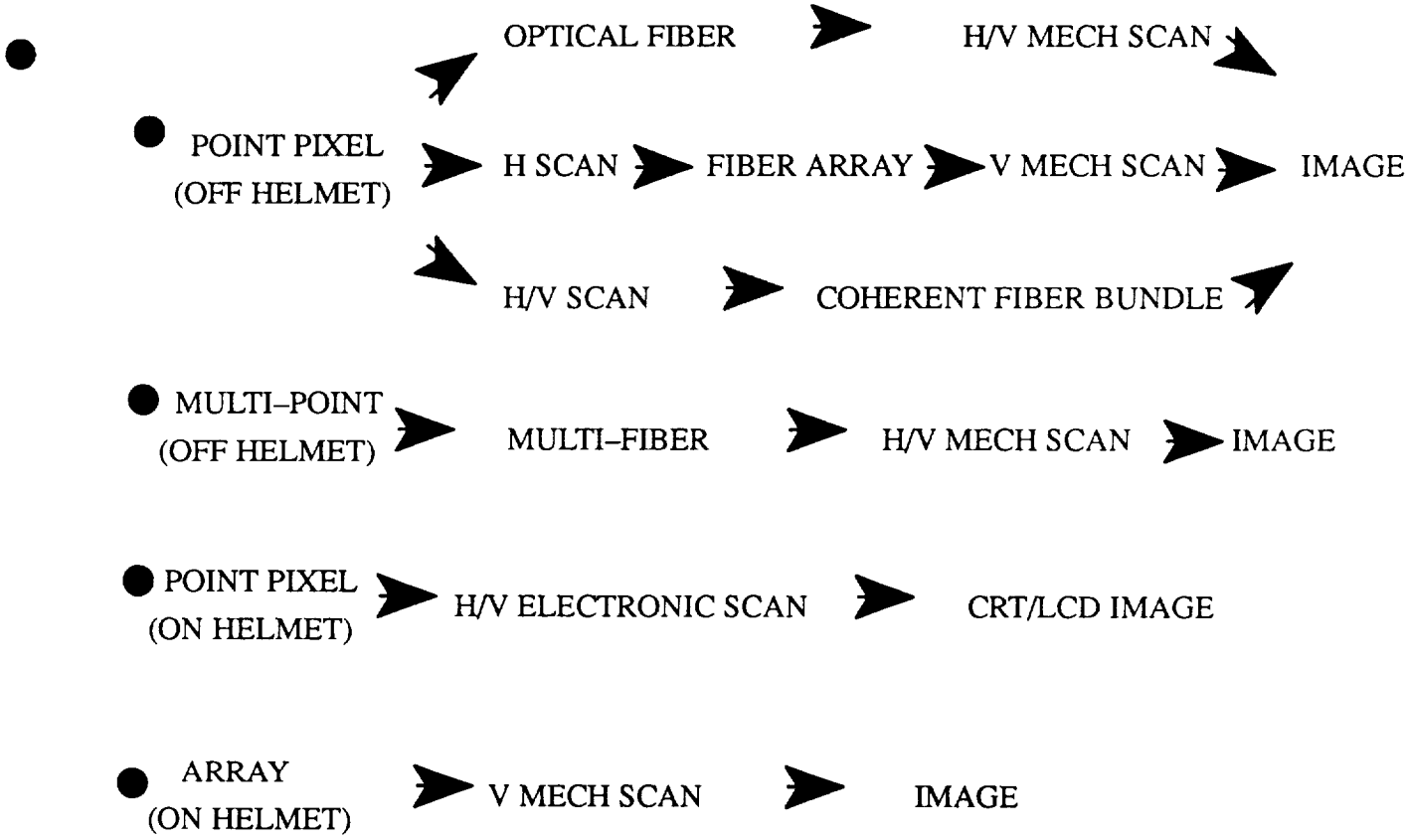

Figure 4.2–1. Raster Image Generation Approaches WSB 4/20/89

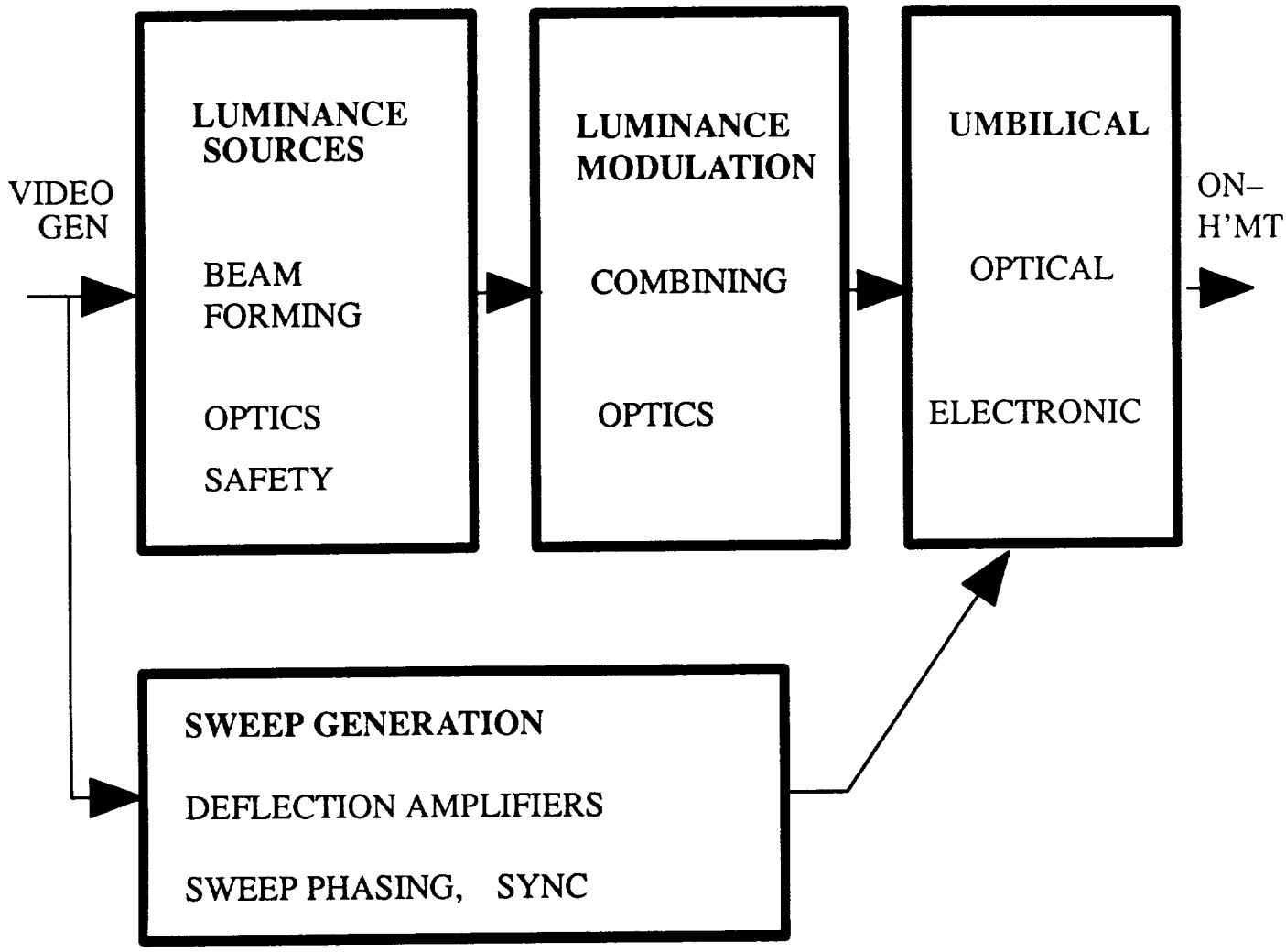

Figure 4.2.1.1–1. Off–Helmet Raster Generator Functions (Baseline)

4.2.1.2 ANALYSES REQUIRED

a. **Laser output power** – The laser output power should be analyzed relative to the selected fiber optic bundle characteristics, length and eye safety requirements.

b. **Solid state lasers** – Solid state lasers which can be directly modulated are preferred over gaseous laser which require external modulation hardware. The performance of solid state lasers should be investigated in light of their potential payoff.

4.2.1.3 DEVELOPMENT RISK

The key technology associated with the off–helmet raster generator are low. RGB lasers are readily available, as are the modulators and optics required. The primary risk is in designing a mount for all of the associated hardware and optical components which permits ease of alignment and performance calibration. These factors may influence the image quality of the displayed image.

a. **Red, Green and Blue Lasers** – Lasers of sufficient power are off–the shelf items. Output power requirements will be set by requirements for displayed scene luminance and the optical efficiency of the system, including the raster generator, the modulators, the optics, the fibers, the optics, screen and visor assembly on the helmet. Overall efficiency is expected to be only a few percent, but the displayed image is small. Solid–state devices are currently in accelerated development and at least one company sells RGB units. These may be directly modulated, thus saving the cost and alignmenment problems associated with the acousto–optic modulators (AOM). Risk is associated with the modulation bandwidth of any solid state laser which generates the correct wavelength light by means of frequency doubling crystals (KDP). These crystals apparently have limited modulation response frequencies and frequency doubling thresholds as well. Conventional gas or HeNe lasers are low risk, solid state units with the required wavelength are considered medium risk in the near term.

b. **Multi–beam unit (MBS)** – The optical derivation of multiple RGB laser beams is a low risk area. Size reaquirements are not stringent, as the unit is off–helmet.

c. **Acousto–optic modulators (AOM)** – Acousto–optic modulators with analog input and wide bandwidth (>20Mhz) are off–the shelf devices. The input response of the analog units is not linear, but more closely follows an "S" curve. Provisions to adjust the gamma and voltage range for each modulator can be provided by look–up tables in the video generator unit. These AOM units, when mounted, must be carefully aligned with the incoming laser beams and optical lenses to focus the incoming beams. Solid–state lasers with sufficient modulation bandwidth will not require AOMs. A mix of direct and AOM modulation is possible, with reduced cost and size benefits. The AOMs are low risk, the solid state lasers in all wavelengths and with direct modulation capability are medium risk, and are being developed by several companies.

d. **Beam combiners and fiber coupling optics** – Each RGB beam set must be combined optically to form a color pixel for transfer to the on–helmet scanning process. A dichroic cube, prism or mirror system may be used to form a single beam. A lens with

focal length appropriate for the fiber's numerical aperture (NA) will be required for each of the 16 fibers. Optics and beam combiners (dichroics) are off–the–shelf components. The mounts are not commercially available, and must be designed for rigidity and yet allow alignment. A mechanical or electronic safety system must be designed to block the light to the fibers if excessive laser output is detected or if one or more scanning elements fails to operate. Manual safety control should also be provided. This is a low risk area.

e. **Optical fiber mount** – The optical fiber mount must be designed with a quick–disconnect feature to allow the helmet to be removed from the fixture. The quick disconnect would include both optical fiber and electrical wire connectors. Beam expansion coupling methods will reduce coupling variance as the disconnect feature is used. This unit must be designed. Some risk is associated with obtaining suitable couplers for he small fiber sizes employed here. Couplers should be stacked in a common unit for ease of use. The electrical quick–disconnect may be an off–the–shelf unit. The multi–fiber optical connector is low to medium risk, the electrical unit has no risk. f.Mounting assembly and alignment. – The mounting assembly may require the use of a small optical bench for rigidity. The mount and optical alignment fixtures may be off–the shelf units to reduce cost at the expense of (off–helmet) assembly size. This approach is low risk.

g. **Safety subsystem** – A mechanical or electronic safety subsystem employing laser output level and scanner function sensing shall be provided, along with a manual control feature. The system may be an off–the–shelf solenoid–type unit and power sensing may employ solid–state sensors, but the control circuits must be designed. This is a low–risk area.

h. **Laser/fiber coupling efficiency** – Coupling efficiency variation is to be expected and may be controlled by alignment and video signal level conversion in addition to the normal gamma correction functions. The primary design risk is associated with alignment stability and range of video level control. These are low to medium risk areas and will affect displayed image quality.

4.2.1.4 CRITICAL TESTING REQUIRED

a. **Laser modulators** – The laser and associated modulators should be tested to verify that the required pixel rate, luminance levels and range of modulation can be achieved.

b. **Coupling efficiency** – The design shall ensure that optical alignment stability is maintained and that adjustments and measuring may be easily performed. Variation among units should be held to a practical minimum of no more than two to one.

c. **Output at end of fiber** – Optical alignment and electronic voltage conversion techniques shall enable displayed luminance and color variation to be virtually indiscernible at the display.

4.2.1.5 COST ESTIMATE

The raster generator (off–helmet) subsystem hardware has been estimated to be of medium cost.

4.2.1 ON–HELMET SUBSYSTEMS

4.2.2.1 COMPONENTS

The on–helmet optical and mechanical components which produce the color image must be robust and be configured so that adjustments may be made for scene overlap, interocular variation among observers, and focus. Scene alignment and derotation may be assigned either to the raster generator or the IRIS image generator system. The raster generator and visor subsystem coupling must allow these adjustments to be performed easily and with repeatability. The mounting assembly for the on–helmet components must be lightweight, rigid and protected by a conferral shell to prevent damage or misalignment of components due to normal handling and usage. The primary risk areas for the on–helmet components are weight, size and center of gravity of the design, since unconventional processes may be employed to generate high resolution color images. The on–helmet components are also most likely to be the main components which contribute to the image quality of the observed scenes.

The selection and configuration of the on–helmet components is of high risk, since color generation, high resolution and light weight require novel design solutions for the configuration of the on–helmet portion of the raster generator. The major risk area is the optical layout and expected performance of the scanning process. Scan stability and adjustment processes are also high risk, as is image quality The baseline on–helmet functions are indicated in Figure 4.2.2.1–1.

4.2.2.2 ANALYSES REQUIRED

a. Raster scanner

   1. Linearity

   2. Drift

   3. Stability

b. Synchronization signal

4.2.2.3 DEVELOPMENT RISK (ASSOCIATED WITH THE BASELINE APPROACH)

The key technology risks associated with the on–helmet raster generator are the raster scanner, the synchronization feedback required for raster stability, the size and weight of the components and the image quality that is produced.

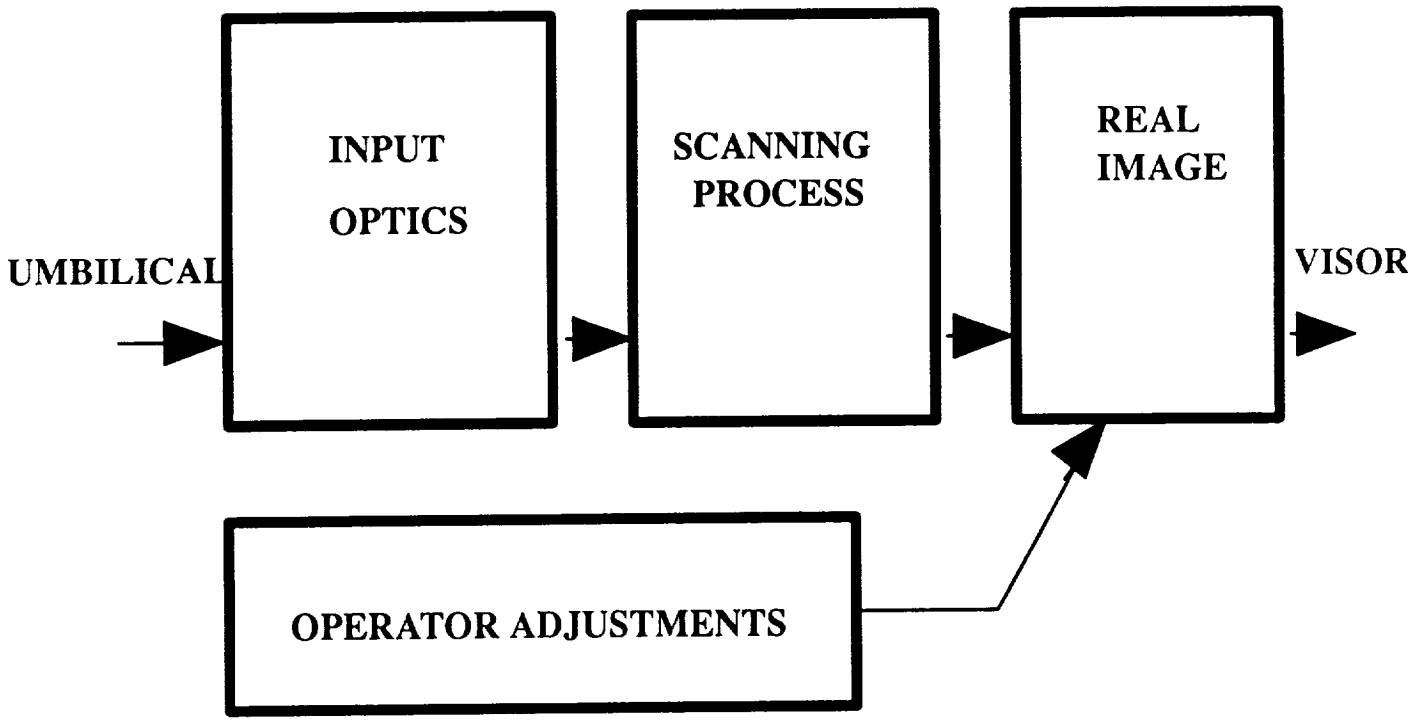

Figure 4.2.2.1–1 On–Helmet Raster Generator Functions (baseline)

The on–helmet components serve to produce the left and right eye images in a manner suitable for the visor optic subsystem to produce stereoptic, overlapping, high resolution color images for
the observer. Each of the following areas are potentially a development risk area for any specific on–helmet configuration.

a. **Optical fiber pixel image plane** – The optical fibers and their mounts are one of the most critical components of the HMD system. The fibers have to be precisely separated and aligned such that a continuous image is formed without visible segmentation in the observed image. Visible segmentation may be formed by inaccuracies in any one of four processes:

   1. **Fiber position** – The fibers must lie in a plane (object plane), be precisely separated, and have precise ends so the luminance from each fiber is effectively gathered by the input lens.

   2. **Color variation among the RGB sources** – Color variations among the fibers are minimized by obtaining raw red, green and blue luminance from the same

source. Wavelength variance is thus nil. Separate sources, such as solid state diode laser sources, will have to be chosen for very close wavelength matching.

3. **Color variation with AOM modulation** – Modulation variance can be minimized by using lookup tables for each of the video voltages sent to each modulator. The lookup–tables are used to equalize the input voltage/output modulation response among modulators which feed each fiber. Each RGB emitter will have to be setup for equal gray scale response so that mixed colors are depicted the same by each segment. AOM response has both innate and alignment position factors. Both must be minimized.

4. **Scan process nonlinearity** – Non–linearity must be minimized or compensated for in order to produce an artifact–free image.

b. **Scanning process** – The particular scanning process employed must exhibit a high degree of stability and freedom of displayed scene perturbation with normal handling. Scan non–linearity must be minimized or compensated for. The configuration must be amenable for coupling with the visor subsystem and allowing interocular and image positioning adjustments to be made by the observer. Weight and size are key issues, as is the resulting physical arrangement and its contribution to overall HMD shape and CG when coupled to the visor. A design opportunity exists to integrate portions of the scanning subsystem with the design of the visor optic subsystem in order to reduce overall weight or to provide a more compact arrangement on the helmet. The performance of the scanning process and the visor optics are the two most critical factors in the overall research HMD design.

4.2.2.4 CRITICAL TESTING REQUIRED

a. **Optical alignment accuracy** – The on–helmet optics must be capable of precisely coupling with the visor optics. These tests should be integrated with appropriate visor tests.

b. **Fiber optics performance** – The fiber optics performance should be measured to confirm the manufacturer's specification data.

c. **Scan format and stability** – The design shall produce a raster format with the required active line count in a format required by the visor optic system. Interocular and position adjustments shall be made while maintaining a useful raster format.

d. **Image quality** – Measure active line numbers, pixel counts and the overall image for lack of discernable artifacts. Luminance and chrominance variation across the image should be held to less than 5% within the central 50% area of the image and less that 10% in the outer regions.

4.2.2.5 COST ESTIMATE

The cost for the raster generator (on–helmet) subsystem hardware has been estimated to be at low cost.

4.3 VISOR SUBSYSTEM

4.3.1 COMPONENTS

The visor optics subsystem serves to couple the twin raster images from the on–helmet raster generator to the observer as collimated, wide field–of view (FOV), high resolution color images with an adjustable central overlap area of stereo overlap. The images are collimated and are adjustable for the degree of stereo overlap and for the interocular variance of the fifth through 95th percentile male pilot population. The visor optics subsystem consists of attachments for mounting the visor optics to the helmet shell, relay lens(es), holographic lens elements, reflector assemblies, and adjustment controls for position, interocular distance, focus and alignment. The visor subsystem (Figure 3.1.3–1) is fully color corrected and components are constructed of non–frangible materials for safety. Eye relief is sufficient for the use of vision correcting spectacles.

4.3.2 ANALYSES REQUIRED

a. **Optical design and performance** – A detailed optical design and performance analyses should be performed on the visor assembly as part of the total LS/HMD optical design. This will enable the LS/HMD design to be optimum in terms of weight and performance.

4.3.3 DEVELOPMENT RISK

The key technology risks associated with the visor assembly is that a visor assembly providing the required performance of the LS/HMD does not exist at this time. Visor technology utilizing holography for instance, is still an emerging technology. As a result the responsiveness to the specified LS/HMD performance will not be known until a detailed analyses and design is performed. Such issues as eye relief, fields–of–view, color correction, interocular adjustment range and so forth will drive the design but the actual performance which can be achieved is yet to be determined.

The visor system performance and weight are relatively high risk factors in the design of the HMD system. Development risk is moderate for full color correction and low distortion. The configuration of the visor must also lend itself to the configuration of the raster generator such that images produced by the raster generator may be efficiently coupled to the visor subsystem, while allowing for interocular and overlap adjustment.

4.3.4 CRITICAL TESTING REQUIRED.

a. Optical testing – A controlled optical laboratory test of the visor assembly inherent performance should be performed prior to its mating with the helmet. This will be required since the visor assembly will be a subcontract item being designed and manufactured to its own specification.

4.3.5 COST ESTIMATE

The visor subsystem hardware has been estimated to be at high cost.

	RISK AREA		
	HIGH	MEDIUM	LOW
Overall design			
weight	X		
configuration		X	
image quality (color)			X
Relay lenses			
weight	X		
layout, coupling		X	
adjustment ass'y		X	
Visor optic/reflector			
overall configuration		X	
field of view		X	
eye relief		X	
color correction		X	
distortion		X	
holographic elements		X	
adjustment ass'y		X	
see–through			X
throughput efficiency			X
Development sequence			
relay lenses			
ray trace/CAD programs			X
visor optic elements			
holographic elements		X	
Overall configuration			
weight	X		
CG, shape	X		
coupling to raster gen		X	
adjustment capability		X	
Alignment procedures			
focus		X	
overlap/field of view		X	
interocular distance		X	
scene registration		X	
boresight		X	
resolution test		X	
color test		X	

Figure 4.3.2–1. Development Risk, Visor Subsystem

4.4 HELMET SUBSYSTEM

4.4.1 COMPONENTS

The helmet assembly consists of a durable helmet shell, an adjustable liner which permits fitment to head sizes for 5th through 95th percentile male pilots, a detachable protective outer shell over the exposed optical components in the raster generator, a boom microphone and its attach mounts, a pair of headset speakers and the electrical audio communications umbilical cord. The headtrack position coil shall be attached to the center rear of the shell with its umbilical attached so as to not restrict normal head motion while the pilot is seated.

For a research application, the helmet shell does not require the impact protection afforded by a flight–rated helmet. The primary purpose of the helmet shell is to serve as a mount for the on–helmet raster generator components, the visor subsystem, the communications microphone and headset, the umbilical from the off–helmet raster generator, and the headtrack receiver module. Adjustment devices for setting the interocular position, visor position and image overlap should be easily adjustable by the user. Designing for low weight and ease of fitting to a wide variety of subjects are the primary risk areas

Fitting the helmet snugly and comfortably to a wide variety of head sizes requires the use of devices such as inflatable bladders or insertable foam pads to allow the interior space of the helmet shell to conform to a given head size and shape. Once snugly fitted, the visor screens must be adjusted to depict both scenes in their proper position and attitude using the adjustment knobs provided. A good solution for the fitting problem has low to medium risk.

Helmet shell weight is a function of materials chosen and fabrication of the shell. Kevlar fiber has been successfully used in the design of some light weight, flight–rated HMD designs. Using a lightened flight–rated helmet shell is low risk, designing a very lightweight shell has low to moderate risk. The proportion of total weight contributed by the shell approximately 20 percent of the HMD, the raster generator and visor being the heaviest elements.

4.4.2 ANALYSES REQUIRED

a. Optical design and performance. – A detailed optical design and performance analyses should be performed on the visor assembly as part of the total LS/HMD optical design. This will enable the LS/HMD design to be optimum in terms of weight and performance.

4.4.2.1 HELMET WEIGHT ANALYSES

A helmet weight analyses should be performed which will rule out obvious hardware and configurations which will lead to unacceptable results. The design and analyses should include a weight budget for the helmet, visor and all on–helmet assemblies in order that the 5 pound total weight requirement can be achieved if possible. In addition, each assembly should be broken down into its unique components in terms of weight and location in order that the total inertia can be computed. A weight control plan shall be implemented during the development program to monitor and control on–helmet weight.

4.4.3 DEVELOPMENT RISK

The key technology risks associated with the helmet assembly in combination with the on–helmet and visor hardware includes achieving a weight of 5 pounds or less.

4.4.4 CRITICAL TESTING REQUIRED

a. **Comfort** – The helmet assembly should be tested for comfort for a full range of head sizes and shapes.

b. **Weight** – The helmet assembly should be tested for weight for a full range of head sizes and shapes.

c. **Stability** – The helmet assembly should be tested for stability for a full range of head sizes and shapes over a full range of head movements utilizing a dummy load which simulates the operational weight and inertia.

d. **Head tracking subsystem** – The head tracking subsystem should be integrated into the stability test in order to be able to correlate head movement data with test subject comments.

4.4.5 COST ESTIMATE

The helmet subsystem hardware has been estimated as medium cost (Figure 4.4.5–1).

	AREA		
	HIGH	MEDIUM	LOW
Overall design			
shell material		X	
shell construction		X	
weigh	X		
Raster gen mounts			X
Visor mounts			X
Adjustment ass'y		X	
Communications mounts			X
Headtrack receiver mount			X
Umbilical mount			X
Boresight mount			X

Figure 4.4.5–1. Design Risk for the Helmet Shell

4.5 HEAD TRACKING SUBSYSTEM

4.5.1 COMPONENTS

It is anticipated that the head tracking subsystem will consist of off–the–shelf hardware and custom design tracking algorithms.

The headtracker subsystem serves to measure the observer's head position and translation with respect to a fixed reference point on the test cockpit structure and send that angular information to the IRIS image generator, which responds by adjusting the view window of the displayed scene to correspond to the current head position. The subsystem consists of a data computer with or without a console, software programs which allow boresight, calibration and alignment, distortion compensation and monitoring of the head position and angles, an interface to the image generator and the transmitter and receiver modules which mount on the cockpit structure and the helmet shell.

4.5.2 ANALYSES REQUIRED

a. **Algorithm** – Prior to system integration the response time associated with the head tracker algorithm should be analyzed and established relative to a full range of selected training tasks.

4.5.3 DEVELOPMENT RISK

All of the components and much of the software are off–the–shelf items of low risk. The remaining areas requiring development pertain to the integration of the unit into the HMD system with the image generator and the production and testing of additional software which are required for data transfer, or filtering, rate prediction or other methods of transport delay reduction. This risk is low, as many systems are currently in use. The key technology risk associated with the head tracker subsystem relates to the tracking algorithm which is to be implemented in conjunction with the LS/HMD. Smoothness, transport delays, and so forth can be optimized in the tracking algorithm for a specific hardware implementation. In all other regards head tracker technology has been successfully implemented in a number of devices over the past ten years and should not present a problem. A summary of the head tracking development risks is provided in Figure 4.5.2–1.

4.5.4 CRITICAL TESTING REQUIRED

a. **Algorithm** – After system integration the head tracker algorithm should be evaluated relative to displayed image motion, quality and transport delays.

4.5.5 COST ESTIMATE

The headtracking subsystem hardware has been estimated to be low cost.

	AREA		
	HIGH	MEDIUM	LOW
Overall subsystem design			X
headtrack unit selection			X
computer selection			X
IG interface select			X
test, align, boresight software			X
boresight test fixture			X
filtering and prediction software			X

	AREA		
	HIGH	MEDIUM	LOW
Integration and test			
integrate, test components			X
write, debug additional software			X
integrate with IG, test			X

Figure 4.5.2–1. Development Risk, Headtrack Subsystem

4.6 SYSTEM INTERFACES

4.6.1 COMPONENTS

The LS/HMD interface components will varies with each subsystem interface as follows:

a. **IRIS workstation/video generator** – Possible IRIS workstation frame buffer modification, D/A or D/D video transmission cables, possible custom video generator frame buffer and synchronization signal cables from the IRIS workstation.

b. **Video generator/raster generator (off–helmet)** – Analog video and synchronization signal cables.

c. **Raster generator (off–helmet)/raster generator (on–helmet)** – RGB laser light over fiber optic light cables and raster sweep signals.

d. **Raster generator (on–helmet)/vision** – Optical coupling of the full color raster image.

e. **Raster generator (on–helmet)/helmet** – Mechanical attachment of the raster generator (on–helmet) component to the helmet.

f. **Helmet/visor** – Mechanical attachment of the visor to the helmet.

g. **Helmet/head tracking** – Mechanical attachment of the head tracking radiator to the helmet.

h. **Head tracking/IRIS workstation** – 6 degree of freedom head signals to the IRIS workstation via the head tracking computer.

4.6.2 ANALYSES REQUIRED

The analyses which should be performed during Phase I of the development program consist of the following:

a. **IRIS workstation/video generator** – The impact/benefits of modifying the IRIS workstation frame buffer configuration relative to the required LS/HMD system performance (e.g., transport delay, etc.).

b. **Video generator/raster generator (off–helmet)** – The format of the transmitted raster video.

c. **Raster generator (off–helmet)/raster generator (on–helmet)** –The format of the transmitted laser light.

d. **Raster generator (on–helmet)/visor** – The optical coupling design between the raster generator optics and the visor optics.

e. **Raster generator (on–helmet)/helmet** – The attachment and adjustment techniques to provide a rigid frame with minimum weight.

f. **Helmet/visor** – The attachment and adjustment techniques to provide a rigid frame with minimum weight.

g. **Helmet/head tracking** – No unique analyses is required.

h. **Head tracking/IRIS workstation** – The algorithms which will be utilized with the LS/HMD to provide maximum head position accuracy with minimum transport delay.

4.6.3 DEVELOPMENT RISKS

Interface development risks are a function of the specific LS/HMD system/subsystem concept. Two generic development risks are, however, worth noting. These are the ability to achieve the specified operational helmet weight of 5 pounds or less and the system transport delay. All other required interface developments can be approached with straight forward engineering techniques.

4.6.4 CRITICAL TESTING

Critical testing is a function of the recommended program phases as follows:

a. **Phase II** – The subsystem integration tests associated with the raster generator and the visor are critical.

b. **Phase III** – All system integration tests.

4.6.5 COST ESTIMATE

The interface subsystem hardware has been estimated to be as medium cost.

4.7 SYSTEM INTEGRATION

4.7 SYSTEM TESTS

4.7.1 IN–PLANT

It is recommended that in–plant tests include the total LS/HMD integration including one Government–Specified Graphics Generator workstation. Stereopsis tests can be performed utilizing recorded video from the single workstation and with specially produced test patterns.

4.7.1.2 ON–SITE

It is recommended that on–site tests include the total LS/HMD integration with two Government–Specified Graphics Generator workstations.

5.0 COSTS ESTIMATES

5.1 SUBSYSTEM ESTIMATED HARDWARE COST AND MANHOUR SUMMARY

The summary of subsystem estimated costs (total of recurring and nonrecurring costs) presented herein is provided below:

	Hardware	Manhours
Video generator	LOW	
Raster generator (off–helmet)	MEDIUM	
Raster generator (on–helmet)	LOW	
Visor	MEDIUM HIGH	
Helmet	MEDIUM	
Head tracking	LOW	
Interface	MEDIUM	

The cost estimate for the entire system is between $1 and $2 million.

5.2 DEVELOPMENT PLAN PHASING ESTIMATED COSTS

Development plan phasing estimated costs includes both the estimated hardware costs and manhours. Based on a $1.5M estimated cost, the design is expected to be approximately one–third the total cost. This allows balanced phase costs to be estimated as shown below.

	Hardware costs	Manhours
a. Phase I.	Design	$0.5M
b. Phase II..	Fabrication	$0.5M
c. Phase III.	Fabricate interface	$0.5M
		$1.5 M

6.0 PROGRAM MANAGEMENT

The integrating contractor should establish a program management organization for LS/HMD which will be capable of managing both their own resources and those of any required subcontractors. LS/HMD involves a wide range of technologies and their management can best be handled by a systems house which has the necessary broad base of experience.

The program management, in addition to forming the best team, will have to monitor the design progress of LS/HMD through periodic design and progress reviews. Locations of such meetings may vary according to the status of a critical aspect(s) of the program and the best location for the review.

Following is a list of tasks and subtasks for each Phase of Development, which would be expected to be completed within the 30–40 month time frame of the development contract.

a. Overall Detailed Design and Analysis

b. Select overall approach

c. Apportion functions to on– and off–helmet locations

d. Detailed analysis and design of all modules

e. Video generator IRIS interface, data

f. Raster generator off–helmet on–helmet raster performance

g. Visor optics conjoint design

h. Helmet shell mounts, adjustments

i. Headtracker interface, data

PHASE II
Procurement, Fabrication and Testing

a. Procure visor optics

b. Fabricate, test raster gen

   1. off–helmet assy

   2. on–helmet assy

c. Integrate, test raster gen and visor optics

PHASE III
Procurement, Fabrication and Testing

a. Fabricate, test video generator add I/F, modify IRIS

b. Procure, modify helmet

c. Procure, test headtracker, S/W

d. Fabricate mounts, assemble HMD

e. Test overall performance

APPENDIX B
SPECIFICATION

FOR A

LASER SCANNER
HELMET–MOUNTED DISPLAY

APRIL 13, 1990

NASA–LANGLEY RESEARCH CENTER

HAMPTON, VA

23665–5225

1.0 SCOPE

This specification establishes the design, development, characteristics, interface and test requirements for a Laser Scanner Helmet Mounted Display (LS/HMD) system and associated subsystems for a selected responsive baseline system to be used in a rotorcraft flight simulation research environment with growth potential for use with flight simulators. The baseline system represents a generic laser scanned helmet mounted display technology to provide wide field of view, full color images to each eye with an adjustable area of stereoptic overlap.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply. (Per NASA Requirements)

2.1 OTHER PUBLICATIONS.

The following documents forms a part of this specification to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

a. Proposal for Raster Graphic Helmet Mounted Display Study, November 30, 1987 by General Electric Company

b. Statement of Work – Raster Graphic Helmet–Mounted Display Study October 19, 1987 by NASA Langley Research Center

c. American National Standard for the safe use of lasers (ANSI Z136.1–1986)

3.0 REQUIREMENTS

3.1 Item definition. – The LS/HMD when integrated with Government–Specified Graphics Generators shall be capable of displaying variable performance including real–time stereopsis imagery utilizing two instantaneous overlapping views. The Government–Specified Graphics Generator imagery shall be controlled in direction of view by closed loop command inputs from a tracking radiator attached to the observer's helmet and a proximity sensor.

3.1.1 ITEM DIAGRAM

The LS/HMD system block diagram is shown in Figure 3.1.1–1

3.1.2 INTERFACE DEFINITION

The contractor shall be responsible for the interface design and hardware between the LS/HMD, its subsystems and the Government–Specified Graphics Generator graphics generators. The interface design shall be optimized for maximum processing and display performance respectively for both the Government–Specified Graphics Generators and the LS/HMD for all modes of operation as described below. All interface designs shall be approved by a cognizant NASA technical representative prior to design freeze and shall be documented in the Interface Control Document (ICD) and the Prime Item Development Specification (PIDS).

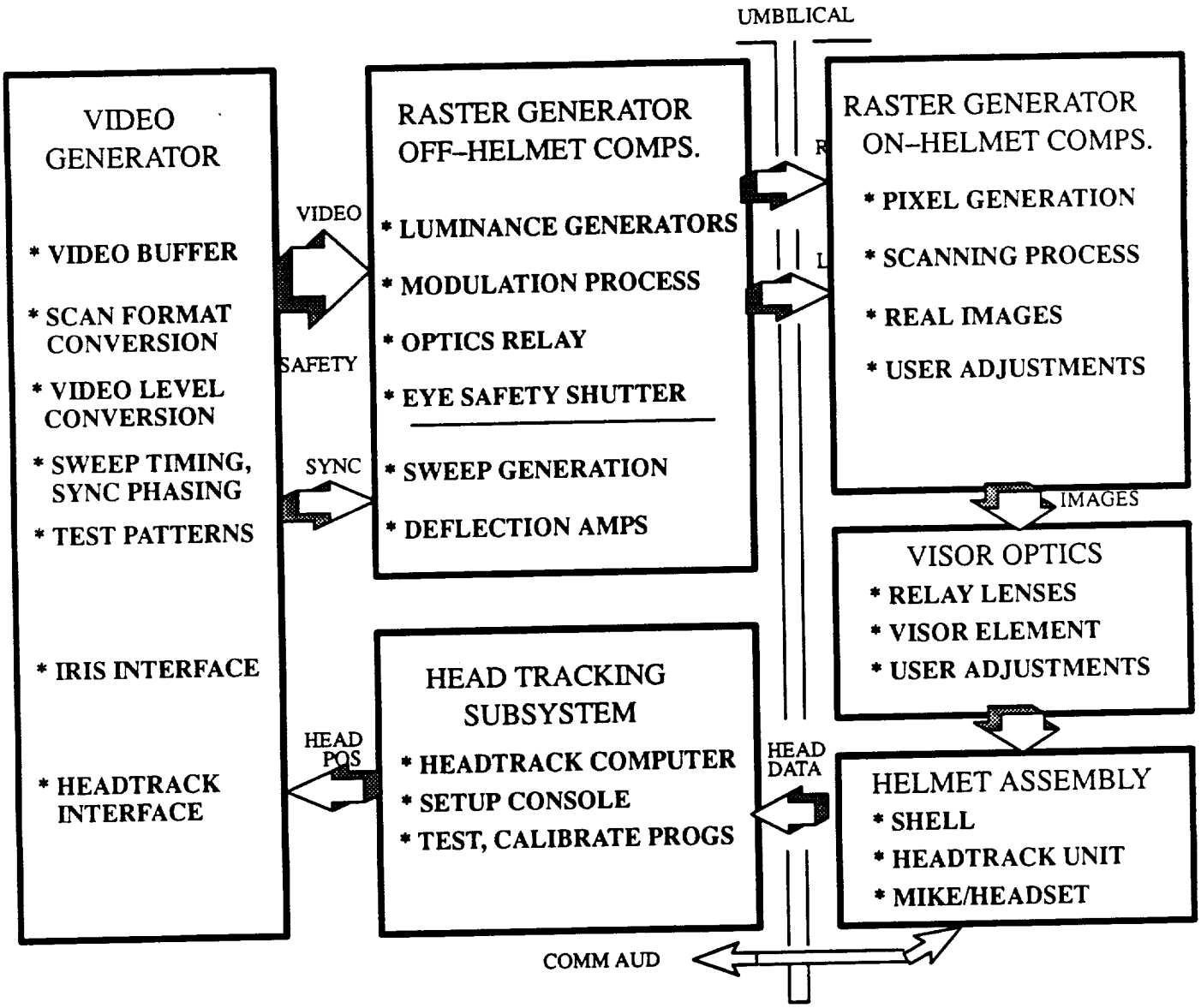

Figure 3.1.1–1. LS/HMD System Block Diagram (Baseline System)

3.1.2.1 MECHANICAL INTERFACE

No mechanical interface requirements exist between the Government–Specified Graphics Generators and the LS/HMD. A mechanical device for clamping the helmet in a fixed position referenced to the cockpit structure for the purpose of initially boresighting the headtracker subsystem shall be provided by the NASA LaRC. All such mechanical test fixtures shall be located out of the required total field–of–view of the observer for modes–of–operation where external detail to the visor is illuminated and can be seen by the observer.

3.1.2.2 ELECTRONIC INTERFACE

The electronic interface requirements shall consist of all circuity, cabling and connectors required to receive compatible and timely RGB digital video and sync signals from the Government–Specified Graphics Generator graphic generators and the appropriate conversion/scanning to achieve the required full color imagery. Interface circuits as required to format the host bus of the Government–Specified Graphics Generators shall be provided. The interface circuits shall provide necessary control signal generation, logic level shifting, signal buffering, blanking waveforms to luminance generator, synchronizing and deflection waveforms to the deflection amplifiers as required for proper electronic interface. The electronic interface design shall provide for operation of the Government–Specified Graphics Generators when the LS/HMD is both operative and inoperative. Standard off–the–shelf computer to computer I/O interfaces shall be utilized where possible. Shielded data and video lines shall be utilized throughout the LS/HMD. The design and fabrication of the interface printed wiring boards shall be in accordance with standard commercial practice. The electronic interface with the Government–Specified Graphics Generator is shown in Table 3.1.2.2–1. The signal flow diagram for the LS/HMD between the Government–Specified Graphics Generator and its respective LS/HMD subsystems is shown in Figure 3.1.2.2–1

Table 3.1.2.2–1. IRIS 4D/70 Electronic Interface

Image memory. – Eight 1280 X 1024 color bit–planes, expandable to 24

Video interface. – (1) RGB levels 0.7 V p–p into 75 ohms or 10.0 V p–p with sync on green, (2) Separate composite 2 V p–p sync into 7 ohms, (3) 60 Hz non–interlaced, 1280 X 1024 resolution, (4) 30 Hz interlaced, 1280 X 1024 resolution

Color range. – (1) Color map mode (12 bits), 4096 colors displayable,
(2) RGB mode (24 bits), 16.7 million colors displayable

Chassis. – 12–Slot VMETM card cage

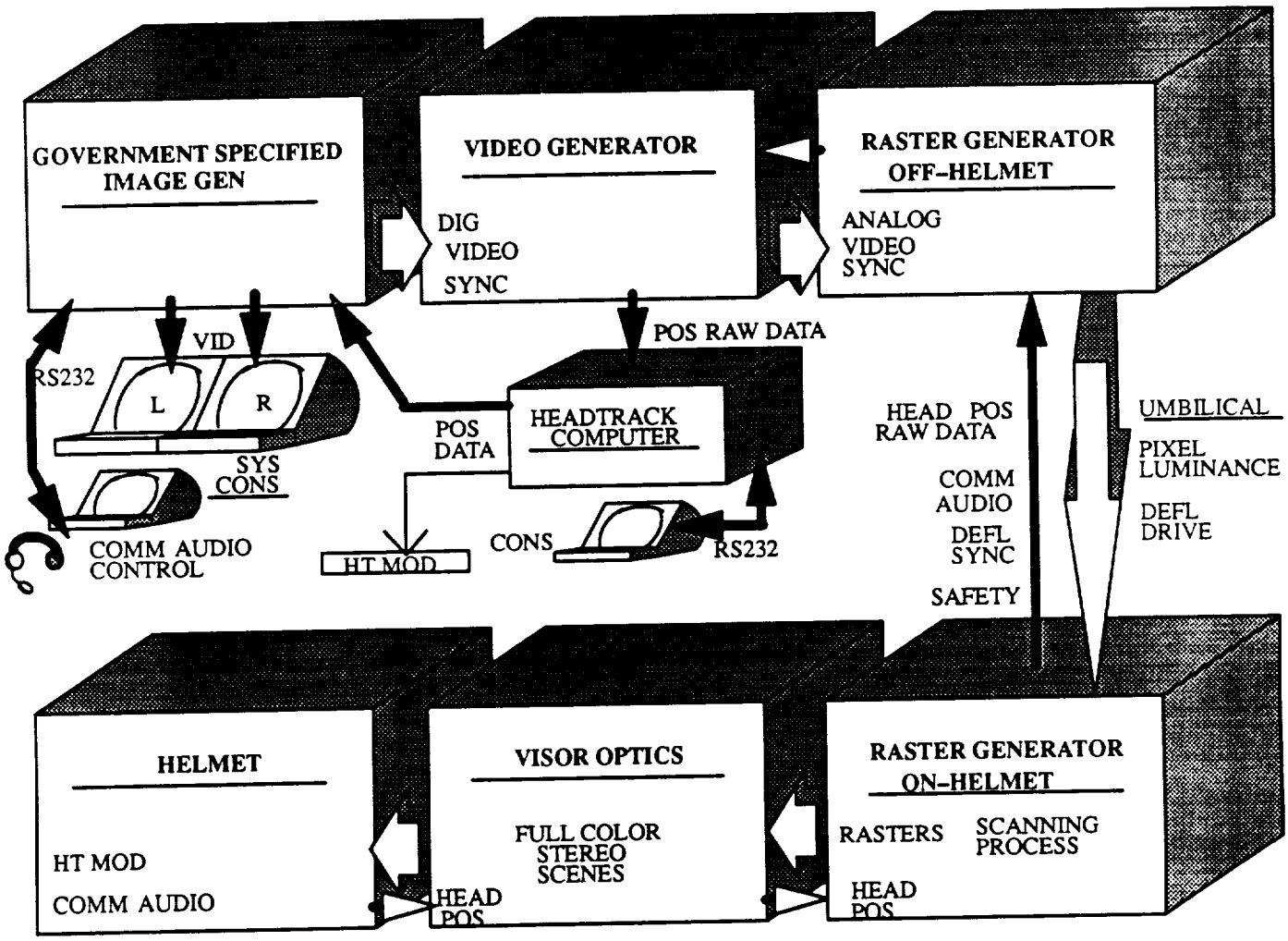

Figure 3.1.2.2–1. LS/HMD Signam Flow (Baseline System)

3.1.2.3 SOFTWARE INTERFACE

The software interface shall include all software necessary to properly integrate the LS/HMD with the Government–Specified Graphics Generators to provide the performance specified herein.

3.1.2.4 OPTICAL INTERFACE

No optical interface is required between the LS/HMD and the Government–Specified Graphics Generators. The Government–Specified Graphics Generator(s) display shall be utilized without modification as the remote monitor(s) of the imagery being displayed to the observer.

3.1.2.5 ELECTRICAL POWER INTERFACE

The electrical interface shall include all hardware, cabling and connectors required to interface each of the LS/HMD with the facility power.

3.1.2.5 INTERFACE CONTROL DOCUMENT

The contractor shall be responsible for the generation of the Interface Control Document (ICD) between the Government–Specified Graphics Generators and the LS/HMD. The ICD shall completely define the mechanical, electronic, optical, software and electrical power interfaces between the LS/HMD, its subsystems and the Government–Specified Graphics Generators. The ICD shall include, but not be limited to the following:

a. Mechanical interface requirements which document the implementation of the requirements of 3.1.2.1 including drawings of the helmet tracker support structure.

b. Electronic interface requirements which document the implementation of the of the requirements of 3.1.2.2 including diagrams of equipment locations and cable routing. Video and sync signals, interrupt signals, computational update frequency (as appropriate), scanner sync signals and helmet tracker command outputs shall be documented.

c. Software interface requirements which documents the implementation of the requirements of 3.1.2.3 identifying scope and content of the required program modules for both the Government–Specified Graphics Generator and LS/HMD.

d. Optical interface requirements which documents the optical interface implementation between the appropriate LS/HMD modules.

e. Electrical power interface between the designated NASA laboratory facility and the LS/HMD system including all power requirements, cables, connectors, cable routings and emergency off switch designs.

3.1.3 MAJOR COMPONENTS LIST

The major components which comprise the LS/HMD shall be as specified below. The major component functions of the baseline LS/HMD are provided as a subparagraph to each of the required basic modular components.

3.1.3.1 IMAGE GENERATOR SYSTEM

The LS/HMD shall be integrated in–plant (contractor) and on–site (NASA) to a Government owned Government–Specified Graphics Generator Image Generator IG) through a video generator subsystem specified below. The delivery of an IG system is not a requirement of this specification. The IRIS 4D/70D IG hardware shall not be modified in satisfying the specified performance herein.

3.1.3.2 IMAGE DISPLAY SYSTEM

The LS/HMD which comprises the image display system shall convert and process the video signals from the IG into dynamic head tracking 3D visual images to a single observer. The image display shall be comprised of the following specific components.

3.1.3.2.1 VIDEO GENERATOR SUBSYSTEM (BASELINE). The video generator subsystem shall provide the buffer, line drivers, gamma correction, timing, head tracking interface, test and alignment patterns associated with the LS/HMD.

3.1.3.2.2 RASTER GENERATOR SUBSYSTEM (BASELINE). The raster generator subsystem shall be comprised of both off–helmet and on–helmet components as follows. The design goal of the LS/HMD shall be to locate all large and heavy hardware with the hardware associated with the off–helmet raster generator and thereby minimize the weight and inertia of the helmet and its associated on–helmet hardware.

3.1.3.2.2.1 OFF–HELMET HARDWARE (BASELINE). The off–helmet hardware functions associated with the raster generator shall interface with the video generator and consist of a full color (RGB) laser, optics, modulators, fiber optic relay, safety shutter, sweep waveform generators, deflection amplifiers and raster geometry. The block diagram for the off–helmet raster generator subsystem is shown in Figure 3.1.3.2.2.1–1.

3.1.3.2.2.2 ON–HELMET HARDWARE (BASELINE). The on–helmet hardware functions associated with the raster generator shall interface with the off–helmet raster generator hardware and consist of mounting assemblies, horizontal and vertical galvanometer scanning mirrors, imaging lenses and high resolution screens.

3.1.3.2.2.2.1 COMMUNICATIONS SYSTEM. The LS/HMD shall provide an audio communication system between the observer and operating personnel. The communication system shall be capable of both voice activation and hot mike at all microphones.

3.1.3.2.3 VISOR OPTICS SUBSYSTEM. The visor optics subsystem hardware functions shall be optically coupled to the on–helmet high gain screens and consist of relay lenses, holographic elements, adjustments for interocular and overlap conditions and mounting assemblies.

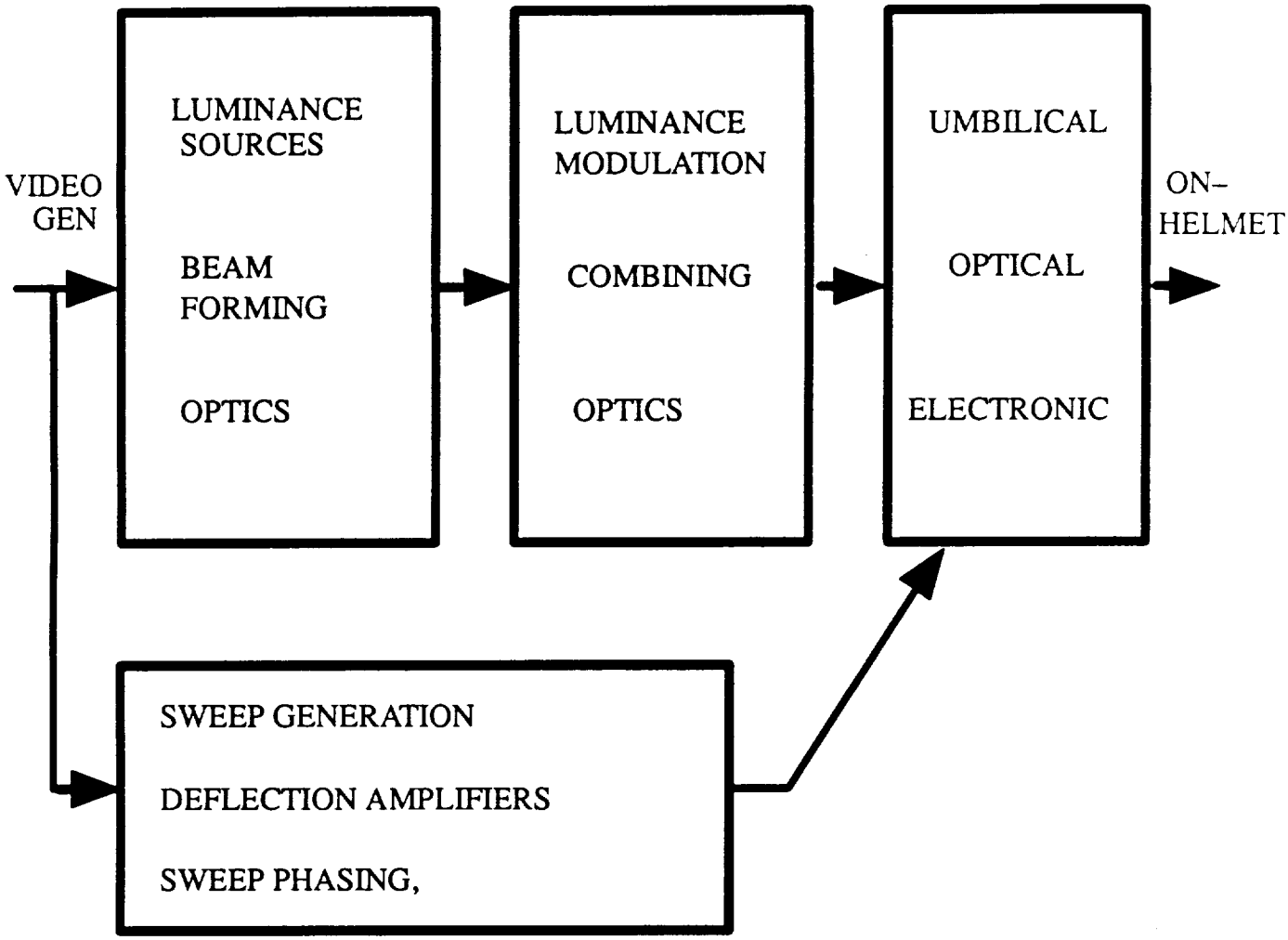

Figure 3.1.3.2.2.1–1. Off–Helmet Raster Generator Subsystem Block Diagram

3.1.3.2.4 HELMET ASSEMBLY SUBSYSTEM. The helmet assembly hardware subsystem shall consist of a helmet shell, conformal cover, head tracker transmitter, audio headset and mike. Unmodified flight helmets (except for visor removal) shall be capable of being used as the required helmet assembly (design goal).

3.1.4 GOVERNMENT FURNISHED PROPERTY

No Government furnished property shall be provided as part of this specification.

3.1.5 GOVERNMENT LOANED PROPERTY.

An Government–Specified Graphics Generator 3D work station shall be loaned on a short term basis (3 months) for preliminary in–plant integration, alignment and tests of the LS/HMD. The Government–Specified Graphics Generator shall be returned to the Government at the completion of in–plant tests. The contractor shall have the responsibility of all required packaging, handling and shipping of all loaned property. The contractor shall be liable for any and all damage to all loaned property.

3.2 CHARACTERISTICS (SYSTEM REQUIREMENTS)

3.2.1 PERFORMANCE

The LS/HMD shall convert the video signals from Government owned Government–Specified Graphics Generator IG graphic generators into a video signal format for display of full color 3D imagery utilizing two instantaneous high resolution overlapping views. The LS/HMD shall produce successive collimated images at a rate sufficient to give the impression of smooth motion to the observer. The LS/HMD shall provide a see through capability to the physical surroundings of the observer in all regions of the field–of–view including where imagery is displayed. The LS/HMD shall not be limited except as specified herein.

The LS/HMD shall provide the integrated system performance specified below over the required interocular range for both aided and unaided eye conditions (e.g., full field–of– view vision shall be provided with corrective glasses etc.).

3.2.1.1 FIELD–OF–VIEW

The field–of–view (FOV) shall be capable of being manually adjusted to vary both the total and overlap fields–of–view as stated below.

3.2.1.1.1 FIELD–OF–VIEW (TOTAL/EACH EYE). The total field–of–view provided by the LS/HMD to each eye of the observer shall be a minimum of 60 degrees vertical by 75 degrees horizontal.

3.2.1.1.2 FIELD–OF–VIEW (STEREOPSIS). The field–of–view of stereopsis shall be provided by controlling the overlap of each eye's field–of–view from 0.0 to 40 degrees horizontal.

The amount of image overlap which produces the 3D imagery shall be variable and correlatable within both the Government–Specified Graphics Generator and the LS/HMD.

3.2.1.1.3 FIELD–OF–VIEW (TOTAL/COMBINED). The total combined field–of–view provided by the LS/HMD shall be a function of the single eye and the selected overlap fields–of–view as shown in Table 3.2.1.1.3–1.

Each eye is provided a 60 by 75 degree field–of view which may be overlapped for a central stereopsis region of from zero to 40 degrees.

Table 3.2.1.1.3–1. Total Horizontal Field–of–view Range Capability

Stereopsis		Total (Combined)
Vertical FOV (Degrees)	Horizontal (FOV) (Degrees)	Horizontal (FOV) (Degrees)
60	0	150
	40	110

3.2.1.2 EXIT PUPIL

The exit pupil shall be a minimum of 15 mm in diameter simultaneously for each eye for the full range of interocular distances.

3.2.1.3 IMAGE STABILITY

Following a 30 minute warm–up and normal daily adjustments the displayed image shall not drift in position more than 5 arc min per 4–hours of continuous operation under the specified operation conditions. Short term image deviations such as jitter and oscillation shall not exceed two arc minutes for the specified operation conditions. There shall not be any discernible relative motion between fixed objects in the displayed image except as processed by the Government–Specified Graphics Generator graphics generator. Drift shall not result in any visual system parameter deviation from the specified values by more than 20 percent at any time during an 8–hour operating period

3.2.1.4 SMEAR

Smear due to image motion shall not degrade resolution in excess of the value specified or be noticeable in the displayed images.

3.2.1.5 FLICKER.

Flicker due to image refresh rate shall not be detectable for the image luminance as specified.

3.2.1.6 STEPPING

Discernible stepping or other discrete artifacts due to the scanning process shall not be discernible in the displayed images.

3.2.1.7 WEIGHT

The on–helmet weight shall not exceed 5 pounds (design goal) when operationally configured. The off–helmet hardware weight is not specified.

3.2.1.8 COLOR

The LS/HMD shall be capable of displaying the full visible spectrum of colors within the limits imposed by three color laser spectral coordinates. A minimum of 8 bits RGB unique chrominance values and 16 shades of grey shall be capable of being discriminated by the

observer and displayed. The required continuous range of chrominance values shall be capable of being demonstrated by direct viewing through the visor.

3.2.1.8.1 COLOR PROCESSING. Luminance and chrominance video processing shall be accomplished with sufficient resolution and accuracy to insured stable, continuous, color at the display. Bandwidth, signal–to–noise ratio (SNR) and other video parameters shall be accounted for in the LS/HMD design. The LS/HMD design shall ensure compatibility of subsystems regardless of signal magnitude, dynamic range, video non–linearities, or other factors.

3.2.1.8.2 COLOR REGISTRATION. Dynamic registration of color shall be less than 0.1 percent of the raster diagonal within a circle centered on the display channel and whose diameter is 0.6X the raster diagonal. Divergence may uniformly increase to a value not exceeding 0.2 percent off the raster diagonal outside the circle.

3.2.1.9 LUMINANCE

The "white" luminance of the displayed images shall be controllable and selectable from 0.0 to 10.0 foot Lamberts at the observer's eyepoint. Individual control of the red, green and blue laser outputs (e.g., weightings) from the minimum to the maximum required luminance shall be provided.

3.2.1.10 GEOMETRIC DISTORTION

The total geometric distortion from all LS/HMD causes (e.g., video generation, scanned raster, optical) for each display channel shall not exceed 1.0 percent of the displayed image raster diagonal within a circle whose diameter is 0.6X the displayed image raster diagonal, centered at the display channel center as measured from the observer's eyepoint. Geometric distortion outside the 0.6X diameter circle shall not exceed 2.5 percent of the displayed image raster diagonal.

3.2.1.11 RESOLUTION

The resolution across the total field–of–view to each eye shall be as depicted in Table 3.2.1.11–1. The stereopsis field–of–view shall be capable of being aligned from zero to 40 degrees of overlap. In Table 3.2.1.11–1 the vertical resolution represents the vertical raster spacing for a single eye's display channel. Horizontal resolution is in subtended arc–minutes per pixel. Raster prominence shall be reduced by focus control during set–up such that the raster structure is not prominent.

Table 3.2.1.11–1 . Resolution Requirements

FOV (Degrees)	Resolution Vertical (Arc mins/pixel)	Resolution Horizontal (Arc mins/pixel)
60 X 75	3.6	3.5

3.2.1.12 COLLIMATION

The LS/HMD shall provide the capability to adjust the nominal center collimation independently throughout the range of 27 inches to infinity focus during the initial bench testing and setup of the visor unit, if required for research.

Collimation shall be consistent (+/–5 percent) throughout the field–of–view .

3.2.1.13 CONTRAST RATIO

The contrast ratio between any two adjacent squares for a mosaic of three by four alternating black and white squares shall be a minimum of 12:1 for a white square luminance of 10 ft Lamberts and zero external ambient luminance. Contrast ratio shall be defined as B_{white}/B_{black} where B_{white} is the maximum brightness from any white squared and Bblack is the minimum brightness from any adjacent black square.

3.2.1.14 TRANSMISSIVITY

The visor shall transmit an average of 50 percent of the normal external incident light throughout the full visible spectrum (400 NM to 700 NM).

3.2.1.15 STEREOPSIS IMAGE ACCURACY

The left and right channel images shall be capable of being aligned for stereopsis purposes to within 5 arc min at the center of the field–of–view for the full range of interocular distances. Scene edges depicted by the raster for each eye shall align within +_ 20 arc min.

3.2.1.16 STEREOPSIS LUMINANCE/COLOR MATCHING

The left and right channel images shall be capable of being balanced in terms of luminance and color so as to display an unobjectionable difference to the observer.

3.2.1.17 EYE RELIEF

The distance between the cornea of a 95th percentile observer's eye and the nearest optical element of the visor shall be a minimum distance of 30 mm for straight ahead viewing in order to support the wearing of corrective glasses.

3.2.1.18 STRAY LIGHT

The helmet/visor shall be designed to prevent unwanted stray light and/or unwanted images including ghost images from entering the eyes of the observer under all modes of operation.

3.2.1.9 JITTER

Jitter shall be less than 0.05 percent under static viewing conditions.

3.2.20 GAMMA

Gamma shall be adjustable over the range of 0.5 to 3.0.

3.2.2 MODES OF OPERATION

The LS/HMD shall be utilized to provide the capability to operate in each of the following modes of operation.

a. Wide field–of–view without stereopsis

b. Wide field–of–view with stereopsis

Each of the two modes of operation above shall be capable of being performed, as appropriate, with either c. or d. below.

c. External transmitted imagery through visor present

d. External transmitted imagery through visor not present.

3.2.3 PHYSICAL CHARACTERISTICS

3.2.3.1 INTEROCULAR ADJUSTMENT

The LS/HMD shall be capable of accommodating a range of interocular distances of from 58 to 72 MM.

3.2.3.2 OVERLAP ADJUSTMENT

The LS/HMD shall be capable of displaying a range of display overlap from 0 to 40 degrees for each of the two required vertical fields–of–view.

3.2.3.3 WEIGHT

The design goal for the operational helmet/visor weight shall be 5 pounds or less. Overhead support to achieve the required weight shall not be permitted.

3.2.3.4 CENTER OF GRAVITY

The operationally configured LS/HMD shall have its center of gravity between the ears (design goal).

3.2.3.5 HELMET/VISOR FITTING

3.2.3.5.1 HELMET/VISOR PRE–MEASUREMENTS. The capability to pre–measure and record each observer's head/eye dimensions off the helmet/visor for proper fitting with the operational helmet/visor shall be provided. Pre–measurements for the purpose of determining each observer's required adjustments shall include but not be limited to the following:

a. Interocular distance

b. Eye location

c. Head dimensions

d. Padding or adjustments required

3.2.3.5.2 HELMET/VISOR ALIGNMENT. As a design goal, the capability to initially align the helmet/visor for each observer on the basis of the pre–measured data for optimum fitting shall be provided. Optimum fitting is defined as an alignment which centers the observer's pupils within the display's exit pupils with a snug fitting helmet. The capability for the observer while wearing the helmet/visor to make any necessary final adjustments shall be provided. Operator alignments relative to all helmet/visor adjustment capability when the helmet is donned shall remain fixed until intentionally changed. All controls for operator adjustment on the helmet/visor shall be a convenient size to grip and conveniently located and oriented to adjust with the helmet donned while observing test patterns to assure alignment.

3.2.3.5.2.1 HELMET/VISOR ALIGNMENT PROCEDURE. The helmet/visor alignment procedure shall consist of the following.

a. Interocular distance. – The interocular distance shall be properly set for a specific observer.

b. Helmet boresight alignment. –The initial helmet boresight wit respect to the cockpit or test structure shall be by a test fixture mounted on the structure which will easily position the helmet such that boresight data may be quickly obtained. The fixture shall consistently position the helmet within +_ one degree in all axes.

c. Observer boresight alignment. – A combination of displayed test patterns and a mechanical device such as an alignment tube mounted on the test structure shall be used to allow the observer to properly register the displayed scenes. Provisions shall be made to input the observer's interocular distance and boresight/alignment data to the image generator.

d. Alignment patterns. – The contractor shall design alignment patterns for use with the Government–Specified Graphics Generator which will indicate to the observer that both the stereopsis and monocular fields–of–view are properly aligned relative to the observer's eyes and for the display collimation. The variation of interpupillary distance with the display or range of display collimation for each observer shall be taken into account in the design of the alignment patterns.

3.2.3.6 HELMET/VISOR REMOTENESS

The helmet/visor shall be capable of being operated a minimum distance of six (6) feet from all supporting hardware except for the head tracking sensor. The head tracking sensor shall be located as close to the helmet as is practical in order to reduce noise in the head position data, while not obscuring anything in the displayed scene within the normal range of head motion.

3.2.3.7 HELMET/VISOR DISCONNECT

As a design goal, the visor shall be capable of being attached and disconnected from the helmet while being worn by the observer. As a design goal, the helmet and helmet/visor shall be capable of being disconnected from all attachment cables (e.g., fiber optics, communication cables, etc.) at the helmet with quick disconnect connectors. Attachment of all fiber optic cables shall not require realignment for proper operation of the LS/HMD. The helmet/visor shall be capable of being quickly removed by either the observer or an assistant in the event of an emergency.

3.2.3.8 HELMET/VISOR DURABILITY

The helmet/visor shall be designed to withstand each of the following:

a. Normal flexing of all cables (e.g., fiber optics, communication cables, etc.)

b. One (1.0) "G" shock to either side of the helmet without the need for realignment.

3.2.3.9 HELMET COVERS/SHROUDS

The operationally configured LS/HMD helmet shall be equipped with protective covers and shrouds which shall provide a light tight environment to the on–helmet hardware.

3.2.4 MAINTAINABILITY

The display contractor shall establish and publish maintenance/adjustment procedures for all HMD assemblies and field adjustable components. Assemblies and components requiring factory repair or replacement shall be indicated.

A maintainability block diagram of the display system shall be developed by the LS/HMD contractor. Allocated and predicted mean–time–to–repair shall be assigned to each block. Where predictions exceed the maintainability allocation, design alternatives shall be investigated. If the allocated maintainability cannot be attained by design alternatives, the procuring activity shall be notified.

The LS/HMD contractor shall be required to provide safe maintenance access to all modules of the LS/HMD. Paramount in the maintenance procedures to be developed is safety for both the operators and the observer. Eye safety and electrical shock protection are the two most important safety areas for consideration. LS/HMD optical component cleaning shall be capable of being performed without the need for realignment (Design Goal).

3.2.5 ENVIRONMENTAL CONDITIONS

The LS/HMD and its associated equipment shall meet the following operating and storage requirements:

a. Ambient light

   1. Operating – 0 to 100 foot candles

   2. Storage – N/A

b. Temperature

1. Operating – +15 to +30 degs C (+59 to + 86 degs F)

2. Storage – 0 to + 50 degs C (+32 to +122 degs F)

c. Motion

1. Operating – The helmet and all on–helmet components shall be capable of maintaining alignment while being operated through the normal range of head motions

2. Storage – Capable of being stored in a protective case which is not to be dropped, etc.

3. Ambient light, temperature, motion environment.

3.2.6 TRANSPORTABILITY

The LS/HMD shall be designed to be transportable to the installation site by standard commercial transportation. Major design components and modules shall be constructed such that installation and assembly can be accomplished without the need for special tools. Major components and modules shall be interconnected by cable assemblies. Design shall be such that assembly and disassembly of the LS/HMD can be accomplished without the necessity for soldering, welding, unsoldering, cutting, crimping, or destruction of material. The video generator and the raster generator off–helmet components shall be provided with lifting and carrying handles for use by two personnel. The helmet assembly including visor optics will be packaged in a suitable lockable and protective case for easy shipment. All other components and modules, if size permits without unnecessary teardown shall be packaged in a suitable lockable and protective case for easy shipment.

3.3 DESIGN AND CONSTRUCTION

The LS/HMD shall be designed for integration with two Government–Specified Graphics Generator graphics generators and for providing the display performance as specified herein. The design and construction of LS/HMD shall be to best commercial practice utilizing commercial off–the shelf hardware to the greatest extent practical. The design and construction of LS/HMD shall be safe and free of hazards to all personnel. The LS/HMD shall be free of all sharp edges. Integration of the LS/HMD with the Government–Specified Graphics Generator graphics generators shall be accomplished in accordance with current fire and safety standards/requirements of the local and Federal Governments and the provisions of this specification.

3.3.1 LASER SAFETY

The associated lasers of the LS/HMD shall conform to the safety requirements of ANSI Z136.1.1986 (American National Standard for the safe use of lasers). Safety precautions shall be provided, including but not limited to the following.

a. All lasers shall be appropriately labeled in terms of a Laser Hazard Classification

b. All locations where laser radiant power can be potentially viewed directly by any person, by specular and diffuse reflection under any condition shall be designed with a

protective shield, barrier, shroud, beam stop or cover and appropriately labeled with a cautionary note

c. All wavelengths outside the visible spectrum (e.g., <400 and >700 NM) shall be filtered to an eye safe level

d. Two pair of laser eye protection goggles shall be provided

e. Interlocks shall be designed into the LS/HMD to prevent unintentional access to areas where eye hazards exist

f. All scanning devices shall incorporate a means to prevent laser emission if scan failure or other failure resulting in a change in either scan velocity or amplitude would result in failure to fulfill an eye safe condition

g. The LS/HMD observer shall be provided with a master switch which can disable the laser system

h. The active helmet assembly shall be provided with the means to verify that an eye safe condition exists utilizing a meter measurement prior to the donning of the helmet

i. The LS/HMD helmet/visor images shall be produced by means of only diffuse light. The helmet/visor shall be designed to exclude all direct and indirect specular light.

j. The LS/HMD operational/maintenance manual specified herein shall carefully outline the appropriate operation and maintenance (including alignment) procedures which shall be adhered to relative to laser safety.

3.3.2 MATERIALS, PROCESSES AND PARTS

The basic requirements for materials, parts and processes are established by best commercial practice and shall apply only to the LS/HMD interface design. Commercial off–the–shelf equipment is exempted from these requirements. The following shall also apply.

3.3.2.1 SELECTION OF PARTS

The LS/HMD is a research tool and as such does not require flight–rated hardware. Parts selection shall be made on the basis of achieving the required performance stated herein while not compromising the safety of all operators and observers. The safety of the observer (eye, electrical, mechanical, etc.) shall be paramount in the overall LS/HMD design and the selection of all parts.

One goal of the LS/HMD shall be to provide a helmet/visor design which is upgradable to flight–rated status with minimum redesign. In this regard the selection of minimum weight on–helmet parts and their placement is critical in terms of the LS/HMD's total weight and inertia. Consideration shall be given to the utilization of a lightweight Kevlar helmet shell. All off–helmet parts shall emphasize maximum performance and minimum cost.

3.4 DOCUMENTATION

All documentation requirements are contained in the noted section of this specification.

3.5 LOGISTICS

3.5.1 MAINTENANCE

All commercial off–the–shelf hardware (e.g., lasers, head tracker, etc.) shall be exempt from the following. All non–commercial off–the–shelf hardware (e.g., video generator, sweep waveform generators, deflection amplifiers, etc.) shall be provided with one spare part or component in order to minimize the LS/HMD downtime.

Special tools and test equipment shall be kept to a minimum. Any special tools developed for the LS/HMD shall be designed to best commercial practice.

3.5.2 SUPPLY

The contractor shall provide a list of LS/HMD spares which will be required to be located with the LS/HMD.

3.5.3 FACILITIES AND FACILITY EQUIPMENT

The LS/HMD shall be designed to integrate with two Government–Specified Graphics Generator's at NASA Langley Research Center; Hampton, VA; Building 1268A, Room 1141.

a. **Grounding** – The building ground system shall provide convenient attachment locations in the installation areas for attaching the LS/HMD grounds. The contractor shall be responsible for attaching to the building ground connections provided.

b. **Power** – 120 VAC, 60 Hz, single–phase, three wire commercial grade power to convenient room electrical receptacles shall be provided. A minimum of 20 amps per electrical branch circuit will be available from three (3) separate electrical circuits.

c. **Air conditioning** – Room air conditioning shall be provided which shall maintain the ambient temperature between 60oF and 80oF.

d. **Lighting** – Ambient room lighting shall be controlled by rheostat switches such that ambient light may be varied from dark to 40 footlamberts.

3.6 CHARACTERISTICS OF MAJOR COMPONENTS (BASELINE SYSTEM)

As a goal, the design shall stress high luminance, full color, high resolution and wide field of view performance for HMD, as is consistent with the requirements for use as a research HMD system which may be further developed into flight–rated hardware. Effort shall be made to reduce the all up weight of the HMD including, but not limiting the design by, the apportionment of bulky or heavy components in the display to an off–helmet location. The design shall be sufficiently durable to withstand the rigors of normal handling consistent with a research setting. Effort shall be made to design all adjustments required to calibrate the helmet to normal flight–crew populations such that research time is maximized.

Known color HMD concepts may be characterized by Figure 3.6–1, which depicts the possible logical arrangements of the color raster generator portion of the HMD design. The raster generator and visor subsystems are the two most critical designs for color HMD performance. The baseline system, depicted in block diagram form in Figure 3.6–2 indicates one possible arrangement in which the laser pixel generators and modulators are positioned off–helmet and the scanning process is on–helmet, resulting in the appropriate allocation of bulky and heavy components. The baseline design consists of five major subsystems, one of which is subdivided into on– and off–helmet assemblies.

3.6.1 VIDEO GENERATOR

The video generator subsystem receives video data from the IRIS image generator and converts it to the appropriate form for use by the raster generator's pixel generation and deflection functions. All synchronizing waveform generation, scan line and field phasing, video data conversion, gamma compensation and video driver functions are performed by this unit. The preferred method for video data transfer from the IRIS to the video generator is via the system buss or in digital from the video board, whichever provides the least transport delay. A design goal is to include processes which minimize any transport delay associated with the use of the video generator. Transport delay through the video generator shall be one field (16.67 ms) or less. A safety system to prevent eye hazards in case of deflection loss shall be included and shall be capable of manual initiation

3.6.1.1 VIDEO GENERATOR INTERFACES

The video generator shall interface with the IRIS image generator, the raster generator and, if required, the headtrack subsystem. The video generator to IRIS interface shall function to provide RGB digital scene data and timing data to the video generator for conversion to the format required by the raster generator. High speed digital interfaces are preferred, with digital to analog and gamma conversion functions performed by the video generator. Gamma conversion for each primary color and each channel shall have a minimum of 8 break points, which may be easily adjustable. A design goal is not to have to modify boards in the IRIS unless significant transport delay or cost improvements can be incurred.

The video generator to raster generator interface shall consist of analog video and digital sweep synchronizing data sent to the raster generator and additional status functions being sent from the raster generator, such as the safety laser shut–off in case of sweep failure. Voltage levels shall be as appropriate for the configuration chosen in the design.

An interface from the headtrack subsystem to the video generator and from the video generator to the IRIS is included in the baseline solution only as one possible solution to reducing the number of high speed data links required to/from the IRIS image generator.

- PIXEL TYPE/SCAN/TRANSFER/RASTER IMAGE COMBINATIONS

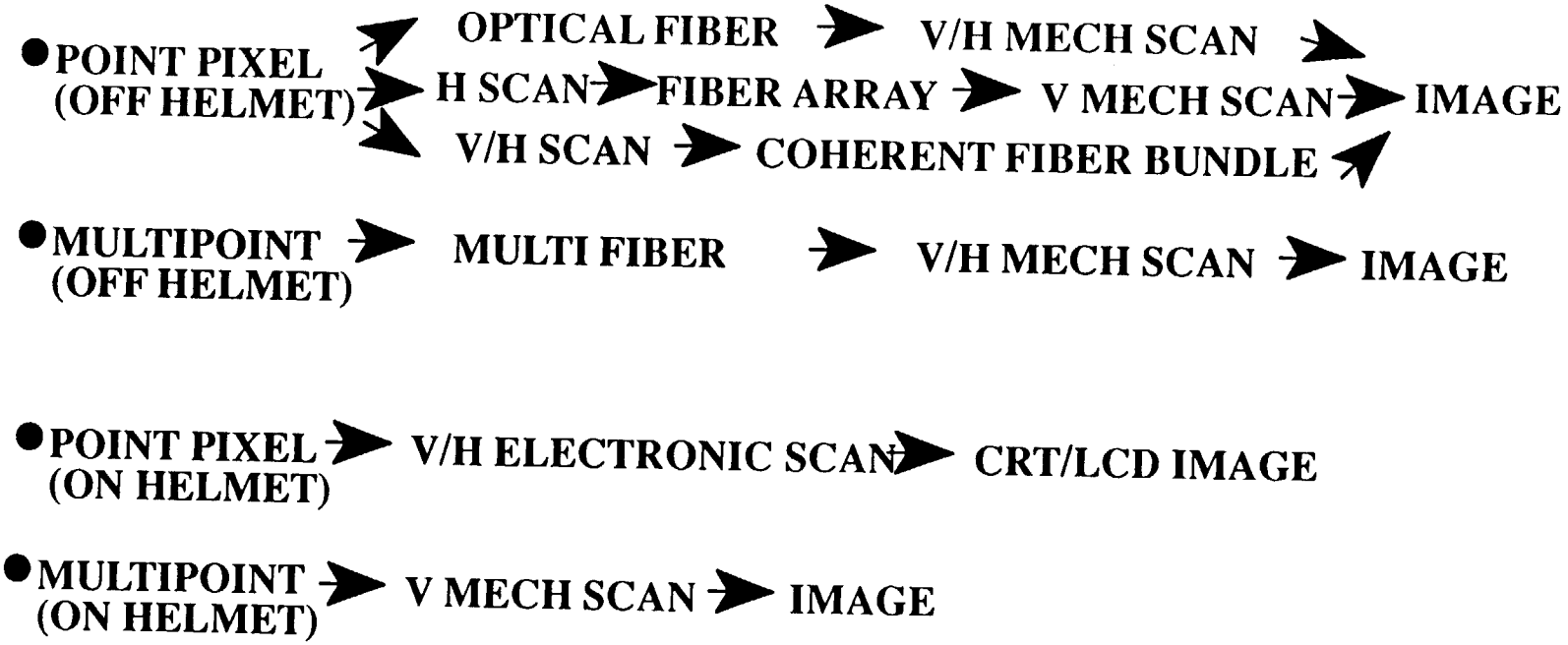

Figure 3.6–1. Raster Generator Factors

WSB 4/20/89

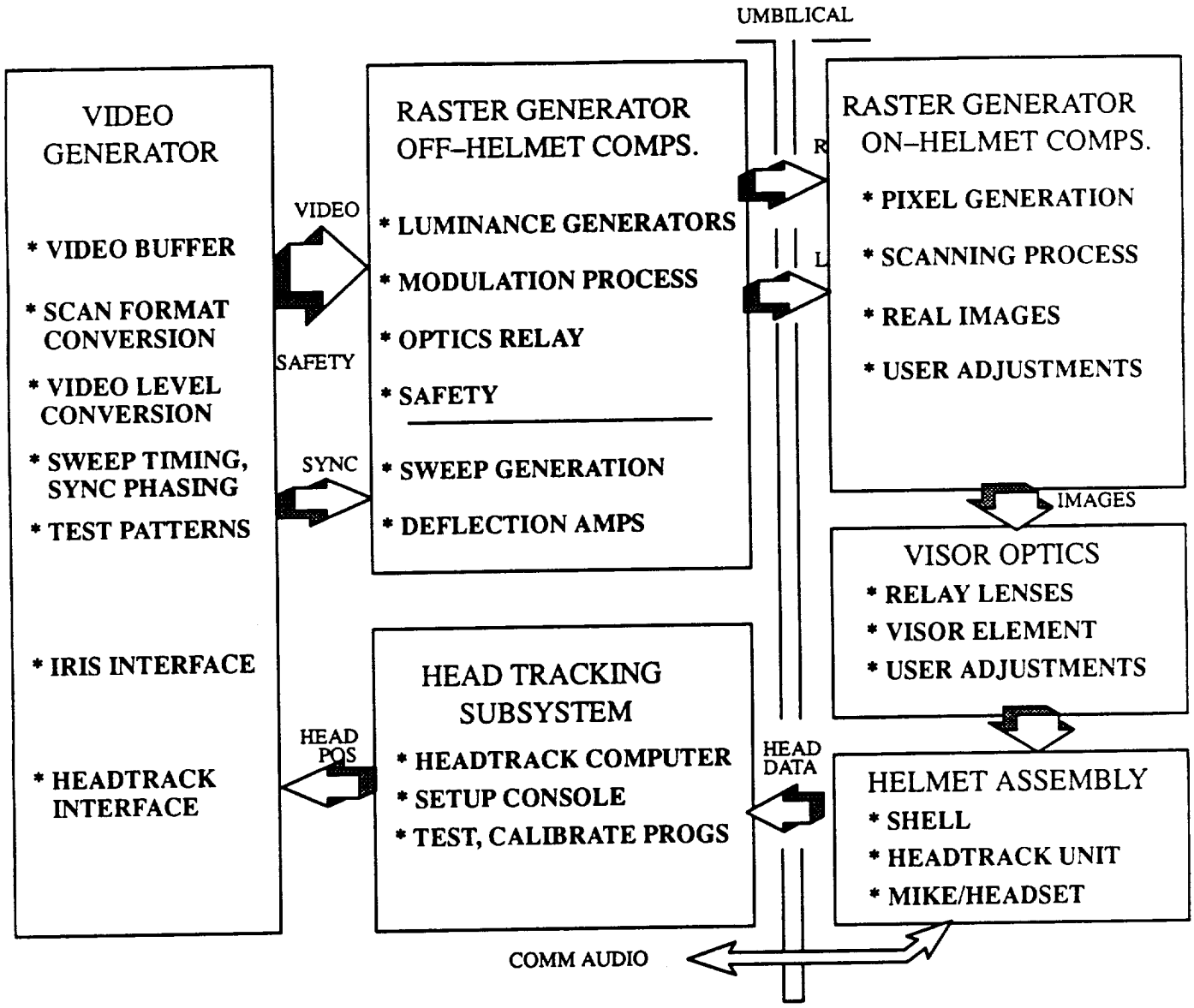

Figure 3.6–2. Baseline Block Diagram

3.6.2 RASTER GENERATOR

3.6.2.1 OFF–HELMET COMPONENTS

The off–helmet raster generator components shall consist of primarly two subsystems for each display channel: (1) a luminance generation subsystem capable of converting pixel data (e.g., analog video voltage) into pixel luminance data for transmission to the on–helmet components and (2) a subsystem capable of providing the necessary sweep deflection drive waveforms to produce a color image from the pixel luminance data on the helmet. The pixel luminance data is transmitted to the on–helmet subsystem by means of a small fiber optic umbilical which does not impede normal head movement from a designated position. The off–helmet hardware shall consist of all of the large heavy hardware.

3.6.2.1.1 OFF–HELMET COMPONENT INTERFACES. The baseline system requires an interface from the video generator to the off–portion of the raster generator for the purpose of conveying RGB analog video pixel data to the luminance generator/modulator and synchronizing signals to the deflection amplifier electronics. An optical interface from the off–helmet portion of the raster generator to the on–helmet portion of the subsystem consists of a set of optical fibers protected by a flexible, small umbilical. An electronic interface is required for the deflection, communications and headtracking functions. This umbilical containing optical fibers and electrical wires must be robust to resist damage from normal handling and head movement and, as a goal, be provided with a quick disconnect feature at the off–helmet side.

3.6.2.2 ON–HELMET COMPONENTS. The on–helmet portion of the raster generator components shall generate two complete full color rasters from scanned pixel luminance data received from the ff–helmet components which is suitable for use by the visor optics subsystem. The helmet shall utilize only light weight rigidly mounted components in order to maintain high image stability within the required total weight. All on–helmet components shall be fully protected from both physical damage and stray light. A design goal is to provide light weight components on–helmet and have the HMD system be both conformal and maintain the CG within normal limits ,of that of the head within a flight helmet. A design goal is for an all–up helmet/display weight of less than 5 lbs.

3.6.2.1 RASTER GENERATOR ON–HELMET INTERFACES

Interfaces are to the raster generator, the visor, the helmet and the user.

The interface to the off–helmet portion of the raster generator is through the specially constructed umbilical containing both scanner electrical and image pixel optical data. The umbilical shall be mounted on the helmet in such a way as to prevent damage from tension on the umbilical of up to 10 lbs. The interface to the user shall consist of mechanical adjustments necessary to set interocular distance variances of 58 to 72 mm. These may be combined with visor adjustments.

The visor interface shall provide a 19mm, 3:4 aspect ratio full color, high resolution image at the appropriate location and orientation for use by the visor subsystem. The interface shall be adjustable but rigid enough to prevent unwanted scene motion due to normal head movements. A design opportunity exists to integrate optical elements of the visor and the raster generator to further reduce weight.

The user shall have adjustment knobs for interocular distance spacing and for image positioning to facilitate the initial scene alignment.

3.6.3 VISOR OPTICS

The visor optics shall be designed to display the on–helmet rasters as full color, high resolution, wide field–of–view, collimated, stereo images to the observer. All visor optics shall be capable of being easily attached to and removed from the helmet. The visor shall utilize fully color corrected non–frangible optics for maximum performance and safety. Eye relief shall be sufficient for use of vision correcting spectacles. The visor shall be sufficiently transparent to permit viewing the environment beyond the visor. Visor display performance shall be as stated elsewhere herein.

3.6.4 HELMET–TRACKING SYSTEM

The helmet–tracking system shall consist of a radiator/sensor pair which shall provide the following performance.

a. Angular coverage. – 4 pi steradian coverage relative to radiator.

b. Static position accuracy. – 0.1 inch RMS

c. Static angular accuracy. – 0.5 degrees RMS

d. Position resolution. – 0.03 inches

e. Angular resolution. – 0.1 degrees

f. Output update rate. – 60 Hertz

g. Radiator/sensor operating range. – +30.0 inches (without metal interference or post processing)

h. Transport delay. – 16.6 msec

i. Noise. – Noise from all helmet–tracking system sources shall not cause the output to command a perceptible dither to the displayed image.

j. Working volume. – The helmet–mounted sensor shall operate reliably within a volume prescribed as a box of at least 16 in. on a side. The structure mounted sensor component shall be outside that volume.

3.6.5 HELMET ASSEMBLY

The helmet assembly shall consist of a durable helmet shell, an adjustable liner which permits fitment to head sizes for 5th through 95th percentile male observers (e.g., pilots), a detachable

protective outer shell(s) over the exposed optical components in the raster generator, a boom microphone and its attachment mounts, a pair of headset speakers, an electrical audio communications umbilical cord and a helmet tracking radiator. The head tracking position coil shall be attached to the center rear of the shell with its umbilical attached so as to not restrict normal head motion while the observer is seated. The construction of the helmet shall be a light as is practical for the research application of the HMD system in order to reduce the overall weight of the display to design goals.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 GENERAL QUALITY ASSURANCE PROVISIONS

Unless otherwise specified herein, quality assurance provisions shall be in accordance with best commercial practice. The quality assurance program shall ensure quality throughout all areas of the specification requirement, including design, development, fabrication, processing, assembly, inspection, test, maintenance, preparation for delivery, shipping, storage, and site installation. The contractor's quality assurance program shall be planned and utilized in a manner to effectively support the contractor's reliability and maintainability programs.

4.2 RESPONSIBILITY FOR INSPECTION

Unless otherwise specified n the contract or purchase order, the contractor is responsible for the performance of all inspection requirements. Except as otherwise specified in the contract or order, the contractor may use his own or other facility suitable for the performance of the inspection requirements, unless disapproved by the procuring agency. The procuring agency reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure that critical LS/HMD requirements are satisfied.

4.2.1 TEST CONDITIONS

All tests shall be conducted under the following conditions.

4.2.1.1 IRIS SIGNAL OUTPUTS

Video test signals from the Government–Specified Graphics Generator graphics generator shall be defined and software prepared by the LS/HMD contractor to insure proper and comprehensive test conditions.

4.2.1.2 TEMPERATURE

Unless otherwise specified, all tests shall be made at prevailing room temperatures between 60oF and 80oF.

4.2.1.3 TEST EQUIPMENT AND INSTRUMENTATION

Test equipment shall be checked or calibrate prior to conducting the test program. Test equipment shall include a suitable multichannel recorder, x–y recorder, meters, oscilloscopes, magnesium carbonate reflective block, spectral radiometer and luminance meter.

4.2.1.4 ALIGNMENT

The LS/HMD shall be aligned by the contractor on all NASA and contractor test personal prior to the initiation of the first set of test programs. A NASA designated test engineer shall be

instructed by the contractor for purposes of helmet alignment and shall align the LS/HMD on all NASA and contractor test personal prior to the initiation of a second set of test programs.

4.2.1.4.1 CHANGES DURING TESTING. All changes made in the alignment, programming, and adjustments during the testing program shall be recorded. Any test conducted prior to such adjustments shall be repeated unless results can conclusively prove and demonstrate that such changes have not invalidated the related test data.

4.2.2 TEST METHODS

Test procedures shall be in accordance with the approved Test Procedures and Results Report (TPRR). Test procedures shall be written with all steps shown in sequence. The TPRR shall be formatted to include a signoff space for both the contractor and NASA test engineer.

4.2.3 QUALITY CONFORMANCE INSPECTION

Quality conformance inspection shall be in accordance with the approved TPRR of the contract and shall consist of the following tests.

4.2.3.1 PERFORMANCE TESTS

The contractor shall develop a complete set of performance tests to demonstrate and substantiate the required performance of the LS/HMD. The test procedure report shall be approved by the procuring officer's cognizant technical engineer.

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FINAL REPORT

16. Abstract

A design of a helmet-mounted display system is presented, including a design specification and development plan for the selected design approach. The requirements for the helmet mounted display system and a survey of applicable technologies are presented. Three helmet display concepts are then described which utilize lasers, LCD's, and sub-miniature CRT's, respectively. The laser approach is further developed in a design specification and a development plan.

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