CIG VISUAL SYSTEM FOR THE T-37B JET TRAINER (ASUPT)

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The Computer Image Generation (CIG) System was developed for the Air Force Advanced Simulation in Undergraduate Pilot Training (ASUPT) Program by General Electric Company. The technology represented by the ASUPT system was developed partly by General Electric Independent Research and Development and partly on the Air Force Human Resources Laboratory, Air Force Systems Command Contract.

The ASUPT System is a simulator for the T-37B aircraft. The T-37B aircraft is a jet aircraft used by the Air Force for training of undergraduate pilots. The T-37B is a two-place side by side twin engine jet aircraft with the student occupying the left-hand seat and the instructor pilot occupying the right-hand seat.

The ASUPT simulator system consists of two complete motion base mounted cockpits with visual displays driven by common general purpose and special purpose computer hardware. Figure 1 represents a top level hardware block diagram of the ASUPT Simulator System. The solid line blocks of the diagram represent the parts of the ASUPT Simulator System that were developed as a part of the ASUPT CIG Development Contract. The ASUPT Simulator includes a 6 degree of freedom motion base upon which a T-37B cockpit is mounted. Also mounted on the motion base and completely surrounding the cockpit is a full field of view visual display. The motion base, cockpit controls and indicators, and flight dynamics are determined and controlled by a General Purpose Digital Computer and special interface hardware. The visual display scene is generated by a mosaic of seven large cathode ray tubes and infinity optics, associated drive electronics, a Special Purpose Computer and a dual CPU General Purpose Computer.

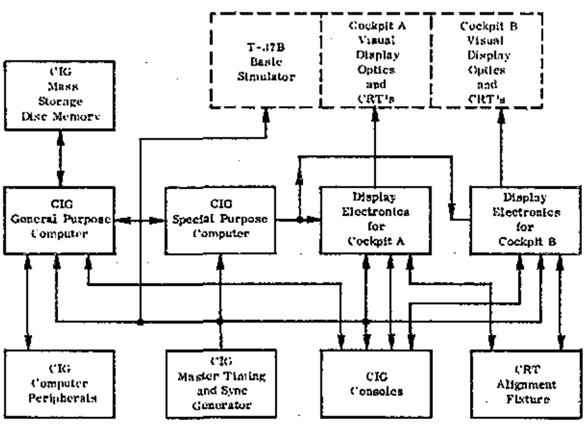

Figure 1. ASUPT Simulator System Hardware Block Diagram

This paper will discuss the overall ASUPT CIG System giving some of the more significant features of the system as well as the basic system architecture. The ASUPT System is presently operational at Williams Air Force Base, Arizona, in the Air Force Human Resources Laboratory Flight Training facilities. The ASUPT CIG System was accepted by the Air Force in September 1974, with total integrated tests completed in February 1975. Since Air Force acceptance, the system has been used by the Air Force Human Resources Laboratory Flight Training for pilot training research. However, this paper will only discuss the ASUPT CIG System and not the research program that it is being used to support.

ASUPT CIG SYSTEM FEATURES

The features of the ASUPT CIG System can best be illustrated with photographs taken of the system output. The CIG System generates a visual image similar to the real world scene that is observed through the wind screen of the T-37B aircraft. The photographs were taken of a console black and white TV monitor that was displaying the forward looking channel of the CIG Display System. The horizontal field of view represented by the photographs is about 75 degrees and the vertical field of view is about 55 degrees. The first ASUPT CIG System generated picture, Figure 2, is a view looking across part of the runway and taxiway area toward the hangar and tower complex at Williams Air Force Base. The computer generated and processed environment model used by the ASUPT CIG System is modeled after the actual real world environment surrounding Williams Air Force Base. Runway and taxiway surfaces and markings can be noted in the photograph. Also three-dimensional hangars and the control tower can be noted on the far side of the field. Mountains can be seen behind the hangar complex on the horizon. All three-dimensional features can be flown over, around and through, for that matter, since complete freedom of movement and attitude is allowed by the CIG System. In fact, many pilots have flown the ASUPT Simulator through one of the open ended hangars at Williams Air Force Base.

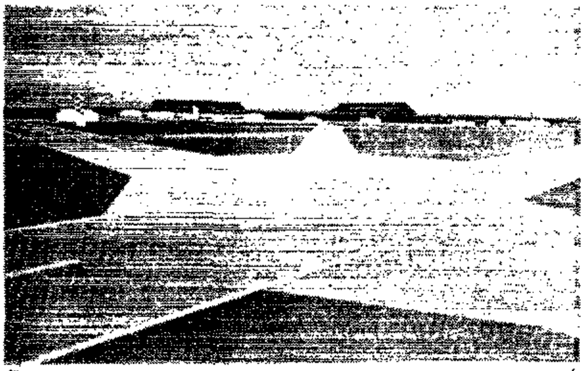

Figure 2. ASUPT CIG Generated Picture of WAFB Hangar Area

The next picture, Figure 3, shows a dusk landing approach with runway lighting turned on. The ASUPT System includes a full landing approach lighting system on all runways just like the real runways at Williams Air Force Base. When a full night scene is desired, the taxiway lights are also included in the visual scene. Runway light intensity is controlled by the console operator. Approach strobe lights are also included.

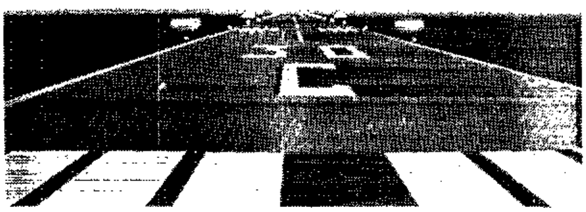

Figure 3. ASUPT CIG Generated Picture of WAFB Dusk Landing Approach

The next picture, Figure 4, shows a landing approach under normal visibility conditions. Note the hangars in the far distance near the horizon. The following picture, Figure 5, shows the same approach only under limited visibility conditions. Visibility has been reduced to approximately 1500 feet which obscures the distant hangars seen in Figure 4.

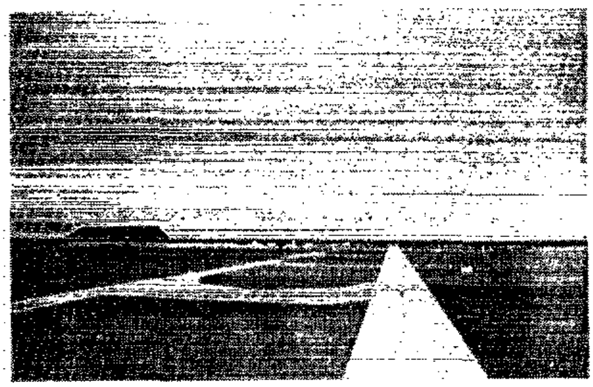

Figure 4. ASUPT CIG Generated Picture of WAFB Clear Day Landing Approach

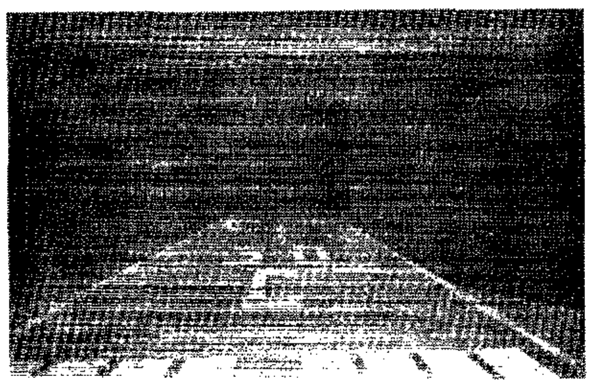

Figure 5. ASUPT CIG Generated Picture of WAFB Low Visibility Landing Approach

A lead aircraft moving model is provided for formation flying. A picture of the lead aircraft is shown in Figure 6. The lead aircraft represents the most complex model in the ASUPT CIG environment data base. Note the aircraft markings and the smooth curved appearance of the fuselage and wing areas of the aircraft. The ASUPT CIG System provides both curved surface and sun illumination effects. Note the lower surfaces of the wing area are a darker shade than the upper surfaces. This is due to sun illumination from the top of the aircraft since the surfaces of the wings and fuselage are all modeled the same gray shade just as the real aircraft is a uniform color. The smooth curved surface appearance of the aircraft remains constant independent of relative aircraft and viewpoint attitudes. Likewise, the sun illumination effect remains true to the real world in that as the aircraft attitude changes relative to the specified sun illumination direction, the shade effect on the aircraft changes such that the portions of the aircraft facing away from the sun are darker as observed in the real world.

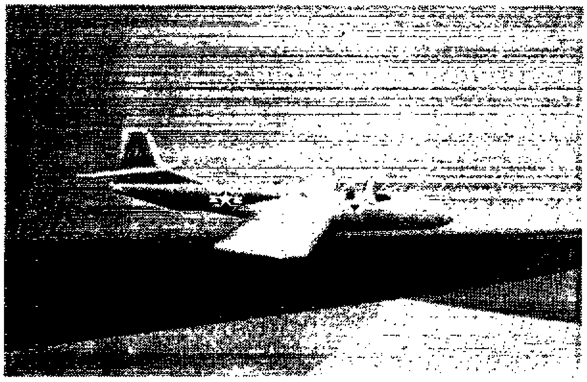

Figure 6. ASUPT CIG Generated Picture of T-37B Aircraft

The next picture, Figure 7, is also of the lead aircraft moving model except that rather than including all the details shown on the previous picture, the simplest or lowest level-of-detail version is shown. Levels of detail of models within the system are changed automatically as a function of the distance between the pilot's viewpoint and the model. Thus, when a great distance exists between the viewpoint and a model, a simple version of the model is displayed or the model is completely eliminated. As the distance between the pilot's viewpoint and the model decreases, the level of detail is increased. Four levels of detail including elimination of the model from the display image are included in the ASUPT CIG System. Determination of what level of detail should be displayed is based on the projected image size and is done automatically by the General Purpose Computer software.

The ASUPT CIG System has a display capacity of 2,500 edges including 500 edges to provide for system over-capacity correction and left-hand boundary edge generation. The 2,500-edge capacity can be divided in any ratio between the two cockpit displays or, for that matter, between the 14 display channels (7 display channels for each cockpit). Any mixture of display edges can be used to define both two-dimensional surface features and three-dimensional solid features.

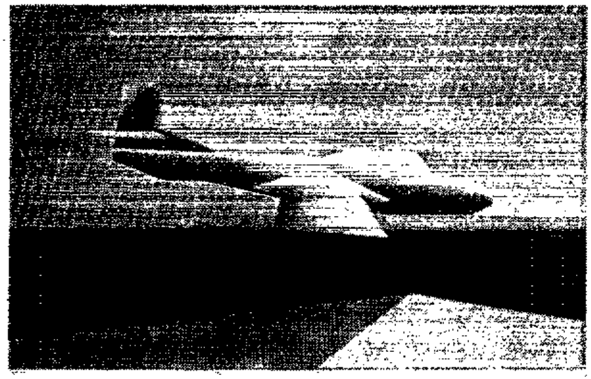

Figure 7. ASUPT CIG Generated Picture of Reduced Detail T-37B Aircraft

At any instant of time, 256 display objects of two-dimensional or three-dimensional type can be within the field of view.

Lights are generated and displayed in true perspective utilizing as many edges as the modeler determines necessary to provide the desired visual appearance. Lights are displayed as two element by two line dots when the display image size of the light reduces to a two element or less dimension. Provision is also made for up to thirty directional lights which are only visible from view angles specified at the time the light is modeled. All lights are displayed when they are in the field of view until the distance between the light and the viewpoint is equal to or exceeds the extinguishing range which is specified at the time the light is modeled.

The ASUPT CIG environment data storage capability is 600,000 edges which are processed to select only those edges that are a part of objects within the range of view of the instantaneous viewpoint location. A sophisticated algorithm is used to continuously monitor the viewpoint location within the environment and select the object edges from the total environment storage.

Display edges are grouped together to form two- or three-dimensional objects which can consist of up to 32 edges. The flat surfaces of an object are called faces and up to 16 faces can be included in each object.

Complex shapes are formed by grouping objects together to make up a model such as the lead aircraft. Models can also exist in several versions, each of which represents a different level of detail. Part of the selection process to determine which object edges are within the field of view includes determination of which level of detail a model should be displayed at.

The gray shade of any face of any object can be independently specified from one of 64 shades ranging from black to white.

ASUPT CIG SYSTEM CONCEPTS

The ASUPT CIG System concepts are based on providing a visual display image that is completely generated from numerical data using digital computer techniques and displayed on a standard 1,000 line, raster-scanned, television display. By employing these concepts, a visual display system was built which always displays an image in correct perspective, always displays an image that is completely within focus (infinite depth of field) and provides complete freedom of viewpoint movement and attitude within the environment. Position translation and attitude angular rates are unconstrained. The viewpoint can be positioned right on the ground surface plane, and no viewpoint attitude or succession of attitude changes are precluded.

The ASUPT CIG concepts can be very simply stated with the aid of Figure 8. The environment within which the viewpoint flies and the environment from which the visual image is generated were numerically defined and stored on the General Purpose Computer disc memory. The numerical definition of the environment was derived from maps, photographs, and architectural drawings of the real world environment to be modeled. Those features that were to be included in the ASUPT CIG System environment were determined and numerically encoded in the form of dimensions and gray-shade coloring of the surfaces of the objects. The encoded data is processed by General Purpose Computer software which organizes and validates the data.

The ASUPT CIG System then generates a true perspective image projection of the numerical environment data on the display raster planes (one plane for each display channel). The projected display plane image is then generated in a raster scan television format for display on the actual display CRT's. The whole process is analogous to what happens when a television camera views the real world and forms a perspective image on the camera tube plane except that the ASUPT CIG System has an infinite depth of field.

Each of the seven display channels or display planes in the ASUPT CIG System represents a complete and independently generated picture image. By mosaicing seven channels, a large field of view is provided by the display system (240 degrees horizontal and plus 120 degrees and minus 60 degrees vertical).

In addition, the use of infinity optics provides both eye relief and a continuous uninterrupted image with a plus or minus 6-inch head movement.

For more information on the considerations and concepts used for the ASUPT CIG System see "An Approach to Computer Image Generation for Visual Simulation" by James D. Basinger, Air Force Human Resources Laboratory, Wright-Patterson AFB, Ohio.

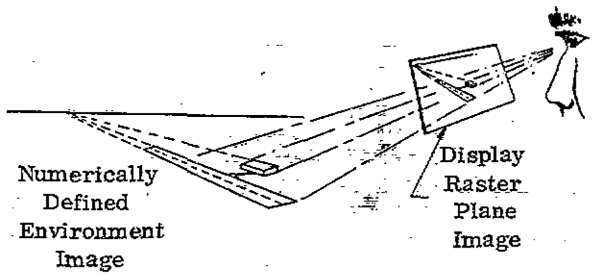

Figure 8. ASUPT CIG System Environment Image Projection Concept

ASUPT CIG SYSTEM ARCHITECTURE

The top level CIG System architecture is shown in Figure 9. The CIG System generates a complete new set of pictures (14 television channels) each television frame time (1/30 second). The CIG System uses numerically defined environment data, the viewpoint location and attitude within the environment, and the fixed relationship of each display channel relative to the viewpoint to generate a picture. In addition, when using the lead aircraft moving model, the position and attitude of the lead aircraft are used to generate a picture.

Each of the 14 television display channels is a unique and independently generated picture. Each display channel contains 985 active television raster lines and 1000-line elements.

Each of the 985,000 picture elements per display channel is encoded to be one of 1024 (10 bits binary) gray shades ranging from black to maximum brightness. Thus, each 1/30 of a second (one television frame time) the CIG System processes and outputs 14 times 985,000 times ten or 137,900,000 bits of information. Therefore, the CIG System outputs 4137 megabits per second.

The basic system architecture consists of a dual CPU 600-nanosecond cycle time, 32-bit word, General Purpose Computer that, in general, processes the non-repetitive non-arithmetic data required to generate a picture. The major functions of CPU B are selecting the portion of the total

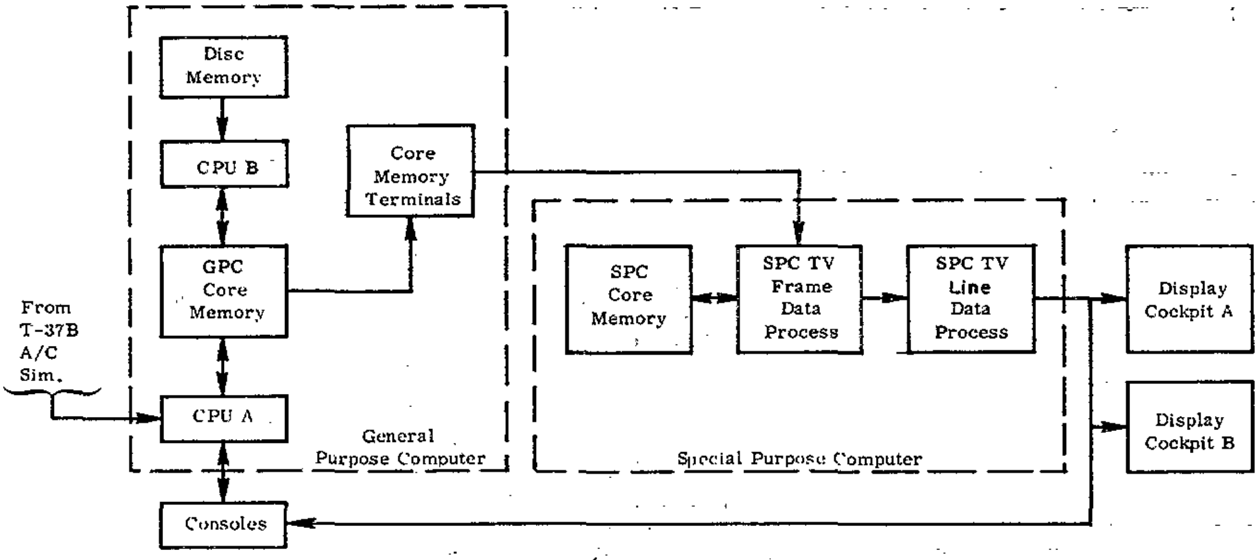

Figure 9. ASUPT CIG System Architecture

environment data base that is within range of view (including level of detail) and loading the Special Purpose Computer (SPC) core memory with the within-range-of-view portion of the environment. This is essentially a file manipulation function using files stored in the disc memory and the special purpose computer core memory.

The disc memory (actually a dual disc unit) has about a 4.2 million, 32-bit word storage. The SPC core memory is equivalent to a 152-thousand, 32-bit word storage.

The basic function of CPU A is to perform coordinate transformation and other tasks required to provide the Special Purpose Computer with data that is constant throughout the television frame time.

Core memory terminals provide direct access to the General Purpose Computer core memory. This allows data transfers to and from the General Purpose Computer core memory independent of CPU A and CPU B.

The Special Purpose Computer is functionally divided into two parts; one which performs the once-per-picture (television frame) calculations and a second part which performs the once-per-picture line (raster line) calculations.

The 14 channels of video output from the Special Purpose Computer drive the two identical displays each of which consists of 7 channels. In addition, the video of all 14 channels is distributed to the consoles' television monitors.

General Purpose Computer Hardware Architecture

The architecture of the General Purpose Computer hardware is shown in Figure 10. To obtain an access time of 1/30 second and 4.2 megaword storage, a dual synchronous fixed-head disc memory was configured. The disc controller was designed to interface both discs to appear as one large disc memory to the General Purpose Computer.

Each of the two CPU's has a direct memory input/output system that handles I/O traffic independent of the CPU.

The 32K core memory is organized in 8K blocks each of which has a 4-port memory interface unit. The memory interface unit provides priority multiplexed access to the memory by 4 independent devices.

Serial data terminals are used to transfer control and indicator data to and from the consoles.

Memory terminals provide 32-bit parallel full independent access to the General Purpose Computer core memories for the large amount of traffic between the General Purpose and Special Purpose Computers.

The General Purpose Computer architecture proved to be very efficient and effective for a real-time system. All processing units and input/output can take place simultaneously with a minimum of interference and dead time.

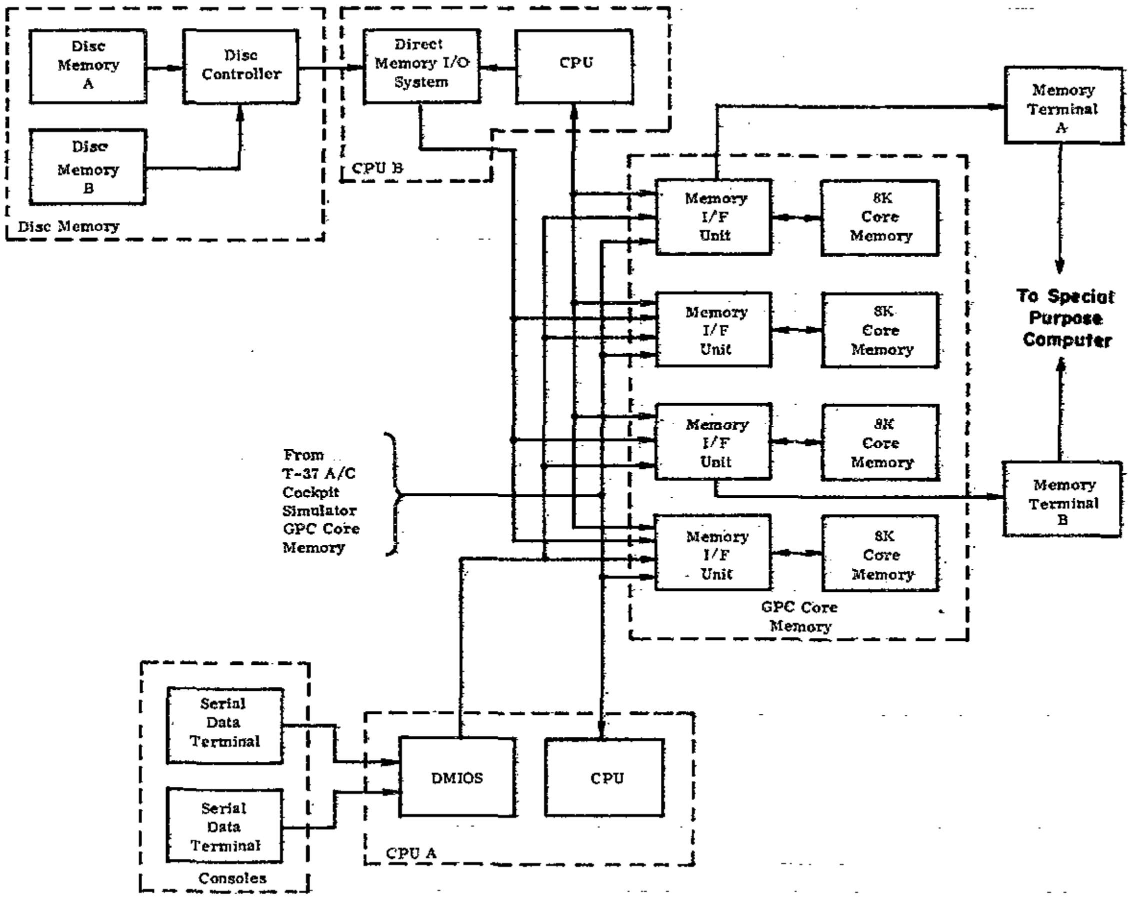

Figure 10. ASUPT CIG System General Purpose Computer Hardware Architecture

General Purpose Computer Software Architecture

Figure 11 shows the sequence of functions performed in one television frame time (1/30 second) by the General Purpose Computer software. The following capitalized headings correspond to Figure 11 block titles.

SHIP DYN DATA—Transfer to the special purpose computer the view window coordinate, fading and viewpoint position data.

READ SIM INPUT—Retrieve from shared core in the simulator computer the viewpoint and lead aircraft position and attitude data.

UPDATE R_p-C_m FOR LOD—Compute the vector from the current eyepoint position to each active model centroid.

COMP ELEV DATA—Adjust the viewpoint altitude from above mean sea level to above ground elevation.

X FORM LA COORD TO REF—Perform vector transformation to get lead aircraft position and attitude data into the moving model coordinate set.

SET-UP DIR LT TEST—Format data buffer and transfer that buffer to the dot product calculator so that directional light visibility may be determined.

X FORM VIEW WINDOWS—Transform the viewpoint attitude data into each one of the 14 view windows coordinates.

ROTATE SUN ANG MATRIX—Rotate the sun illumination direction vector for the correct attitude.

SHIP CA DATA—Form the channel assignment data block and transfer the data to the dot product calculator.

FORM PE VECTORS—Compute the vectors from the eyepoint to the left-hand boundaries for each of the 14 view windows.

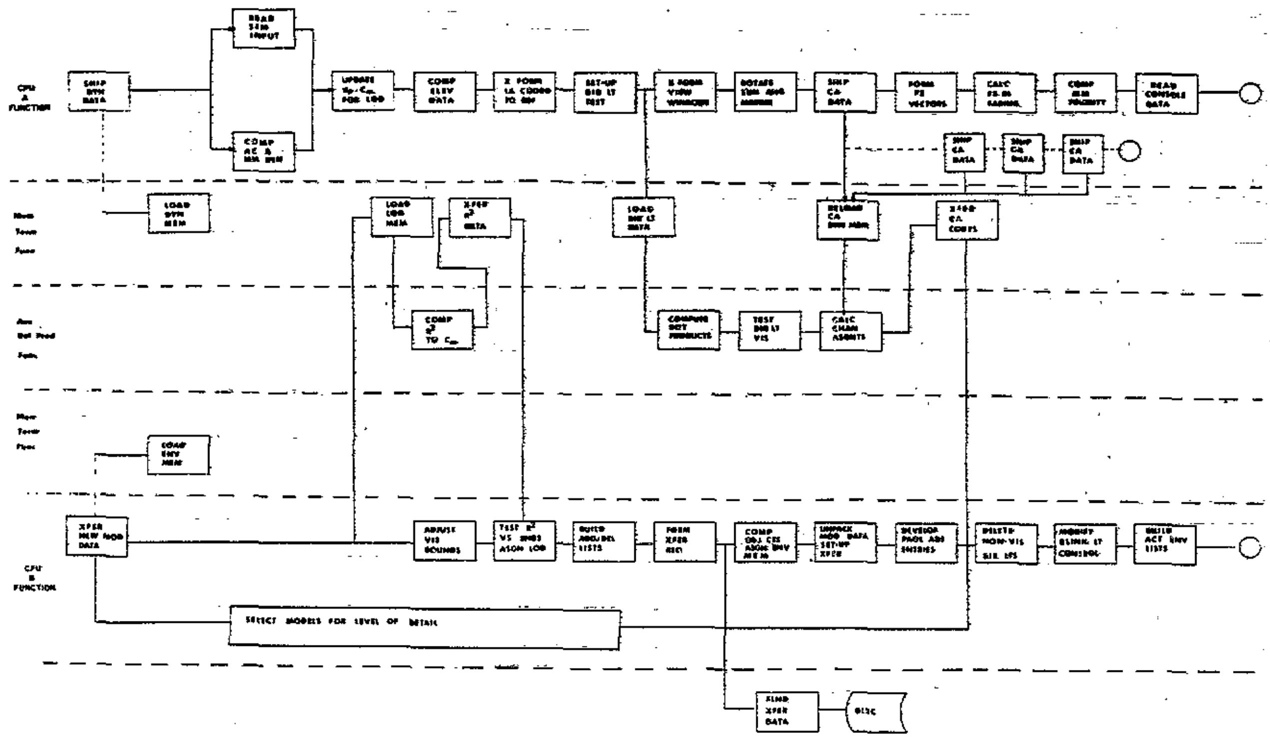

Figure 11. ASUPT CIG System General Purpose Computer Software Architecture

CALC FR III FADING—Using the view window coordinate system for each window, determine the fading coefficients to be used by the video processor to fade surface features.

COMP MM PRIORITY—Compute the start and stop vertex of the moving model to be used in FR II to resolve moving model priority.

READ CONSOLE DATA—Read and process the variable data input from the control consoles.

XFER NEW MOD DATA—Transfer, if required, a new definition to the environment storage in the Special Purpose Computer to update active environment.

ADJUST VIS BOUNDS—Make overload corrections to the coefficients used in determining model level of detail.

TEST R^2 VS BNDS ASGN LOD—Using the coefficients of level of detail and range squared from the eyepoint to the model centroid, determine for each model in range of view, the correct level of detail.

BUILD ADD/DEL LISTS—Adjust the models level of detail by adding the correct level of detail to the add list and the old level of detail to the delete list.

FORM XFER REQ—Access the disc and retrieve that model at the top of the add list.

COMP OBJ CTS ASSIGN ENV MEM—Determine where in the environment storage of the Special Purpose Computer the new model will fit.

UNPACK MOD DATA SETUP XFER—Reformat the model data from the disc into a form ready for transfer to the Special Purpose Computer.

DELETE NON-VIS DIR LTS—Eliminate from the active object list, those lights which have been determined to be non-visible due to the viewpoint being located outside of directional light field of view.

MODIFY BLINK LT CONTROL—Determine the off/on status of blinking lights for the current frame.

BUILD ACT ENV LISTS—Develop the active object list and the active model list.

SELECT MODELS FOR LEVEL OF DETAIL—Process by which the model pointer data for all models within range of view is retrieved from the disc and stored in General Purpose Computer memory. This process is performed as required and is not a regular frame time function.

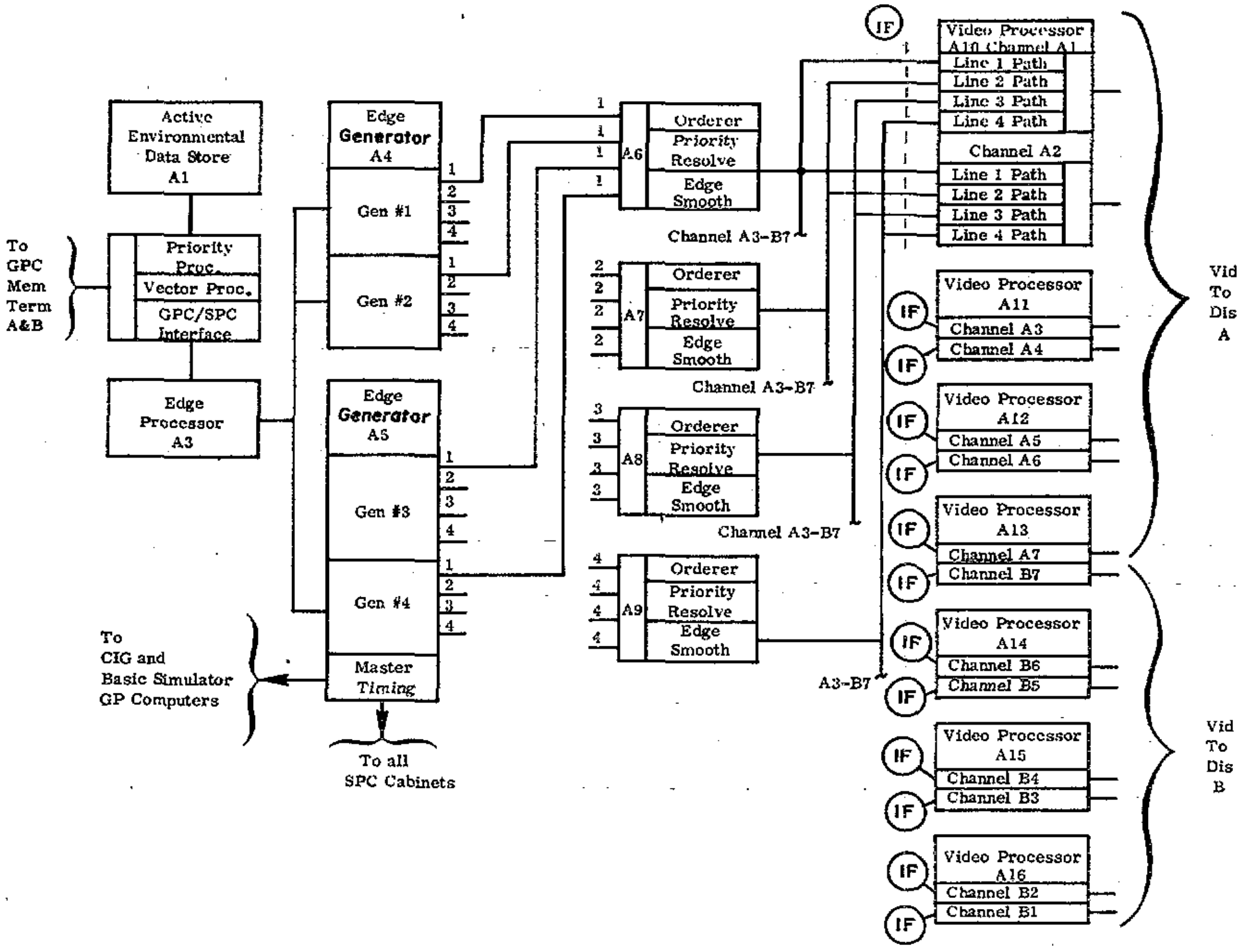

Figure 12. ASUPT CIG System Special Purpose Computer Architecture

Special Purpose Computer Architecture

The architecture of the CIG Special Purpose Computer is shown in Figure 12. Each block of the diagram represents a hardware cabinet as well as a basic function of the Special Purpose Computer. *The cabinets are physically arranged in single line* in order of A1 through A16. The major function and cabinet number are contained in each box of the diagram. The Special Purpose Computer television frame data processor block shown on Figure 9 consists of blocks A1, A2 and A3. The remaining blocks are a breakdown of the Special Purpose Computer television line data block of Figure 9.

The Active Environment Data Store cabinet A1 (SPC core memory) is equivalent to 152,000 words of 32-bit length and is a core memory. The interface between the core memory and the General Purpose Computer memory terminal B is handled by the GPC/SPC interface function contained in the Priority Processor cabinet A2. As viewed from the General Purpose Computer the SPC core memory is a 152,000 word by 32-bit per word memory. However, as viewed from the Priority Processor and Edge Processor functions, the core memory is five individual memories of word length from 16 bits to 192 bits. The core memory is operated at a 1-microsecond cycle time.

The Priority Processor cabinet A2 contains the General Purpose Computer and Special Purpose Computer interface function. The GPC/SPC interface is designed around a data bus concept. Two 32-bit parallel data buses are used. One data bus connects the General Purpose Computer memory terminal B and the Special Purpose Computer core memory. The other data bus connects the General Purpose Computer memory Terminal A and 32 different points throughout the Special Purpose Computer. In addition, the Special Purpose Computer data buses are accessible from a manual data entry and display panel which is a part of the Special Purpose Computer. The data bus system is used to handle housekeeping and control data, maintenance data, and all other data between the General Purpose Computer and Special Purpose Computer.

The Priority Processor function contained in cabinet A2 operates independently obtaining input data from the SPC core memory, and the General Purpose Computer via the data bus.

The Vector Processor contained in cabinet A2 interfaces with the General Purpose Computer via the data bus and is used by the General Purpose Computer to provide high speed vector arithmetic data processing.

The Edge Processor cabinet A3 performs edge projections, curved surface shading calculations, three-dimensional object fading, and light brightness control. Inputs to the Edge Processor cabinet are obtained from the SPC core memory, the Priority Processor, and the General Purpose Computer via the data bus.

The output of the Edge Processor is a series of display edges that are sequentially loaded into the Edge Generators 1 through 4 located in cabinets A4 and A5. A capacity of 2560 edges is divided evenly between the Edge Generators (640 edges each). However, only 2500 edges are processed each television frame time. The four Edge Generators each process edge data simultaneously for approximately 1/4 of the total edges.

Each Edge Generator simultaneously generates television raster scan line edge crossing data for the same four successive television field raster scan lines. The output lines labeled 1, 2, 3, and 4 on the Edge Generator block of Figure 11 represent the four scan line outputs.

Each Orderer cabinet (A6 to A9) processes raster line edge crossing data for one out of every four television field raster lines. Orderer A6 receives only the data for the first raster line of every four-line group. Orderer A7 receives only the second raster line data of every four-line group. Similarly, Orderer A8 gets the third line and Orderer A9 gets the fourth line. Within each Orderer cabinet, the raster line edge crossing data is ordered in raster line element sequence and then the Priority Resolver resolves priority conflicts that occur when two or more objects are in line with each other and the viewpoint. In parallel and simultaneously, the digital edge smoothing calculations are performed.

The output of each Orderer cabinet is put on a data bus that connects the output to the input of one of the line paths in all 14 Video Processor channels. There is one Video Processor for each display channel. Within each Video Processor, four television raster lines are simultaneously processed, one raster line per line path. The Video Processor outputs one television raster line at a time in sync with the display television raster. In addition to synchronizing the picture data with the television raster, the digital edge smoothing, curve surface shading, ground surface fading, and horizon effects are generated. The last step just before the Video Processor output is to convert the 10-bit binary gray shade of each display raster line element into a television video signal by means of a precision, high-speed, digital-to-analog converter.

The Master Timing generator produces all of the basic timing clocks for the Special Purpose Computer and Display Electronics. The Master Timing also provides 30-per-second interrupts to both the CIG General Purpose Computer and the basic simulator General Purpose Computer. Synchronization of the total ASUPT Simulator is provided by the Master Timing, which is a part of cabinet A5.

It can be seen in Figure 12 that all data for all 14 display channels is processed together up to the Video Processors, which are dedicated for each channel with two per cabinet. Further, it can be seen that the number of Video Processor cabinets is determined only by the number of display channels. Thus, a one-channel system would require only one-half a Video Processor cabinet. If the system only processed one-half the display edges, 1250 compared to 2500, then only one Edge Generator and two Orderer Cabinets would be required. Thus, the system would be reduced to 7 cabinets instead of 16 for one channel and 1250 edges.

ASUPT CIG DISPLAY ELECTRONICS ARCHITECTURE

The architecture of the Display Electronics is shown in Figure 13. The Display Electronics is divided between equipment mounted on the motion platform display structure and equipment located in standard rack cabinets.

The Sweep and Function Generator provides nominal sweep waveforms, video processing functions, and coil drive functions common to all seven display channels.

These nominal functions and video are then modified or refined to satisfy the unique requirements

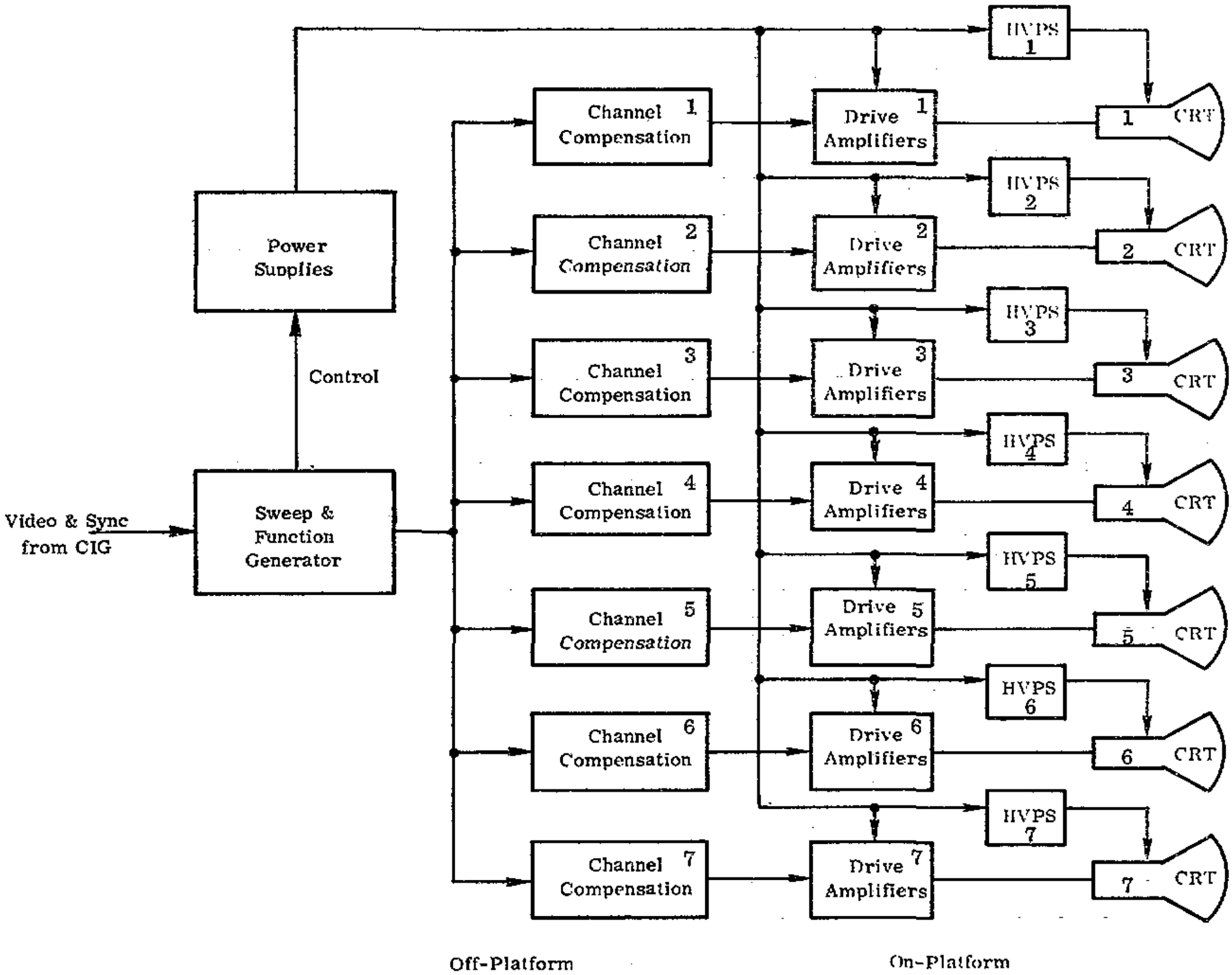

Figure 13. ASUPT CIG System Display Electronics Architecture for Each Cockpit

of each CRT Amplifier, Deflection Yoke, and Coil Assembly by the Channel Compensation circuits. The power supply set provides both common and individual power to the Drive Amplifiers, high-voltage power supplies (HVPS), and the CRT's.

ASUPT CIG SYSTEM HARDWARE

The ASUPT CIG General Purpose Computer, Special Purpose Computer, Display Electronics, and Console hardware represents a large highly complex hardware system. Some of the vital statistics of the system are given in the following paragraphs. The General Purpose Computer is a dual CPU 600 nanosecond cycle time processor with 32 kilowords (32-bit words) of core memory and a 4.2-megaword, fixed-head, synchronous disc memory. The General Purpose Computer operates in a real-time mode with a 33-millisecond processing cycle time and about 10,000 program instructions.

The Special Purpose Computer hardware consists of 16 rack cabinets, one of which contains the equivalent of 152,000 of 32-bit word core memory that is used for active environment storage. The remaining 15 cabinets contain about 120,000 integrated circuits of which about 30,000 are 256 by 1 integrated circuit memories and 60,000 are Schottky TTL integrated circuits with the remaining integrated circuits consisting of high-speed TTL integrated circuits. The logic circuits are clocked at 8 or 10 MHz with almost all of the logic circuits operated synchronous. The Special Purpose Computer is all digital integrated circuit logic with the exception of one digital-to-analog converter circuit per display channel. The logic is packaged on large swing frames that contain wrapped wire interconnections using about 1,500,000 interconnecting wires. The 5-volt, TTL logic is powered by 114 individual 5-volt, 100-ampere power supplies with up to 8 supplies located in each logic cabinet.

Several data bus systems are used throughout the Special Purpose Computer including a 32-terminal data bus which is accessed by the General Purpose Computer and is used to carry both operational and control data between the General Purpose Computer and various locations within the Special Purpose Computer. A significant additional use for this data bus is to carry test data for maintenance test and diagnostics. General Purpose Computer programs are used to aid in Special Purpose Computer maintenance.

The Display Electronics consists of two identical sets, one for each cockpit display. Each set consists of six rack cabinets, four of which contain power supplies, and two contain sweep generation and video processing circuits. There are five amplifier and drive assemblies mounted adjacent to each display CRT. In addition, a 38-kilovolt high-voltage power supply is mounted adjacent to each display CRT. The Display Electronics for each cockpit display includes approximately 10,500 discrete electronic components. The yoke and coil assembly includes a deflection yoke, a focus coil, stigmatism coil and two beam bending coils.

There are three sets of ASUPT CIG System Console hardware. There are two Instructor/Operator Consoles each of which contain CIG control panels and two television monitors that the console operator can use to view any of the 14 display channels. In addition to the Instructor/Operator Consoles, there is a CIG Maintenance Console which contains all of the CIG controls, two television monitors, and includes the General Purpose Computer Control Consoles. The CIG System control and maintenance operation is handled at the CIG Maintenance Console.

ABOUT THE AUTHOR

MR. HARRY W. BEARDSLEY, JR. is Manager of ASUPT Site Operations, General Electric, Space Division, Ground Systems Department, Daytona Beach. He holds a B.S. degree from The Rochester Institute of Technology and a Master of Engineering degree from the University of Florida. He has also done post-masters work towards the Ph.D. from University of Florida. Mr. Beardsley has spent the past 5 years working in the development of computer image generation technology and systems. As Project Engineer for the ASUPT computer image generation system developmental program, he was responsible for all engineering effort on the system from the proposal through site acceptance. As Site Manager for the ASUPT CIG Engineering Maintenance Services, he was responsible for both maintenance and system improvements. Prior to his experience in computer image generation technology, Mr. Beardsley worked in research and development in computer and communications technology. He also has experience in radar and communications system design and analysis.