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STATUS OF NASA/ARMY ROTORCRAFT RESEARCH AND DEVELOPMENT PILOTED FLIGHT SIMULATION

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INTRODUCTION

Rotorcraft research and development (R&D) piloted flight simulation is currently experiencing a quantum leap forward in capability, both for the major airframe companies and for the NASA/Army facilities. The need for sophisticated simulation capabilities is being driven by the Army's advanced mission requirements, as exemplified by the new light helicopter (LHX) series of aircraft, and by the high cost of flight development. The advanced mission requirements are moving Army helicopters toward extensively integrated systems that closely couple flying and mission management tasks, resulting in the need to simulate such systems in piloted ground-based facilities. The concomitant revolution in electronics technology has enabled these simulation needs to be met, although not at an insignificant price, both by the rotorcraft airframe companies and by the Army and NASA. Clearly the companies are achieving, for the first time, major in-house simulation capabilities. The NASA/Army capabilities are also undergoing major steps forward in their continuing role of providing more advanced R&D capabilities than are affordable by the individual companies.

The purpose of this paper is to review the status of the major NASA/Army capabilities in piloted rotorcraft flight simulation. This paper will address the requirements for R&D piloted simulation, as well as the capabilities and technologies that are currently available or are being developed by NASA and the Army at Ames Research Center to meet these needs. The application of revolutionary advances--in visual scene, electronic cockpits, motion, and modelling of interactive mission environments/vehicle systems--to the NASA/Army facilities will be addressed. Particular attention will be devoted to the major advances made in integrating these individual capabilities into fully integrated simulation environments that have been or are being applied to new rotorcraft mission requirements. The specific simulators to be discussed are the Vertical Motion Simulator (VMS) and the Crew Station Research and Development Facility (CSRDF).

THE ADVANCE OF FLIGHT SIMULATION TECHNOLOGY

The requirements for piloted R&D flight simulation emanate directly from the advanced mission capabilities that are needed by the Department of Defense, and the resultant advanced vehicle/systems that are required to meet these needs. The government facilities are being pushed towards the leading edge to address the most advanced of these mission applications and future vehicle/system concepts.

Advanced Mission Requirements

Advanced mission requirements are pushing simulation technology in two related but different directions: towards the modelling and perception of the complete external environment, and towards the modelling and representation of the on-board mission systems.

The LHX, particularly in its scout/attack (SCAT) mission in the context of a single-pilot battle captain, exemplifies this simulation challenge. This simulation requires very comprehensive modelling problems to be solved in real-time and very sophisticated cockpit and perception capabilities to be represented. The environment and mission equipment package include the role of battle captain for 11 other friendly aircraft; a threat environment with tanks, SAMs, DZUs, air-to-air Hinds, etc.; intensive communications environment with ground and air forces to include data link; extensive automatic survival equipment (ASE) and countermeasures to include RF/IR/EO/laser receivers and jammers and chaff/flares; and an extensive weapons suite to include guns, air-to-air missiles and air-to-surface missiles. The cockpit and perception capabilities include: a voice recognition and synthesis system; touch screen CRTs; programmable push buttons; data entry keyboards; and wide field-of-view helmet-mounted display with forward-looking infrared radar (FLIR) and superimposed symbology for flightpath control and targeting.

Advanced missions are requiring a much closer coupling and automation of the flight control and mission management systems with higher-level decision-making incorporated in the systems. This coupling is requiring a significant increase in the fidelity of the simulation of the mission environment and equipment, and the integration with the flight control system, the cockpit visual system and the piloting tasks. The real-time computation implications and the requirements for visual fidelity are significant.

Advanced Vehicle Configurations

Advanced vehicle configurations are pushing the requirements for simulation in two directions: representation of the basic air vehicle, and representation of the advanced systems necessary to control the air vehicle. The X-wing concept exemplifies this simulation challenge, requiring very difficult modelling problems to be solved in real time. The basic vehicle concept covers a speed range from hover to 400 knots; includes fixed, rotating and conversion operation of the rotor system;

and uses leading and trailing-edge blowing for control. The modelling of the systems required to fly the air vehicle poses even more difficult real-time modelling challenges. The fly-by-wire flight control system includes pneumo-dynamic control of rotor blowing through 20 valves; higher harmonic and rotor moment control for conversion; and transition of integrated flight/propulsion control from rotary-wing hover through conversion to fixed-wing high-speed forward flight.

Advanced vehicle systems are requiring a much closer coupling between the flight control system and the basic vehicle. This coupling is requiring a close integration in modelling the aerodynamic, structural, propulsion, and control characteristics of the vehicle with much higher-order dynamics than in the past. The real-time implications are very difficult.

GOVERNMENT SIMULATION OVERVIEW

Figure 1 summarizes the characteristics of the VMS and CSRDF in relation to advanced rotorcraft vehicle configurations and mission requirements. The government facilities at the Ames Research Center have been developed to address both of these needs, particularly through advocacy and funding by the Army.

The VMS was designed to study the flying qualities of advanced rotorcraft and VTOL aircraft. Through the years it has been enhanced to examine state-of-the-art vehicle configurations such as the tilt-rotor and the X-wing. The VMS has also been enhanced to examine more advanced mission requirements, such as air-to-air combat and single-pilot SCAT operations, with the focus on flying qualities rather than mission management. It is currently undergoing an Army-funded upgrade, called the Rotorcraft Systems Integration Simulator (RSIS), to expand its ability to support rotorcraft flying qualities simulation, particularly in the context of advanced nap-of-the-Earth (NOE) missions.

To address the combat-oriented full mission, the Army is also funding the development of the CSRDF, to be located at Ames. The simulator is being designed to study the issues of mission management for advanced missions of the future with the near-term emphasis on the battle captain for the LHX SCAT. The simulator will also include representation of advanced vehicle configurations and control-systems automation to provide proper flying-qualities consideration, but in a fixed-base mode.

The separation between flight and mission management is disappearing in advanced vehicles. The pilot and the aircraft systems must do both tasks in an integrated manner. This integration is being forged into the VMS/RSIS and CSRDF simulation capability at Ames and will provide the Government with a powerful capability to conduct rotorcraft research and development programs in a most effective and efficient manner.

VERTICAL MOTION SIMULATOR (VMS)

The VMS consists of a large motion base, interchangeable cab/cockpits, a computer-generated imagery system, and a CDC-7600 computer.

The VMS Motion Base

Description/Capabilities- The VMS motion base (fig. 2) is built around a horizontal beam which rests on two vertical pistons. The pistons are pneumatically pressurized to bring the beam to neutral buoyancy and are each driven by four 150 HP dc motors to provide the large (60 ft) vertical motion capability. A hydraulic hexapod motion system, manufactured by CAE Industries, is mounted to a lateral carriage on the beam. The lateral carriage is driven by four 40 HP dc motors to provide the second degree of large (40 ft) linear motion. The CAE motion base provides the three rotational degrees of freedom.

As part of the RSIS upgrade to the VMS (fig. 3) the CAE motion base is being replaced with the Rotorcraft Simulator Motion Generator (RSMG), a high performance, custom-designed motion base. The objective is to increase the angular rate and acceleration capabilities to those required for simulation of state-of-the-art rotorcraft in aggressive NOE flight. The third linear degree-of-freedom is also being provided. While the motion capabilities are driven by rotorcraft requirements, the resultant VMS will have enhanced capabilities for all vehicle classes. Table 1 shows the motion capabilities of the VMS, both in its current configuration and after the RSIS upgrade has been accomplished.

Motion Fidelity Effects- Two recent experiments on the VMS investigated the effects of motion cueing on rotorcraft control. The first experiment (ref. 1) investigated a helicopter autorotative landing task. Variations were made in the motion constraint logic ranging from full VMS motion through intermediate motion values typical of a large-travel hexapod and a small-travel "nudge" base down to no motion in fixed base. As shown in figure 4, landing performance degraded with restrictions in motion cueing. In addition, figure 5 shows that pilot control technique degraded with reduction in motion cueing as exhibited by collective control technique during the flare and touchdown. The second experiment (ref. 2) investigated the effect of motion variation on height control and target tracking with a simple hovering math model. The bandwidth and phase margin of the pilot-vehicle system were used to quantify the effects (fig. 6) of motion variation on the fidelity of the simulation. In holding position in the presence of vertical disturbances, pilot control gain and resultant open-loop crossover frequency were significantly depressed as the fidelity of vertical motion was reduced. In height tracking of a moving reference, gain and crossover were not greatly affected, but phase margin and tracking performance improved with increased motion fidelity. Also, figure 7 shows pilot opinion ratings of varied vehicle vertical-response characteristics were degraded with reduction in motion-cue fidelity.

The VMS Cab/Cockpit

The VMS cockpits are enclosed in cabs that are quickly interchangeable on the motion base. The basic concept is to have a pipeline of interchangeable cabs (ICabs) where one is being used for the current simulation, another is undergoing fixed-base checkout for the next simulation, and the third and fourth are being built-up for subsequent simulations. This approach significantly improves efficiency since the down-time of the motion base for cab reconfiguration is only about 4 hr. To minimize cab modifications, four ICabs have been built with their configurations optimized for specific vehicle configurations. The key consideration in cab layout (fig. 8) is the location of the CRT monitors that are used to present the outside scene to the pilot(s). The cab configurations are a single-seat rotorcraft cab, the right seat of a side-by-side dual-seat rotorcraft cab, a side-by-side dual-seat transport/Space Shuttle cab, and a single-seat fighter cab.

The RSIS upgrade to the VMS will include a new cab concept called the advanced cab and visual system (ACAVS) (fig. 9) in which a dome projection system is used to present the outside scene to the pilot(s). The cab will be compatible with the interchangeable cab interface of the motion system so that it or ICabs can be used (fig. 10). Cockpit reconfiguration will be achieved through interchangeable cockpit modules in the cab. Several modules, tailored to particular configurations such as single pilot and side-by-side dual pilot, will be developed.

The requirements to simulate cockpit systems such as heads-up displays and digital maps on the VMS continue to escalate. The specific capabilities developed to date will be covered in the section on Sample Advanced Simulations.

The VMS Visual Imagery Generation

Description/Capabilities- The VMS uses two computer-generated imagery (CGI) systems to provide out-the-window display. Both systems provide full-color, wide field-of-view scenes that accurately depict scene movement based on pilot input and aircraft response. The first CGI system acquired was a Singer Link DIG-1. It provides four channels displayed on collimated, vertical raster, 1000-line CRT monitors mounted in the cockpit with partial coverage of a field-of-view of 30° vertical by 144° horizontal. The system can display 6,000 edges at a 30 Hz frame rate.

The recently acquired Evans & Sutherland CT-5A system provides three channels projected adjacently on a dome via General Electric light valves. The field-of-view completely encompasses 60° vertical and 138° horizontal. The system can display 12,000 edges at a 25 Hz frame rate.

Fidelity Understanding/Improvements- While the Singer DIG-1 CGI, as delivered, greatly expanded the peripheral vision through the four-window cab as compared to a single CRT camera model-board system, it provided a very low level of near-field detail. It became quickly obvious, through pilot commentary, that it was crucial to be able to tailor the database to provide the cues necessary for the pilot to fly the specific task being studied. The capability to build new CGI databases and to rapidly modify the CGI databases supplied with the DIG has been developed and used.

Both the DIG-1 and the CT-5A systems allow real-time modification of many display parameters. These include environmental effects (time of day, clouds, rain, sun angle), lighting effects (airports, cities), and weapons effects (smoke, explosions, tracers, missile trail). Each system can display a variety of moving models within the display including airborne, ground and waterborne craft.

Ames currently has the capability to develop databases for both systems to display virtually any real or imaginary scenes. Currently the databases must be created on separate development systems using various types of source data including maps, photographs, and scaled drawings. A database development system resident on a graphics workstation is currently being implemented that will allow modification and creation of databases for both systems and conversion of either type of database to the other.

The knowledge about visual-cue requirements for simulation of rotorcraft is extremely limited. Information from the VMS has been acquired mainly through experience with on-going simulations and several limited experiments to specifically study the subject. This knowledge is based mainly on pilot commentary and observations with little quantitative data. As reported in references 1 and 2, window placement is extremely important so that consistent and easily recognized position, attitude and speed cues can be obtained from the scene.

A key issue in the use of CGI systems for flight simulation has been the effect of transport delay. The issue becomes crucial for tasks that require high bandwidth control, in the range of 10 rad/sec. To mitigate the impact of transport delay in CGI scene presentations, a discrete prediction algorithm has been developed at Ames (ref. 3) for application to both rotational and translational drive signals. The "McFarland algorithm," as it is called, capitalizes on the low-pass nature of these signals and its use requires the selection of a cutoff bandwidth that is small with respect to the simulation bandwidth, but larger than the pilot's operational bandwidth. Scene dynamics then exhibit significantly improved fidelity in the frequency range up to the cutoff bandwidth.

Figure 11 shows the phase and magnitude deterioration that occurs versus frequency when the simple technique of linear projection is applied to the problem of predicting signals 66.7 msec in the future (a typical CGI transport delay). Pilots invariably object to the performance obtained with this technique. Figure 12 presents similar data using the McFarland algorithm for the same prediction interval (66.7 msec). The compensation algorithm is a function of both the selected bandwidth, 2.5 Hz in this example, and the mainframe computer cycle time, a parameter shown in the figure. For the worst case shown, the selected bandwidth, 2.5 Hz, is 20% of the simulation bandwidth, 12.5 Hz (40 msec produces a Nyquist frequency of 12.5 Hz). Computer-generated image signals within the cutoff frequency of 2.5 Hz have negligible errors; that is, CGI presentation does not manifest any transport delay.

The amplification beyond the cutoff bandwidth has not appeared to influence rotorcraft simulations, even those with high N/rev frequency content. A special processing technique to handle turbulence modelling (a broad-band phenomenon) had to be developed.

The VMS Computer System

The primary simulation computer for the VMS is the CDC 7600, a 1970s vintage high-performance computer designed for batch operation. Ames has developed a real-time operating system to support simulation on the VMS. While the resultant computation capability of the CDC 7600 is fairly fast, on the order of 10 MIPS in closed-loop real-time operation, it suffers from a severe memory limitation that requires the heavy use of overlays in all simulations.

Even with this significant level of computational performance, the CDC 7600 does not satisfy several existing requirements and many upcoming needs. The computational shortcomings result from the modelling requirements of advanced vehicle/rotor configurations and advanced rotorcraft on-board systems. Specific vehicle modelling needs include blade flexibility, in-flow dynamics, engine dynamics, rotor/fuselage interactions, and unique concepts such as circulation control rotors. Specific vehicle systems modelling needs include extensive on-board digital computation for integrated controls at very high frequencies such as integrated flight/propulsion control or higher harmonic control. These requirements affect the needed computational speed in two ways: 1) more equations of increased complexity must be solved, and 2) the equations must be solved at much higher computational frequencies to assure numerical stability at the higher frequency contents. Ames is currently in the process of upgrading its simulation capability by replacing all of its simulation computers through competitive procurement (ref. 4). The requirements are based upon analysis of the previously described needs for the next 10 yr. Two classes of computer performance are being sought with the replacement for the CDC 7600 being targeted for nominally greater than 20 MIPS in real-time operation. The speed requirements are stated in terms of benchmark programs that must meet specific time requirements.

Sample Advanced Configuration/Mission Simulations

The capabilities and the technology limitations of the VMS are best understood in the context of the leading edge simulations that have been conducted with the VMS. The following simulation programs resulted in the state of the art of VMS being expanded in many different directions.

<u>RSRA X-Wing Vehicle Development Simulation</u>- The RSRA X-wing research aircraft has undergone three piloted simulation investigations on the VMS: no-rotor, stopped-rotor, and rotating-rotor configurations. The computational requirements to simulate the X-wing far outdistance the capabilities of the CDC 7600 computer. The computational requirements are essentially driven by three unique aspects of the X-wing rotor system: 1) the circulation-control airfoil used in the rotor system;

2) the pneumodynamics of the circulation control system; and 3) the conversion from rotating rotor to fixed rotor and back.

The circulation-control rotor, using trailing-edge blowing over a Coanda surface, complicates the aerodynamics of the airfoil. Lift and drag coefficients over the angle-of-attack range of interest are typically stored in tables for maximum speed in real-time operations. These tables must also include variations of blowing coefficients at each of the previous data points. Since blowing effects vary with Mach number, the aerodynamic inputs to the simulation are no longer linearly normalizable by dynamic pressure.

Circulation control is used not only for performance benefits through increased lift, but also to control the lift distribution over the rotor plane. Air from a gear-box-driven compressor is provided to the slots on the aerodynamic surfaces. The flow is varied to increase lift on the retreating blade side (in rotary wing mode) and to provide maneuver control of the vehicle. Since the valves controlling the internal airflow are located in the hub, the pneumodynamics of the flow inside the blades (including compressibility of the air) must be included in the simulated control-system model.

In the past, structural dynamics did not significantly affect handling qualities. The X-wing, with forward swept wings (blades) in the stopped mode and a rigid rotor system in the rotary-wing mode, introduces structural dynamics effects into the handling qualities. Even though the X-wing blades (wings) are necessarily very stiff, they do flex under load thereby altering the load distribution and moments generated by the X-wing. In addition, the rigid rotor (no flapping or lagging hinges) transmits vibrations to the body that are not present in conventional helicopters. The X-wing design includes higher harmonic control in the pneumatics of the flight control system to counter these effects, thereby further complicating the simulation.

<u>Helicopter Air-To-Air Combat Simulation</u>- The air-combat role for Army helicopters has rapidly become a critical issue for research and development activities within the government and industry. Since Army aircraft frequently operate at NOE altitudes, encounters with threat aircraft are likely to occur at this low level. Fixed-wing manned simulators in government and industry have not been easily adapted to helicopter engagements because of aircraft modelling complexities and the lack of high-fidelity, low-level visual scene-generating systems. It was desired, therefore, to design a simulation system which would allow the effects of terrain to be included in an investigation of helicopter air-combat maneuvering. The helicopter modelling capability, the wide field-of-view CGI display, and the large motion travel of the NASA Ames Research Center VMS were well suited for this task, although new system capabilities were required.

These new capabilities included a dual eyepoint CGI real-time software program which allowed for two independently maneuverable views of a common visual data base. The data base was specially designed for this project as was a system of head-up and panel-mounted information displays. The enemy aircraft pilot station and equations of motion were added along with a weapons model and scoring algorithms.

Two helicopter air-combat simulation experiments have been conducted on the VMS air combat system to date (ref. 9). Numerous other studies have utilized the capability for a sub-task portion of a particular handling qualities or flight controls experiment. Example study topics have included maneuver envelope requirements, roll-control performance, tilt-rotor and longitudinal-force control comparisons, and command-augmentation system studies. Planned improvements to the system would expand the pilots' field of view, a critical factor for air combat, and allow for encounters involving multiple opponents. Nevertheless, pilot comments rate the encounters flown on the current system as very representative of flight test engagements and have praised the usefulness of the simulator tool for this task.

Side-Arm Controller and Helmet-Mounted Display Simulation- A recent requirement for the replacement of conventional cockpit controls with smaller, integrated, multi-axis controllers led to a series of VMS investigations of the effects of side-stick controller characteristics on rotorcraft handling qualities for terrain flight (refs. 5 and 6). Because of the need to evaluate a wide variety of controllers, an extremely adaptable mounting technique was devised which allowed not only the easy installation of the various controllers but also the adjustment of the position and orientation of each controller with respect to the pilot (fig. 13). This adjustment was found to be critical in determining the acceptability of any particular controller configuration. Careful calibration of the force-displacement characteristics of each controller was required to ensure the validity of the experimental results.

For these investigations, visual flight tasks were flown over a specially designed CGI database presented on the four-window display in the VMS (fig. 14). Careful design of this visual scene, especially terrain texture and obstacle placement, was required to provide compelling visual cues of the pilot's position and orientation with respect to the terrain and other obstacles (ref. 7).

To assess the effects of reduced visibility conditions on the experimental results (ref. 8), the Army's Integrated Helmet and Display Sight System (IHADSS) was installed into the simulation (fig. 15). The IHADSS is a visually coupled, helmet-mounted display of infrared (IR) imagery from a nose-mounted sensor and superimposed symbology currently operational in the AH-64 Apache helicopter. To achieve a simulation of the operational system, the simulated IR sensor image was produced by a camera-and-terrain-board visual system which responded to both aircraft and pilot head motions. The simulation software which drove the camera was run at a cycle time half that of the aircraft model to ensure a smooth response to anticipated pilot head motions. Some difficulty was encountered in mixing the stroke-written symbols with the raster IR simulation, and the resulting superimposed symbols were not as clear as in the actual system. However, the IHADSS simulation was judged to be very representative of the actual system by an experimental test pilot experienced in its use.

CREW STATION RESEARCH AND DEVELOPMENT FACILITY (CSRDF)

Introduction

The capabilities of the CSRDF are driven by emerging Army rotorcraft requirements while its architecture capitalizes on the burgeoning developments in simulation technology. The Army urgently needs a full-combat mission simulator to conduct advanced rotorcraft R&D with evolving materiel and doctrinal concepts in a realistic scenario. The requirements for the CSRDF were developed to meet both the near-term critical needs of the LHX development program and the far-term R&D needs of future Army development programs.

Overview

CSRDF has been designed to permit evaluation of either a single or a two-crew aircraft when operating as part of a full SCAT team in a scenario that exercises friendly and enemy systems of operational significance to the crew.

The scenario participants include: 1) the crew station battle captain; 2) up to three SCAT teams of four aircraft each; 3) a utility helicopter; (4) other friendly units such as AWACS aircraft, Ranger teams, and Battalion commanders; 5) up to three enemy helicopters; and 6) up to 110 ground-based threats and targets. The participants are fully active with 1) the SCAT, threat and utility aircraft under real-time control and interaction by human experimenters; 2) the friendly forces in real-time communication and interaction by human experimenters; and 3) the ground-based threats in real-time interaction by computer control.

Simulation of aircraft systems includes cockpit systems, aircraft survivability equipment, mission equipment packages, navigation, communications, and battle resource management. Each of the systems in these six categories has been simulated in consonance with modern SCAT rotorcraft technologies. The effects of variations in these systems will be assessed in the context of a full-combat situation.

A multiple deployment scenario, divided into three successive 45 min engagements, has been developed. As the mission progresses through the three engagements, the loading from threats, communications and fatigue will increase. The composite mission scenario has been designed to provide a realistic workload for the battle captain so that the mission effectiveness and associated workload can be assessed.

Facility Elements

The tandem crew station, shown in figure 16, has been designed around a fiber-optic helmet-mounted display (FOHMD) that is worn by the pilot in one of the two crew station positions. The FOHMD (fig. 17) presents a panoramic view of either the out-the-window scene or the image from a head-tracked sensor. The field-of-view of the display (fig. 18) includes a high-resolution binocular insert where computer-generated symbology is mixed with the scene.

Figure 19 shows the components of the FOHMD system. The orientation of the helmet is tracked by an IR tracking system with acceleration compensation to minimize latencies. The orientation commands, in consonance with the aircraft motions, are used to drive the computer-image generator which calculates the proper scenes for each channel in the image presentation. The image generator drives light valves through an optical combiner to produce the picture for each eye. These pictures are transmitted by fiber-optic bundles to the helmet. The head-tracker capability results in a very large field-of-regard.

The layouts of the two crew stations are shown in figures 20 and 21. The flight controls in each crew station consist of two four-axis, limited-displacement controllers plus rudder pedals. The longitudinal, lateral, directional, and collective controls may be dynamically assigned to any combination of hand controllers and pedals in a given crew station. Systems management displays permit control of aircraft systems via various tactile entry devices such as touchpads and touchscreens. Monitoring of the combat situation is achieved through the tactical situation display (TSD) by means of a scaleable plan view of the gaming area with overlays for threat and friendly units. These may be modified using the touchscreen, as may the navigation and tactical overlays.

The simulation does not provide motion or vibration cues; however, great attention has been given to the sound and noise environment. A six-channel sound system provides directional sound cues for such items as rotor and transmission noise, weapon firing effects, dispensing of chaff and flares--all with noise levels comparable to that experienced in flight.

Blue/Red Team Stations (fig. 22) are used to control the interaction of the SCAT team members, the enemy aircraft and the utility helicopter with the crew station within the tactical gaming area. Plan-view and stylized forward-view displays (fig. 23) are the chief references for flight control. Control of the team station aircraft is through a simple joy stick. Selection of weapons, control of flight modes, and receipt and transmission of data link messages are all achieved through soft key selections on the touchscreen.

The White Team Station (fig. 24) provides the simulation of the communication intensive interactions with all elements external to the SCAT team. Ten channels of communication, with provisions for voice alteration, background chatter, and frequencies assigned under experimenter control, add realism and completeness to the simulation.

The control and coordination of the experiment is achieved through the experimenter/operator console (EOC) (fig. 25), where a team of Army experimenters and NASA personnel will control and monitor the mission scenario.

The computer architecture for CSRDF is shown in figure 26. The simulation is run under the control of a VAX 8650 host computer, iterating at the basic rate of

60 Hz. It is coupled with an array processor, running a blade-element rotor model at a 120 Hz rate. Four Microvax II microcomputers and 12 Silicon Graphics IRIS graphics workstations are connected to the host by Ethernet serial data buses. The Digital Imagery Generator (DIG) from Singer Link utilizes a Perkin Elmer PE 3250. Real-time software in the host consists of two basic parts: 1) simulation of the air vehicle, the crew environment and the system software furnished by CAE, and 2) simulation of the threat environment and crew station tactical systems provided by Flight Systems, Inc. (FSI). CAE is primarily responsible for cockpit systems, navigation, communication, and battle resources management and overall systems integration; FSI is primarily responsible for threat models and tactics, aircraft survivability equipment, target acquisition, and weapons modelling. In addition, the full visual scene, covering a 32 by 40 km database with appropriate threat systems, is provided through the Singer Link DIG.

Any simulator designed for research and development applications must be quickly and easily reconfigurable. With the CSRDF architecture of programmable displays and software modules, interactive graphics editors are provided to allow displays to be built and changed. Similarly, a syntax editor allows the voice input and output systems to be modified to suit the particular goals of each experiment. Database processors can extract macro-terrain information from the DIG to build forward-view displays and tactical-situation contour displays. Utilities allow the threat positioning and characteristics to be modified.

CONCLUDING REMARKS

Clearly the separation between flightpath management and mission management is disappearing in advanced vehicles. The pilot and the on-board systems must do both tasks in an integrated manner. This integration is being forged into the VMS/RSIS and CSRDF simulation capability at Ames. The focus of the VMS is on flying qualities/control investigations in the context of representative mission environments. On the other hand, the focus of the CSRDF is on mission-management investigations in the context of representative vehicle/control characteristics. The combined facility base provides the United States with a powerful capability to conduct leading-edge rotorcraft research and development programs in a most effective and efficient manner.

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TABLE 1.- VERTICAL MOTION SIMULATOR MOTION SYSTEM PERFORMANCE LIMITS

	Displacement ft deg		Velocity ft/sec deg/sec		Acceleration ft/sec^2 deg/sec^2	
	Original	RSMG	Original	RSMG	Original	RSMG
Vertical	±25	±25	±16	±16	±24	±24
Lateral	±17	±17	±8	±8	±15	±15
Longitudinal	±0	±4	±0	±4	±0	±10
Roll	±19.5	±18	±19.5	±40	±57.3	±115
Pitch	+20 -24.5	±18	±19.5	±40	±57.3	±115
Yaw	±34	±24	±19.5	±40	±57.3	±115

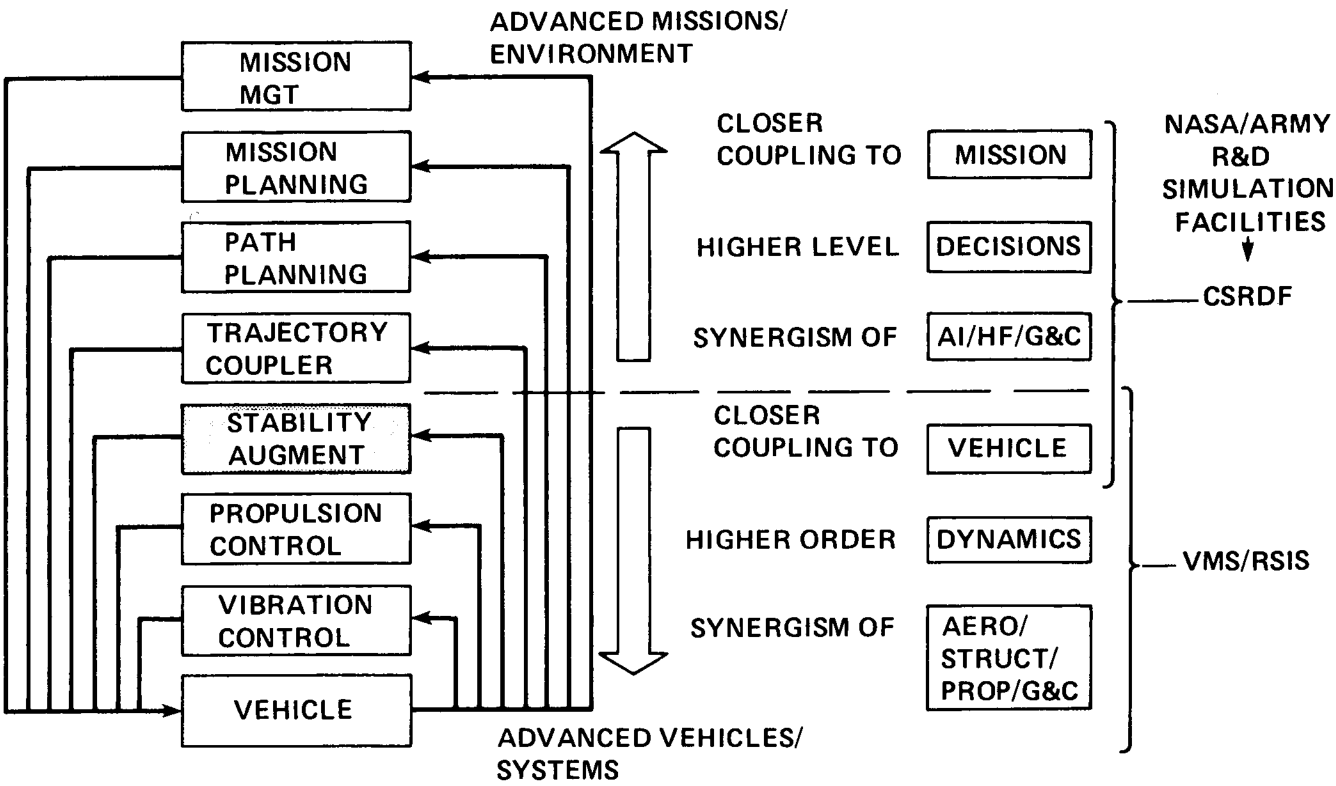

Figure 1.- Direction of rotorcraft/simulation technology.

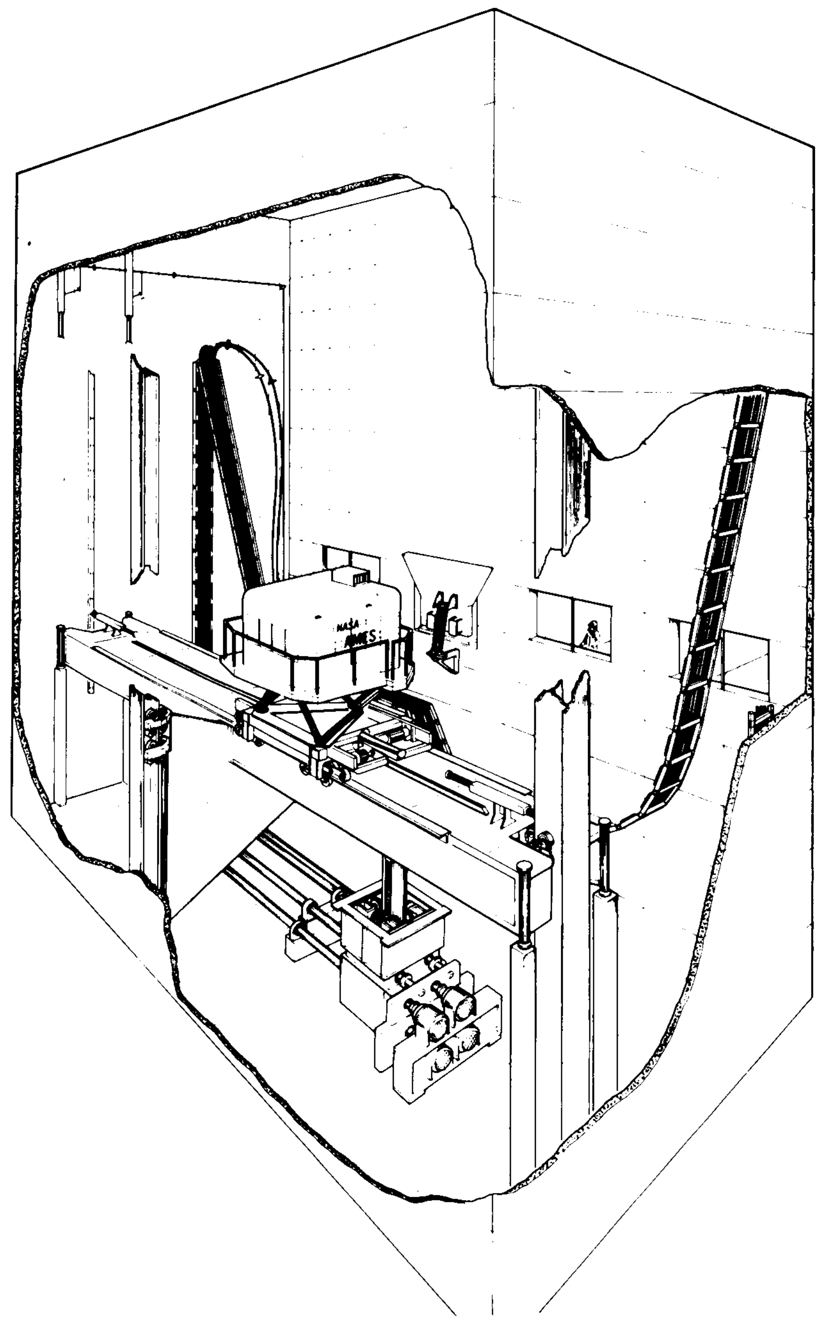

Figure 2.- Vertical Motion Simulator.

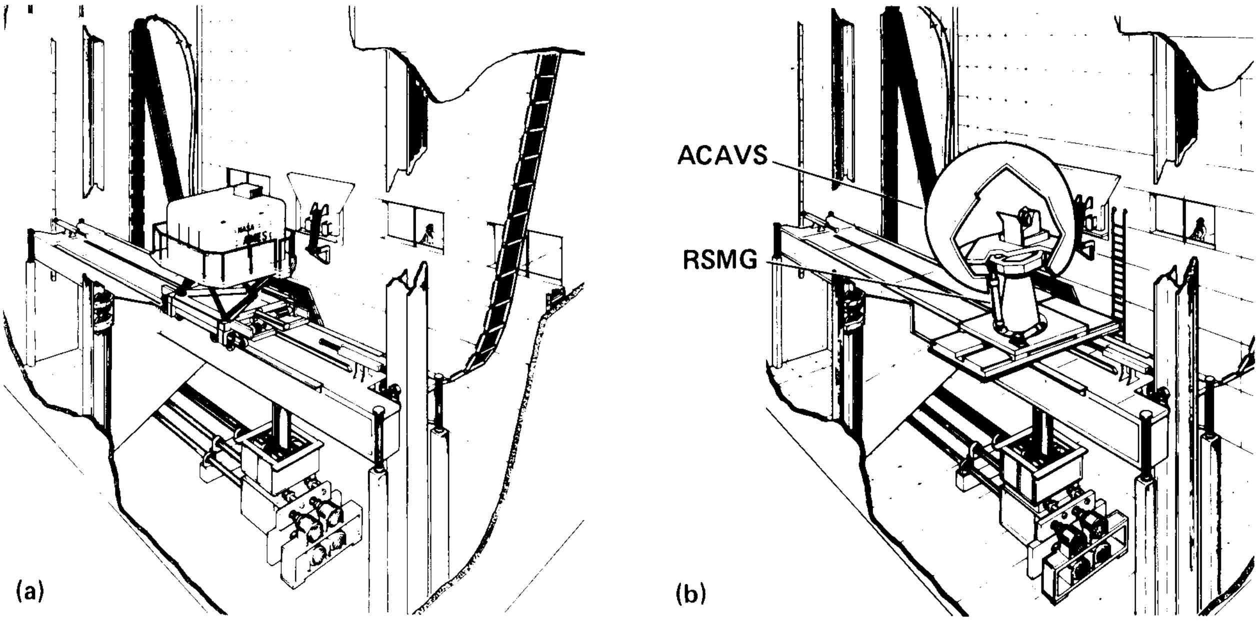

Figure 3.- Vertical Motion Simulator. (a) Existing VMS; (b) future VMS.

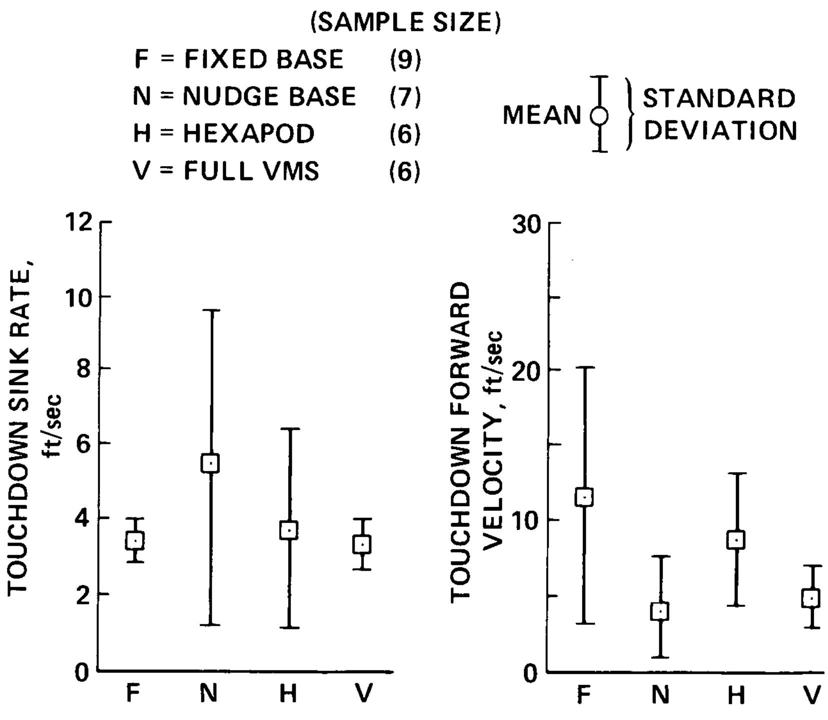

Figure 4.- Motion restriction effects on autorotation landing performance.

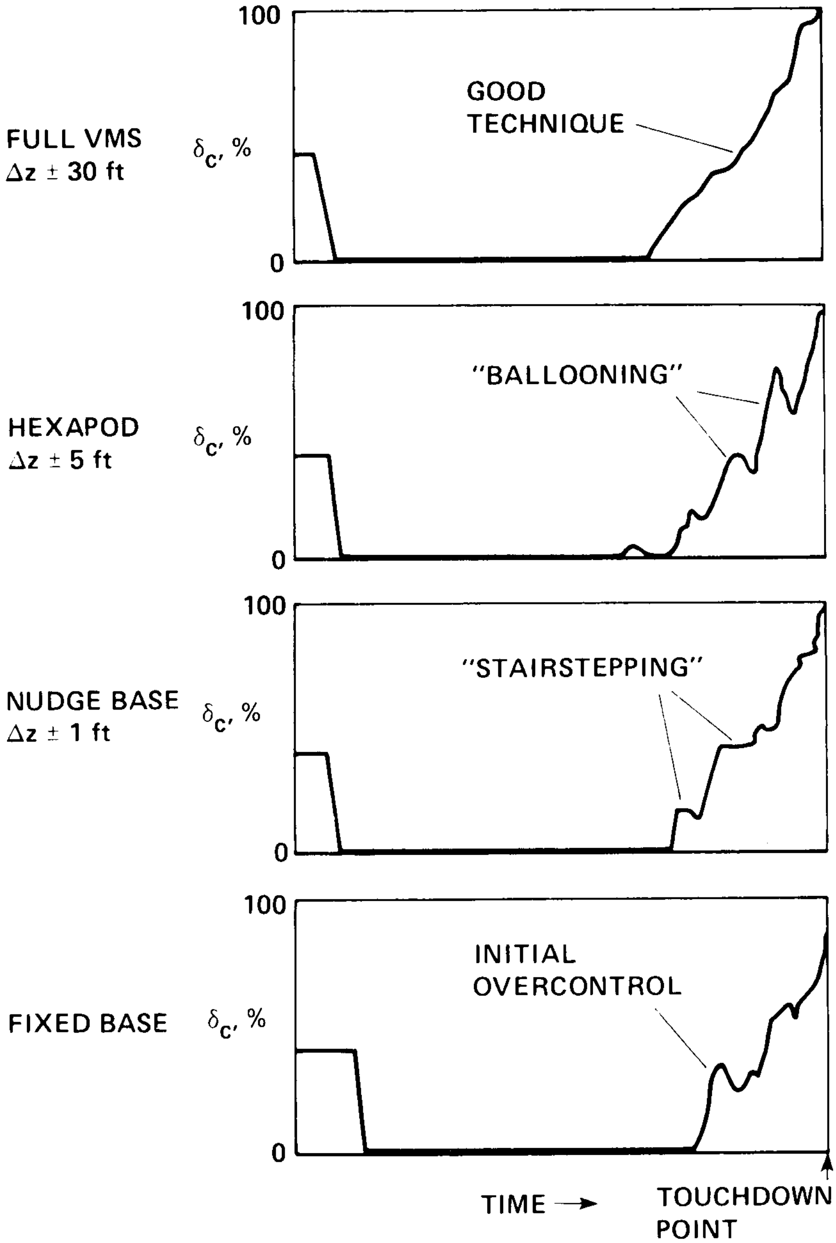

Figure 5.- Motion restriction effects on autorotation control technique.

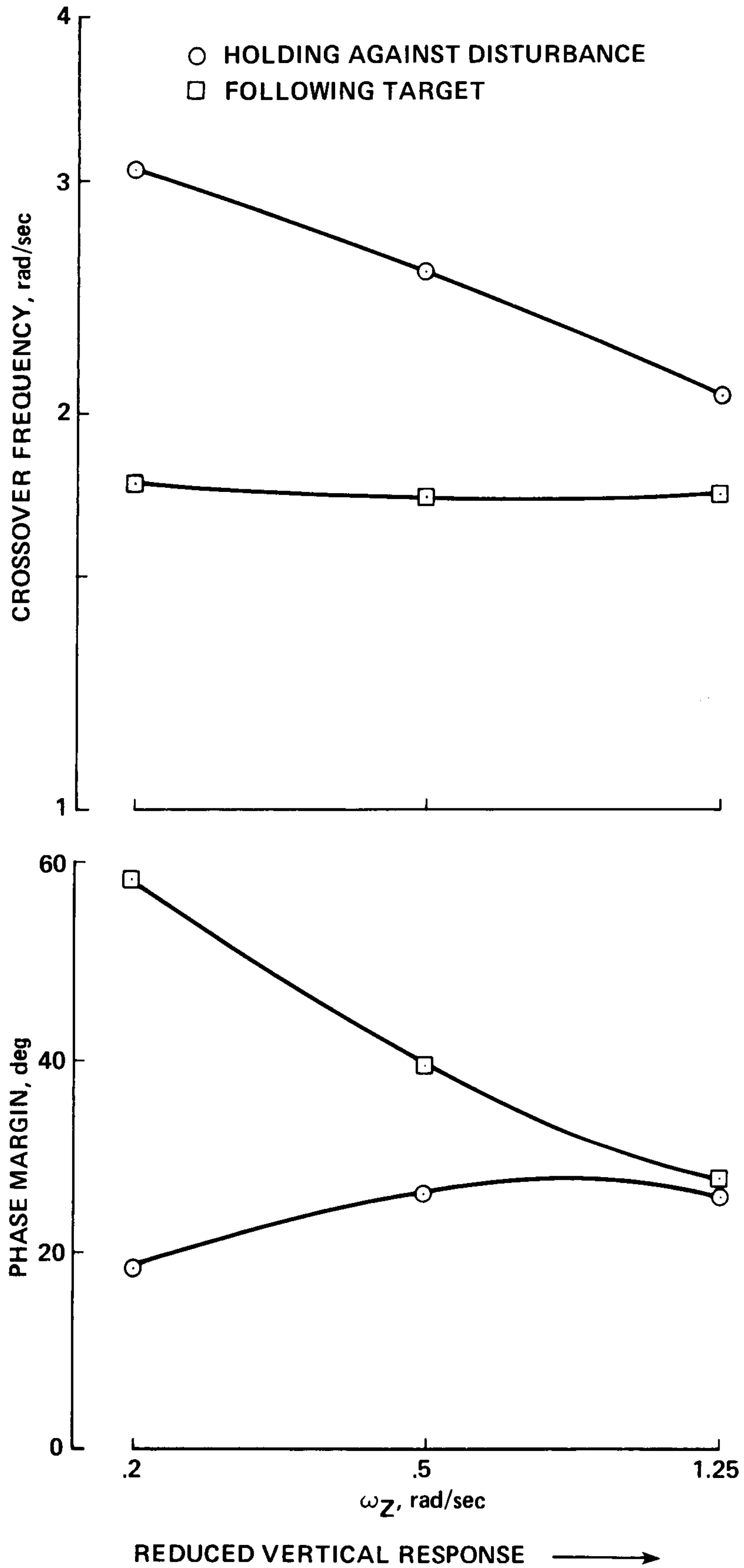

Figure 6.- Motion restriction effects on pilot/vehicle simulation fidelity.

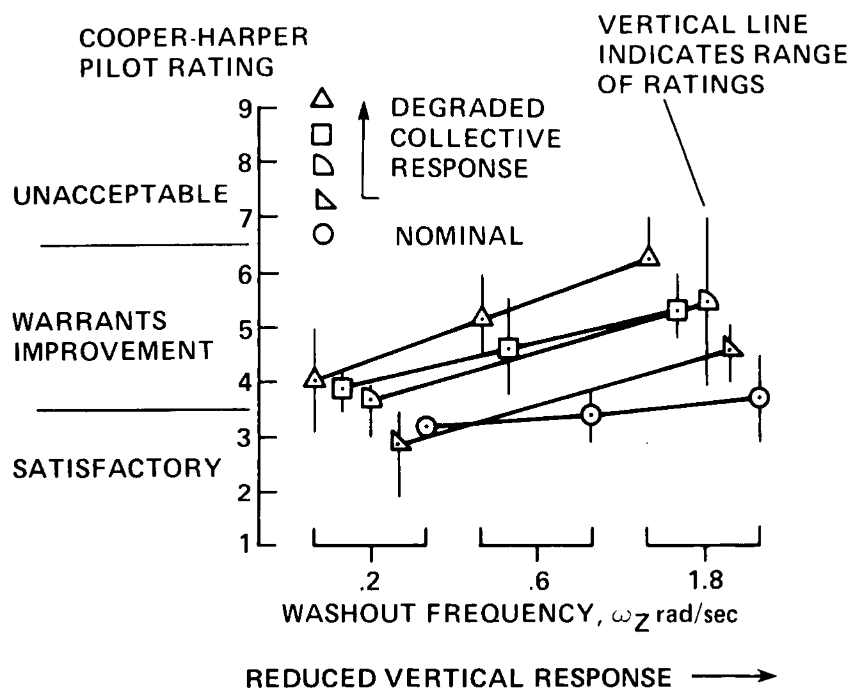

Figure 7.- Motion restriction effects on simulation fidelity for various vehicle characteristics.

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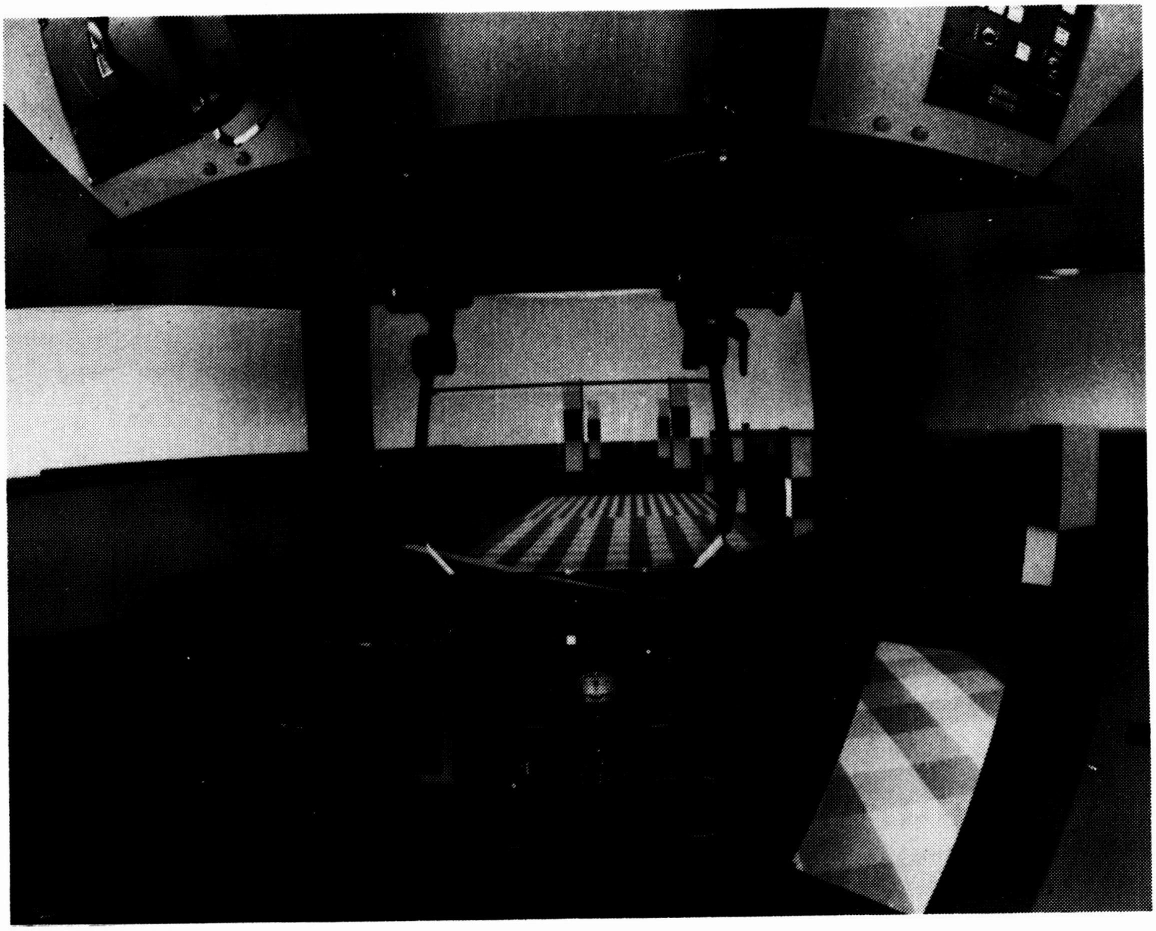

Figure 8.- Typical interchangeable cab layout.

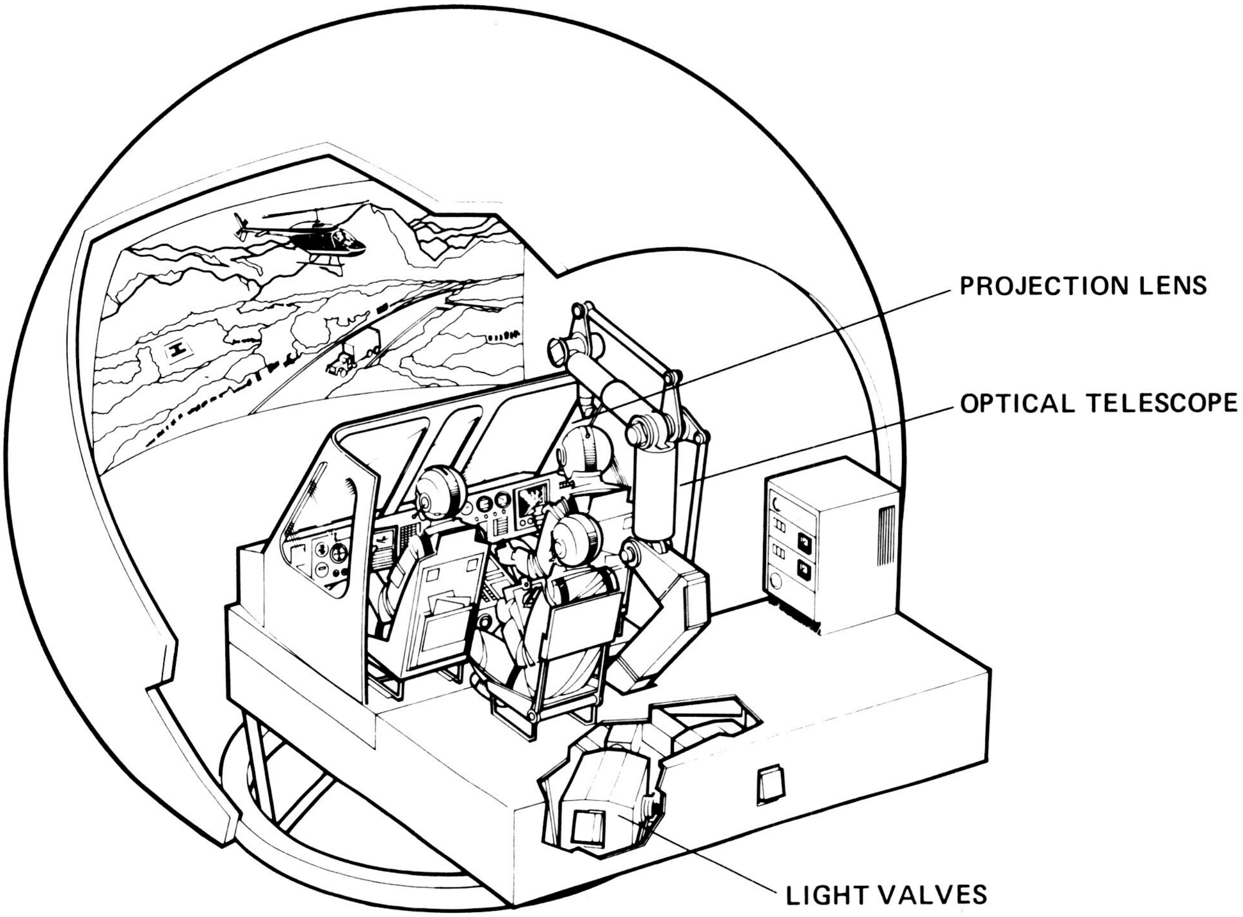

Figure 9.- Advanced cab and visual system (ACAVS).

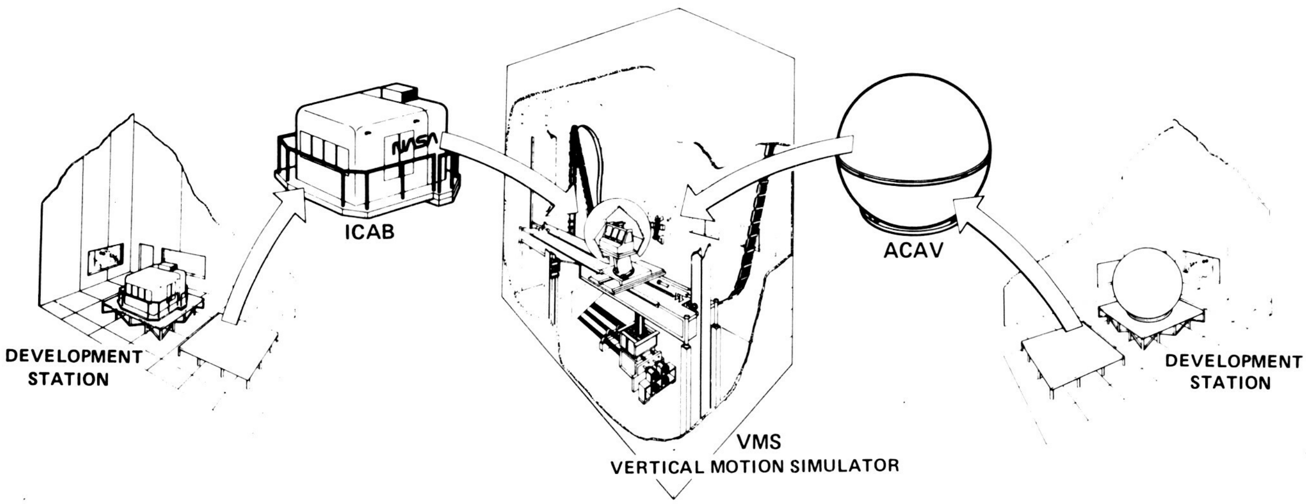

Figure 10.- VMS cockpit systems.

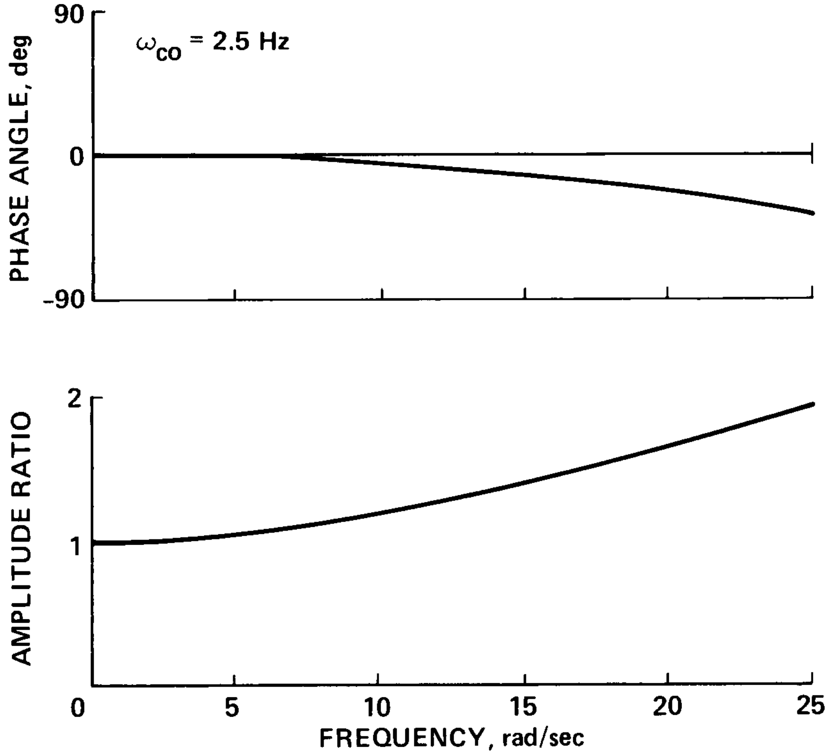

Figure 11.- CGI delay compensation with linear projection.

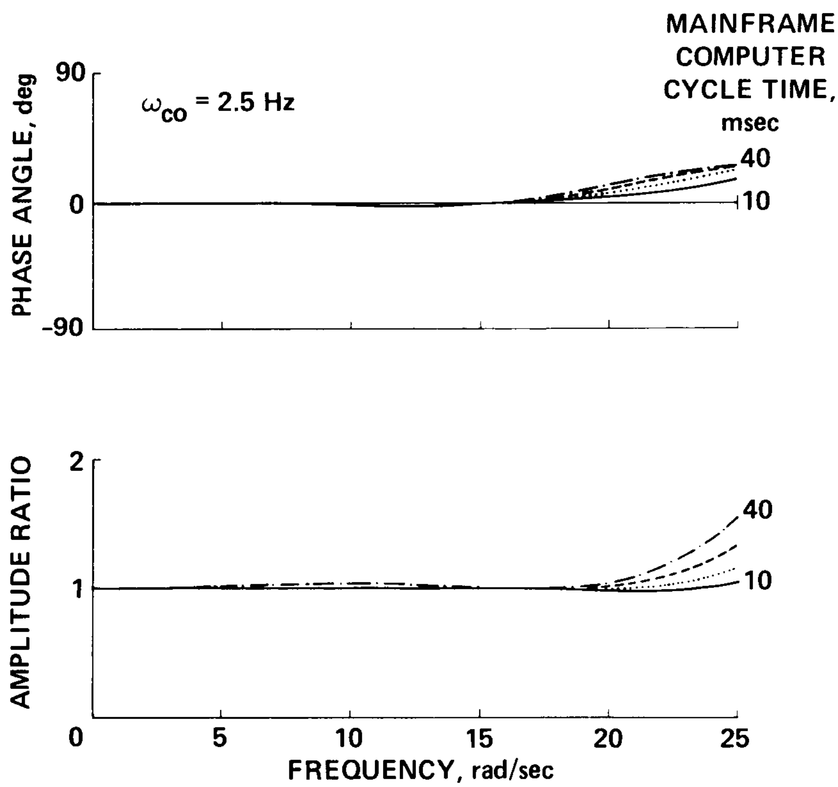

Figure 12.- CGI delay compensation with McFarland algorithm.

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Figure 13.- Side-stick controller installation.

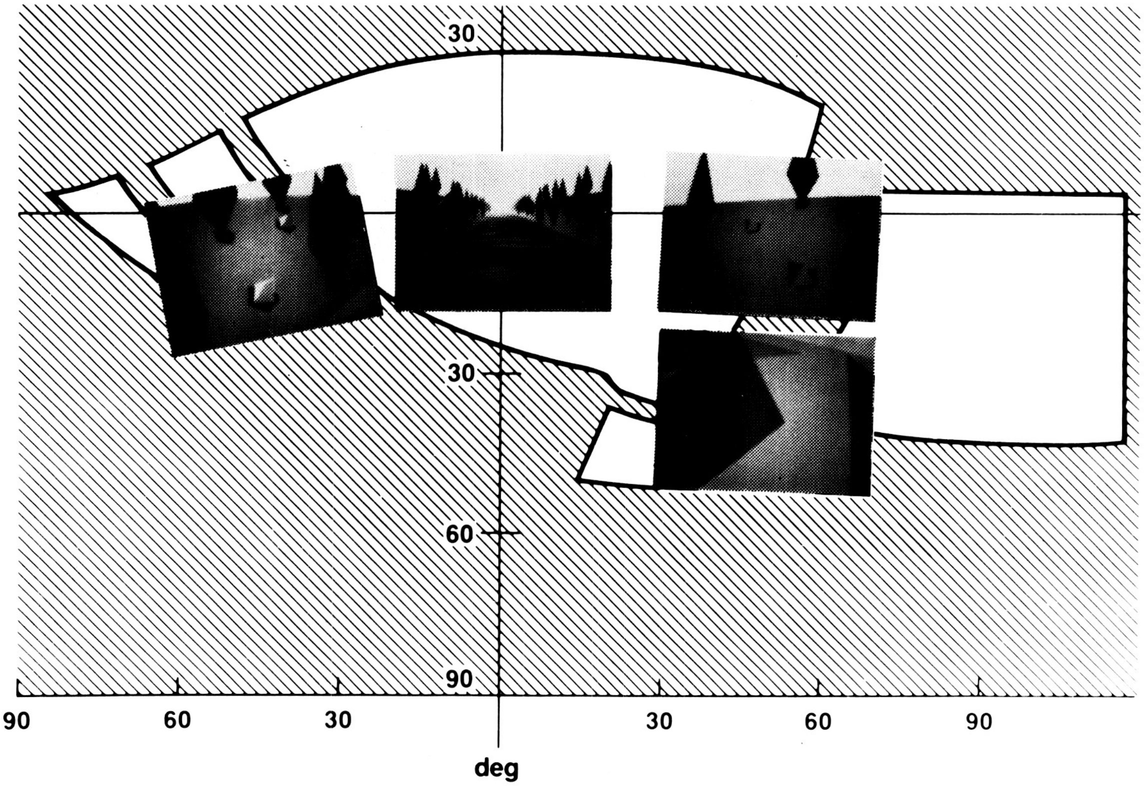

Figure 14.- Four-window computer-generated display of terrain scene.

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Figure 15.- Integrated Helmet and Display Sight System (IHADS).

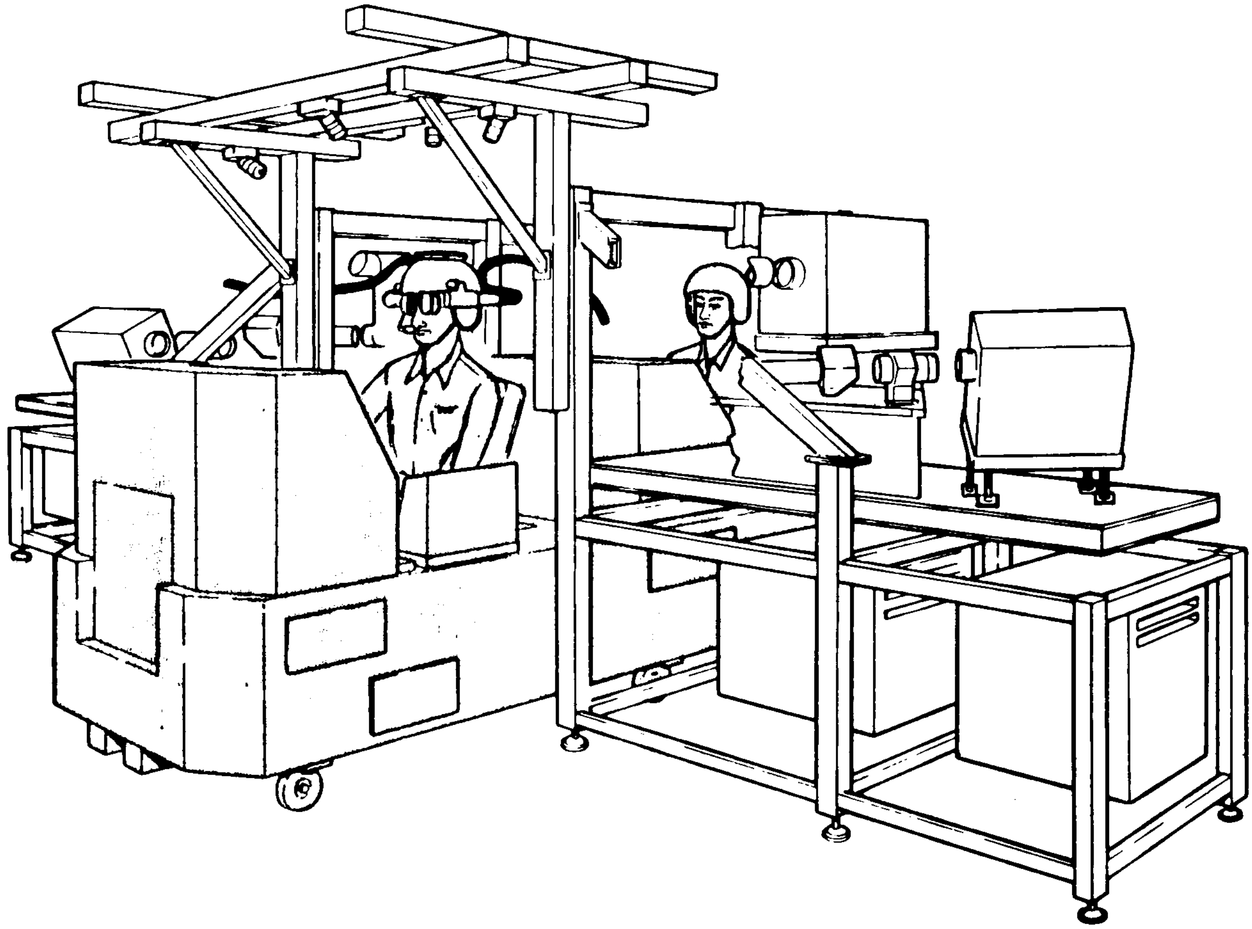

Figure 16.- Crew station structure.

Figure 17.- Fiber-optic helmet-mounted display (FOHMD).

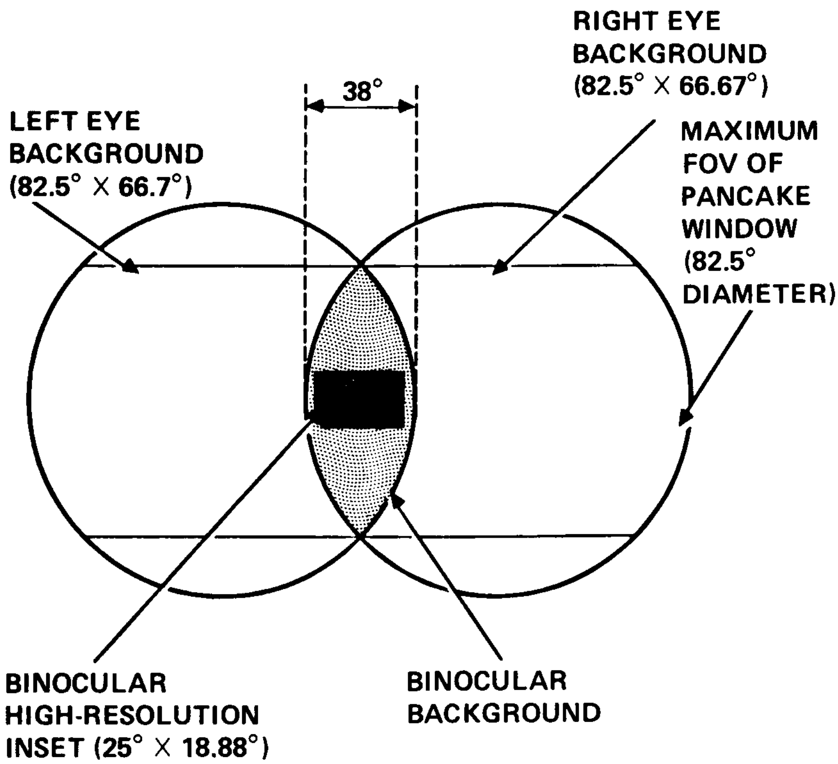

Figure 18.- FOHMD fields of view.

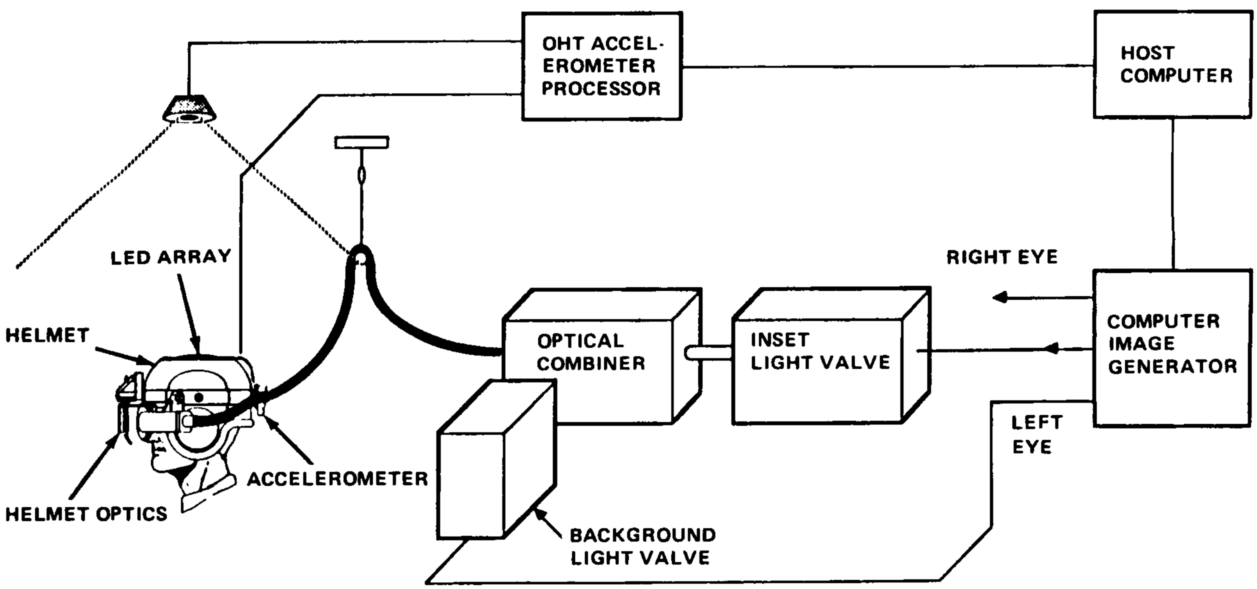

Figure 19.- FOHMD system components.

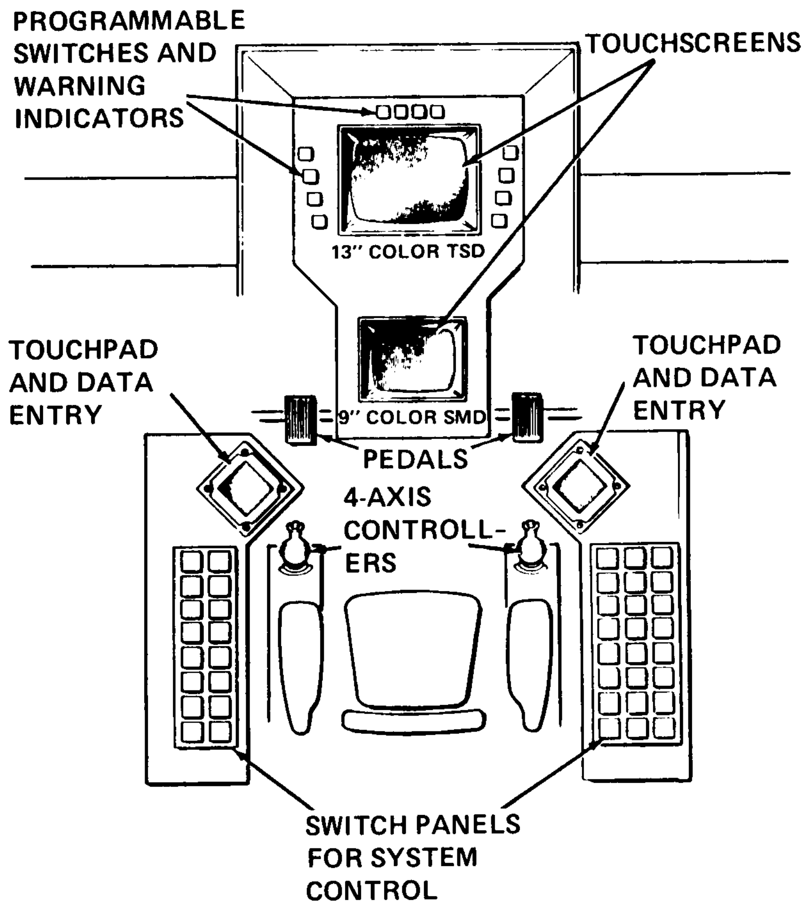

Figure 20.- Front crew station.

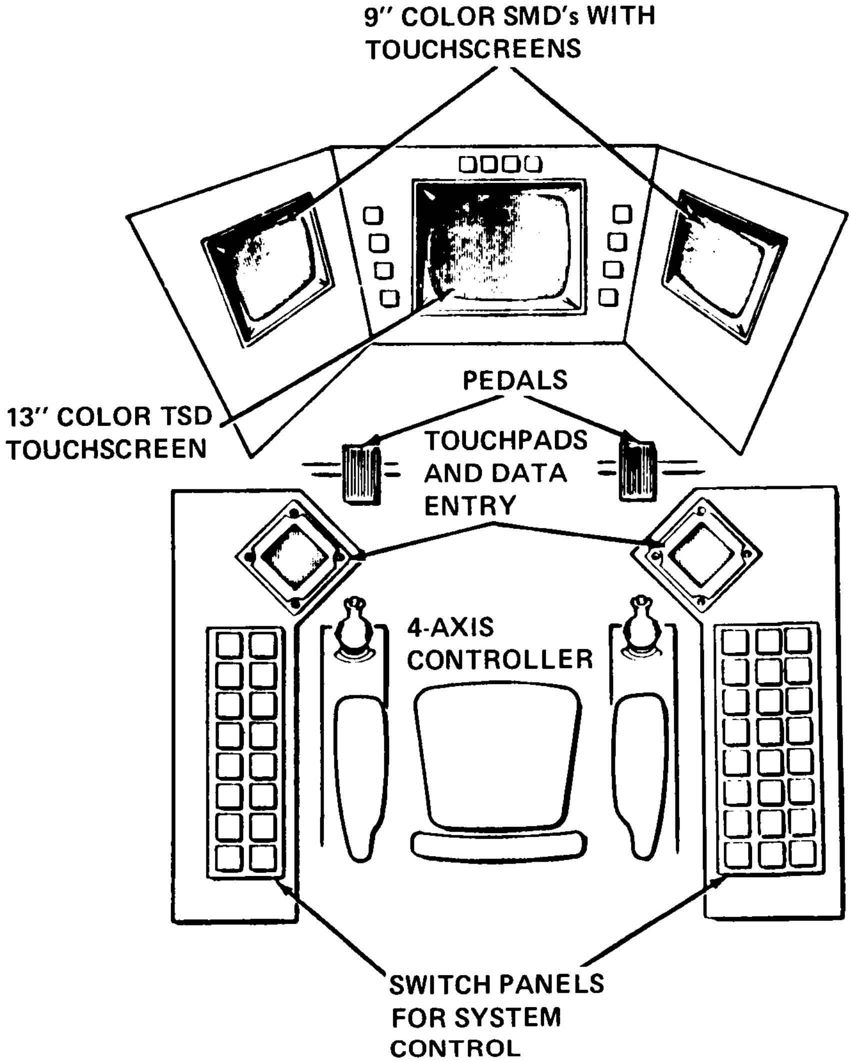

Figure 21.- Rear crew station.

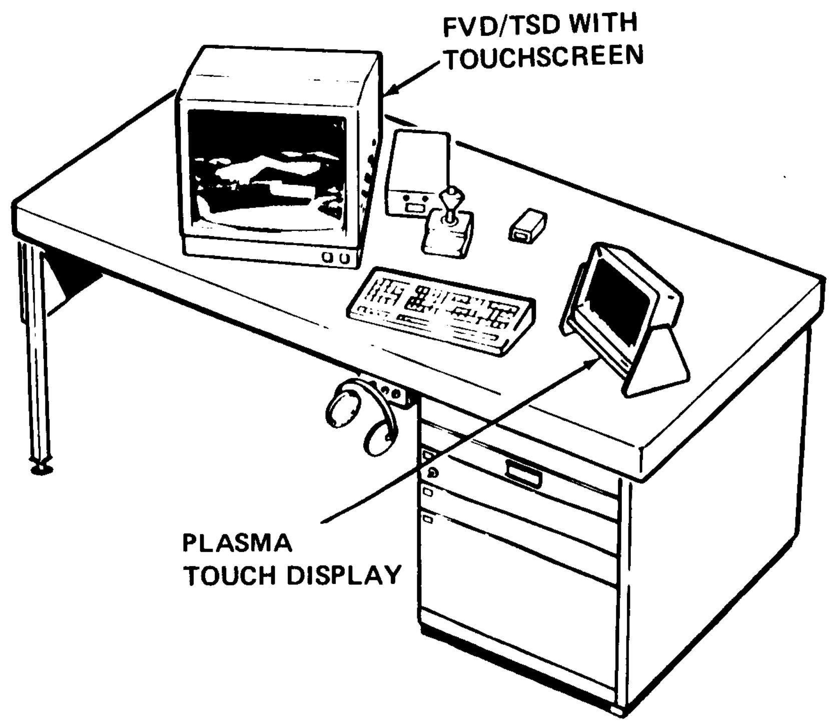

Figure 22.- Blue/Red Team station.

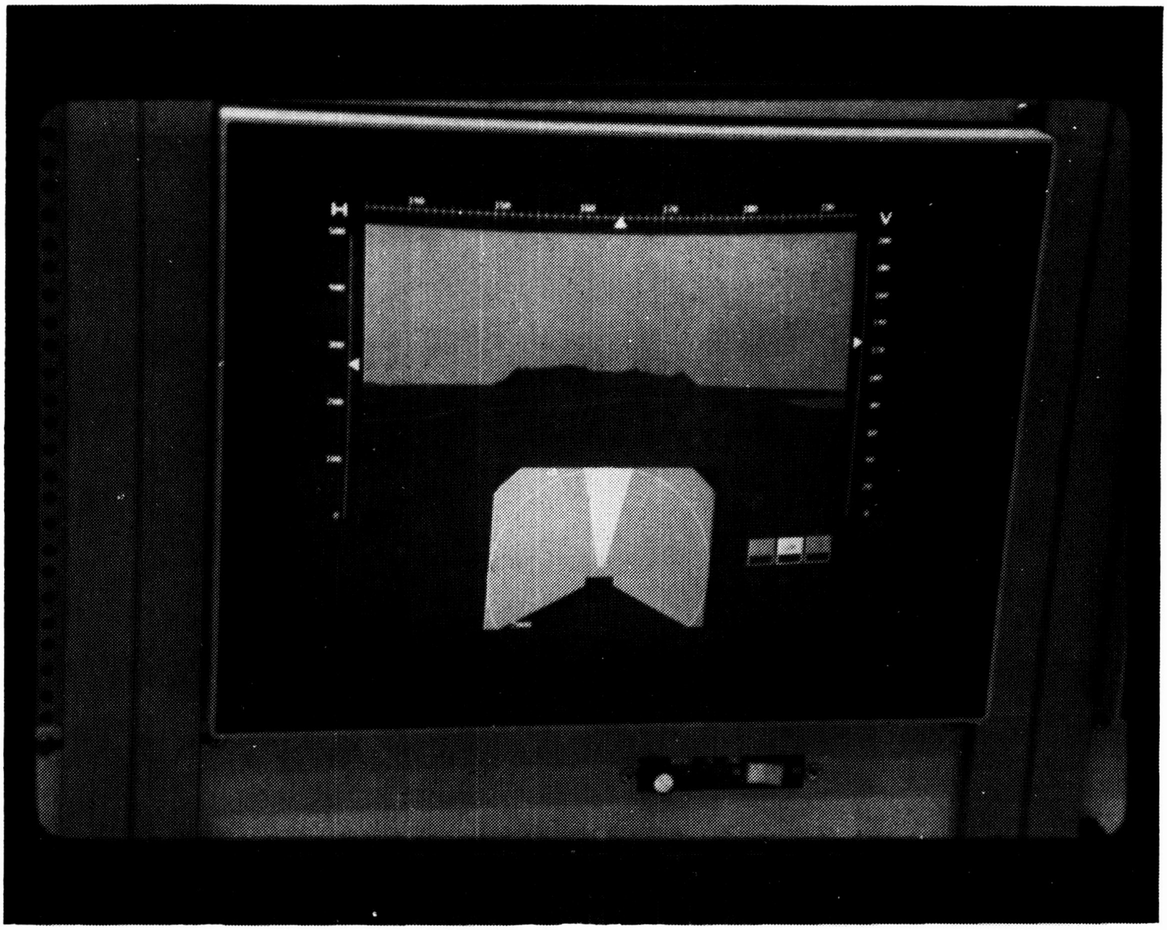

Figure 23.- Blue/Red Team forward-view display.

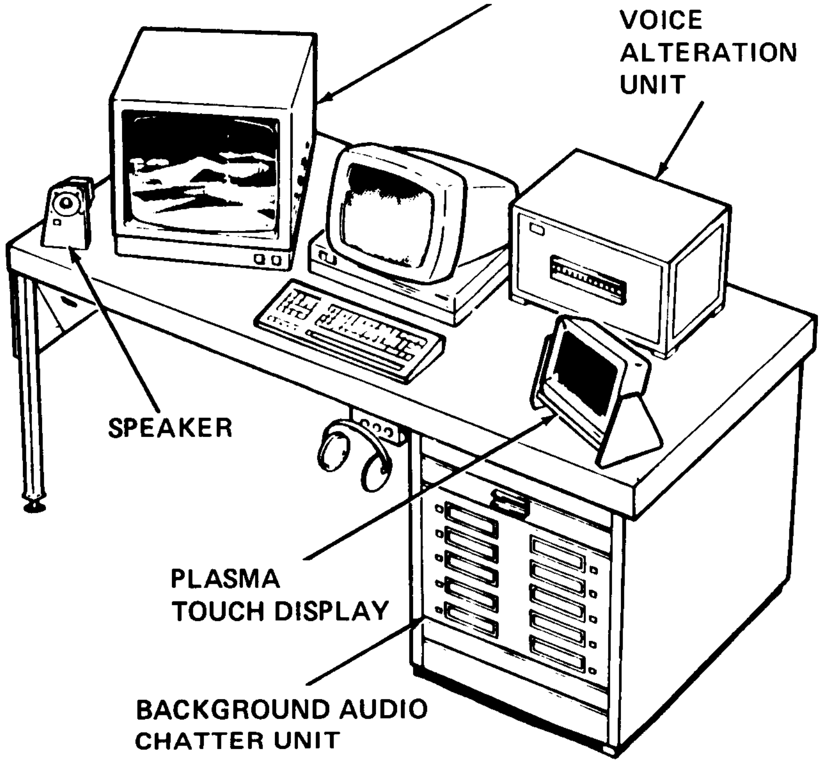

Figure 24.- White Team station.

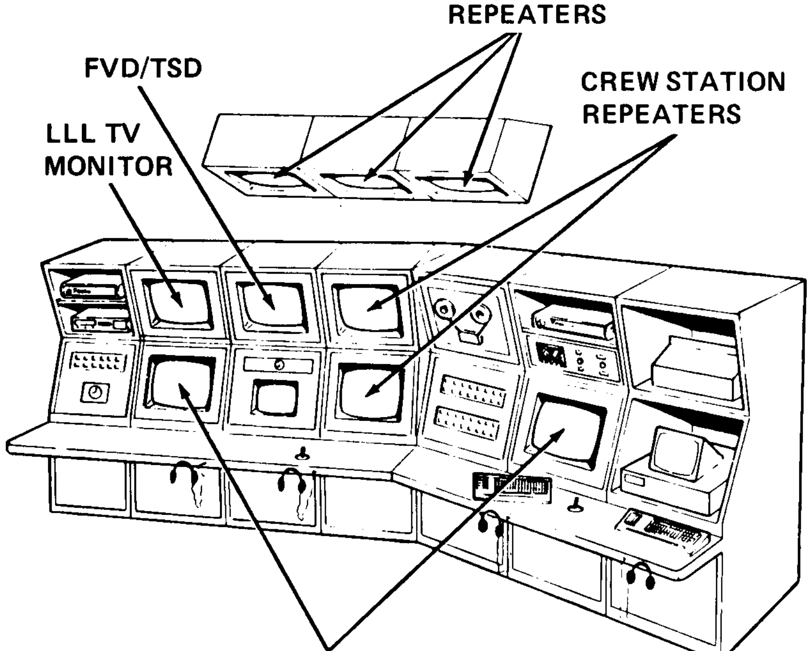

Figure 25.- Experimenter/operator console.

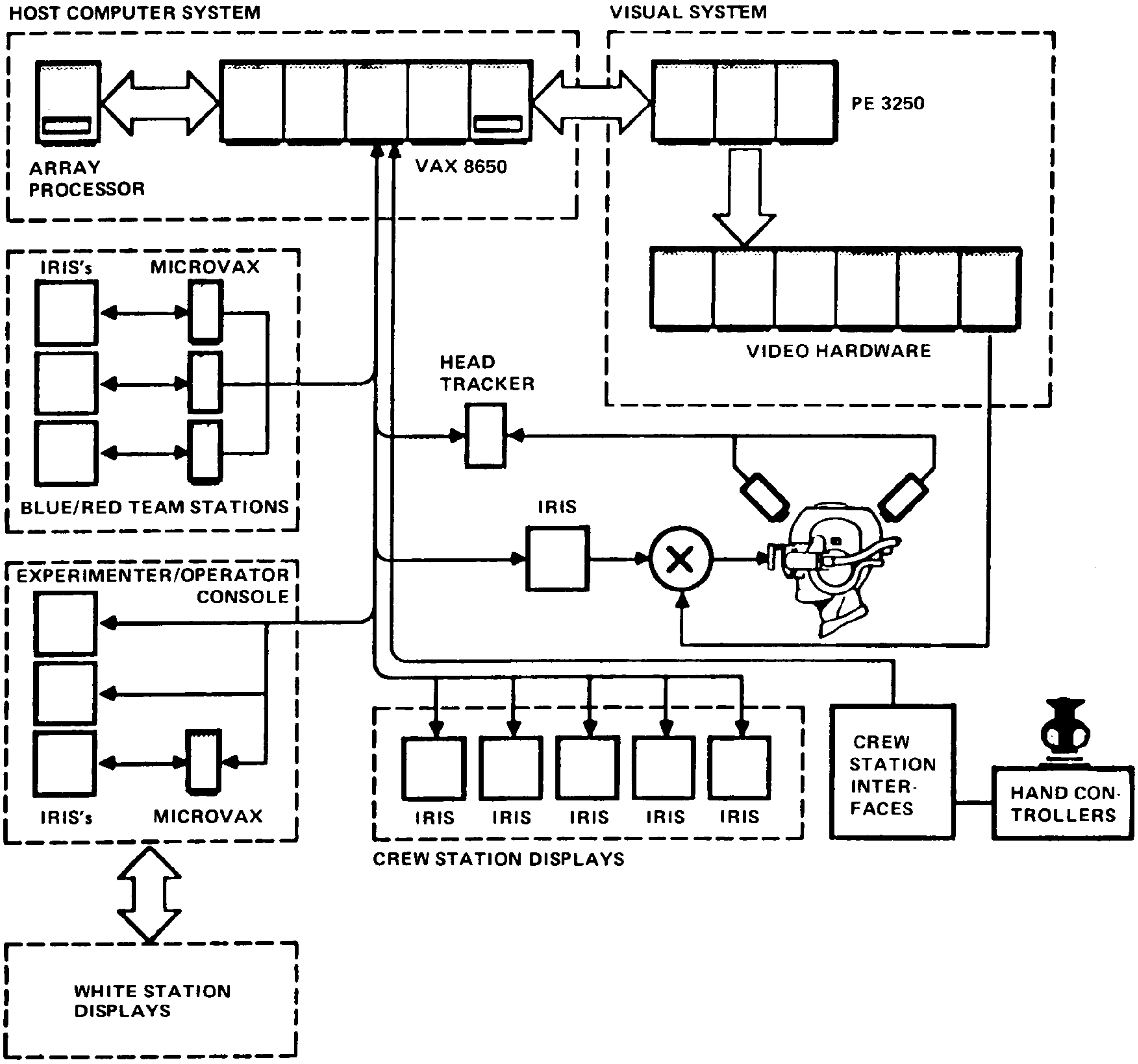

Figure 26.- CSRDF computer architecture.