

APPLIED VIRTUAL REALITY AT THE RESEARCH TRIANGLE INSTITUTE

R. Jorge Montoya
 Senior Research Engineer
 Manager, Virtual Reality Group
 Research Triangle Institute
 P.O. Box 12194
 RTP, NC 27709-2194

ABSTRACT

Virtual Reality (VR) is a way for humans to use computers in visualizing, manipulating and interacting with large geometric databases. This paper describes RTI's VR infrastructure and its application to marketing, modeling, architectural walkthrough, and training problems. VR scientific integration techniques used in these applications are based on a uniform approach which promotes portability and reusability of developed modules. For each problem, a 3D object database is created using data captured either by hand or electronically. The objects' realism is enhanced through either procedural or photo textures. The virtual environment is created and populated with the database using software tools which also support interactions with and immersivity in the environment. These capabilities are augmented by other sensory channels such as voice recognition, 3D sound, and tracking. Four applications are presented: a Virtual Furniture Showroom, Virtual Reality Models of the North Carolina Global TransPark, a Walkthrough of the Dresden Frauenkirche, and the Maintenance Training Simulator for the National Guard. Degree of realism and update rate requirements for these applications posed significant implementation challenges which were met in every case. These applications demonstrate the viability of VR and show great promise for VR as a cost effective marketing, training, and teaching tool.

INTRODUCTION

Virtual Reality is an exciting new approach to human-computer interactions. Based on long-established computer graphics techniques and benefiting from recent advances in computer hardware and software, this technology supports the creation of and interaction with "worlds" which are either faithful replicas of existing ones or evoke the existence of yet-to-be-created ones. In its purest form, VR is the presentation of and interaction with a synthetic, computer-generated, 3D world, so realistic that the user feels as if he/she were experiencing reality. Over two and one-half years ago,

RTI made a market and technology analysis that concluded that virtual reality was a technology poised for transfer from basic research laboratories to applied research institutions such as RTI. Based on this conclusion, RTI developed a business plan that defined the VR market segment which it would pursue, identified areas in which it would invest internal research and development (IR&D) funds, and mapped out the hardware and software configuration necessary for the development of an advanced VR laboratory which would serve as the foundation for its work in Virtual Reality.

The market analysis recommended that RTI concentrate in a market consisting of architectural walkthroughs, marketing, rapid prototyping, and training applications. These application areas would allow RTI to take advantage of its strong multidisciplinary background and provide value added as scientific and engineering integrators with the appropriate mixture of technology and domain experts to accomplish a specific job.

This paper describes the RTI VR Laboratory infrastructure and several VR projects which the institute has undertaken. The projects described in this paper are examples of the application of Virtual Reality to marketing (a Virtual Furniture Showroom), planning (Virtual Models of the North Carolina Global TransPark), architectural walkthrough (a Walkthrough of the Dresden Frauenkirche), and training (A Maintenance Training Simulator for the National Guard).

The paper includes a description of the methodology used to implement the various applications and a discussion of the system performance achieved in each of these applications.

THE RTI VIRTUAL REALITY LABORATORY

RTI is an independent, not-for-profit corporation founded in 1958 by the University of North Carolina at Chapel Hill, North Carolina State University, and Duke University. RTI conducts applied and basic multi-

disciplinary research for governmental agencies and commercial clients.

RTI has developed a nationally recognized program in computer graphics applications over the past twenty years [1, 2, and 3]. The emphasis of RTI's work in computer graphics has evolved and advanced as hardware capabilities have improved and software tools have become more sophisticated [4 and 5]. In keeping with its tradition of conducting advanced multidisciplinary applied research, RTI has established a state-of-the art Virtual Reality laboratory with an investment of well over \$1,000,000 over the last two years.

Hardware:

The VR laboratory infrastructure is shown in Figure 1. The backbone of the laboratory is a network of computers that includes the full range of VR capabilities. The computing environment consists of platforms ranging from PCs (Pentiums, 486s, and Apple's Quadra 840 AVs) to the Silicon Graphics deskside Crimson Reality Engine and the rack mounted Onyx Reality Engine2. It also includes two IBM RS-6000s, a model 320 and a model 570. The environment also supports full immersion with a Virtual Research's EyeGen3 head mounted display (HMD) and see-

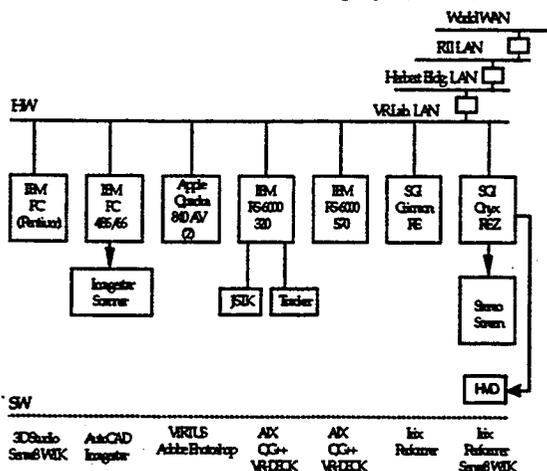


Figure 1 RTI VR Laboratory Infrastructure

through immersion with Stereographics' CrystalEyes shuttered glasses; tracking with a Polhemus magnetic tracker and an acoustic Logitech tracker; navigation with a joystick or mouse; a stereo projection capability using the VREX-1000 system; a wide range of modeling and rendering software environments; and speech recognition and sound output capability.

The Crimsom and the Onyx are used for high-quality, high-performance graphics rendering. The Pentium PCs

equipped with optional graphics cards are used for low-end graphics rendering. In addition, as shown in the figure, this core VR computational and graphics facility is networked to the rest of the computer infrastructure at RTI and to extramural computer facilities such as the supercomputer from the Microelectronics Center of North Carolina.

Software:

The programming environment in the laboratory is Unix based. The SGI graphics workstations operate under the Irix operating system. Software packages used at RTI include Performer, Inventor, and Explorer. In particular, Performer provides a high-level application programmers' interface (API) for rendering the high-quality images which are characteristic of high-level VR applications. The IBM RS-6000 computers operate under AIX. The Apple Quadra PCs operate under the Apple OS operating system and the IBM PCs operate under the DOS operating system.

The programming model for the development of VR applications is illustrated in Figure 2. Using a variety of modelers and format translators, RTI has developed the capability of providing cost-effective VR solutions and to deploy them on the most appropriate platform from PCs to Silicon Graphics. One such approach is based on a rapid VR prototyping capability developed by RTI under an IR&D project and based on the low-cost modeler Virtus Walkthrough Pro®. Annotated polygonal databases are created in the modeler, either from electronic data or from drawings, and the results are transferred electronically into one of the Silicon Graphics workstations where the virtual environment is composed by the application of shading, textures, and light sources. The textures are derived from photographs of real objects scanned into the system through one of the IBM PCs. Textures can also be implemented procedurally. Once the environment is completed, interaction with the model is added using VR-DECK [6], a C-based software package developed by IBM T.J.Watson Research Center, in one of the RS-6000s. This package supports the instantiation and interaction of modules dedicated to specific functions in support of interactivity with and immersivity in the virtual environment. Thus, for example, there are modules dedicated to the capture of tracking and navigation data. These modules produce events which are used by a graphics-generating module to control the position and view of the camera model "searching" the data base. Additional features, such as speech recognition, sound generation, object behavior, etc., are available or can be added through additional modules. These modules can be distributed within one or many

different workstations in the network, including the Reality Engines. This provides the ability to match the system resources to the application requirements.

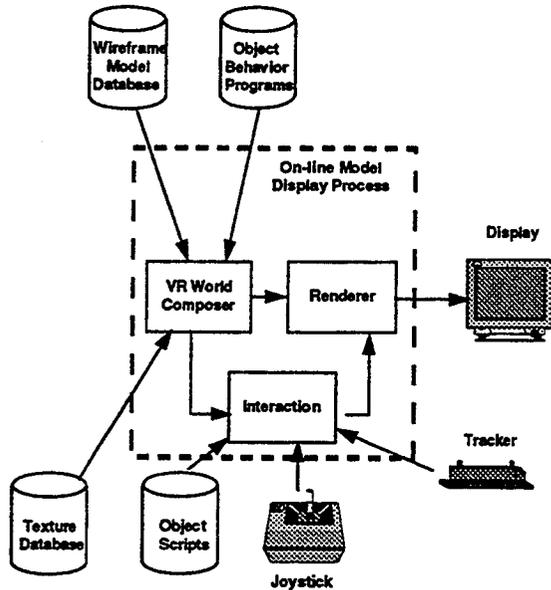


Figure 2 Conceptual Approach to the Implementation of the Virtual Environment

Another application development path in the laboratory uses AutoDesk's AutoCAD to capture or generate data for the models, 3D Studio to generate the models, and Sense8's WorldToolKit for development of the interactions with and immersivity in the resulting virtual environment. This environment is targeted toward the development of environments to be deployed on PC platforms. Current efforts have as a goal the creation of a seamless development environment in which models created by either modeler or from other non-RTI modelers (such as Intergraph's or ProEng) can be used in either the low- or high-end environment easily and cost-effectively.

In addition, the modular software system supports head tracking and stereo viewing to provide a trackable, immersive capability in the application. Further interactions with the virtual environments is achieved through the use of a speech recognition system operating in the RS-6000. Plans call for the development of software to support the integration of a 3D sound system and natural language processing into the applications as necessary.

VR PROJECTS

The Virtual Furniture Showroom:

For the Furniture Manufacturing and Management Center at North Carolina State University, RTI created and demonstrated the Virtual Furniture Showroom. This was a technology demonstration project for the furniture industry. Using drawings and sketches provided by American Drew Inc. and photographs of the real pieces of furniture, RTI developed virtual models of American Drew's Hancock Cherry bedroom collection, replicated synthetically the room in which the real collection was, and arranged the virtual collection and accessories in the room.

Interactivity with the furniture took on several forms. The visitor to the virtual showroom, donning a tracked HMD, could navigate over to a specific piece of furniture by gazing towards the piece and using a four-function joystick to walk over to or away from the piece. Then, by clicking on one of the other two buttons of the joystick, he/she could get a description of the piece through the earphones of the HMD. The application also supported the picking and moving of pieces of furniture as well as the changing of the finish on selected pieces within the collection.

Figure 3 illustrates the resulting virtual environment. This application was developed using Virtus Walkthrough Pro™. Interaction and immersivity was obtained through VR-DECK. Rendering was done in an SGI Crimson and presented in a Virtual Research Eyegen3 HMD. Average scene complexity was on the order of 4,000 polygons with an average pixel depth of 5. The demands for high quality models required a large number of textures which, in some instances, overloaded the texture memory available in the Crimson, thus affecting rendering performance. Stereoscopic update rates on the order of ten per second were achieved when texture paging was not a factor. Update rates dropped substantially from this number when texture paging was a factor. The virtual showroom was demonstrated at the High Point, North Carolina, Fall International Home Furniture Market in October of 1993. The virtual showroom exhibit was located near the room with the real collection. This provided a way for the visitors to do a comparison while their impressions of the virtual room were fresh in their minds. Based on the reaction of the majority of the visitors, the virtual exhibit was a success. From a technology standpoint, it was concluded that VR technology was viable for the furniture industry in at least two areas: rapid prototyping of pre-market collections and interactive electronics catalogue of

collections at high-end furniture stores. Use of this technology in furniture design and in many other applications should be feasible within the next five years as the cost of the technology continues to decrease and its performance continues to increase.

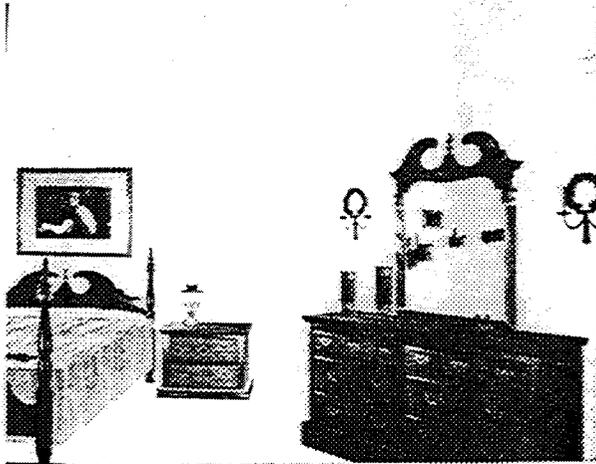


Figure 3 The Virtual Furniture Showroom

A Walkthrough of the Dresden Frauenkirche:

For two-hundred years, the Frauenkirche (Church of Our Lady) stood majestically over Dresden, Germany, as a magnificent example of Baroque architecture and an important expression of the Lutheran faith. On February 15, 1945, the church collapsed as a result of the intense heat produced by fire storms which resulted from extensive Allied bombings of the city. Today, efforts led by the Foundation for the Reconstruction of the Dresden Frauenkirche are under way to rebuild the church.

For IBM Germany, RTI developed an interactive and immersive walkthrough of the Dresden Frauenkirche. The goal of the project is to use the VR walkthrough as an exhibit where people can "visit" the church while it is under reconstruction. Figure 4 illustrates the interior of the Frauenkirche as it was in February, 1945, or as it will be in February, 2006. Thus, with the aid of Virtual Reality the visitor can step forward fifty years into the past and visit the magnificent Frauenkirche.

The interactive model was based on an animation model developed using the TDI modeling package [7]. This model had been derived from an original architectural model of the church done in the CAD software package CATIA™. The system used to implement the interactive and immersive walkthrough of the Frauenkirche

consists of two workstations, an IBM RS-6000/650 and a Silicon Graphics Onyx Reality Engine, networked to accomplish the task. The tasks included tracking the orientation and navigation of the user, "the visitor" to the church, generating events resulting from the interpretation of the position data, updating the camera view of the database, generating a stereo pair of such view, and driving the two eye views of the head mounted display (HMD).

RTI scientists converted the animation model of the Frauenkirche (in TDI format) into a format compatible with the Performer™. Once this was done, application modules were implemented in VR-DECK and instantiated in the RS-6000. These modules included support of the head tracking operation, navigation, by means of the special joystick, and graphics. The latter invoked the rendering software developed for this application in the SGI Onyx. These modules were interconnected and activated in the RS-6000 according to the VR-DECK application protocol [8].

In particular, the graphics rendering module has the task of creating a view of the pictorial database (the church) as dictated by the head orientation and the user's position sensed by the tracker and indicated by the joystick, respectively. In the case of an immersive environment, this module also has the task of generating a stereo pair to support the presentation of a stereoscopic display in the HMD.

The interactive model of the Frauenkirche is one of the most complex models used to date to generate a virtual reality walkthrough application. (See Figure 4). The model consisted of 165,000 polygons, it made use of 12 textures in over twenty locations of the church, and was lit by five light sources. Scene complexity varies from approximately 80,000 polygons in the altar area to 20,000 polygons toward the back of the church with an average pixel depth of 4. Update rates varied depending on the direction of view with views of the altar updating at 3-5 frames per second (in stereo) and views of the balconies and the back of the church updating at 10-20 frames per second (in stereo).

Virtual Reality Models of the North Carolina Global TransPark:

For the North Carolina Air Cargo Airport Authority, RTI developed a series of immersive and interactive virtual models of the North Carolina Global TransPark. The NC Global TransPark is a bold initiative of the state of North Carolina to develop a multi-modal transportation facility built around the existing jetport in Kinston, NC. A development plan for the TransPark

has just been completed. This plan calls for the development of the facility in stages and the models which RTI has implemented represent the various stages of development. Thus, the immersive models show the evolution of and allow planers to visit the concept from the present day to the project's conclusion in the next century. Figure 5 illustrates the resulting virtual models.

The three virtual models of the TransPark were built using the Virtus-based rapid prototyping capability. Unlike the case of the furniture showroom, however, existing CAD data was used extensively in the creation of the models. The first model shows the Kinston, NC, and its significant surroundings. Model 2 shows the intermediate development of the TransPark which includes a 13,000 feet cargo runway, a central cargo facility, a cargo transportation system, and assigned areas for the location of various activities such as office, research, and light industrial activities. Model 3 includes the complete vision of the TransPark which contains a second runway parallel to the original one. A control panel associated with each model allows the visitor to look at the existing wetlands and to visualize how they will change as the development takes place. In addition, time of day and visibility conditions can also be controlled through the panel. Included in all models are "dumb" agents representing activities which will take place in the Park. These include airplanes taking off and landing, trucks moving along highways, and a train moving along the railroad tracks.

There are several display options associated with this application. The models can be shown in a stereoscopic, augmented reality mode either on a monitor screen using shuttered glasses or on a projection screen using passively polarized glasses with no head tracking and mouse-based navigation; or they can be shown in a HMD with head tracking and joystick-based, direction-of-gaze navigation.

The models range in scene complexity from 4,000 to 10,000 polygons with an average pixel depth of 3. Stereoscopic update rate performance varies from 10 to 20 updates per second. Texture paging was not a factor in this application and we also were able to use level-of-detail models to optimize performance.

Maintenance Training Simulator-National Guard (MTS-NG):

For the Advanced Research Projects Agency, RTI has designed and implemented an advanced training system for home-station training of National Guard tank mechanics. The maintenance training simulator for the

National Guard (MTS-NG) is a computer-based instructional system which uses Virtual Reality as the human-computer interface between the trainee (mechanic) and the training system, significantly extending training to personnel at sites without equipment. The MTS-NG integrates VR, multimedia and instructional technologies to provide training to tank turret mechanics (45T) to perform diagnostic and maintenance on M1A1 Abrams Tank and M2A2 Bradley Fighting Vehicle. Figure 6 shows the MTS-NG development team testing the various stages of the advanced instructional system.

This application has been implemented in a 90 MHz Pentium PC equipped with a SPEA Graphiti Series Fire graphics board and a StereoGraphics Corporation's CrystalEyes PC for stereoscopic image generation and viewing. The software development environment consists of Autodesk's 3D Studio modeler for the generation of the databases, Sense8's WorldToolKit for the building of and interaction with the virtual environments, and MicroMedia's Authorware for the generation of the courseware.

The courseware includes the lessons used in the Regional Training Site (RTS). The courseware launches the virtual reality applications when appropriate to the purpose of the lesson. These virtual environments include navigation through and interactions with solid models of the two vehicles as well as cutaways of their interior showing all the Line Replaceable Units (LRUs). They also include the ability to interact with the interior of the gunner's compartment and of the driver's compartment. Using this interactivity, the student may select any of the LRUs in either compartment for closer inspection and in turn switch switches, rotate knobs, etc., which can be used in performing diagnostic tests when used in conjunction with the Simplified Test Equipment (STE) and under the supervision of the training module. The training module guides and/or monitors the students' progress in diagnosing a fault in the vehicle. The student uses military training manuals to perform a series of interactive tests in a manner identical to the ones in the real vehicle.

Scene complexity varies from about 2,000 polygons for the external 3D views of the vehicles to 15,000 polygons for the interior view of the gunner's compartment with an average pixel depth of 3. These are textured polygons. Stereoscopic update rates vary from 1-2 frames per second for the most complex scenes to 10-15 frames per second for the less complex scenes. Texture memory available in the FIRE graphics board (8 MBytes) accommodates the textures used in this application. Anticipated hardware and software

performance improvements will improve current performance. Also, if necessary, improved performance can be attained with a higher-performance platform. This will require a tradeoff between cost and performance since one of the design goals was to deploy this system for less than \$10,000 per copy. Total system cost is \$9,600 per unit.

CONCLUSIONS

Our work and that of many other applied researchers have demonstrated that VR is a viable technology with serious applications in areas other than low-end entertainment (arcades) and high-end simulators. When should one use VR? When the value of applying it exceeds the cost of developing it and also when it supports, enhances, and improves current or anticipated practices. It is our experience that development of a detailed requirements definition as a first step of a VR project leads to the development of cost effective solutions of VR problems. The bottom line is that virtual environments should not be more real than necessary for the application. Hardware and software performance improvements will continue to support more and more sophisticated applications of VR at lower and lower cost. As it was with PCs in the early 1980s, this will lead to the democratization of VR and the proliferation of its applications. We also anticipate wide use of VR technologies in the rapid product prototyping arena.

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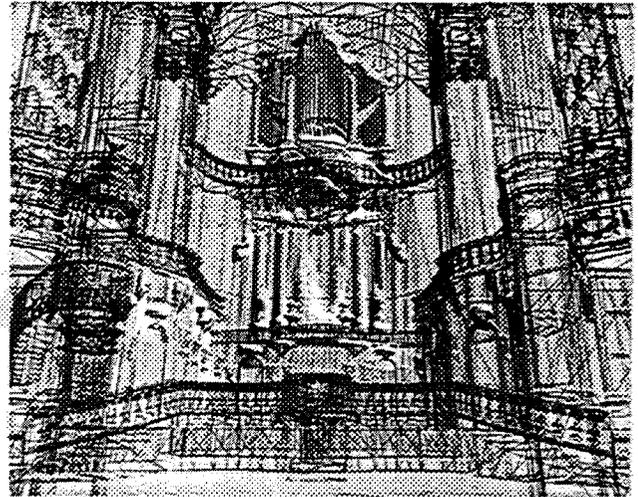
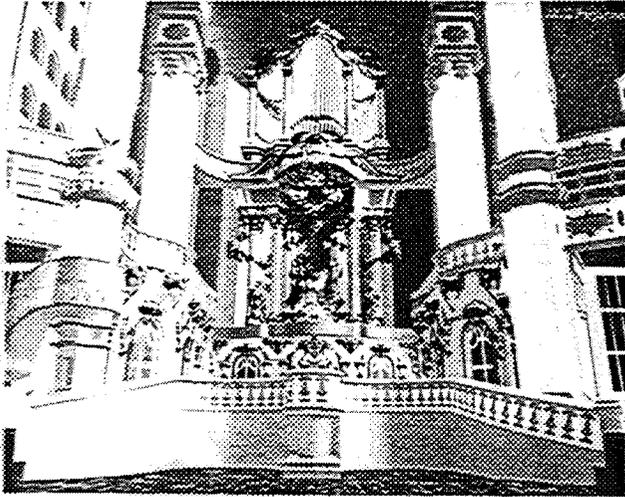


Figure 4 VR Model of the Dresden Frauenkirche

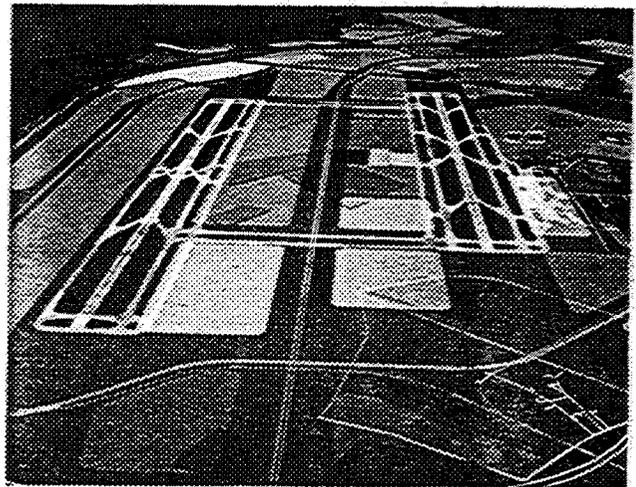
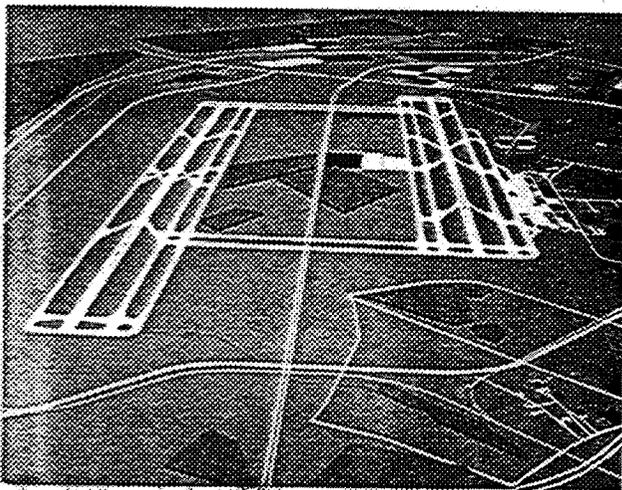
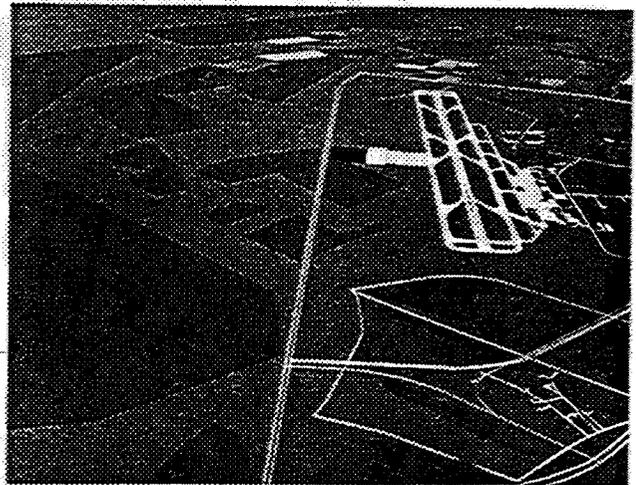
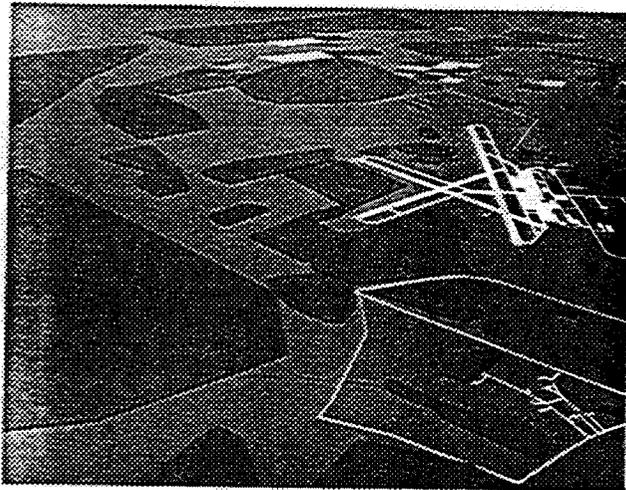


Figure 5 Virtual Models of the North Carolina Global TransPark



Figure 6 Advanced Instructional System for the Maintenance Training Simulator for the National Guard

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