Evolution of Aerospace Simulation: From Immersive Virtual Reality to Serious Games

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Abstract—**In this paper we provide a retrospective overview of the evolution of simulation hardware and software technologies, beginning from the early days of the NASA VIEW Virtual Reality system, the European Space Agency's first steps in exploring the capabilities and limitations of immersive technologies for visualization and training, and developments underpinning the delivery of the first interactive 3D model of the Roscosmos Virtual *Mir* Space Station. Today's best practice, latest developments and future concepts of human-in-the-loop (HITL) simulation for the aerospace industry will be presented. The paper discusses additional findings relating to the exploitation and testing of a range of recent VR and serious games applications of relevance to aerospace research, development, education and training in the UK and Russia and seeks to define those issues demanding urgent consideration.**

Keywords-aerospace simulation, human-in-the-loop simulation; virtual reality; serious games; interactive 3D graphics.

I. Introduction

From their inception over seventy years ago, HITL simulations, also called interactive simulations, have become an increasingly important paradigm in a wide spectrum of applications, such as hardware design, industrial control, and special training for aerospace systems or complex operating rooms. Allowing human users to manipulate simulation models and steer their execution at run time, HITL simulation systems are essential to study complex problems that are difficult to investigate using conventional methodologies. Aerospace establishments across the globe have long been exploiters of HITL simulation technology, primarily in large-scale simulators designed for such activities as telerobotics or teleoperation (of remotely operated vehicles) and telepresence (at a remote or hazardous site), scientific data visualization and exploration (e.g., computational fluid dynamics data visualization), and, of course, tri-service pilot, navigator and maintenance personnel training.

Currently, HITL simulation technology has been developed to a level when interactive 3D computer graphics (i3D), virtual environment (VE) technology (or "synthetic environments") [1], and computer or video games technology (or "serious gaming") support the creation of realistic technical environments for such tasks as helicopter machine gun and voice marshalling training, parachuting experience, naval helicopter deck landing, space station docking, planetary rover control and many more. Also, as aerospace hardware becomes more advanced, the inevitable reduction in real systems available for training means that computer-based lessons, many featuring i3D, will become an essential tool of the aerospace classroom, helping to familiarize tri-service personnel with the spatial and behavioral aspects of aerospace platforms subsystems. The deployment of highly skilled staff is an essential prerequisite for the safe and effective operation of aerospace systems. Simulation-based training plays an increasingly important role in the qualification of aerospace systems personnel. In the aerospace industry, training simulators have already been successfully employed for many years. Latest developments in real-time simulation technology, i3D, introduction of virtual product and process engineering, as well as serious gaming provide a new technological basis for the cost-effective implementation of training simulators. Therefore, in the near future, the general spread of this technology in aerospace industrial sector and applications is expected to increase almost exponentially, especially for full- and part-task, individual and collective training applications.

Those involved in the mainstream exploitation of simulation technologies for aerospace training, design, rapid prototyping and so on have noticed a recent and massive rise in interest in a technology that claims to be responsible for delivering that which the virtual reality (VR) and early real-time simulation communities failed to deliver in the closing decade of the last century. This technology is popularly known as "serious gaming" (SG). In the very broad terms, SG focuses on the exploitation of high-quality computer games and associated software tools such as those underpinning the "first person shooter" (FPS) or "role-playing" (RP) games currently being enjoyed by youngsters and adults alike, all around the world. These tools take the form of software development kits (SDKs), regularly released by leading games developers shortly after the publication of a new product, together with a growing number of content generation packages becoming available – many free of charge – from the Web. The availability and affordability of these tools have also very rapidly generated interest from another group – the serious applications community – including those responsible for researching and designing training and real-time visualization systems for defense, surgery and education, and aerospace.

In this paper a review of some quite mature applications of i3D/VE/SG to aerospace simulation will be presented. The paper only includes those projects with direct involvement of authors or their respective organizations. Nevertheless, it covers both the aerospace engineering domain and, importantly, common human-centred design issues faced by all potential adopters of this technology. Application projects described in the paper include aero engine design, maintenance evaluation and training, aircraft cabin interior design, the ENHANCE haptic feedback and aero maintenance project, the avionics maintenance training facility, helicopter voice marshalling, virtual reality Mir space station and virtual reality international space station (ISS) project, and planetary rovers using i3D/VE and games engine technologies. Our intent is to discuss some actual approaches to the VE and/or SG use in typical aerospace applications and derive some useful recommendations for future developments.

II. VR-Based Aerospace Engineering

A. Rolls-Royce's VR Trent Aero-Engine

Project Goals: In the early 1992 Virtual Presence (VP) and Rolls-Royce had conducted a short feasibility study to evaluate the role of VR in the future business of aero engine design, maintenance evaluation and advanced training [2]. At the outset, the project focused commercially on how VR technologies and design practices might be used to replace costly 1:1-scale engine mock-ups, known as Physical Pre-Assemblies.

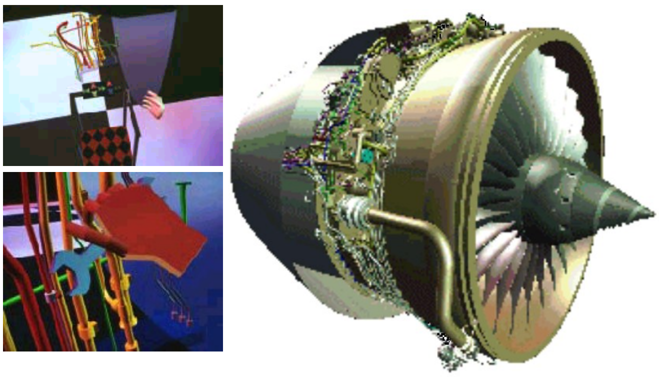

Fig. 1. Early experiments with virtual Trent 800 model

Implementation Details: A basic but robust CAD-to-VR conversion was first demonstrated in 1992 (Fig. 1). This early step into a British engineering application of VR was made possible by a unique parallel processing (transputer-based) computer called Vision, the first commercial prototype developed by Division Limited under contract to VP. Division's next-generation computer, SuperVision was also employed to refine the converted CAD models over a subsequent period of 12-18 months, prior to the market entry of Silicon Graphics' RealityEngine architecture.

By the Spring of 1994, the virtual Trent 800 model had reached a stage whereby usability trials could be carried out. Trial participants, wearing a variety of Head-Mounted Displays (Flight Helmet, dVISOR, Eyegen), together with the Virtex CyberGlove and "wand" devices, were located within a simple wooden framework. On donning the HMD, they could view the framework reproduced graphically in the form of a virtual "cherry picker". By interacting with a simple virtual control panel, this set-up created the illusion that users could move around the virtual engine as if on a gantry or crane (Fig. 1). Simple virtual tools were implemented which allowed the users to release bolt and bracket fittings. On registering a "collision" or "clash" between tool and bolt, a simple animation sequence was generated whereby the bolts automatically unscrewed, leaving the pipe geometry unconstrained. With haptic feedback technologies in a very rudimentary state of development (cf. developments in the ENHANCE project; see later), it was not possible in 1994 to provide a realistic physical restriction of the movement of hand/arm when pipes were in collision (Fig. 1). Consequently a visual solution was developed which involved the instantaneous display of a "ghost" pipe image whenever a collision state with a neighboring pipe was registered. The system prohibited subsequent manipulations of the grasped pipe by forcing it to "spring" out of the user's hand and return to its last legally recorded position, merging with the ghost image.

B. Aircraft Interiors

Project Goals: Supported by Virtual Presence, a Manchester Airport-based company has taken the initiative to investigate and market the potential offered by VR, particularly in the assessment of new corporate styles for seat fabrics and cabin furnishings (carpets and curtains, headrest covers, even luggage bin trims and general finishes) [2]. A single aircraft cabin was initially modelled to high visual detail prior to the application of very high quality textures, scanned from material samples provided by some of the participating airlines - Britannia, easyJet, Airtours, Air 2000 (e.g., Fig. 2).

Fig. 2. 3D Model of aircraft cabin interior

Implementation Details: The geometry and textures for this application have to be of a very high quality, both for real-time performance and visual impact - viewers need to be able to look very closely at the fabric design (including the weave), so pixellation of the textures when very close must be kept to a minimum. Similarly, image degradation must be kept low if the aircraft cabin is displayed to groups of designers and evaluators using video projection techniques. Seat, carpet and curtain textures can be changed instantly, by a single key entry, enabling users to evaluate different design concepts quickly and cheaply, avoiding the need for potentially wasteful physical prototypes.

Results: An interesting and unpredicted use of the technology has been in the sale of designs and fabrics no longer required by an airline company, as was the case in 1996 when, left with many hundreds of meters of unwanted material following one company's bankruptcy, they used VR to market the material and design to others. Later work by VP's French division SimTeam had involved the use of VR to model the interior of customized executive jets, enabling their purchasers to make design changes and decisions prior to the process of fitting out the real cabin.

C. ENHANCE Haptic Feedback & Aero Maintenance

Project Goals: Virtual Presence has completed a project in collaboration with British Aerospace (BAe), part of a larger contribution to the European Initiative ENHANCE (ENHanced AeroNautical Concurrent Engineering) [2, 3]. The ENHANCE sought to strengthen cooperation within the European aeronautical industry by developing common working methods which govern the European aeronautical field, defining appropriate standards and supporting concurrent engineering research. The ENHANCE Consortium consists of the main European civilian aeronautical companies (i.e., Aerospatiale-Matra, British Aerospace, CASA, DaimlerChrysler Aerospace, Dassault Aviation, Alenia), engine manufacturers such as SNECMA and Rolls Royce, equipment manufacturers and airlines, small-to-medium-sized companies (SMEs) and European research centers.

Implementation Details: Virtual Presence's project concerned an advanced VR maintenance demonstrator, which links a virtual mannequin with SensAble Technologies' PHANTOM haptic feedback system. Based on a 3-D model of a conceptual future large civil airliner, the VR demonstration involves progressing the mannequin through aircraft preparation and safety procedures, to permit access to and clearance testing of the retracted main landing gear. Certain key interaction events throughout the demonstration are executed using the PHANTOM device.

In order to define these stages clearly, and to identify those procedures warranting the application of haptic feedback, human factors specialists and engineers from Virtual Presence and BAe worked closely together to carry out a context-specific task analysis, as recommended in the new International Standard ISO 13407 (Human-Centred Design Processes for Interactive Systems) [4]. The task analysis (a small section of which is illustrated below) identified the following key events for implementation via haptic feedback control (Fig. 3):

- Operation of flapper door springed component.
- Button press for access plate to port main landing gear door.
- Main landing gear door "D" handle pull.
- Location of the base of a special clearance tool on main landing gear wheel center.
- Clearance tool plate "snap" effect on to main landing gear bay roof.
- Rotation approximation (ie. within current PHANTOM constraints) for clearance tool dial.

Fig. 3. Virtual manipulations with landing gear

III. VR-BASED AEROSPACE TRAINING

A. The Avionics Training Facility (ATF)

Project Goals: The Royal Air Force (RAF) had a need for a VR-based aircraft maintenance trainer dedicated to train maintenance engineers in the diagnostics and repair of the RAF's Tornado F3 jet fighter [5]. The testing and maintenance of electrical, mechanical and computerized systems of the modern jet aircraft must conform to exceptionally high standards. Consequently, avionics maintenance training is intensive. However, as with many other applications in the military sector, gaining access to appropriate hardware for maintenance training, be it a complete aircraft or even individual functional components (LRUs), can never be completely guaranteed. Overcoming these problems by employing VR technologies in the classroom was the focus of the ATF project undertaken by VP under contract to Alenia Marconi Systems. The company was to develop the avionics training simulator, using VR modeling techniques and open systems run-time software.

Implementation Details: As well as the aircraft shell itself (around which students are free to move), all moving surfaces are present (removable and hinged panels, flight control surfaces etc.), as are internal and external aircraft systems connector points (Fig. 4). Over 450 LRUs feature in the simulation, located in equipment bays around the aircraft and as control and display units within the cockpit. Full cockpit detail has also been delivered, for both the pilot and navigator positions, including geometric and operable representations of toggle switches, safety covers, rotary switches, push buttons, pedals, throttles and joysticks [6]. Once in the vicinity of an avionics bay, hinged panels can be opened and units can be selected and removed by the trainees, manipulated in 3D, tested (using any of approximately 50 additional items of virtual test equipment, each with their associated external and internal connection sockets) and subsequently replaced. Control inputs have been restricted to a conventional 2-button mouse, delivering discrete, momentary and continuous input functions. Every control input made by the trainee results in a realistic and accurate change of state within the virtual *Tornad*o, be it the movement of external flight surfaces, down to the illumination of individual LRU/test indicators.

The system was hosted on a high-specification Intergraph Windows NT system and features 3 screens per workstation (Panoram Technologies' PowerView display's also supported), each displaying different working views of the aircraft, avionics bays, LRUs and/or virtual test equipment. Ten such workstations were produced, fully networked, allowing up to 8 students to be trained and supervised by 2 instructors in basic and advanced *Tornado* F3 avionics maintenance routines.

Results: In contrast to the training facilities described earlier, the ATF facility, now at RAF Marham has been in existence for only 10 months and, in that time the course time has been reduced from 13 (GR4) and 11 (AGTR) to 9 weeks with no downtime. ATF supports 8 students and 2 trainers, although there is no reason why each workstation could not support 2 or 3 students. Initial feedback from the Marham trainers suggests that, in contrast to previous courses, ATF students "grasp the concept" (i.e., gain enhanced spatial and procedural knowledge) after nearly two-thirds of the time taken by previous non-ATF students.

Fig. 4. Virtual *Tornado* aircraft shell and avionics LRUs

IV. SERIOUS GAMING AND AEROSPACE SIMULATION

The Human Interface Technologies (HIT) Team at the University of Birmingham, a member of the UK's MOD initiative in the SG arena, the Commercial Off-the-Shelf Evaluation Unit (COTSEU), and one of the academic partners in the UK's Human Factors Integration Defense Technology Centre (HFI DTC) consortium (www.hfidtc.com), is coordinating a wide variety of serious gaming projects. Together with TruSim and Welwyn Garden City-based VEGA Group, the University has launched the UK Serious Games Alliance – a partnership formed to deliver affordable interactive 3D training solutions to users in defense, medical and government sectors (to mention but three) through the application of computer gaming technology to lifelong learning and technology-based training programs in defense.

A good number of the HIT Team's projects rely on an ability to develop credible "mini" demonstrators, often at short notice. Therefore, to have access to a reconfigurable generic virtual environment is both important and, ultimately, highly cost-effective. In addition, the ability of that environment to accept static or animated 3D models and other assets reasonably seamlessly, plus provide support for storyboarding and scenario generation, is also of considerable value to human factors personnel. The Generic Applications Support Tool is based on the Crytek "CryEngine" and "Sandbox Editor", in conjunction with a large database of 3D assets – some purchased from Web sources, others built in-house using free 3D content generation tools such as "Gmax". Already used to excellent effect in the early Alchemy projects (see below), the Tool has formed the basis of the majority of demonstrators delivered from the HFI DTC research program.

The rapid development of urban and Middle Eastern scenarios for testing new defense systems, such as small UAVs and robotic land vehicles, and for evaluating new forms of human interface devices to control those systems, are key areas of research interest. The HIT Team is also working with Midlands-based Kestrel Aerospace to develop concept visualization, ergonomic solutions and training programs for radically new manned and unmanned air vehicles.

A. Alchemy 1&2 Unmanned Vehicle (Land/Air) Demos

Project Goals: Project Alchemy was conceived to demonstrate how low-cost, games technology-based simulations could be used to support the development of new guidelines and standards relating to operator display and control requirements for Intelligence, Surveillance, Target Acquisition & Reconnaissance Unmanned Air Vehicles (ISTAR UAVs), deployed in support of homeland security operations in urban environments and close-combat missions in foreign environments (Fig. 5).

Fig. 5. Alchemy – VR unmanned vehicle demonstrators

Implementation Details: Alchemy builds upon a real-time, i3D demonstrator originally developed by a Birmingham University Undergraduate Final Year project called TOMSAV (Teleoperation Of Multiple Semi-Autonomous Vehicles). TOMSAV was a project investigating human operator situational awareness display requirements for the control of a fleet of robot submersibles deployed to carry out surveillance activities around a disabled nuclear submarine. The original Alchemy 1 test bed took the form of a zero cost reconfigurable Synthetic Environment (SE) system, based on Microsoft's Managed DirectX 9.0 API, the C# .NET language and appropriate games engine technologies. Later, with Alchemy 2, the test bed has been ported onto the CryEngine and developed further to demonstrate the deployment of ISTAR UAVs in support of special operations.

Results: The Alchemy 2 environment is currently being used to support the introduction of new uninhabited vehicle (medium-altitude / urban combat support), single-person turbofan (Personal Air Vehicle - PAV) concepts for Gress Aerospace International, a small Canadian/British company.

B. *Helicopter Voice Marshalling*

Project Goals: This project was designed to assess the role of vibration in the tasks undertaken by Helicopter Voice Marshals – aircrew located in the rear cabin of helicopters whose job it is to guide the pilot using verbal instructions during an approach toward a target (on land or sea) for the purposes of rescue or load deposit.

Implementation Details: The original VM student's training station took the form of a simple wooden framework as a representation of the rear door of the *Griffin* helicopter, provided that the door height was the same as that in the real aircraft and that handholds were located reasonably accurately in parallel with the open doorframes. A wooden framework would also provide an ideal distortion-free environment for the Polhemus electromagnetic tracking system. (Fig. 6).

Fig. 6. Early VM student's training station and VM entertainment motion simulator

The early versions of the VM simulator were based on a single, standalone dual-processor Pentium IV 1.7 GHz PC, each equipped with 2 graphics cards – an NVIDIA GeForce 3 TI-500 for the handling of the 3D Virtual Environment rendering and a GeForce 2 PCI 32Mb for generating the Instructor's Scenario Control Interface, based on plan, or "overview" displays of the VE. As well as the overview display, a second monitor presents the Instructor with a view of the VE as seen by the Student. The chosen HMD for this application was the Kaiser *ProView XL-50*. These headsets do not fully enclose the eye orbits of the Students (i.e. are *semi-immersive*). The tracking system of choice in this instance was Polhemus Inc's FASTRAK (single source, single sensor) system. Virtual Environment software was based on *kRender*, a scene graph-based real-time renderer for Windows 2000, supporting such features as full dynamic lighting, per pixel bump mapping, environment bump mapping, rigid body dynamics and procedural tessellation.

Results: The first phase of the current project resulted in the development of a vibration sensing device which was flown on an EC-203 helicopter whilst performing a range of typical marshalling manoeuvres. The data collected were then used to drive a 3-axis modified entertainment simulator motion base (Fig. 6), linking the simulator motion and vibration to interactive 3D graphics developed using Microsoft's Flight Simulator 2004. A more permanent control system supporting the integration of gaming technologies with the motion base platform is being developed for use in conjunction with developments in the application of games engine technologies to the design of, and training for future specialized air vehicles (as investigated under the Alchemy programme).

C. *Kliper 2.0 Phisics Education Game*

Project Goals: Kliper 2.0 is a serious game concept demonstrator to show how games-based technology could be applied for serious purposes in this case the teaching of Newton's Laws of Motion in a zero gravity environment to secondary school physics students through interactive game play. Players must use momentum to guide the Kliper shuttle around an obstacle in a confined area with limited fuel. After completion, the player is tasked with answering questions that relate to momentum to advance their understanding of the subject area.

Implementation Details: Taking advantage of the real-world physics capability of computer games development tools, Kliper 2.0 was developed based on Russia's Kliper space vehicle designed to be a replacement for the Soyuz spacecraft. Kliper 2.0 is an enhanced version of a Kliper Commander game originally developed by one of Professor Bob Stone's final year students in the School of Electronic, Electrical and Computer Engineering at University of Birmingham. More recently, Digital Native Academy, a company based in Walsall, has built on the original Kliper game to produce a 3D web version aimed at schools where users of the physics simulation were able to take control of the Kliper spacecraft and attempt to dock it with the International Space Station (ISS) in a series of exercises which required them to understand Newton's Laws of Motion to achieve a successful docking (Fig. 7). Throughout the development process links were made with both teachers and pupils at local schools in order to ensure the embedded learning aligned with the National Curriculum and to test the demonstrator.

Fig. 7. Physics simulation of Klipper docking with the ISS

Results: The demonstrator went a long way to achieving its primary objectives i.e. building a solution that illustrated real-world physics in action and to which pupils positively responded in their appreciation and better understanding of mathematical and physics concepts. As a result of the demonstrator activity the development partnership is being progressed to explore future developments of Kliper 2.0 and other interactive learning solutions.

D. Planetary Rovers Project

Project Goals: Birmingham-developed computer simulation technology borrowed from the world of gaming is used to help with projects like Aurora, a European Space Agency initiative which sets out to explore the solar system over the next 30 years – starting with the robotic exploration of Mars as a precursor to the human mission. Academics from the University of Birmingham, led by Professor Bob Stone, are linking up with Russian space experts to apply the region's expertise in creating computer simulations to robots exploring the Red Planet, tapping into gaming technology to do so.

Implementation Details: Professor Stone's students have been involved in the simulation of space robots – they have finished a series of projects using games technology using a roving robot which can trundle over the surface of Mars (right lower corner of Fig. 8). The most recent demo looks at a multi-window situational awareness concept for subsea robotics and planetary rovers using games engine technologies (Fig. 8).

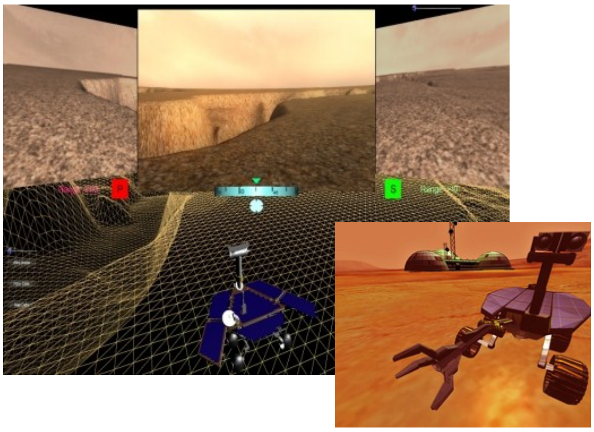

Fig. 8. Planetary Rover situational awareness display concept

V. RUSSIAN VR APPLICATION TO COSMONAUT TRAINING

Pioneering in Russian efforts of VR application to human operator training is the Yu.A.Gagarin Cosmonaut Training Center (GCTC) in Star City, a famous location near Moscow. Space program cuts in 90s resulted in part in serious delays in delivery of new space vehicle mock-ups for the GCTC's cosmonaut training facilities. This fact in concert with the advent of a cheaper computer graphics power and advances in human-computer interfaces are instrumented in the GCTC's initiative on integration of VR capabilities into cosmonaut training process. This initiative aimed at upgrades to the conventional and sometimes outdated training means with a new digital media and (as the possible ultimate goal, yet not attainable) at reduction and may be elimination of training in expensive mock-ups.

The early VR projects, performed under contract to GCTC, concerning the execution of navigational and manipulation experiments, and ultimately leading to the development of a VR training facility, has been carried out since mid 1990s by Space Simulator Center (SSC Ltd) in cooperation with the i3D/VR team at Moscow State Institute of Electronics and Mathematics (MIEM) [8].

A. The VR Mir Space Station

Project Goals: The principal aim of the first 6-months (to December 1995) study of the series was to develop a virtual human-interface demonstrator for use later as a test-bed for cosmonaut training experimentation. This VR test-bed should help to derive preliminary requirements for a VR space station simulator system, with reference to diverse intra-vehicular activity (IVA) model scenarios. These scenarios included simple navigational tasks as likely related to the cosmonaut trainee mastering the spatial orientation skills within the space station environment. Also a cosmonaut trainee could accomplish manipulations in the "servicing" of an experimental payload in the working area of space station module. Study analyses focused on defining the requirements for the trainee and instructor-operator workstations, such as identifying basic ergonomic requirements for workstations, defining training strategies, developing graphic screen formats for the supervision or direct control of the training session and the VR simulation, and the potential applications of multimedia and networking technology.

Implementation Details: The space vehicle to be used for the purposes of IVA demonstrations was a core module of the *Mir* space station, 3D computer graphics model of which was created to include most of important interior features and details as the central control station, working/dining area with articulated table, crew member sleeping chambers, etc. (Fig. 9). As a focal points for human operator manipulations in virtual environment a transformable table and a medical experimentation payload unit were chosen incorporating drawers, VCR with certain controls, handles, switches and opening panels as points of interaction.

VR demonstration of the *Mir* space station was developed using Superscape's VRT package. It is based on non-immersive VR technology, using 3-D accelerated PC-based computing platform. Control inputs are restricted to a conventional mouse and single function key, delivering discrete, momentary and continuous input functions, supporting spacecraft walk-throughs; panel opening; switcher and handle operation (e.g., opening table compartments, releasing drawer); medical payload experiments simulation (e.g., running video on VCR).

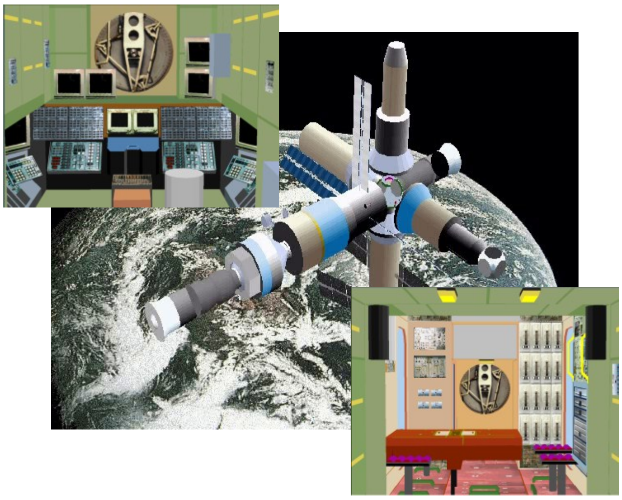

Fig. 9. Virtual Mir space station's views

Results: The virtual *Mir* space station although never used in actual cosmonauts training process has played its positive role in establishment and development of a strong VR force in GCTC's training facilities. Although the original project was based on the early training and craft familiarization needs for cosmonauts destined to accomplish missions aboard the *Mir* space station, the results of the project received serious consideration for other long-term space missions and future stations such as International Space Station (ISS).

B. VR International Space Station Application at GCTC

Project Goals: International Space Station (ISS) project is a largest on-going program at Russian Aerospace Agency (Rosaviakosmos) today. Respectively, the major modeling and simulation efforts at GCTC are concentrated now around ISS crew training needs. Number of training modules currently exist. The real versions of the most of ISS elements are already in orbit, with one more module expected to be deployed in orbit in 2012 (Russian *Nauka* Multipurpose Laboratory Module) to complete the ISS construction. The overall GCTC's requirements for what is referred to as *the VR-based system for the cosmonauts group training* relate to initial position of a PC-based trainer (CBT) which will enable students to become familiar with the layout of the target space station module, including compartments, key items of equipment, main service routes, safety equipment and so on.

Implementation Details: In brief, the VR system for pre-mockup familiarization training of space station crews has been designed, incorporating a general purpose instructor operator station, a reconfigurable cosmonaut trainee workstations and an onboard systems simulator station. Following a period of close liaison with the GCTC specialists and users of an ISS training environment, the approach recommended for developing and delivering the training system was hybrid VR-multimedia in nature, relying on a carefully implemented blend of 3D engineering data, digital images (e.g., photographic records of a space module, training manuals) and videos (MPEGs/AVIs), and basic 3D models (i.e. VRML) of selected items of equipment, with animated features as deemed necessary. These data are all structured within a 3D virtual geometric space station shell (itself based on converted engineering drawings data from the space station developers). Developers from SSC in cooperation with specialists within the GCTC and MIEM have produced a first class real-time training demonstrators of the Zarya and Zvezda modules, with multiple PCs and a low-end SGI machine on a local area network. The detailed 3D computer graphics models of the ISS modules were created (see Fig. 10). Interaction with and display of the hybrid data sources is carried out via a "minimalistic" user interface (for both trainees and instructors). The source drawings data are converted (using proprietary and in-house data conversion procedures) into a form suitable for re-working into a fully interactive and real time virtual space station model, supplementing the data with unique items of geometry as necessary (e.g., using other proprietary modeling packages). By doing this the processing speed on the part of the graphics workstation is optimized by employing such cost-effective techniques as zone (e.g., module) culling and level-of-detail management [9].

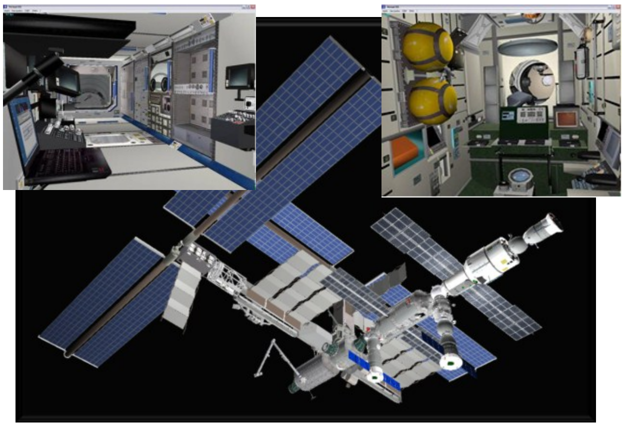

Fig. 10. Virtual ISS views

Results: The use of CBT-VR facility in cosmonaut training process substantially facilitates familiarization (pre-simulator) training and increase training efficacy [10]. VR ISS in CBT-VR class demonstrated several clear advantages over physical model (mock-up) including trainee's ability to see simultaneously control station and panels in defferent modules (spacecraft) with the references to certain craft; navigate immediately between modules; and experience (see) response on virtual information displays/instruments to cosmonaut's control inputs as accomplished through virtual controls. Other advantage of the CBT-VR test-bed is that during the training session in virtual space station cosmonauts use a standard commissioned onboard documentation. This permits them, on the one hand, to better understand this documentation, and, on the other hand, to generate their comments and amendments (if any) to the documentation arrangement and content on the early stages of preparation to mission.

VI. CONCLUSION

The work being done in the USA, the R&D within the aerospace community, and defense, and also in Europe and Russia in terms of i3D/VE/SG, led to the following results:

a) Improved Situational Awareness.

b) Positive Transfer of Training or Enhanced Information Recall.

c) Objective, Comparable Performance Records.

d) Cost-Effective Procurement of Technology.

e) Significant Cost Savings (COTS Technologies).

f) Reduction of Training Time.

g) Elimination of Down-Time of Reusable Data and Methodologies.

h) Intranet and Internet Delivery.

Given these advances, what kind of future can we expect for HITL simulation in aerospace domain?

As i3D/VE/SG matures, so its accelerated uptake by aerospace industry will depend on the provision of professional case study material and the availability of practical guidelines and techniques for assessing user performance and application relevance. As far as the former issue (case study material) is concerned, this paper has only touched on a small number of projects. However, increasingly the i3D and Human Factors communities are providing project examples that can be used to help overcome the initial barriers to adopting VR or SG by companies large and small. Gradually, more and more valid and reliable results are appearing in reputable journals, based on experimental trials from the growing installed base of experimental simulator prototypes (the shift of commercial applications from the expensive graphics "supercomputers" to more affordable Windows-based machines and game consoles has contributed enormously here).

As far as the latter issue is concerned, in the view of the authors, there is a desperate need for practical, easy-to-apply, objective human performance assessment techniques to measure situational awareness, transfer of training (over and above those measures discussed above), spatial "proficiency", presence, psychomotor skills and so on. Urgent developments in these areas are central to the pursuit of human factors excellence in industrial and commercial applications of i3D/VE/SG. VR and SG are, first and foremost, a suite of technologies which provides the ergonomics and human factors community with a "toolkit" for optimizing the design of the human-system interface for numerous applications. Ergonomics, sometimes (ignorantly) underrated as a technological field of endeavor, has a significant contribution to make to the development of VR and SG into this Millennium. Not just as a means of alerting VR and SG users to negative and sometimes scare-mongering issues, such as the potential side effects of "immersion", but in the development of methodologies to measure and report the positive effects of applying this exciting human-centered technology throughout industry.

Already the serious gaming community is experiencing a "period of elevated hype", in exactly the same manner as that witnessed at the beginning of the 1990s, when VR first emerged onto a worldwide stage and then gradually deteriorated into a technology-push fiasco as the closing decade of the last century progressed. The serious gaming bandwagon is rolling. There is little doubt that the widespread availability of gaming related software tools will enable many more individuals than was the case in the VR era to become involved in the creation and delivery of high quality, distributable virtual environments. There is also little doubt that, given time, a good number of organizations will adopt serious gaming for a range of applications (particularly training related). But forcing an early step change will meet with failure as it did in the VR "era". Technology of this nature has to be designed in conjunction with the end-user, packaged in a form that the end-user can understand and taken out to the end-user for immediate use; this is where the VR centre of yesteryear failed. It is vital that the proponents of serious games technologies learn from the harsh lessons of the recent past. Otherwise, history will repeat itself and large sums of money will be wasted.

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