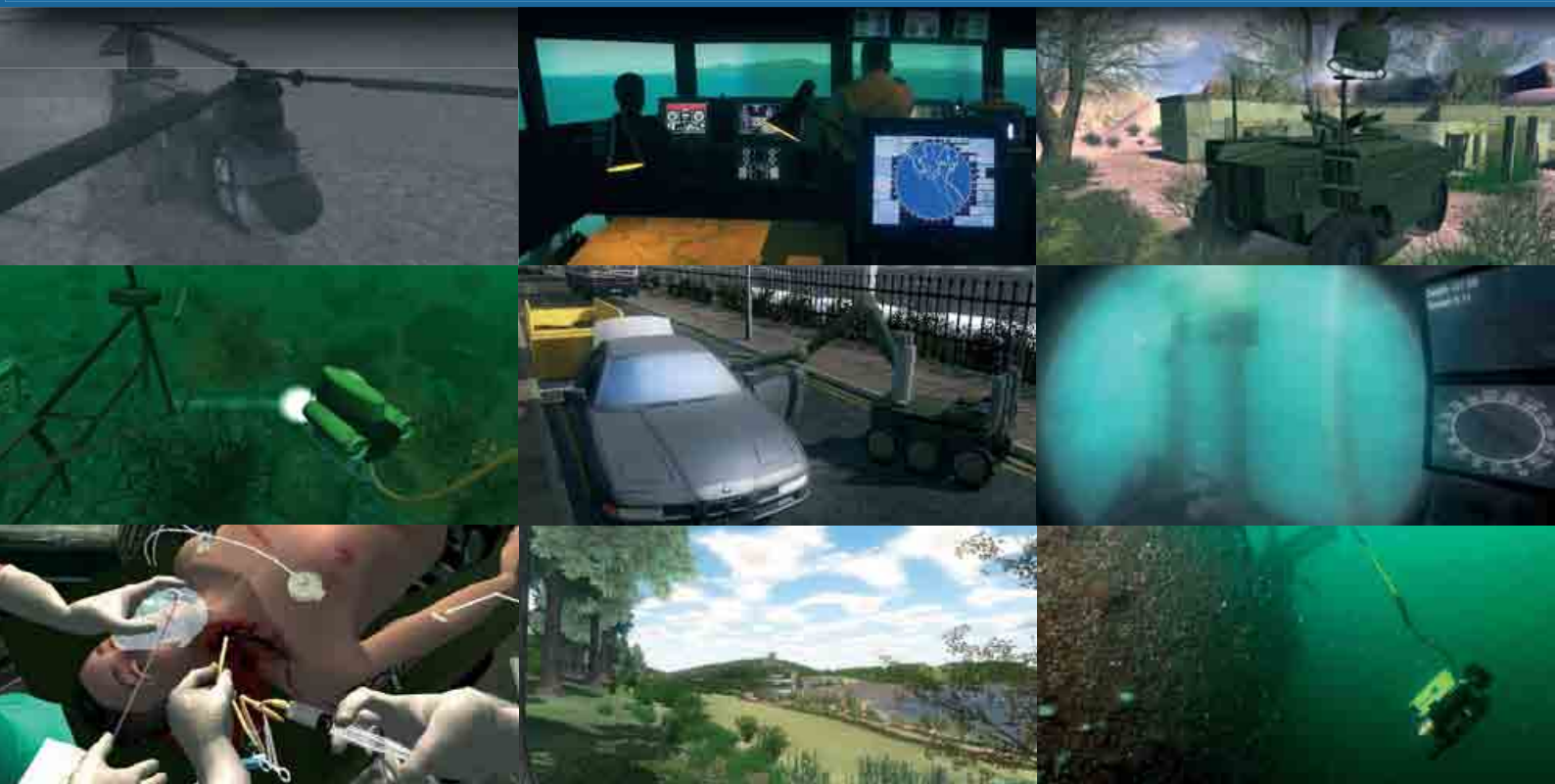# Human Factors Guidance for Designers of Interactive 3D and Games-Based Training Systems

## Human Factors Guidance for Designers of Interactive 3D and Games-Based Training Systems

Please note that due to the size and format of this Handbook, pictures and diagrams are for illustrative purposes only.

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Professor Robert J. Stone
Human Factors Integration Defence Technology Centre.
Director, Human Interface Technologies Team, University of Birmingham (UK)

# FOREWORD
## by Dr Dai Morris - Head of Joint Training, Evaluation and Simulation Capability

Over the last decade the commercial sector has made substantial investments in both hardware and software to support the development of ever more immersive and realistic virtual environments. In these environments people 'play' games, either alone or with others across networks, and use technologies to interact with systems that only a few years ago would have been the exclusive preserve of research laboratories. For example, motion capture systems that are now to be found in many homes, allow users to interact in virtual environments much as they would in the real world. As the interaction technology has become more sophisticated, the visual environments themselves have become more realistic, incorporating new '3D' displays. The behaviour of entities in virtual environments, such as avatars, are being driven by increasingly sophisticated artificial intelligence techniques designed to replicate the behaviours exhibited by individuals, groups, and even crowds. The drive for increasing realism and enhanced user experience/satisfaction continues to stimulate innovation in this rapidly advancing field.

It is therefore essential that MoD considers the utility of these technologies for applications such as training so as to leverage the commercial investment and deliver more cost-effective training systems in defence. The Strategic Defence and Security Review (2010) highlighted the potential benefits of using more simulation within training to reduce the ever-increasing costs of military training. In moving from live training to increased use of simulation, we in MoD must examine such technologies carefully to determine how they may best be used to support the development of military capability.

However, we must avoid being seduced by the superficial attraction of such technologies – the very properties that make them appealing to consumers. Some of the features which make technologies attractive in the retail market are very relevant to defence applications, but others are not and we must maintain a clear view of the most important factors in providing tools that are suitable for *training* military tasks. As part of this systematic evaluation process Professor Stone has undertaken

an impressive set of over twenty case studies to determine how best to use these technologies to develop effective training applications. From these case studies he has collated his findings into practical, Human Factors guidance that can be used by all those involved in the design of training systems utilising 3D and games-based technologies. I am confident that this Second Edition of the document will be as well received as the First, published in 2008. It supports MoD in acting as an intelligent customer for many of the new developments available from industry. Professor Stone's erudite approach to the topic and clear exposition of the benefits and potential pitfalls of using these technologies in this updated document provides much needed guidance and promotes understanding of this complex and dynamic area.

PART ONE - HUMAN
FACTORS, SIMULATION &
VIRTUAL ENVIRONMENTS

1

# INTRODUCTION

The first edition of the Human Factors (HF) Guidelines for Interactive 3D (i3D) and Games-Based Training Systems Design, published in 2008 by the present author, was distributed nationally and internationally and made available on the Human Factors Integration Defence Technology (HFI DTC) Website (www.hfidtc.com; Stone, 2008). The motivation for publishing such a document came about due to a realisation that *technology push* was, once again, dominating a rapidly growing branch of the Synthetic Environments (SE) community, whilst *market pull* and, more importantly, the needs, capabilities and limitations of the human user were being relegated to an "also ran" status in procurement and delivery processes.

The inclusion of the words "once again" in the preceding sentence is important and relates specifically (but not exclusively) to the exploitation of games-based technologies in the quest to deliver affordable, accessible and distributable forms of simulation-based training. Often referred to as "Serious Games" – games with an "explicit and carefully thought-out educational purpose … not intended to be played primarily for amusement" (Abt, 1970) – these technologies are being held up throughout the international defence arena and in other educational market sectors as a global revolution in i3D technology for training and 21st Century learning. The proponents of Serious Games promise that the technology will deliver intuitive, affordable, accessible and familiar training environments for a wide range of applications, from medicine and healthcare to defence training for urban and special operations combat; from national heritage to multi-cultural interaction.

However, an almost identical scenario with almost identical claims was played out in the 1990s. Then it was called *Virtual Reality*, or VR – once described as "the most significant technological breakthrough since the invention of television". VR was popularised by a myriad of technologies – head-mounted displays, instrumented gloves (Figure 1), motion capture suits, and multi-screen rooms or "Cave Automatic Virtual Environments" (CAVEs). By the end of the 20th Century, VR was to render the keyboard, mouse, joystick and computer monitor redundant, in favour of sophisticated interfaces and multi-sensory 3D environments that would support "natural" human interaction within a 3D computer-generated world. Such interaction, accompanied by a "sense of belief" on the part of the user in the environment in which he or she was "present", was labelled "immersion" – a term that is misused as much today as it was in the 1980s and 90s. However, despite sizeable early investment, national initiatives, expensive (and unexploited) international collaborative projects and the widespread rise of so-called centres of academic excellence, VR delivered very little of use to the world of interactive media, let alone the defence training sector.

To those who were involved in the VR era, there is absolutely no doubt that gaming technologies can deliver much more than the promises and hype of their primitive predecessor – affordability and accessibility, in particular. But, at the time of writing, a truly widespread uptake of the technology has yet to be seen (and this is an observation not only restricted to the defence community). Many of the trends witnessed and mistakes made in the 1990s are being made yet again throughout the games-based training arena (Stone, 2005). Mistakes like the re-emergence of groups touting all manner of sophisticated and unproven wearable, mobile computing and data input/display devices. Mistakes like the establishment of fixed-location "centres of excellence", demanding significant investment, but failing to deliver high-impact solutions. Mistakes like the publication of over-optimistic market surveys by authors with little direct experience of the sectors they are selling their over-priced documents into. Mistakes like premature software standardisation, based on the illusion that, by adopting just one of today's interactive 3D toolkits, asset sharing and interoperability will guarantee an effective and seamless simulation capability between national and international armed forces. At the present time, and in part due to the mistakes of the closing decade of the 20th Century, newcomers to the games-based training arena, not to mention those who were misled into investing into the VR technology of the 1990s, are demanding – quite rightly – business cases based on sound evidence (which includes examples of successful uptake elsewhere) and financial justification, particularly important in today's climate of financial austerity.

So, what of the evidence? It is fair to say that pockets of evidence are emerging (albeit very slowly) that support the exploitation of "Serious Games" (and, indeed, games in general) in training and education. Increasingly, examples of articles presenting laboratory-based experimental results of games-based simulation and training studies are appearing regularly in high-impact academic journals, such as *Nature*. For example, at the most fundamental perceptual-motor and cognitive skills level, experimental evidence suggests that games players tend to show superior performance in a range of tasks (Boot *et al*., 2008; Dye *et al*., 2009; Green & Bavelier, 2003, 2007), such as those demanding an ability to:

- track fast-moving objects
- track multiple objects simultaneously
- filter irrelevant visual information and identify targets in clutter (decision making in a "chaotic" environment (e.g. Roman & Brown, 2008)
- multi-task effectively and switch between multiple tasks
- react to changes in briefly-presented visual stimuli
- mentally rotate three-dimensional objects.

However, these studies, unless they are carefully interpreted into the language of potential investors, will not – on their own – kick-start a strong uptake of games-based simulation across the defence sector (or elsewhere, for that matter). On a more general level, and with reference to defence operations at a tactical or

strategic level, concrete or definitive evidence is more difficult to find and relevant, tangible material is often "hidden" in lengthy texts discussing the general pros and cons of games-based simulation. As pointed out by Hays (2005), as part of quite a thorough review of evidence-based learning using gaming technologies, "empirical research on the instructional effectiveness of games is fragmented, filled with ill defined terms, and plagued with methodological flaws". Hays' review uncovered only 48 out of 270 publications reviewed that contained empirical data on learning effectiveness of games-based instructional tools.

Another important issue here is that good-quality studies are currently few and far between, due in part to the fact that many defence establishments are (unsurprisingly) not receptive to their training régimes being compromised, or their classes being split up into control and treatment groups. A related concern is the possible negative impact on the performance and attitudes of control group participants who discover that they may, as a result of the random condition allocation process, have been "deprived" of access to a new and exciting learning technology. Furthermore, measuring the outcomes of games-based training in naturalistic settings – the military classroom and the training or operational field – is far from straightforward.

Nevertheless, as with the scientific literature, one is witnessing an increase in the publication of results of games-based simulation and training in defence conference proceedings, such as those accompanying the annual I/ITSEC event in the US. Just one example is the US DARWARS project – an extensive initiative sponsored by the Defense Advanced Research Projects Agency, DARPA (DARWARS is a shortened version of DARPA WARS) to accelerate the development and uptake of low-cost military training systems. Presented regularly for some time now at the annual I/ITSEC conference, DARWARS exploits PC, gaming, Web and Commercial Off The Shelf (COTS)



**Figure 1**

technologies to demonstrate the art of the possible, often driven by specific US requirements and often accompanied by strong evaluation components. For instance, in one particularly impressive study (Wiederhold & Wiederhold, 2006), the effectiveness of desktop training simulators in the teaching of tactical skills (building entry and clearance during simulated urban combat) was demonstrated, along with the practice of stress management (as supported by physiological measures applied during the experiments) and the improvement of performance during real-life combat situations. In addition, the researchers showed that PC-based training improved spatial awareness, reduced the need for frequent communication during a building entry operation and fostered better anticipation of other team members' movements. One can only hope that, in time, evidence-based reports and papers such as this become the norm rather than the exception.

Having pointed out some of the limitations inherent in the serious games-for-defence arena, it should be said that, despite the limited concrete evidence, there does seem to be a widespread belief and acceptance that games-based simulation will support a more effective transfer of information from the classroom to the real world than conventional methods (e.g. PowerPoint, "chalk-and-talk", sandbox or scale model techniques). Under certain circumstances and for some students, such simulation can help facilitate positive attitudinal changes toward the subject being trained (e.g. Bredemeier & Greenblat 1981; Stone *et al*., 2009a, b). Furthermore, games-based learning activities that engage the interest of the learner are often accompanied by more time spent on those activities than would be spent otherwise, leading (as found by Lepper & Malone, 1987) to better learning of the instruction and a more sustained interest in future exposures to the instructional content.

Although the criticisms of Hays and others relating to the lack of empirical data are

acknowledged and accepted, the author of the present document is of the firm belief that the defence training community cannot wait *ad infinitum* for the appearance of experimental evidence to cover every aspect of simulation-based training that may be presented for consideration. In the absence of empirical studies, or, indeed the opportunity to conduct empirical studies (due to some of the barriers described above), the HFI DTC games-based training teams have turned instead to the collation of well-documented case studies, especially those that have benefited from strong stakeholder and end user input from the outset.

The present document, therefore, is based not so much on empirical evidence relating to the effectiveness of games-based simulation, as many of the case studies presented are, at the time of publication, still very much at a concept demonstration phase. Nevertheless, it is becoming obvious that early stakeholder engagement in the design of simulation content, early consideration of how best to integrate the media into existing classrooms and training programmes and early – even informal – evaluation on the part of trainees and instructors alike, justify the effort in advocating gaming as an important tool in the future of defence training and education.

One final and important fact to emphasise here is that games-based training will never replace live training. In some cases it can even be shown that the technology will not even *reduce* live training (Roman & Brown, 2008). However, this finding is increasingly being challenged, especially in instances where live training is dependent upon the availability of scarce physical assets, as is the case, for example (and in the UK, at least), with submarines, or specialist bomb disposal remotely-controlled vehicles (both of these applications are discussed later in the document). However, much of the evidence does point to the importance of games as "training multipliers", making live training more effective (Roman & Brown, *op cit*.). Brown (2010) goes further and

emphasises that, although gaming at the military unit level can be considered a training multiplier, the capability of the unit's instructors in administering games-based training plays an important role in determining the effectiveness of the training tool. Indeed, this is a conclusion of the HFI DTC research team involved in the *SubSafe* project, as described later under Case Studies 8 and 9.

Consequently, it is always important to treat the adoption of games-based simulation not as a solution to training in its own right, but as part of a *blended* learning programme, in which the needs of both the trainees and instructors are accommodated and in which the *fidelities* of virtual and real-world elements are balanced and exploited to achieve the best and most credible learning experience. For that very reason, the focus of the current document (and that of the earlier edition) is very much on simulation fidelity – in the view of the author the key to delivering usable content and training effectiveness.

# 2. Document Scope
# - Qualifying Comments

The focus of both this and the previous edition remains on individual and small team training. Despite a preoccupation with collective training within defence communities at the time of writing, it has become apparent, as the projects described herein have evolved, that there are still many, many instances in important defence domains where aspects of individual training have been compromised, even neglected, with potential negative impact on larger team and collective training régimes.

Elements of text from the first edition have been re-used in the present document, although these have been presented in summary form. It should be stressed that the present document has not been designed to be read *instead* of the first edition, which still contains detailed descriptions of many of the important issues relating to the development of appropriate content and usability issues with games-based simulation and VR. The present document is very much focused on real-world experiences and lessons learned, and, to that end, includes over 20 case studies illustrating a wide range of HF guidance and recommendations.

Where relevant, reference to the original Guidelines (Stone, 2008) throughout this document is keyed by the use of the marker [G1] in the text. In the following sections, preceding the case study summaries, reference to specific case studies is keyed by the use of the marker [ n ], where n refers to the case study number.

It should further be noted here that the case studies presented are not exclusively those conducted during the eight years in which the HFI DTC has been in existence. Some early and important experiences have also been drawn from the author's previous history of involvement with defence projects and in one or two non-defence sectors as well.

References to specific software tools only occur where it is relevant to do so. In the main, the HFI DTC has tried to remain software "agnostic" throughout the execution of the projects described herein, choosing instead to deliver simulations using only those tools that are capable of achieving the levels of sensory, behavioural and interactive fidelity demanded by the Human Factors analyses and the needs of the trainees and their instructors. Having said that, at the time of writing, it can be stated with confidence that there is not one package on the market capable of fulfilling all the requirements demanded by defence games-based simulation, and this situation is likely to continue for some time to come.

# 3. Fidelity

In general terms, *fidelity* is a term used to describe the extent to which a simulation represents the real world, including natural and man-made environments (e.g. Figure 2), systems and, increasingly, participants or *agents*. However, when applied to simulation, it becomes apparent from the literature that there are many variations on the theme of fidelity.

*Physical* fidelity, or engineering fidelity (as coined by Miller (1954)), relates to how the Virtual Environment and its component objects mimic the appearance and operation of their real-world counterpart. In contrast, *psychological* fidelity can be defined as the degree to which simulated tasks reproduce behaviours that are required for the actual, real-world target application. Psychological fidelity has also been more closely associated with positive *transfer of training* than physical fidelity and relates to how skills and/or knowledge acquired during the use of the simulation — attention, reaction times, decision making, memory, multi-tasking capabilities

— manifest themselves in real-world or real operational settings. Recent experience in developing serious games or Virtual Environments for part-task training applications (in defence and medical sectors, at least) suggests that, when observing tasks, there are four key classes of fidelity to be aware of, each of which impact on defining the ultimate physical and psychological attributes of the simulation and each of which will be discussed in more detail in subsequent sections of this document. These are summarised in Table 1, below.

Throughout the 23 Case Studies presented at the end of this document, specific reference is given to fidelity assessment and considerations, in order to illustrate the significance of the different types listed above. In a number of cases, examples illustrating the detailed fidelity issues with these Case Studies are presented in the original Guidelines [G1].



Figure 2

**Table 1**

| | |
|---|---|
| **TASK FIDELITY (Section 3.1)** | The design of appropriate sensory and behavioural features into the end user's task that support the delivery of the desired learning effect. |
| **CONTEXT FIDELITY (Section 3.2)** | The design of appropriate "background" sensory and behavioural detail (including avatar/agent styles and behaviours) to complement — and not interfere with — the task being performed and the learning outcomes. |
| **HYPO- and HYPER-FIDELITY (Section 3.3)** | The inclusion of too little, too much or inappropriate sensory and/or behavioural detail (task, context and interaction systems) leading to possible negative effects on serious game/simulation performance and on knowledge or skills transfer [3] [4] [8] [15]. |
| **INTERACTIVE TECHNOLOGY FIDELITY (Section 3.4)** | Defined by real-world task coupling observations ([G1]), interactive technology fidelity is the degree to which input (control) and display technologies need to be representative of real life human-system interfaces and, where they are not, the careful management of control-display mapping and acknowledgement of human stereotypes (this includes understanding the benefits and limitations of virtual *vs.* real control set-ups). |

## 3.1 TASK FIDELITY

Broadly speaking, the term *task fidelity* refers to the design of appropriate sensory and behavioural features within the simulated task(s) that support the delivery of effective skill-based and cognitive training (i.e. features that support the delivery of high psychological fidelity through the exploitation of appropriate "physical" fidelity).

In many examples of simulation design it has become apparent that physical and psychological fidelities do not necessarily correlate well – more and more physical fidelity does not necessarily guarantee better psychological fidelity [1]. Establishing the components of a task that will ultimately contribute to how psychological fidelity is implemented within a simulation is not an exact science (Tsang & Vidulich (2003)). Human Factors task analyses (observational, hierarchical or cognitive) and end user briefing techniques need to be selected and conducted with care if those human performance elements of relevance to the design of i3D and VE simulators are to be isolated effectively.

Of particular concern are:

(a) whether the tasks to be trained are fundamentally **perceptual motor** (e.g. skills-based [1]) or **cognitive** (e.g. decision-based [16] [17]) in nature, or a combination of the two ([6] [7] [11]), and
(b) whether or not all or only a percentage of the members of a target audience possess pre-existing (task-relevant) perceptual-motor skills and domain knowledge.

The impact of these issues on physical and psychological fidelity is of considerable importance, as is their impact on such issues as the choice of hardware and software, the balance between live and synthetic training and, of course, developmental costs. Some general Human Factors principles follow. These are discussed in greater detail in the original

Guidelines publication (Stone, 2008; see also Stone, 2011) including the merits of egocentric ("first-person") *vs.* exocentric ("third-person") views or reference frames and "task coupling" (describing how a user's performance is influenced by the features and qualities of his or her immediate working environment, including special items of equipment and tools).

If the target training application is primarily **perceptual-motor** (skills-based, requiring manual handling, hand-eye coordination or dextrous activities, for instance), or designed to foster simple, sequential procedures (characterised by limited cognitive effort), then experience shows that it is not necessarily important to endow the simulator content with *high physical* fidelity. This is true as long as the low(er) fidelity objects and scenes have been designed such that they are reasonable representations of real-world activities – or credible *abstractions* of the tasks being trained [1]. In other words, their visual appearance and/or behaviour should not introduce any performance, believability or "acceptability" artefacts, thereby compromising skills transfer (or related measures, such as skill/knowledge fade).

As an additional attempt to "enhance believability" in this respect, simulation projects that have resulted in low physical fidelity content have benefited from the exploitation of "real-world equivalents" when it comes to interface devices [1]. There is also an issue here that relates to whether or not the perceptual-motor skills may be better trained using real, as opposed to virtual, physical objects, such as – in the case of medical/surgical training – part-task mannequins, or – for close-range weapons training – real but inert weapons [6]. An early Human Factors analysis should be able to help support the choice between real *vs.* virtual, or a blend of the two.

If the target training application is primarily **cognitive** (decision-based, navigation-/spatial awareness-based, etc.), then experience shows that it is important to endow the simulator content with appropriate, but typically *high* physical or

engineering fidelity in order to preserve high psychological fidelity. Experience also shows that, typically, the end user already possesses the basic perceptual-motor and manual handling skills that underpin the decision-based training. Therefore, any manual or dextrous activities featured in the simulator can be committed to decision-triggered animation sequences [3]. Consequently, the need for realistic (real-world equivalent) interface devices is typically minimised (although it is accepted that there will be exceptions).

Finally, if the target training application is a **combination** of perceptual-motor skills and more complex procedural decision-making tasks, then a "blend" of interactive hardware and software fidelities will be necessary in order to maintain high psychological fidelity. This may occur when the early task analysis highlights the need for a simulator to possess higher physical fidelity in one sensory attribute over another. In such a case, it may become necessary to develop, procure and/or modify special-purpose interfaces in order to ensure the stimuli defined by the analysis as being essential in the development of skills or knowledge are presented to the end user using appropriate technologies. Needless to say, this situation is slightly more difficult to define accurately, although its inclusion here evolved from experiences with a range of projects (many of which are described in the Case Studies presented later), where the skills to be trained were mostly perceptual motor in nature, but the decisions were also complex (and safety-critical), albeit at certain stages of the task (i.e. not continuously [2] [6] [7]). Therefore, it was not possible to separate perceptual-motor and cognitive elements in the training analysis.

## 3.2 CONTEXT FIDELITY

The term *context fidelity* refers to the design of appropriate "background" sensory and behavioural detail in i3D or serious games systems. Background effects and scenarios should complement – and not interfere with – the task being performed and, therefore, the learning outcomes. Unfortunately, the design of contexts in simulations often leaves a lot to be desired from a Human Factors perspective. It is evident that, on occasions, simulation and game designers adopt an attitude that their end users are "blinkered" and somewhat naïve individuals who are likely to be so engrossed with the task that cutting corners during the design of scenarios will be tolerated or missed altogether. In other cases, examples of hyper-fidelity (see Section 3.3) abound in background contexts and serve only to distract the end user considerably from his or her task.

Equal Human Factors attention needs to be given to the content and fidelity of the scenario as to the design of the simulated tasks themselves. Furthermore, as the simulated context will feature heavily in the end user's navigation, exploration and event recall behaviours, close attention to issues such as believable content, fidelity and consistency is of crucial importance. From a Human Factors observational perspective, the following basic issues need to be addressed [G1].

**Are there elements of the context(s) that directly support the performance of the task? These elements could be identified by Cognitive Task Analysis techniques or similar and might include:**

- Features of the immediate workspace or bodyspace [1] [2] [3] [6] [7] [19];
- Features of the immediate workplace – internal and/or external scenarios (the space around the body [8] [9][10]);
- Features of the navigation space [16] [17] [18] [20];
- Presence of other actors (e.g. team members [15] [16] [17]);
- Normal or special environmental conditions (relevance of sensory cues – including sound – plus physically constraining features [5] [6]);
- Health and safety issues [6] [21].

**Are there elements of the context(s) which, if implemented inappropriately in an i3D or game-based simulation, may adversely affect or hinder the performance (or believability) of the task? Areas of concern here include:**

- Background/ambient sound [4] [9][16];
- Ambient visual conditions [10] [12];
- Features of the navigation space [15] [18];
- The degree of environmental "clutter" (natural or man-made) [10] [17] [18];
- The behaviours of, or interactivity with other actors [4] [9] [16] [17].

*Are there any specific context features that, if not implemented consistently within or across a scenario, may present inappropriate cues and, thus, confound the end user's task performance?*

### 3.2.1 AVATARS

The presence of, and interaction with, other "actors", is one of particular Human Factors interest. Whilst task and context fidelity play a key role in both engaging the end user and in supporting his or her effective learning uptake from Virtual Environment or game-based training technologies, the visual and dynamic (including sound) qualities of actors or *agents* within those contexts – specifically virtual humans and animals – can make or break the acceptance and credibility of the simulation at a very early stage [4] [15].

Of particular interest are "NPCs", or non-playable (non-player) characters, as these tend to be the more prevalent in first-person games at the present time (although networked versions of First Person (FP) games enable players to control their own avatars and view the avatars controlled by other players). In mainstream games, NPCs can be adversaries, allies, or simply bystanders, their behaviours typically triggered by specific events throughout the game or by the actions of the player. The extent to which those behaviours are scripted (i.e. pre-programmed procedural actions) or based on Artificial Intelligence (AI) depends on the complexity of the game design. In parts of the game *FarCry*, for example, small groups of NPCs were programmed with two basic levels of AI, such that their retaliatory behaviour when attacked depended on whether or not their "leader" had been terminated at the outset. Without a leader, NPCs would exhibit more unfocused and uncoordinated retaliation strategies than was the case when the leader was still present in the game. In *Assassin's Creed*, and despite the mixed reviews of the game's AI, the NPCs in crowds reacted to the player's in-game behaviour – the more extreme the behaviour, the more members of the crowd exhibited fear or intolerance; the more "acceptable" the behaviour, the more the crowd supported the player's attempts to "blend in" ("social stealth").

The visual detail of avatars, regardless of their player-controlled or NPC status, must be given adequate and early Human Factors attention. For example, unless the simulation has been intentionally designed using a low physical fidelity approach (such that agents in the virtual scenario can be represented by simplified human representations without compromising the psychological fidelity) and/or a high- (and distant) projection exocentric frame of reference has been adopted, avatars with identical features should be avoided. Low-fidelity avatars for online community applications, such as *Second Life*, are acceptable (at the time of writing), as the myriad of activities one can experience in that environment outweighs the shortcomings of the task and context fidelities.

As a general rule, if the chosen modelling tools or simulation/games engines are incapable of supporting an acceptable level of visual and dynamic detail for human or animal avatars, then, to preserve the engagement of the end user, one should consider either static avatars ("placeholders" [9] [15] [16] [17]) or simplified/symbolic representations of human and animals (e.g. flat shaded models [6], even billboards). "Blending" static, billboarded characters with dynamic avatars in a scene is also acceptable, as long as those characters display context-appropriate background static poses (e.g. waiting in a queue, making a mobile 'phone call, standing in front of a shop window or kiosk, etc.). Static, billboarded representations of avatars with context-inappropriate or an "on-the-move" pose can be distractive and will do little to enhance the believability of the simulation. From a Human Factors perspective, it is far better to introduce very low physical fidelity representations from the outset, rather than risk early disengagement on the part of the end user because the avatars are "not quite right".

### 3.3 *HYPO-* AND *HYPER*-FIDELITY

Given the visual and dynamic qualities available with today's serious gaming and simulation tools, there is an understandable tendency for developers to stop at nothing to endow their simulations with what *they* believe to be the highest (and, therefore, the most appropriate) fidelity possible. Cursory glances at the effects in such titles as *FarCry, Crysis, Half-Life 2* and *Call of Duty* demonstrate this. The impressive images of helicopter down-draught effects over water, vehicle explosions, weapon discharge and the use of "rag doll physics" to simulate the flailing bodies of the recently deceased certainly capture the attention of the player.

There is no doubt whatsoever that these effects far outclass anything the VR and simulation communities has had to offer to date. However, do these effects actually contribute positively to the development of relevant skills and learning? Do they improve the probability of the transfer of said skills and knowledge to real operational settings? Does it actually matter that the underlying particle physics engine is capable of supporting real-time water spray or the dynamic collision effects of barrels rolling down uneven terrain? Are these wonderfully impressive visual and behavioural effects actually representative of what happens in the real world, or have they been exaggerated to achieve maximum player satisfaction? Just as the VR community was plagued throughout its early existence by the proponents of "reality or nothing", so too are the current and future developers of games-based simulations. In some instances, their perception of reality may result in the delivery of one special effect too many.

*Hypo-* and *hyper-fidelity* are terms used to describe the inclusion of too little, too much or inappropriate sensory and/or behavioural detail into a simulated task or context which may, certainly for serious applications of gaming, be highly distractive and may lead to negative knowledge or skills transfer from the virtual to the real. In the majority of cases, hypo- and hyper-fidelity effects can be overcome following a few pre-training exposures of the end user to the simulation. In the case of hyper-fidelity, once what can only be described as the "wow" effect has subsided and the

simulated features are no longer seen as a novelty, then it is likely that many users will ignore them. However, it is also likely that there will be tasks, especially those associated with rapid completion times and decision pressures, where extreme hyper-fidelity effects will distract, no matter how much the end user has appeared to have adapted or "desensitised" him or herself. In addition, resources spent delivering hyper-fidelity effects during development could be put to better use elsewhere.

The case for *hypo*-fidelity is of greater concern, as an absence of appropriate content, or effects that are below an end user's expectations for a given task and/or context can lead to poor learning uptake, a lack of credibility, negative transfer, and so on. Examples of hypo- and hyper-fidelity are provided in some of the Case Studies presented at the end of this document [3] [8] [15].

## 3.4 INTERACTIVE TECHNOLOGY FIDELITY

In the context of the present document, *interactive technology fidelity* relates to the procurement, modification or bespoke design of appropriate data input and display technologies and their subsequent integration and use with the i3D task(s) being undertaken.

Of direct relevance to interactive technology fidelity is the notion of "task coupling" [G1]. Task coupling is a term used to describe how a user's performance in real-world settings is influenced by the features and qualities of his or her immediate working environment and how these features drive decisions relating (in particular) to the interactive hardware and workspace features implemented in the final simulation system. Task elements relevant to coupling include components of the user's immediate working environment (such as the close proximity of other team members and the effect of the environment on his or her working posture and motion envelopes) and special items of equipment and tools that physically link the user to a task [2] [6] [7] [19] [21]. The degree to which a user is coupled to his or

her task in a real-world setting [G1] will influence:

(a) decisions relating to those elements of the human's real working environment that should be implemented as real and/or virtual objects, together with appropriate levels of physical and psychological fidelity [2] [6] [7] [21];

(b) decisions relating to whether or not the use of COTS interface devices are appropriate to enhance the interaction with, and "believability" of the virtual representations;

(c) the selection of appropriate non-COTS hardware for the physical interface to the simulation. Such hardware may vary from purpose-built mock-ups [21], through replica interfaces [19], to the integration of real equipment (e.g. inert weapons [7]).

End user observations and task analyses [G1] will help support early design decisions relating to the selection of appropriate interactive hardware devices, be they "traditional" (keyboard, mouse, joystick, flat screen, projector, etc.), or "non-traditional" interfaces (see Section 3.4.1). The reader's attention is drawn to the contents of Table 2.

Given the failure of the VR community to achieve its end-of-20th Century human-system interface "domination", it is perhaps understandable that today's i3D end users — a good number of whom will have been "victims" of the 1990s VR "bursting bubble" — will be very sceptical about novel COTS input devices. Whilst this scepticism is understandable, it can actually cause its own Human Factors problems. In the recent experience of the author, there are groups of researchers who, whilst still recovering from their VR experiences of the late 20th Century, are restricting their outlook by only considering interface designs based on the basic mouse and keyboard. Their negative, historical experiences with novel interactive devices seem to be preventing

them from devoting at least a small amount of attention — suitably underpinned by Human Factors principles, of course — to alternative solutions. When this happens, there can be a tendency to expect too much of the mouse and keyboard [G1].

### 3.4.1 "NON-TRADITIONAL" INTERFACES

In the excellent book, *HCI Beyond the GUI*, the editor, Philip Kortum, introduces the term "non-traditional" interfaces (Kortum, 2008) to cover a variety of human-computer interaction technologies, in particular those that attempt to "satisfy" most, if not *all* of the sensory and motor (including locomotion) qualities humans are born with. To quote from Kortum's introductory chapter,

"Many of these interfaces will evoke a strong "wow" factor (e.g. taste interfaces) since they are very rare, and commercial applications are not generally available. Others … may not seem as exciting, but they are incredibly important because they are widely deployed, and generally very poorly designed". (Kortum, 2008; page 1).

It is not the intention of the present author to reproduce the contents of Kortum's book. However, based on recent experiences with defence-related projects, there are five classes of non-traditional interfaces that are worthy of mention, if only to highlight some of the key Human Factors concerns with regard to their adoption in current or near-term simulation projects. These are:

- Head-Mounted Displays
- "Enclosure"-Based Display & Interaction Systems
- Haptic "Displays"
- Olfactory "Displays"
- Mobile Computing Interfaces

**Table 2**

| TASK EXECUTION SUPPORT | How appropriate are the interaction devices selected in terms of how well they physically support the role and activities expected of the end user – navigation, object selection/interrogation, manipulation and relocation, function actuation, object construction and so on? Specifically, under which of the following categories do the devices fall, and how might this influence their adoption (including generating possibly prohibitive costs if COTS devices need to be modified or non-COTS solutions have to be developed?). | |
|---|---|---|
| | 1 | From an ergonomic design and system integration perspective, do the interaction devices possess features highly likely to support the user in performing observation, exploration or modification activities intuitively within the simulation? |
| | 2 | Do the interaction devices require minor modification and/or integration with other device(s) to become suitable in the support of the user in performing observation, exploration or modification activities intuitively within the simulation? In an unmodified form, will the devices require some adaptation on the part of the user, making it appropriate for some tasks only (i.e. excluding those of a safety critical nature)? |
| | 3 | Do the interaction devices require significant modification and/or integration with other device(s) to become suitable in the support of the user in performing observation, exploration or modification activities within the simulation? |
| | 4 | Do the interaction devices show potential for supporting the user in performing observation, exploration or modification activities within the target application, but require further research / experimental investigation in order to make confident recommendations? |
| | 5 | Are the interaction devices totally unsuited to supporting the user in performing observation, exploration or modification activities within the target application? |
| DISPLAY MAPPING | How well do discrete and dynamic input commands from the interactive device map onto the displayed functions? How intuitive is the mapping between the human source of input (and this could range from basic keyboard inputs and mouse or joystick movements, to arm/head/eye tracking and direct voice input) and the on-screen activities? | |
| ERGONOMICS | Are the ergonomic design features of the interactive devices themselves acceptable (wearability, short- or long-term use, health and safety, layout of multifunction components, component coding, etc.)? | |
| MATURITY | Does evidence exist supporting the maturity of the device under consideration (including whether or not there is evidence that the device is already "in the field", or "operational", or confined to one or more research laboratories)? Defining *Technology Readiness Levels* (TRLs) may also be useful here[1]. | |
| COSTS | Have the costs of the interactive device been fully taken into account? Costs in this sense not only refer to the initial outlay, but also include annual maintenance/support and software developments. In the case of COTS devices, can assurances be obtained that, should a particular vendor cease trading, the devices selected can effectively be replaced from other sources? | |
| EVIDENCE | Does evidence exist (from Human Factors references and literature searches) that supports the application of the specific device to a specific i3D/serious games training, education or prototyping role (including any established guidelines or standards that may exist)? One of the major problems with the Human Factors and i3D community generally is that, whilst it is possible to find isolated papers in conference proceedings and journals of relevance to a guidance document such as this, there is (as yet) no single publication that attempts to collate the most relevant findings from the research community and publish them under a single cover. | |

[1] http://www.mod.uk/NR/rdonlyres/BB63DF2A-EEA7-4328-A685-5E1349AE2B62/0/20090331FATS3_AnnexGtoSch1U.pdf

**Figure 3**

### 3.4.2 HEAD-MOUNTED DISPLAYS (HMDs)

The term "immersion" first appeared in the early days of the Virtual Reality "era" (late 1980s and early '90s) and was used to describe the sense of being "present" in a synthetic, computer-generated world. Since that time, proponents of immersive virtual environments have constantly advocated the use of specialised wearable data input and data display devices in the quest to enhance the user's immersive "experience". For this reason, the HMD has become synonymous with VR, even though the technology has a very chequered and controversial history. Indeed, despite having attracted a variety of academic and philosophical debates on the topic, hardware technology-driven immersion is still the "Holy Grail" of some (but, thankfully, not all) synthetic environment or simulation developers.

The use of HMDs, such as that shown in Figure 3 (an early 1990s system), is not new. Many researchers acknowledge the pioneering 1960s HMD efforts of Morton Heilig. As well as developing the world's first single-person virtual arcade system, *Sensorama* (Heilig, 1962). Heilig also produced an HMD design concept called the *Telesphere Mask*, which incorporated plans for the delivery of 3D auditory and olfactory stimuli. Philco Corporation's *Headsight* HMD system was developed to introduce a sense of telepresence to security monitoring and remote surveillance applications. Ivan Sutherland's experimental system, the ceiling-mounted, 40° field of view *Sword of Damocles* HMD, was sponsored by the US Advanced Research Projects Agency, and provided the first concrete example of allowing its wearers to visually explore simple wire-frame three-dimensional objects from many angles. However, the VR technologies being marketed today owe their existence and form to research addressing telepresence for space robots at NASA Ames, with subsequent exploitation of emerging Liquid Crystal Display (LCD)-based HMD designs by US company VPL Inc., and in the development of the

*SuperCockpit* concept at the Wright Patterson Air Force Base, specifically the VCASS System (Visually-Coupled Airborne Systems Simulator).

Today, HMDs are experiencing something of a revival. The rapid growth of mainstream and serious games markets seems to have prompted "cottage" developers and large companies alike to – once again – make all manner of wearable technologies available to an uninformed end user community. However, it is fast becoming apparent that many of the commercially available products that are in existence today, not to mention those being touted for future release, suffer from the same Human Factors issues as their VR predecessors of the 1990s – low resolution, small fields of view, large visible areas of optical housing, inadequate provision for wearers of spectacles, poor build quality, lack of ruggedisation, and so on. The same revival is being driven by developments in Augmented Reality (AR), where the headset-based displays, when integrated with the output of miniature head-worn cameras, support the fusion of real-world and virtual imagery. The aim of this is to provide the wearer with real-time information superimposed on the real-world view that is normally invisible or can only be visualised using other forms of media and/or interactive display technologies.

Therefore, given the "state-of-the-art" with COTS HMD technologies at the time of publication, and from a Human Factors perspective, it is **strongly recommended** that alternative forms of presenting simulated or virtual imagery to the end user should be investigated **before** adopting a HMD solution [7].

Having said that, it has to be accepted that there are situations where, again from a Human Factors perspective, the use of a HMD offers a logical solution to the delivery of simulated training scenarios. For example, in tasks where the early HF observations identify crucial tasks that require regular head movements (for activities such as scene scanning, visual

contact with other local system participants) and/or tasks where the hands are not free (due to constraints imposed by the real-world workspace, for example), then a HMD solution is worth considering [6] [21]. Even then, extreme caution must be advised, regardless of the outward improvements in design that are becoming evident in current-generation products – low weight, glasses-style mounts, Organic Light-Emitting Diode (OLED) displays, and so on. The key issues to consider are:

- Fully face-enclosing HMDs should be avoided, unless the user is seated or otherwise constrained or supported. Under NO circumstances should current generation, COTS full-face HMDs be used for applications which require the user to stand unaided or move around freely.

- Even with non-face enclosing HMDs, users should be provided with some form of nearby support and preferably one that reinforces the peripheral perception of the upright or is relevant to some feature that will be available in the real-world application [21].

- Similar attention needs to be paid to HMD cabling, as cables can exert considerable forces and torques on the human head and neck if snagged or pulled.

- Hygiene is often overlooked in HMD usage. Optical assemblies need regular attention, in order to promote cleanliness and to avoid artefacts compromising the already-poor quality of displayed imagery in many COTS HMD products.

- Consider testing users for stereo blindness or related visual defects before exposing them to stereoscopic imagery via a HMD. Whilst the literature is often contradictory in this field, there are claims that stereo blindness affects between 3% and 15% of the population. The key causes of such blindness are amblyopia ("lazy eye"), or strabismus ("crossed eyes") and another more common condition, called non-strabismic binocular vision dysfunction where individuals exhibit poor control over the movement of their two eyes. There are also claims that 56% of individuals aged between 18 and 38 have one or more problems which can compromise their binocular vision (Montes-Mico, 2001). Individuals with stereoscopic or binocular vision defects cope by exploiting monocular depth and distance cues, such as motion parallax, light and shadows, focus, geometric overlap (interposition), aerial perspective, relative size and size/shape constancies.

- Even screening out stereo-blind users may not be enough to prevent usability problems with HMD and stereoscopic technology (and these comments apply to other forms of stereo display as well – for further details, refer to Stone, 2012). One of the well-known Human Factors issues with 3D displays is the mismatch between visual accommodation and convergence. When observing a real-world scene, as one's viewpoint changes (or the locations of objects in the scene change), one's eyes will both converge on objects in the scene and re-focus to keep the imagery sharply registered on the retinas. However, when viewing a 3D virtual environment via a display, as objects are approached (or themselves approach the viewer), the viewer's eyes begin to behave asynchronously. They converge on the virtual object, but the focus remains more-or-less constant as a result of the fixed position of the plane of the screen (or, indeed, the structure onto which the screen is mounted). This mismatch can rapidly promote visual fatigue, discomfort and disorientation (three of the precursors to simulator sickness). It is known that mismatches become more of an issue the closer one is to a screen. So, although the effect can be seen in 3D cinemas and home video "studios", it becomes more pronounced with HMDs.

- Regardless of which form of HMD is selected, their use should only be permitted with an appropriate head tracking system. Dynamic images displayed to HMDs that are not under the head-tracked control of the wearer may well result in disorientation and other forms of malaise.

- Strict attention to health and safety issues should be maintained, before, during and after a simulation session involving ANY form of HMD. Simplified guidelines are presented at the end of this section. These were originally developed by the author (Stone, 1997), based on project experiences and the excellent overview provided by Kolasinski (1995) to support the use of HMDs in defence part-task simulators ([6], [21]; poster versions of these pages are available from the author).

- Simulator users who experience repeated exposure to virtual environments have been shown to adapt to those environments, with an accompanying reduction in the incidence of sickness reports. Recommendations on the length of the time interval between exposures vary in the literature. It is generally accepted that users should be exposed to "long" periods of immersion when first coming into contact with the HMD system (i.e. 15 to 30 minutes plus). Subsequent exposures should occur within 2-3 days of the first exposure.

**Table 3**

| POST-SESSION TIME PERIOD | PERCENTAGE OF USE SAMPLE |
| --- | --- |
| 30 minutes - 1 hour | 14.6% |
| Over 4 hours | 6% |
| Over 6 hours | 4% |
| Spontaneously-Occurring Effects | 1% |

# HEALTH & SAFETY GUIDELINES
## Virtual Reality Head-Mounted Displays (HMDs)
## GUIDANCE NOTE 1



## CHECK BEFORE USE

Participants reporting/showing any signs of the following should NOT take part in HMD-based trials

NB: The HMD shown above - the Rockwell Collins ProView XL50 is now an old and discontinued product (however, see Case Studies 6 and 20) - the HMD is presented here for general illustration only

- Conjunctivitis
- Corneal Ulcers
- Corneal Infections
- "Dry Eye"
- Iritis
- Cataracts or Glaucoma
- Pregnancy (heavy or 5months+)
- Ear Infections/ear disease
- Influenza
- Head Colds
- Respiratory Ailments
- "Heavy" Hangover

Participants reporting/showing any signs of the following should be OBSERVED CLOSELY whilst taking part in HMD-based trials and should be debriefed after trials to ascertain their state of health:

- Extreme Fatigue
- Emotional Stress
- Digestive Problems
- Mild Hangover
- Significant Sleep Loss
- Anxiety

Ensure that the HMD is aligned straight on the User's head (see picture above).
To avoid any visual disturbances caused by the tracking system recording abnormal elevation angles at start-up.

## CHECK DURING USE

Observe Participants at regular periods during each trial and take immediate action (halt the simulation and stand easy) if they report symptoms such as disorientation, nausea, eyestrain or any form of malaise.

## CHECK AFTER USE

- Does the participant show any signs of **disorientation**?
- Does the participant show any signs of **nausea or malaise**?
- Does the participant show any signs of **eyestrain**?
- Does the participant show any signs of **unstable posture**? If unsure, test participant - walking a straight line with eyes closed and arms folded.

**If the answer to any of these is "YES" then instruct the participant to stand down and relax. Do not allow the participant to operate machinery or drive for 60 minutes.**

## IF IN DOUBT - ASK!

# HEALTH & SAFETY GUIDELINES
## Virtual Reality Head-Mounted Displays - GUIDANCE NOTE 2
## BEFORE EXERCISES COMMENCE

**DONNING THE HEAD-MOUNTED DISPLAY (HMD)**

- Ensure familiarisation with the type of HMD being used - different products afford different degrees of facial enclosure and adjustability for the wearers
- Before donning the HMD, ensure the participant is fully familiar with the adjustment mechanisms. Stress to the participant that the mechanisms move freely and **do not require excessive force.**



1. Display Unit Horizontal Adjustment (one for each eye)
2. Flip-Up Display Unit
3. Top Headband Adjustment
4. Display Unit Up-Down Adjustment
5. Display Unit In-Out Adjustment

- Don the HMD slowly, taking special care with spectacle wearers (NB. Not all HMDs are designed to accommodate spectacles)
- With the HMD on the participant's head, guide his/her hands towards the adjustment mechanisms
- Before commencing trials, check to see that the participant is wearing the HMD comfortably and can see a clear, single ("fused") image - double images must be avoided

ENSURE THAT THE HMD IS ALIGNED STRAIGHT ON THE USER'S HEAD, TO AVOID ANY VISUAL DISTURBANCES CAUSED BY THE TRACKING SYSTEM RECORDING ABNORMAL ELEVATION ANGLES AT START-UP.

On first using the HMD, encourage the participant to look around and actuate any additional motion controls. This familiarises them with the concept of head tracking and helps them to adapt to being "within" a virtual environment, even if small lags exist between real-world motions and their virtual world equivalents.

**AFTER THE EXERCISE HAS BEEN COMPLETED.**

**DOFFING THE HEAD-MOUNTED DISPLAY.**

- Carefully loosen the HMD adjustment mechanisms prior to doffing
- If necessary, raise the display housings away from the participant's face or spectacles
- Slowly doff the HMD
- Check for any symptoms as listed on Guidance Sheet 1
- CLEAN THE HEADSET DISPLAY HOUSINGS and STOW CAREFULLY

- Long-duration use of HMDs is to be discouraged. Expose users to this form of imagery presentation for no longer than 30 minutes. Individuals susceptible to HMD-induced malaise will most likely present symptoms of malaise within the first 5-10 minutes of use.

- HMD-induced disorientation effects are also known to persist for a period after the "immersion" session, as listed in Table 3, (page 14).

- In general, the HMD health and safety guidelines presented on the previous two pages are just as applicable to other forms of so-called "immersive" VR technologies (including enclosure-based systems, such as CAVEs, Domes, Spheres, etc. – see Section 3.4.3). It is likely that they are also applicable to large-screen implementations.

## 3.4.3 "ENCLOSURE"-BASED DISPLAY & INTERACTION SYSTEMS

The term "enclosure", used here in the context of non-traditional display and data input technologies, refers to large-scale Virtual Environment facilities which use front-screen or back-screen projection-based imaging systems, to create a "wrap-around" effect, thereby (the designers claim) enhancing the user's or users' sense of immersion in the computer-generated scene. One of the earliest versions of such an enclosure – and one that is still prevalent today - was the "Cave Automatic Virtual Environment" (CAVE - a trade name originally applied by the University of Illinois).

Often quoted as a credible alternative to the HMD, the CAVE (Figure 4) is, in effect, an enclosure within which a small number of users are surrounded by whole-wall displays onto which the virtual images are back-projected using high quality video projectors and expensive image blending electronics. CAVE users may be provided with special liquid crystal "shutter" glasses, synchronised with the projectors, so that each alternate scan line of the display triggers one of the shutters, presenting left-eye or right-eye images

only, thus creating a 3D effect ("active stereo"). A variation on the CAVE concept is the immersive projection sphere. One not particularly commercially successful example of which (the *Cybersphere*) consists of an acrylic sphere, 3.5m in diameter, within which the user stands. The sphere is supported by bearings mounted within a large horizontal ring. Within the area of the ring is a smaller sphere surrounded by rotational sensors. By walking within the main sphere, the developers claim that the user can explore virtual environments intuitively, via images displayed on its translucent surface, by means of a series of high power projectors. There are many variations on the theme of enclosure-based displays – some are fixed geometries, such as the CAVE, others are reconfigurable to suit a particular application (the "RAVE"). Some consist of just a small number of screens, others attempt to create an entire range of scenarios which change as the users move from one enclosure to another (such as the US Wide Area Virtual Environment, or "WAVE"). Unfortunately, whilst systems such as the CAVE, WAVE and *Cybersphere* appear quite impressive at first sight, they suffer from two fundamental and practical problems which have hindered their uptake as serious facilities with which to exploit real-time interactive virtual worlds. First and foremost is the cost of the physical enclosures, the multiple projectors and the computing platforms required to "edge-blend" the individual image elements or "patches" together (a process which is more often than not unsuccessful, leading to visual artefacts and image depth distortion). A related cost issue is the significant amount of floor space required to house the facilities.

The second problem is that, despite the engaging nature of the immersion or inclusion effect, these systems do not foster a 1:1 proprioceptive[2] relationship between the user or users' bodies and limbs and the virtual world. Unlike the case for the head-mounted display, which, by virtue of the fact it is worn by the user, preserves some degree of correlation between the sensed positions of the head,

hand (or arm) and their virtual counterparts, the CAVE or sphere user is physically divorced from the display and its virtual images. Thus, the user has to spend time adapting to this separation by controlling what is effectively a remote virtual "cursor" or some other 3D feature. Some users will be unable to adapt effectively to this form of interactive set-up.

Perhaps the greatest concern of all, at the time of writing, is the fact that there is very little empirical support or justification for these extremely sophisticated systems. Indeed, there is no conclusive evidence to suggest that large-scale enclosures, such as the CAVE or its many variations, offer any enhancements at all to the performance of the end user(s) or their sense of "presence" or "immersion" over and above less sophisticated systems, such as those hosted on desktop computers. One study, reported by Loftin *et al*. (2004) conducted an evaluation of participant performance using a CAVE "immersive" VE, comprising only two large walls at quite a low resolution (1280 x 1024) and field-sequential glasses to support stereoscopic imagery (although no rationale for the use of stereo was provided). Performances in the "CAVE" were compared with those using a desktop VE, based on a slightly less powerful computer, but with a non-stereo 18-inch flat screen. The scenario in this study involved the virtual reconstruction of a military checkpoint. Participants were required to undertake a variety of activities according to established procedures and, on occasions, their performance in following protocol and exercising judgment was put to the test by introducing a number of what the authors call "critical scenarios". These included being able to handle matters of urgency (checkpoint conflicts) according to procedure, being able to resist social pressures, demonstrating an ability to recall and identify vehicles, people, and license plates from a predefined target list, and detecting inappropriate objects (e.g. "virtual contraband") or the absence of requested information – all whilst maintaining a global situational awareness of the checkpoint status and its environs.

**Figure 4**

The results of the research showed that overall, participants' performances were superior using the CAVE-based simulation, when compared to those using the VE desktop system. However, the authors go on to say "... although this difference was found across groups and conditions, the magnitude of the difference was not dramatic. Thus, the ability to port a similar training experience to a less expensive PC platform without major performance differences underscores the potential for providing greater access to this type of VE training in a much more cost effective medium".

There have been one or two relatively successful practical applications of CAVE technology, such as recreating the $360^\circ$ view from a vehicle cab (i.e. where the occupant maintains a relatively "fixed", seated posture as opposed to one that is free-standing and mobile, within the confines of the CAVE), but, even then, it is not clear whether or not the desired effect (for the specific task under investigation) could have been achieved using a less expensive solution employing a series of smaller flat panel displays. Of course, this "fixed-posture"/cab approach is not that different to flight and vehicle simulators, many of which have been in existence and providing excellent training experiences long before the launch of the CAVE concept.

[2]Proprioception - A subconscious and instantaneous human ability to sense joint position, orientation and movement.

Figure 5:     "Haptic Workstation" Source: vrlab.epfl/ch

### 3.4.4 HAPTIC "DISPLAYS"

One technological area that has developed at quite a pace since early mechanical and pneumatic attempts in the 1990s is that of *haptics*. The term "haptics" refers to the "science of touch" and is considered by many to be crucial for human exploration and manipulation of the world, be that real world or virtual (Burdea, 1996; Stone, 2000). Many of the systems evident today have their roots in teleoperator developments in the nuclear industry, where sophisticated bilateral master-slave manipulators and exoskeletons or "man-amplifiers" were developed over a period of at least three decades. Indeed, many early force feedback interfaces for VR applications – drug synthesis, molecular docking experiments and so on – were based on these large electromechanical systems, donated to US universities by nuclear power installations. Haptic technologies have now been developed that are capable of delivering believable sensory stimuli – for some, but **not all** SE/VR applications – at a reasonable cost, using human interface devices of a practical "desktop" size.

Another trend evident in the interactive device and gaming market relates to the development of haptic feedback systems, as mentioned earlier, and the Internet is awash with good sites detailing new research developments and listing proprietary products.

It is important to understand that, at the time of writing, there is no one haptic feedback system that is capable of delivering completely realistic, universal tactile or force sensations (including impedance and gravity) that is freely wearable and unintrusive. Even considering human tactile sensing mechanisms alone, the multiplicity of cutaneous and subcutaneous sensory systems[3] cannot be served by any one current generation tactile transducer. Some of the haptic feedback scenarios one sees on the internet and in marketing material – for example, showing gloved hands interacting with apparently solid virtual steering

wheels and other equipment – are cases of "wishful thinking". In addition, the very complex and costly arm-hand exoskeleton-glove combinations (e.g. Figure 5) are still unproven from a real-world application perspective and will probably remain interesting devices for research within academic and government research laboratories for the foreseeable future.

Having said that, there are some excellent haptic devices on the market that lend themselves very well to certain applications, such as specific surgical interventions – laparoscopy and mastoidectomy, for example [2]. Indeed, any procedure which requires an intermediate structure or fixed point to couple the end user (e.g. the surgeon or the Remotely Controlled Vehicle (RCV) operator) to objects in the real world (e.g. a patient or an IED (Improvised Explosive Device)) may well benefit from the exploitation of current COTS haptic devices. This fixing point enables the haptic feedback system to generate realistic simulations of forces and torques, by exploiting a dependency on physical structures, rather than attempting to reproduce the effects of gravity and forces experienced during free-space manipulation (e.g. when trying to handle objects that are not immediately connected to physical features in the real world).

If the Human Factors observations or task analyses isolate interactive events that would benefit from (or, indeed, are dependent on) the implementation of a structurally-supported haptic feedback system, then haptic feedback technologies are worth considering. However, designers must be certain from the outset that implementing complex haptic feedback within an interactive 3D (i3D) simulation or serious game adds value and does not compromise the end user's performance. Designers must also be sure that what is actually needed is haptic feedback as opposed to *haptic cueing*, where simple tactile stimuli (e.g. "rumble" or vibrotactile functions in mice and gamepads) are used to cue features of the Virtual Environment that are either invisible to the end user or

cannot be adequately displayed using the visual and auditory senses alone.

[3] For example, *Ruffini Endings* (Skin Pressure), Hair Follicle Endings (Hair Displacement), Free Nerve Endings (Mechanical, Thermal, Chemical), *Meissner Corpuscles* (20-40Hz Vibration), *Pacinian Corpuscles* (150-300Hz Vibration), *Krause Corpuscles* and *Merkel Cells* (Pressure), to mention but a few.

### 3.4.5 OLFACTORY "DISPLAYS"



**Figure 5**

Since the emergence of Virtual Reality in the late 1980s, applications in design, prototyping, training and education have been dominated by the delivery (in many cases using unproven interactive technologies) of real-time visual and auditory interactive content, with force and touch (haptic) stimulation gradually becoming evident as the delivery technologies have slowly evolved (e.g. Burdea & Coiffet (2003), Burdea (1996)). Virtual olfactory stimulation and simulation has, more or less, been ignored until quite recently, despite the use of synthetic odours in Heilig's original *Sensorama* single-person interactive kiosk (e.g. Heilig, 1962) and the widespread use of scents in departments of retail outlets or superstores.

As pointed out by Barfield & Danas (1995) "olfactory information has been mainly ignored as input to the virtual environment participant, in spite of the fact that olfactory receptors provide such a rich source of information to the human". One of the prime reasons for this, of course, could be the lack of applications until quite recently. Even before the paper by Barfield & Danas, Cater (1992) theorised about the importance of exploiting ambient odours from a physical environment to create a sense of presence in a virtual environment. Recent developments in generating synthetic odours, from systems supporting therapies for post-traumatic stress disorder (e.g. Rizzo *et al*., 2006) to others developed for NASA to provide the "steak, hot metal and motorbike welding" smells, characteristic of working in space, have led to more compact technologies, suitable for PC control and the integration with virtual or games-based environments. The *ScentPalette™* system mentioned earlier is an example of a commercially available system that has evolved over a number of years, from *Sensorama* in the 1960s, through entertainment devices in the 1980s, to a variety of false starts and failed attempts in the early 2000s (e.g. Kortum, 2008).

One of the best overview texts on the science and psychology of odours has been published by Herz (2008). Although the work suffers from a somewhat misleading title - *The Scent of Desire* – the book does contain a range of interesting facts regarding olfaction and the loss of the olfactory sense (*anosmia*) due, for example, to injury affecting the olfactory bulbs, located just above the human eyes. Just some of these facts (with others added from http://www.senseofsmell.org/ and specific references, where quoted) are listed in Table 4, overleaf.

Defence interest in the exploitation of olfactory stimulation in simulated or virtual environments is quite restricted at the time of writing. However, the ability to deliver odours (and simulate *absence* of familiar smells) in order to create an "ambience" effect, as might be delivered in, for example, an urban patrol training context [4], continues to attract interest from certain quarters. Another potential application is to simulate the smell of safety-critical incidents, such as smoke in an adjacent compartment onboard a naval vessel (an enhancement to [9], for example), an otherwise-concealed electrical fire, or fluid and vapour leakages. There is also some discussion regarding the merit of replicating key odours in simulated defence medicine contexts, such as anaerobic infection or malaena. Unfortunately, given the current state-of-the-art in scent delivery systems for video

Table 4: A Selection of "Olfactory Facts"

**Table 4**

| "OLFACTORY FACTS" |
| --- |
| Humans possess 20 million olfactory receptors (both nostrils) and can recognise 10,000 separate odours. |
| There are more olfactory receptors than for any other sense except vision (however, olfaction is covered by only 0.1% of the brain). |
| The human olfactory system is the first to develop and is fully functional by Week 12 in the womb. |
| No two people smell an odour in the same way. |
| Smell can be influenced by genetic factors, health, medicines, diet, mood and the weather. |
| Smell influences taste (~80%; without smell humans would only taste sweet, sour, salt, bitter and the relatively newly-defined taste of "unami" (savoury/meaty)). |
| Human sense of smell has a spatial (direction) component. Krueger (1995) found that a peppermint odour gave superior performance to a lavender odour or no odour at all in spatial visualisation tasks. |
| Note that the aroma of peppermint has been associated by many researchers with a cognitive-enhancing property (e.g. Raudenbush, 2004). |
| The ability to perceive odours increases as the day progresses. |
| Odour adaptation occurs after 15 minutes. |
| Females have superior "odour" acuity when compared to males (although this is influenced by menstrual cycle and hypothalamic control). |
| "Olfaction is also similar to the visual and auditory modalities with regard to age-related changes, in that olfactory sensitivity deteriorates with age. Peak performance in olfactory identification is reported to occur between the third and fourth decades of life" (Barfield & Danas, 1995). |
| Odours play a significant part in *context-dependent memory* (CDM; e.g. Baddeley, 1999) or context-dependent learning (learning associated with how one feels in a particular context). Specific odours have also been shown to improve an individual's recall of information that was originally learned in the presence of that odour (Hoffman, 1987; Smith *et al.*, 1992). |

or gaming applications, it will be some time before credible experiments can be conducted to ascertain whether or not odour effects can be delivered in a way that adds to, as opposed to detracts from, a simulation that already demonstrates appropriate levels of sensory and behavioural fidelity. Current issues preventing the technology from becoming "mainstream" include:

- Primitive delivery technologies – systems are typically noisy (due to the presence of compressors and high pressure dispersal techniques) and difficult to control (in terms of odour intensity and odour removal [4]). If odours cannot be delivered quietly, then it will be impossible to verify their impact on simulated environments and end user performance (as the user may well be responding to the system noise – cueing the onset of an odour, as opposed to the presence of an odour *per se*).

- Odour persistence – many systems rely on delivering as intense a burst of subsequent scents as were delivered in the first release. Not only does this create inappropriate "peaks" of odour sensation, it also contributes to the difficulty in removing the scent, or masking it with another, as the simulation user moves on to a different spatial location.

- The mixing of odours – some current systems seem to be incapable of delivering multiple odours in a believable fashion. In some cases, the result of combining odours can be offensive and distractive to the simulation user.

- The "realism" of synthetic odours – the sense of smell can be a very individual experience, with possible cultural influences playing a key role in how believable a specific scent actually is.

- Limitations in the availability of appropriate odours, particularly for engineering, aerospace and defence applications

- The size and "portability" of scent delivery modules (although this issue is becoming less of an issue, given recent developments in the design of systems for gaming applications [4]).

Figure 6:    Modified Use Interfaced Sequence for iPod/iPad Version of SubSafe

Figure 7:    Current COTS Data Input and Display Devices for iPad/iPod - From Top Left, Clockwise: iControlPad, iPhone VR Viewer, Fling, Joystick IT, Zeemote JS1

## 3.4.6 MOBILE / PORTABLE TECHNOLOGIES

During 2009 and 2010, a number of articles appeared in the popular and trade press reporting on an announcement by the Royal Navy that over 200 Sony PSPs (Play Station Portables) had been procured with the aim of helping warfare engineering technicians to "study for exams in the confined conditions of a warship". Since that time, other articles written by members of international military media development agencies have extolled the virtues of using mobile computing for training and education, including the development of Apple *iPad* applications for artillery fire control and vehicle recognition from the air. Whilst many of these developments are still under investigation at the time of writing, some of the initiatives becoming evident leave a lot to be desired, from a Human Factors point of view, particularly in the way in which multimedia delivery techniques are implemented. In a number of cases, it seems as if the drive for exploiting i3D and gaming material is, once again, outweighing the need to design usable and meaningful interactive training information for presentation to the end users. The same is very true of the interactive styles and devices becoming available for mobile computers, tablets and the like. Indeed, it is not only 3D material that is giving cause for concern. During a 2009 UK Maritime Learning Symposium, one presenter actually suggested that the use of unmodified PowerPoint slide material, once ported onto a Sony PSP, would, by virtue of the technology alone, provide for an engaging means of learning mathematical formulae and other, often challenging educational topics.

Given the very few applications that are evident at the time of writing, it is important to advise caution when considering the use of mobile computing technologies for delivering interactive training material. Again, designs must be based on a sound, early analysis of the training needs and the fidelity implications of any proposed content (task, context, interactive). Also needed is a technical appreciation of the delivery capabilities of current hardware and software toolkits, including performance limitations relating to the exploitation of real-time or animated 3D graphics, video, sound and other multimedia material. As is the case with HMDs (Section 3.4.2), mobile computing technologies are also increasingly playing a role in Augmented Reality communities, often providing a form of "window on the world" display, combining "on-the-move" video, as captured by the device's in-built camera(s) and processed in parallel with inbuilt GPS sensors, with additional real-time text, images and animated or real-time virtual material.

Early research conducted by the HFI DTC addressed the use of Apple *iPod Touch* and *iPad* technologies for presenting the content of two of the case studies described later in this document — *SubSafe 1* [8] and *EODSim* [17]. In both instances, it was found that these two computing devices were unable to cope with the complex geometries, textures and environmental effects that were achievable using PC platforms. Removing considerable amounts of visual detail certainly led to demonstrators that enabled the *iPod* and *iPad* to handle some — but not all — real-time elements. It was felt that the i3D databases had been compromised so much that their impact on effective learning (spatial awareness in the case of *SubSafe* and explosive ordnance situational awareness in the case of *EODSim*) would be severely compromised. To overcome some of these concerns, a short developmental investigation was undertaken with the *SubSafe* database. To demonstrate how



**Figure 6**

It is not acceptable simply to transfer conventional or legacy learning assets — unmodified — to a "high-tech" or popular mobile computer in the hope that this alone will motivate trainees to engage with the learning content.

a combination of non-3D interactive data could be used in combination with limited 3D models of individual submarine compartments, an early solution enabled *iPod Touch* users to visualise a virtual submarine alongside a wharf, similar to the PC-based implementation described in the *SubSafe 1* Case Study [8] (see also Figure 34). On approaching the virtual submarine and security hut (or "trot box"; Figure 6, top two images), they were presented with a 2D side elevation schematic of the vessel which, using the *iPod* touchscreen, they were able to scroll left and right (Figure 6 – middle image), bringing the main labelled compartments into view.

On touching one of the compartments, they were then presented with a paragraph or two of text, accompanied by real-world images, describing the role and main safety-critical components of the compartment selected. It was then possible, via a simple touch input, to proceed to a navigable (albeit low physical fidelity) 3D model of that compartment (Figure 6, final image). Some relevant textures were supported by the toolkit used to implement the 3D environment on the *iPod*, but, in the main, the physical fidelity of the compartment was kept to a bare minimum, in order not to compromise the real-time performance of the *iPod* as far as was reasonably practicable. The users could return to the 2D descriptive information and/or the dockside view at any time.

Very similar issues were discovered during early evaluations of the *iPad* version of the *EODSim* demonstrator [17]. The simulated walkthrough and remotely controlled vehicle (RCV) driving activities were actually preserved – no intermediate 2D screens were necessary. However, the key limiting factor with *EODSim* for the *iPad* was low task and context fidelity (Section 3; see also Figure 67). In particular, it was felt the limited fidelity representations of the simulated urban context would compromise the development of a trainee's situational awareness and, thus, the formulation of appropriate Render-Safe Procedures (RSPs).

In addition to the significantly modified 3D for both the *EODSim* and *SubSafe* examples, the interaction style supporting real-time navigation through both the virtual submarine and town was unacceptable, due to the relatively large amount of screen real estate taken up by the active virtual control areas (in essence, two discs in the lower screen corners). This was especially the case with the *iPod Touch*, where, in addition, the absence of a good tactile sensation with the virtual controls resulted in numerous viewpoint movement errors, including motion axis "cross-talk", leading to unintentional – and frustrating – changes in direction.

Undoubtedly, the real-time graphics and data handling capabilities of these and other mobile platforms will develop rapidly over the coming years and on other platforms (including mobile telephones and other devices with very limited screen space). However, the potential benefits delivered by any improvements in the real-time processing power of these devices *must* take second place to (a) the training and operational need to use such equipment and (b) the Human Factors issues – including the impact on information uptake and effective learning – of interacting with small-scale multimedia material, from both a data display and data input perspective. New input and "add-on" display devices for mobile media and computing systems are being launched on a regular basis (and this is a trend that will, no doubt continue over the coming years). Some of the more recent devices are shown in Figure 7. Many of these devices are unproven, certainly from a Human Factors perspective. Some could be pure gimmicks, destined not to survive the marketplace for more than a few months at best. Consequently, extreme caution must be advised when considering their exploitation for mobile simulation projects. Just some of the issues with the products shown in Figure 7 include:

- Significant obscuration of available screen "real estate" by those controls designed to fit temporarily on capacitive touch screens



**Figure 7**

- Significant cross-talk may be evident between the movement input axes of small or thumb-actuated joysticks, leading to unexpected movements of on-screen objects/viewpoints (or, in some cases, no movement at all)
- Too few functions to support a simulation application from a single control device
- Poor ergonomics layout of available controls
- Poor integration (USB, wired, or wireless/via Bluetooth) between the interface device and the host device, leading to unreliable performance and software crashes
- Limited device software (especially for input devices), resulting in poor control laws and, often, very "staccato" on-screen movement

Finally, and in the opinion of the author, "enhanced" optical viewing solutions for devices such as the *iPod Touch* should not be considered for serious mobile computing applications, as image degradation, pixelation and the lack of credible applications warranting image presentation in stereoscopic form will undoubtedly limit the effectiveness of such viewers and could result in eyestrain, visual fatigue and frustration during operation.

# 4. Part One
# - Concluding Statements

If one actually believed the claims of the "purists" throughout the 1990s, Virtual Reality was, by the end of the 20th Century, destined to have helped computer users abandon the keyboard, mouse, joystick and computer display in favour of interfaces exploiting a wide range of natural human skills and sensory characteristics. They would be able to interact intuitively with virtual objects, virtual worlds and virtual actors whilst "immersed" within a multi-sensory, 3D computer-generated world. As is evident today, this brave new world simply did not happen. Despite sizeable early investments, national initiatives, expensive (and unexploited) international collaborative projects and the proliferation of hardware-heavy, so-called centres of "academic excellence", VR delivered very little of use to the global IT community. A handful of organisations actually adopted VR, but most were deterred from doing so by its complexity and cost. Today's VR supply companies have either passed away or are hanging on by a commercial thread. The academic centres have closed, or have been re-branded to fall in line with current research funding initiatives, or have simply become expensive technological museums. And the biggest mistake made by the VR community was that it ignored the human factor.

Well over a decade on and there is little doubt that games-based learning technologies have the potential to deliver much more than the promises and hype of their VR predecessors – affordability

and accessibility in particular. However, to do this, human-centred lessons must be learned. Interactive 3D media has to be designed in conjunction with its end users, identifying the skills that need to be trained or the knowledge that has to be imparted, and then delivering a solution based on appropriate content, fidelity and interactive technologies. Furthermore, the training solutions must be packaged in a form that can be delivered to the end users in their own working environments, as opposed to expecting them to exploit the technology in isolated and restricted laboratory environments. The solutions must be developed so that the end users can understand and benefit from their contents immediately, supporting *their own* modifications through simple-to-use shape, texture and behavioural editors. This is where yesterday's VR failed. This is where today's games-based interactive technologies have the potential to give the i3D community a second chance.

This booklet aspires to be an integral part of the "second chance scenario" and seeks – through case studies and lessons learned (as presented throughout Part Two) – to expose end users and development communities in the games-based training arena to Human Factors and human-centred design principles and techniques. By doing so, the overriding goal of the work is to help ensure that, in future simulation-based initiatives, "human pull" prevails over "technology push".

Human Factors is the study of the relationship between the human and his or her working environment. It makes no difference if the working environment is real or virtual. (Stone, 2008)

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PART TWO - CASE STUDIES

2

# CASE STUDY 1: Minimally Invasive Surgical Skills Trainer

## (Sponsors: Wolfson Foundation and Department of Health; 1995 to 2007)[4]

Figure 8:     The Minimally Invasive Surgical Trainer, *MIST*
Figure 9:     An Example of a Real Gynaecological
              Intervention (Left) and its *MIST* Virtual
              Counterpart (Right)



**Figure 8**

### SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The Minimally Invasive Surgical Trainer (*MIST* – Figure 8) was an influential project in the history of demonstrating the importance of the early application of Human Factors techniques to defining the fidelity of interactive 3D simulation tools. At a time when reports of failed laparoscopic interventions were prevalent in the press, the motivation behind the development of the *MIST* system was the need to improve surgical trainees' performance in basic "keyhole" surgical skills and to generate records of their level of competence. Legacy "box" trainers, containing a variety of synthetic materials, do not provide surgical instructors with adequate, objective levels of confidence relating to a trainee's competence to progress on to conducting a variety of laparoscopic techniques.

### HUMAN FACTORS ANALYSIS & KEY ISSUES

*MIST* was the subject of a Human Factors task analysis undertaken in operating theatres over a period of 4 half-days in conjunction with surgical subject matter experts. It was possible to isolate eight key task sequences common to a wide range of laparoscopic cholecystectomy (gall bladder removal) and gynaecological interventions and then define how those sequences might be modified or constrained by such factors as the type of instrument used, the need for object or tissue transfer between instruments, the need for extra surgical assistance, and so on. The tasks ranged in complexity from simple tissue holding and clamping (single-handed) to procedures requiring activities involving both hands and a foot, as were witnessed, for example, during diathermy cauterisation procedures.

### FIDELITY ASSESSMENT

Given the hardware and software technologies available at the time *MIST* was developed, it was highly unlikely that appropriate levels of realism could be achieved using models of human anatomy. Any attempts to do so would have undoubtedly led to distractive and non-credible experiences on the part of specialist surgical trainees. *MIST* fosters laparoscopic skills *not* by training on virtual human bodies, but on carefully selected task "primitives", such as spheres, blocks, cylinders and wireframe task volumes of low visual detail, or low "physical fidelity" (e.g. Figure 9). Each of these was designed following a psychological breakdown of the perceptual and motor behaviours of observed surgeons and in-theatre activities.

From an interactive technology fidelity perspective, the close "coupling" between the surgeon and the patient, via the laparoscopic instruments, drove an early decision to implement replica instruments, suitably modified to provide digital position and rotational inputs into the computer (Figure 8). Early feedback from the users of *MIST* confirmed that the provision of a realistic instrument frame did much to accelerate their acceptance of *MIST* as a surgical skills trainer. In addition to the use of realistic surgical instruments, offline video sequences of actual operations helped to relate the abstracted task elements to real surgical interventions.

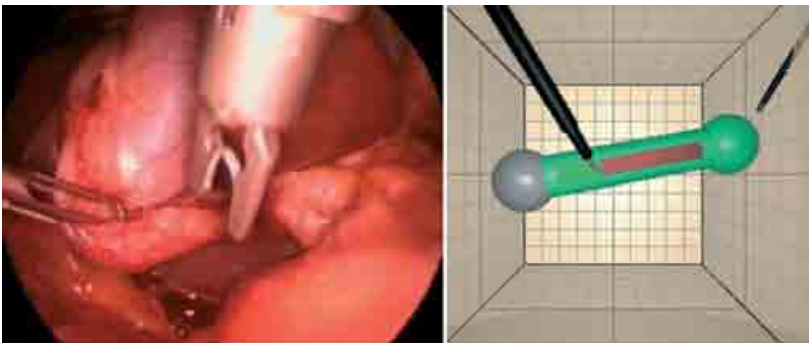[4]Original project conducted by VR Solutions Ltd.

**Figure 9**

## OUTCOME

For well over a decade, and with more clinical and experimental evaluation studies than any other simulation-based surgical skills trainer of its kind, *MIST* helped to train the perceptual-motor skills necessary to conduct basic laparoscopic manoeuvres involved in cholecystectomy and gynaecological minimally invasive interventions. In many respects the *MIST* trainer set the standard for a range of subsequent basic surgical skills trainers (including Surgical Science's *LapSim* and Simbionix's *LAP Mentor* products). In addition, the Human Factors "experience" with *MIST* has been influential in the development of guidelines relating to the use of appropriate task, context and interactive fidelities, proving (amongst other issues) that it is not always necessary to deliver high physical fidelity to achieve psychological fidelity, particularly for past-task skills simulators.

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# CASE STUDY 2: Mastoidectomy Simulator

**(Sponsors: European Union; 2000 to 2001)[5]**

Figure 10: Mastoidectomy/Temporal Bone Intervention in Progress
Figure 11: Stereoscopic Display and Haptic Interface (Left) and a View of the Simulated Volumetric Temporal Bone Model (Right)

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The term "mastoidectomy" refers to a surgical procedure during which volumes of mastoid bone (a prominent feature of the skull located behind the ear) are removed in order to tackle infection or to penetrate deep into the inner ear chambers and associated regions to locate cochlear implant transducers or excise cancerous nerve tissue (Figure 10). With strict and ever-increasing restrictions in access to cadaveric bones and the inadequacies of existing forms of training (synthetic bones and highly limited, two-dimensional multimedia software packages), a new form of interactive training was urgently required by instructors of temporal bone surgical techniques. Training requirements related to the development of fine manual skills involved in drilling through different bone densities and to the recognition of significant – and fragile – anatomical features (e.g. facial nerve and sigmoid sinus).
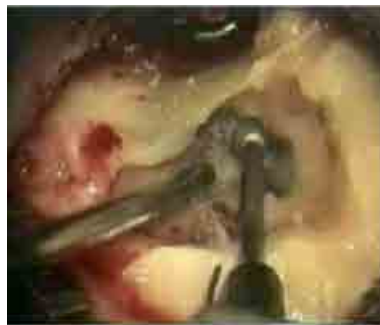


**Figure 10**



**Figure 11**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

Supported by European Union (EU) project funding, the mastoidectomy task analyses were undertaken over a period of 3-4 half days whilst observing Ear, Nose and Throat (ENT) surgeons in theatre. In addition, actual "hands-on" experience using a cadaveric temporal bone was provided, in order to appreciate the role of haptic and auditory feedback in the drilling and burring processes, especially when the drill bits penetrate different densities of bone (from hard mastoid to deeper petrous bone). Commercially available training products (including artificial bone models and a somewhat limited 2D multimedia CD) were also evaluated.

## FIDELITY ASSESSMENT

The outcome of the task analyses drove the decision to adopt a *hybrid* physical fidelity solution (see Figure 11 and Section 3.1), based on:

- a simplified visual representation of the temporal bone region (omitting any features relating to the remaining skull areas or middle/inner ear structures);

- a sophisticated software simulation reproducing the physical effects of penetrating different layers of hard mastoid cortex and air-filled petrous bone with a high-speed drill;

- an interface consisting of a stereoscopic viewing system and two haptic feedback stylus-like controllers (*PHANTOMs*), capable of reproducing the force and tactile sensations associated with mastoidectomy and the vibration-induced sound effects experienced when drilling through different densities of bone.

[5]Original project conducted by VR Solutions Ltd.

## OUTCOME

Since completing the EU-funded element of the research and development programme, the results of the project have featured at 75 events, with over 20 articles published in the media (and many more in peer-reviewed journals). An educational CD has been created to complement the Tempo products and provide appropriate background for potential users. Exploitation into a marketable product still continues, but the project has spawned other R&D opportunities, including the exploitation of bespoke (patient-specific) interactive 3D images for pre-operative rehearsal and in-theatre consultation.

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# CASE STUDY 3:
## Interactive Trauma Trainer (ITT)

**(Stakeholder: Royal Centre for Defence Medicine; 2006)**

### SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The Royal Centre for Defence Medicine (RCDM) identified the need for a form of rapid familiarisation training relating to combat field hospital trauma procedures (Figure 12), particularly for those surgeons deploying to areas of conflict who had little or no prior trauma surgery training. Whilst it was accepted that the basic surgical skills required for trauma surgery were common to other forms of intervention – catheterisation, blood-testing, fluid administration, intubation, and so on – the conduct of said skills under significant time pressure was not. In addition, scepticism within the defence medical services as to the efficacy of interactive 3D simulation warranted the development and demonstration of a proof-of-concept solution. Another motivation for a trauma procedural simulator was a need to reduce the costs of training defence medics by endowing them with basic competencies prior to field exercises, such as those held at HOSPEX or at specially-organised field hospital exercises throughout the UK and elsewhere, and before specialist RCDM training, often held in Johannesburg.

### HUMAN FACTORS ANALYSIS & KEY ISSUES

The task selected for study and implementation related to a Zone 1 neck fragmentation wound, causing pulsatile haemorrhage, airway obstruction and rapid patient decline. With support from RCDM surgical specialists, interventional endotracheal intubation and cricothyroidotomy procedures using a cadaver were filmed and analysed, concentrating on graphical fidelity requirements, future training content and interactive styles (i.e. hands-on *vs.* animated sequences). Additional patient

preparation and handling analyses were conducted during field hospital trials, hosted by 33 Field Hospital. Both sets of observations provided invaluable information, not only relating to the nature and fidelity of the simulator content, but also to key decision stages in the procedure, thus enabling the developers to design a basic after-action review tool supporting "at-a-glance" reviews of trainees' performances (Figure 13).

### FIDELITY ASSESSMENT

The outcome of the analyses described above confirmed that the more dextrous tasks observed (e.g. Airway-Breathing-Circulation (ABC)) checks, use of catheters, Foley's Catheter (Figure 14), syringes, laryngoscope, stethoscope, intubation tubes, etc. should be committed to clear and meaningful *animation* sequences. It was confirmed by subject matter experts that trainee trauma surgeons would already be competent in handling standard items of medical equipment, with the possible exception of a laryngoscope (in which case, the intubation process would be conducted by a more experienced member of the team). Therefore, incorporating commercial off-the-shelf (and to a large extent, unproven) interface technologies in an attempt to reproduce the functions of surgical instruments, or the sensation of "hands-on" interactions with the patients, would have been both risky and costly, not to mention unnecessary from a Human Factors perspective. The ITT, therefore, was designed to deliver *decision-based training* with the aim of enhancing or refreshing the *knowledge* of those defence surgeons being deployed on operations – many of whom may not have had prior exposure to trauma incidents and procedures. In order to foster the correct decision-making behaviours under the pressure of time, the ITT presents trainees with high physical fidelity scenes of the hospital tent environment, not to mention the patient himself. At certain stages throughout the 5-minute virtual life-saving procedure, multiple-choice questions are displayed relating to procedures such as blood testing and fluid administration. Medical instruments are



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**Figure 12**



**Figure 13**

also displayed to a high level of physical fidelity, as are the animations depicting their application to, and effect on the virtual casualty. However, to interact with these high physical fidelity items, the end user only has to undertake simple mouse movements and mouse button clicks, indicating which item he or she requires and where he or she wishes to apply that item.

The Interactive Trauma Trainer was the subject of a number of examples of hyperfidelity (see Section 3.3), both proposed and actual. Some of these were not evident in the final concept demonstrator deliverable, but two are worth mentioning briefly here. During the ABC animation sequence, as the animated representation of the user's hand moved the virtual stethoscope towards the casualty, the tube flailed quite dramatically around the scene which many end users found both comical and distracting. The second example of note related to the virtual "reflection" effect when using the laryngoscope in conjunction with the suction and intubation tubes (Figure 15). Some users noted – having stopped the

intubation procedure – that the reflection on the laryngoscope surface was impossible, in that it depicted the casualty's body, Disruptive Pattern Material (DPM) trousers and nurse – all on the other side of the instrument – instead of parts of the surgeon's own virtual body.

## OUTCOME

Again from a Human Factors perspective, the ITT project was quite successful, in that it confirmed the importance of an early human-centred design input in order to avoid the issues of task, context and interactive technology fidelity, as described earlier in this document. However, the UK's defence medical fraternity did not express a strong desire to pursue simulation for trauma surgery and associated processes at the time the ITT system was delivered and evaluated. Informal evaluations did occur – a system was taken to Johannesburg, for example, where it was quite favourably received. The experiences gained as a result of the ITT project were successfully applied during the development of the US virtual healthcare system, *Pulse!!*, which was funded by the US Office of Naval Research and coordinated by Texas A&M University, Corpus Christi (see Figure 16).

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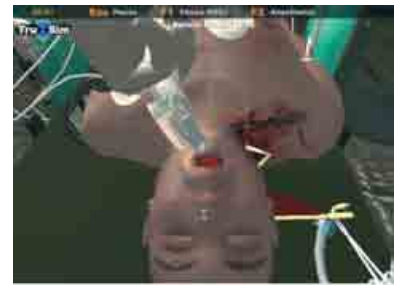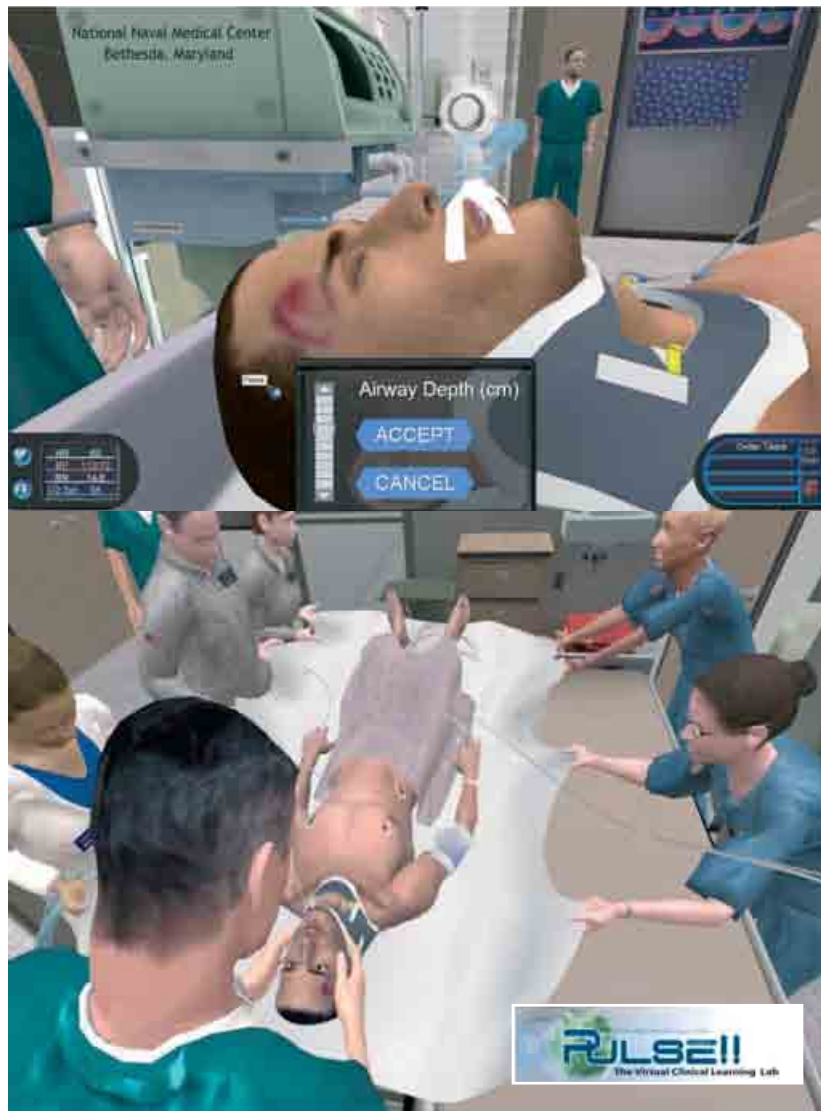


**Figure 14**



**Figure 15**



**Figure 16**

# CASE STUDY 4:
# PTSD Therapy Support Tool

**(Stakeholder: Joint Medical Command (Psychology); 2006)**

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

Presentation of the Interactive Trauma Trainer described under Case Study 3 to members of the MoD Surgeon General's Research Strategy Group elicited an enquiry from defence psychologists relating to the use of games-based simulation technologies for supporting various forms of symptoms and behaviours following post-traumatic events. Previous research, addressing the use of Virtual Reality to the treatment of various phobias and symptoms following major catastrophes, such as the 9/11 attacks in 2001 on the New York World Trade Center, had already been extensively published. The challenge in the case of the UK research was to evaluate whether or not multi-sensory environments of suitable fidelity could be used to support clinical sessions for returning military personnel – possibly complementing, even replacing some of the imaginal or exposure therapies currently in practice. A related area of interest expressed by the defence psychology stakeholders was the extent to which similar technologies could be used to help desensitise military personnel to some of the incidents they might experience during pre-deployment briefings ("stress inoculation").

## HUMAN FACTORS ANALYSIS & KEY ISSUES

Early stakeholder briefings identified two key factors in the delivery of an appropriate therapy support simulation tool. The first was the delivery of accurate representations of scenarios relevant to the Post Traumatic Stress Disorder (PTSD)-eliciting experience(s) of the patients and a means by which the therapist could select, edit and trigger stimuli before and during a therapy session. The second, and perhaps most critical issue, was to assess whether or not such a virtual environment tool could deliver appropriate scenarios within a week or so of the first clinical assessment having taken place. Such a rapidly reconfigurable and cost-effective tool, it was felt, could offer great potential in future MoD duty of care processes.

From an interactive technology perspective, the use of so-called "immersive" VR equipment, as was used in US programmes at the time, also needed to be addressed. This was because it was unclear whether or not the use of head-mounted displays, spatial tracking systems, hand controllers, olfactory units and vibro-tactile stimulation systems, and so on was an appropriate path to follow, especially given the cumbersome nature and lack of sophistication of some of the "non-traditional" technologies involved (e.g. see Section 3.4), not to mention the additional sensory deprivation these technologies could quite easily provoke when used by patients with psychological trauma.

## FIDELITY ASSESSMENT

To develop a virtual environment of appropriate fidelity for the concept capability demonstrator, many sources of information were exploited, from Web-based images of Iraqi urban settings to support from the Armed Forces in helping to acquire specific images and sounds (such as those relevant to a Warrior armoured fighting vehicle (AFV), which was to play the role of a "safe haven" in some virtual scenarios). The military also provided Army personnel clothed in various assemblies to assist in the accurate



**Figure 17**

modelling of 3D Army avatars. The communications security personnel provided sound files of radio "chatter" scenarios relating to fictional incidents and threat escalation, as might be witnessed by a Middle East patrol.

These assets enabled the development of what was, at the time, a medium fidelity 3D model of an Iraqi street, together with a typical, medium-sized Army camp (Figures 17 and 18) and a desert convoy route that, on departure from the camp, progressed from a backdrop of open sand dunes to a partially abandoned town. The latter scenarios were designed to demonstrate how progressive visual complexity could be added to a basic desert scene over time, introducing military vehicles, the camp itself and truck transit from the camp to the town.

During the later stages of this project, an opportunity presented itself that enabled the research team to conduct an early evaluation of the same olfactory (smell) technology that was being used by the US PTSD and VR researchers. Interest was also shown by certain quarters of the MoD in the levels of olfactory realism that could be achieved in future Iraqi and Afghanistan pre-deployment patrol familiarisation simulations (Section 3.4.5). In brief, the system evaluated took the form of an 8-chamber, pressurised air dispenser, with compressor and a selection of paraffin-impregnated scent pots. Unfortunately, an early assessment of the technology drove the decision not to use it as part of the PTSD simulation tool (nor the patrol familiarisation system), due to three fundamental limitations. Firstly, the noise

**Figure 18**

generated by the compressor was far too high to be concealed and acted as an auditory cue to the dispersal of the scents long before they were detected via the recipient's nose. Secondly many of the individual scents were not judged to be representative of the smell features on the label (indeed there may be some cultural issue at work here with regard to US and non-US users). Finally, the system seemed to be incapable of removing old scents once released, which either masked or combined with subsequent releases to produce unpleasant effects. More recent technological developments, using a more compact USB "plug-and-play" system (again sourced from the US), appear to have overcome a number of these problems. The *ScentScape* system consists of a replaceable tray comprising 20 chambers, each containing a small amount of a synthesised scent (the scents can be chosen from a list of alternatives provide by the vendor). Underneath the chambers is a matrix heating element which enables the simulation developer to activate specific scents using software commands. Once the heater is activated, a small (and quiet) fan channels the vapourised olfactory stimulus towards the face of the end user.

**Figure 19**

## HYPOFIDELITY EXAMPLE

The town scenario presented an example of the problems associated with hypofidelity (see Section 3.3). Whilst the early part of the AFV approach routine was very engaging, the scenario was let down by the avatar hypofidelity in the latter stages of the demonstration. In particular, issues were raised relating to the presence of a crowd in the vicinity of the AFV, with accompanying shouts, screams, local gunfire and an explosion during the early part of the approach (Figure 19). Unfortunately, the size and (rather simplistic) visual arm and hand-waving behaviour of the crowd did not match the level of crowd activity suggested by the background sound effects. Another issue related to the reliance on pre-programmed avatar behaviours (delivered with the game engine and editor) to create "realistic" loitering behaviours. Whilst some of the loitering behaviours were acceptable in this context (glancing, turning on the spot, neck scratching), others were not, such as shoelace tying whilst the avatar was positioned with his back to the crowd. This is, in fact, a common problem with many gaming technologies to this day.

## OUTCOME

Despite a recognition that the quality of the virtual environments demonstrated as part of this project were of a very high quality (especially in comparison to the images delivered by other software packages at the time), there were mixed responses on the part of the development team and stakeholders with regard to the simulation's use in developing credible scenarios relating to individual patients' needs and early clinical assessments. One important finding was that, despite the rapid 3D world building capabilities of the games software employed, it would be almost impossible to capture all of the events that lead to the triggering of an individual's personal PTSD experience. Even if one had all of the programming and technical resources of a very large commercial gaming organisation, the production of a highly client-specific simulation within a week or two of an initial psychotherapist referral would be a huge challenge, not to mention prohibitively expensive. This was especially the case for dynamic simulated combat scenarios, where, high levels of fidelity are essential to engage, or "immerse" the patient (and this comment applies as much to non-playable characters or avatars, which still, today, fall far short of the requirements for believability, as it

**Figure 20**

does to the virtual environment in general). Furthermore, there is a belief amongst some UK defence psychologists that recreating combat events in the treatment of PTSD can cause more psychological damage than it solves.

Consequently, the decision was taken to abandon the approach to developing a tool specifically targeting PTSD therapy and to focus instead on more generic tools for promoting mental restoration, well being and rehabilitation by concentrating on generic simulation tools like the Virtual Restorative Environment Therapy system described in Case Study 5. It should also be noted that the "stress inoculation" idea was never taken any further. Finally, the virtual Iraqi street was re-used as a backdrop for other games-based simulation demonstrators, including an early counter-IED project involving the *Cutlass* remotely-controlled vehicle (Figure 20 – see also Case Studies 17 and 19).

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# CASE STUDY 5: Virtual Restorative Environment Tool

**(Stakeholders: Joint Medical Command (Psychology), RCDM and QEHB; 2011)**

Figure 21:  "Work-in-Progress" Screen Capture of "Virtual Wembury"
Figure 22:  Early Image of Participant Testing (the Participant is using a Thumb-Actuated Joystick Unit and has a Pulse Oximeter on the Middle Finger of his Left Hand)

## SUMMARY & KEY REQUIREMENTS

Research conducted since the late 1970s suggests that exposing individuals to natural environments, such as rural and coastal settings and smaller-scale urban areas with natural features (gardens, parks, etc.) can promote stress reduction, enhance mental recovery following tasks requiring high levels of attention, even reduce post-operative recovery times and the need for pharmaceutical pain relief. These "restorative environments" are now recognised as powerful tools in the treatment of a range of psychological conditions and a number of initiatives are being launched to encourage engagement with the natural environment to promote both physical and psychological well-being. This project aims to exploit simulated or "virtual" restorative environments to deliver similar benefits to those individuals who are unable to access and experience real natural environments, such as those in hospitals or civilian and military rehabilitation centres presenting with a variety of psychologically-related conditions (e.g. PTSD, depression, pain and sleep deficit). More recently, the research has been extended in collaboration with the Royal Centre for Defence Medicine (RCDM) and Queen Elizabeth Hospital Birmingham (QEHB) to assess how the same restorative virtual environments can be developed further to deliver contextually-relevant activities, such as canoeing, snorkelling, hang-gliding, etc. Such developments, it is believed, will provide further support to the physiotherapy régimes offered to amputees, and will help avoid muscular atrophy prior to the fitment of bespoke prosthetic devices. The work is also being evaluated with the aim of proposing new techniques for combating phantom limb pain (PLP).

## HUMAN FACTORS ANALYSIS & KEY ISSUES

The Human Factors analysis associated with this project is very much one of early experimentation and technology evaluation. These stages of the research are focused not only on the development of virtual environments of appropriate fidelity (integrating visual, auditory and olfactory qualities), but also on the development of a suite of wearable/wireless psycho-physiological measurement sensors, in conjunction with subjective measures of participants' reactions to these virtual environments (e.g. galvanic skin response, heart rate, basic electroencephalography, together with miniaturised eye tracking and pupillometry systems – see Figure 22). Also under investigation are optimal techniques for allowing end users to interact freely with the environments. This includes an assessment of different data input devices (including Microsoft's *Kinect* for amputee interaction) as well as data display (plasma screens, new, lightweight head-mounted displays, projection screens, etc.). Other projects are addressing the use of digital still and video images to deliver restorative effects. However, this project is focusing on the exploitation of virtual environments so that additional features can be added on a regular basis in order to preserve the longevity of the experience. Such features include incorporating seasonal changes and time-of-day effects, adding new objects and activities (especially for the rehabilitation and PLP extensions to the project) and allowing end users to choose their own locations to witness environmental changes and other events (including underwater or from the air).



**Figure 21**

**Figure 22**

## FIDELITY ASSESSMENT

Two virtual reconstructions have been chosen, based on real-world locations – Wembury Bay and Burrator Reservoir, both scenic locations in the southwest of the UK. The reason for choosing real-world locations relates to a future desire to conduct virtual *vs.* real comparisons, using some of the physiological sensing equipment described above. In addition, whilst working with other organisations in the region (such as the National Marine Aquarium - NMA and the European Centre for Environment & Human Health - ECEHH), there is considerable potential to spin-out the results of this work into civilian applications. To construct the two initial virtual environments to an appropriate level of topographical detail, digital terrain elevation data (DTED) at a point-to-point resolution of 12.5cm have been used, together with high-resolution aerial imagery of the sites (25cm for Wembury, 12.5cm for Burrator). The aerial imagery was pasted onto the converted DTED 3D meshes to provide a template for the placement of natural and man-made objects (Figure 21). Most of the man-made objects within the Wembury virtual environment are at a distance from the main natural areas, so could be modelled and textured at lower resolutions. Many of the natural features of these environments – from plants and trees to dynamic mist effects – are readily available from Web sources, at appropriate levels of fidelity. Others have been modelled and textured from scratch, using appropriate commercial toolkits.

Lighting and shadowing is all-important in enhancing the believability of these environments and, as well as four pre-set times (dawn, midday, dusk and night), the simulation allows the environmental quality to change depending on the real time of day (including sound effects). Example images can be seen in Figures 21 and 23. The integration of high-quality 3D sound effects is considered to be an essential part of these virtual environments. The acquisition of low-cost, high-fidelity coastal sound effects, including ocean waves, wind, birdsong and

so on have transformed the simulation over and above the presentation of visual effects *per se*. The addition of simulated footsteps has also been found, subjectively, to enhance the sense of presence. This is a potentially valuable effect that has been documented elsewhere in the research literature, although additional consideration needs to be given to the nature of the virtual surface upon which the user is "walking", so as not to provide inappropriate auditory fidelities. Other sensory effects are under consideration, including simulated breezes and smells. However, due to the immature nature of these effects, they remain a future research aspiration and will be evaluated as the technologies evolve. A final comment with regard to fidelity also relates to the engagement of the end users, particularly those in, for example, military medical institutions, such as QEHB and the Defence Medical Rehabilitation Centre at Headley Court. Observational evidence suggests that many of the patients at the facilities continue to enjoy playing first-person action games such as *Call of Duty*. One therefore has to question the "appeal" of walking along a virtual beach when compared to the dynamic nature of present-day "shoot-'em-up" games! At the time of writing, work is underway to engage with military patients, exposing them to early versions of the virtual environments, to emphasise the rationale behind the "sedate" nature of said environments and to seek their input with regard to future interactive developments.

Figure 23:   Time of Day Effects - Sunrise and Midday
- at Virtual Wembury Bay



**Figure 23**

## OUTCOME

This particular Case Study describes the early (Summer, 2011) stages of a simulation project that has the potential to revolutionise immediate post-operative recovery régimes and subsequent rehabilitation treatments. As such, the exploitation of the research has not yet taken place, although the deployment of an informal evaluation system within QEHB before the end of 2011 is a very encouraging development. Nevertheless, experiments using non-hospitalised participants (Figure 22) are being conducted, with the aim of producing results to confirm (or refute) that these virtual environments can effect similar psychological changes to their real-world counterparts. In the meantime, other features are being added to both virtual environments on a regular basis, to prevent them from becoming "stale" and to help to further "draw in" the attention of the end user. In the case of the Wembury Bay model, for example, marine craft appear in the Bay, together with distant ferries (as if sailing from nearby Plymouth) and, at night, the sweeping light of the Eddystone Lighthouse. The project is also demonstrating considerable civilian spin-out potential, via, for example, the ECEHH, the National Trust, Devon Wildlife, Wembury Marine Conservation Centre, the National Marine Aquarium (NMA), vascular medicine specialists (for the provision of support for patients with diabetes-related amputation), and palliative and end-of-life care.

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# CASE STUDY 6: Close-Range 20 and 30mm Weapons System Trainer

**(Sponsor: Naval Recruitment & Training Agency; 2002)[6]**

Figure 24:  Overhead View of the Original 20mm Virtual Gunnery Position at HMS Collingwood
Figure 25:  Own-Ship Virtual 20mm Location Engaging Helicopter
Figure 26:  Examples of Low-Fidelity "Targets"

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The requirement to close the naval gunnery ranges at HMS Cambridge in South Devon in 2001 was attributed to the increasing costs of live ammunition (at that time around £1.5 million p.a.), annual maintenance of the coastal base (unknown) and the expense incurred when flying towed targets (around £1.9 million p.a.). A Training Needs Analysis sponsored by the Navy Board concluded that there was an urgent need to replace the live firing facility with procedural gunnery trainers that would allow students to interact realistically with close-range weapons, under the supervision and instruction of Weapons Directors. The Close-Range Weapons System (CRWS) subsequently installed at the Maritime Warfare School (HMS Collingwood) — Figure 24 — was the result of a competitive tendering process designed to elicit "innovative" proposals for a Virtual Environment trainer for the 20mm and 30mm weapons, together with a fall-of-shot "spotting trainer" for the 4.5" Mk8 gun. A later development saw the installation of a basic General Purpose Machine Gun (GPMG) trainer.



**Figure 24**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

Human Factors observations were conducted during live firing trials at HMS Cambridge, prior to the closure of the base, and at weapons emplacements onboard naval vessels moored at HM Naval Base Devonport. In brief, a Weapons Director Visual (WDV) is located on a raised part of the deck (the Gunner Director's Platform, or GDP) and is responsible for relaying target type, bearing and range data from the ship's Operations Centre to the gunnery team and supervising the final stages of the engagement procedure (using binoculars).

The most common close-range deck-mounted weapon in the Royal Navy at the time of the project was the 20mm "Gambo" (Figure 24), a single-barrelled cannon with a range of 2km, capable of firing 800-900 rounds per minute. The aimer adopts a standing posture with this weapon, relying on his/her weight to provide the momentum to move the weapon in azimuth and elevation. A harness supports the aimer's back — an important feature, especially in some late engagement activities, where the aimer can adopt a backward-leaning posture to elevate the

barrel to around 75-80°. At sea, targets are acquired through an RC35 sight, mounted on the top of the weapon, parallel to the main axis of the barrel.

In the case of the second weapon involved, the 30mm cannon, aimers sit in an open "cabin" and, via a small control panel and hand controllers, move the gun mounting in azimuth and the barrel in elevation. At sea, targets are engaged via a similar sight to that used on the 20mm weapon. However on the 30mm system the sight is mounted on a metal bracket that supports it in front of the operator's face. In the case of non-availability of live ammunition, all of the above procedures were followed, up to the point when actual firing would normally take place, whereupon the trainees were required to engage the firing mechanism and shout "bang, bang"!

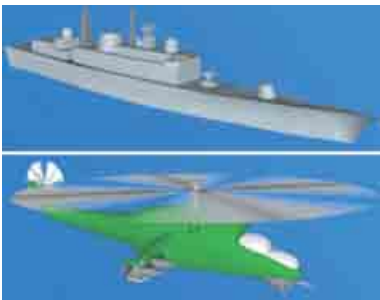[6]Original project conducted by VR Solutions Ltd.

**Figure 25**


**Figure 26**

## FIDELITY ASSESSMENT

It was obvious from the Human Factors observations at HMS Cambridge that a completely virtual implementation of the CRWS would not help trainee aimers to acquire the necessary skills to manipulate the weapons in subsequent real-world firing trials and operational settings. It was therefore concluded that the simulation should be built around inert versions of the 20mm and 30mm weapons, so that the motion characteristics and constraints imposed on both seated and standing operators of both weapons, particularly on target acquisition in azimuth and elevation, could be reproduced, thus adding to the realism of the training sessions. In addition, the regular head movements observed between the weapons aimers and the WDV, coupled with the visual scanning of the horizon and the tracking of close-in targets on the sea surface and just above, independent of weapon movement, drove the conclusion that a helmet-mounted display (HMD) and head-tracking solution was desirable in this instance. However, in order to enhance the simulation experience and with operational health and safety in mind, a non-face-enclosing HMD was chosen, affording the end user peripheral views of their arms and of their immediate real working environment, including the fire control levers on the 20mm weapon and the control panel on the 30mm (see Section 3.4.2 and also Case Study 21). Furthermore, given the ranges over which these visual activities were active, not to mention the limitations in HMDs in presenting reliable and consistent stereoscopic images, the need for 3D viewing was judged unnecessary. Consequently, the virtual imagery was presented *biocularly* (the same rendered image being presented to both eyes). The physical weapon sights were removed from the inert weapons and reproduced virtually, thus allowing aimers to align the virtual reconstructions of their weapons with the virtual targets. The sights removal allowed for the mounting of multi-axis tracking systems, so that the movement of the physical weapons could be recorded. Additional trackers were mounted on the

aimers' HMDs, supporting head movement independent of weapon movement.
The visual fidelity of the scenes and targets presented to the aimer trainees via the HMD was kept relatively low (see Figures 25 and 26), due to the distance at which engagements would occur and the high simulated speed with which some of the targets would approach their virtual own-ship.

Anecdotal evidence from HMS Cambridge and Collingwood instructors suggested that one of the problems encountered during the training of novice weapons aimers was that of "freezing" just before operating the firing mechanism. It was further suggested that the sound and recoil of the weapons – observed by trainees prior to their own session – might be responsible for this form of "anticipatory response". However, technical recommendations from the weapons manufacturers suggested that considerable damage could be caused to the inert weapons through the implementation of simulated recoil (such as that provided by a gas blowback system, for example). Consequently, physical recoil was omitted from the final simulation, although attention was given to the quality of the firing sound recordings (captured earlier at Cambridge), to include at least some form of "shock" stimulus during the engagement process. A simulated visual representation of barrel recoil was also provided, although this was not always visible, due to the low resolution and field of view of the HMD used. Motion base technology was also considered but not included, due mainly to cost constraints, but also to the fact that it was felt that the virtual sea state effects implemented would, when viewed through the HMD, generate an adequate sense of own-ship motion. However, the health and safety concerns with the HMDs used (see Section 3.4.2) meant that, with additional simulated ship motion, even greater attention needed to be paid to adverse effects of the simulation on the user, especially the incidence of postural instability when leaving the CRWS facility.

**Figure 27**

## OUTCOME

The CRWS facility (the 20mm section of which is shown in Figure 24; the 30mm in Figure 27) has been used by the RN since its installation in 2001. Including the expense of modifying the structure of the hall in which the CRWS guns are located plus the development of a Virtual Director Aimer Sight system (for the 4.5" Mk8 gun fall-of-shot training) located elsewhere at HMS Collingwood, the final cost of the simulation system to the RN in 2000 totalled approximately £730,000. Ignoring the estate costs for HMS Cambridge in the years prior to its closure, the early annual savings delivered by this simulation suite amount to £2.7 million. This is based on the cost of 20mm and 30mm ammunition live firings, plus the cost of aircraft-towed targets mentioned earlier (£3.4 million). In the first year of operation, around 1.2 million virtual rounds of ammunition "fired" were recorded (*ab initio* Student throughput totalled 329, spread over 55 courses). In addition, it was calculated that the live firing downtime that was avoided due to previous foul weather conditions at HMS Cambridge amounted to some 33%. Even though the CRWS was only ever procured to support "the training of safe procedural training in peacetime", anecdotal reports from live firing trials off Gibraltar during the years following the installation of the CRWS at HMS Collingwood suggested that those naval ratings who had experienced this form of training performed to a superior level of aiming accuracy than those who had not. The Royal Navy soon acknowledged the immense utility of the system, delivering training (at no cost to the Fleet's ammunition budget) from the most basic procedures to advanced Rules of Engagement in all weather conditions, day or night. At the time of publication (February, 2012), it is understood that the existing CRWS at HMS Collingwood is being upgraded.

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# CASE STUDY 7: Minigun "Desktop" Trainer

**(Stakeholder: Maritime Warfare School, HMS Collingwood; 2006)**

Figure 28: Minigun "Desktop" Simulator Demonstrator
Figure 29: Live-Firing Minigun Trial
Figure 30: Virtual Minigun System. Upper Images - Medium Fidelity Target Models: Jet Ski with Insurgent and Own-Ship; Lower Images - Through-Sight Firing and 3D Minigun Model

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The Royal Navy (RN) has been retrofitting its vessels with a variant of the Dillon M134 Minigun, as a result of patrol experiences during Operation TELIC. In 2005, a challenge was issued by the Maritime Training Systems Integrated Project Team (MTS IPT) to develop, using appropriate human-centred design processes, a Minigun simulator. The aim behind this work was to establish whether or not games-based technologies could offer a credible onboard "desktop" alternative to the training of close-range weapon aimers within dedicated (and costly) land-based ranges or simulators, such as those in place at HMS Collingwood.



**Figure 28**



**Figure 29**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

Observations and "hands-on" experience of live Minigun firing trials were undertaken onboard HMS *Roebuck* (a coastal survey vessel) and the Type 42 Destroyer HMS *Edinburgh*, making use of simple targets constructed by the crews of the vessels concerned. Crewmembers, male and female from age 18 upwards, were given access to the weapons during these trials and many of these were debriefed after the event. From a Human Factors perspective, it became clear very early on in the observations that the main issue with the firing of this weapon was not restricted to aiming accuracy alone. The arming and safeing procedure (including a latched toggle switch), plus the pre-firing and post (check)-firing vocal instructions and responses between supervisors and aimers were considered of equal importance from a safety perspective. In addition, two of the key features of the Minigun when firing were also to play a key role in the simulation development – a momentary delay between pressing the thumb-actuated firing button and the first round entering the firing chamber and a

"kick-down" effect caused by the rapid acceleration and torque of the rotating barrel. These features were mentioned by trainees as contributing to their uncertainty about the behaviour of the weapon, both during their first hands-on exposure and at later stages as well. What appeared to happen was that, in the brief moment of firing delay, the trainees reacted by momentarily relaxing their grip. By the time they had done this, the round had chambered and firing had commenced. The weapon would then kick down. The trainee would instantly reapply a strong grip in order to recover control, but, in doing so, pulled the weapon down in a reactionary fashion. The pattern of rounds hitting the water around the target (e.g. Figure 29) would rapidly approach, then move away from the trainee's viewpoint. By the time the trainee had recovered from the kick-down, a considerable amount of ammunition had been expended, but the target had not necessarily been engaged successfully.

## FIDELITY ASSESSMENT

It became clear from the early Human Factors observations that attention should focus not only on the development of appropriate "own-ship", seascape and target virtual fidelities, but also on the development of hardware and software to recreate the electro-mechanical effects of firing delay and "kick-down" ("interactive technology fidelity" – see Section 3.4). Also as a result of the observations, and unlike the case for the Close-Range Weapon System development described in Case Study 6, the postures of the Minigun users indicated a close coupling [G1] between trainees and weapon, with outboard surveillance and engagement behaviours being marked by a very fixed relationship between the trainee's head and the LC40 Minigun sight. Just prior to firing, trainees were encouraged to bring their heads close in to the rear of the weapon, to gain maximum field of view through the sight. Throughout many of the Minigun trials, this posture was maintained by many of the trainees, even prior to firing. These observations drove the early decision not
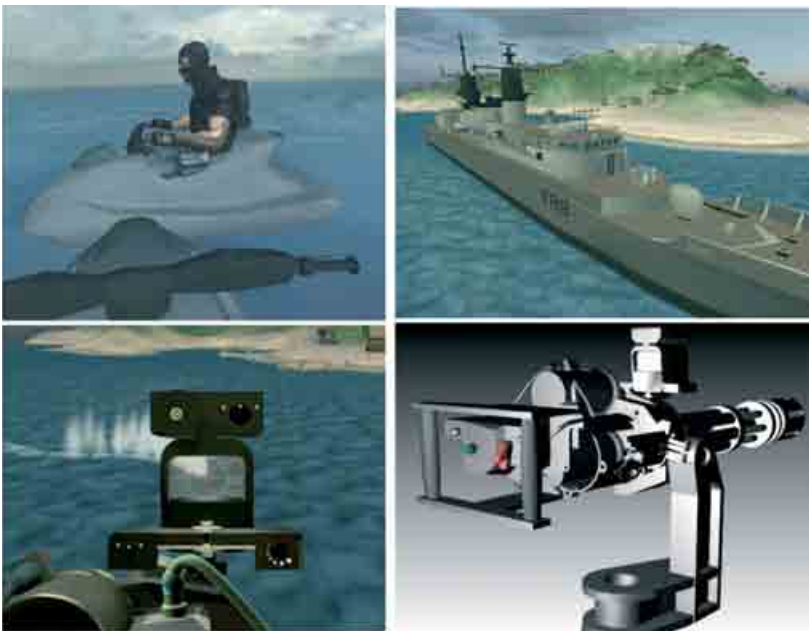
**Figure 30**

to follow a head-mounted display solution (which would involve tracking both the head and the replica weapon separately), but to implement a more reliable and cost-effective "window-on-the-world" system, linking a Liquid Crystal Display (LCD) screen to the physical interface, such that azimuth and elevation slewing motions would account both for surveillance and aiming behaviours (Figure 28). Medium-fidelity targets were developed, as they were likely to come into close visual range, unlike the typical case for the CRWS described in Case Study 6. Target models included small high-speed craft, helicopters and jet skis (Figure 30, upper two images). A relatively detailed 3D model of the Minigun was "constructed" from scratch, but, in the event (and as a result of the "window-on-the-world" display solution), only a template of this model was included in the simulation. A small button on the side of the mechanical interface shown in Figure 28 simulated the bringing of the Minigun sight closer to the aimer trainee, resulting in more of the simulated image becoming visible through the virtual sight optics (Figure 30).

## OUTCOME

This was a highly successful project in terms of the delivery of a working example of a blended physical-virtual simulation solution, even though evaluations of the technology with stakeholders were not possible. The mechanical kick-down and vibration implementation was not as effective as first thought and certainly warrants further investigation, as this was a crucial outcome of the earlier Human Factors investigation. In the event, HMS Collingwood proceeded with the build of a fixed-location training facility for Minigun aimers.

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# CASE STUDY 8:
# SubSafe 1

**(Stakeholder: Submarine Qualification (South), HMS Drake; 2006-2010)**

**Figure 31**

### SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

International submarine fleets are routinely deployed in support of a range of duties, from coastal protection and patrol to the support of scientific research in some of the most inhospitable places on the planet. With such a range of hostile natural and conflict-ridden environments, danger is inevitable and, since the year 2000, there have been a significant number of incidents involving submarines from some of the world's major sea powers[7]. Two specific incidents involving submarines of British origin stimulated a reassessment of the way in which submariners are trained, particularly with regard to their spatial knowledge of onboard safety-critical and life-saving items of equipment. The first occurred in October 2004, when the Canadian diesel submarine HMCS *Chicoutimi* (ex-HMS *Upholder*) was struck by a large wave whilst transiting the North Atlantic. The ensuing fire disabled nine members of the crew due to smoke inhalation, one of whom later died. The second incident occurred onboard the British nuclear submarine HMS *Tireless* in March 2007, whilst conducting under-ice exercises north of Alaska. During what should have been a routine lighting of a Self-Contained

### HUMAN FACTORS ANALYSIS & KEY ISSUES

Briefings and observations were conducted within the Submarine Qualification (SMQ) classrooms at HM Naval Base Devonport (HMS Drake), onboard submarines alongside (when available) and at sea with the crew of HMS *Tireless*. Opportunities

Oxygen Generator (SCOG) the unit exploded, resulting in two fatalities. Innovative technology-based techniques for providing safety training to submariners in a classroom setting, prior to exposing them to a real boat environment, have been under investigation in the US, UK and Australia since the early 1990s (see reference list). From 2006 onwards, interest in the virtual submarine concept accelerated, not only with regard to the levels of visual and functional quality that could be achieved through the use of gaming technologies, but also with regard to the evaluation of such tools in real classroom settings. In addition, with smaller numbers of more capable submarines becoming the norm in the RN, vessels alongside for training purposes can no longer be guaranteed. *SubSafe 1* (Figure 31) was the result of this accelerated interest.

were provided to photograph and measure each compartment forward of a particular point in the *Trafalgar* Class vessels. Note that aft of this point lies the reactor compartment, manoeuvring room and machinery spaces. For security reasons, these areas were not included in the *SubSafe* demonstrator project. In many of the accommodation and messing spaces, important valves were located behind seating cushions and bunk cupboard doors. In an interactive style similar to that adopted for the earlier *Tornado* ATF project (Case Study 20), it was decided that a click-and-remove function would be implemented in the simulation, such that the removal of cushions and opening of doors would be animated to expose underlying objects and a subsequent click would "extract" the object of interest and allow its rotation on-screen.

All objects of relevance to the SMQ training would be associated with a label, such that, during deck-by-deck, compartment-by-compartment navigation, "active" objects would appear to the trainee when an on-screen circular indicator (which was permanently slaved to the movement of the end user's mouse-controlled view) was placed over the object. A simple plan view of the current deck was also deemed to be a useful feature to help with early navigation – recognition of port and starboard, forward and aft, and so on (Figure 32). Movement through the submarine (and on the dockside) was to be kept as simple as possible. Consequently, a basic keyboard input solution (with mouse movement controlling the direction of view) was implemented, with ladder transits being governed by 3D arrows which appeared on approach to ladders between decks. Mouse-clicking a 3D arrow cue actuated a "teleport" function, making the transition between decks less frustrating than negotiating 3D ladder models (as is often found when playing first-person action games, for instance).

[7]http://en.wikipedia.org/wiki/List_of_submarine_incidents_since_2000.

**Figure 32**

## FIDELITY ASSESSMENT

Due to the complexity of a nuclear submarine, it was evident from the outset that, to develop an interactive 3D model featuring all vessels, valves, pipes, tanks, controls and so on would be prohibitively expensive and possibly not beneficial to the SMQ training focus. Consequently, extensive use was made of background textures, imparting a degree of medium fidelity to the submarine as a whole, but maintaining a familiar look-and-feel for instructors and trainees alike. This included the texturing of pressure vessel walls behind other items of equipment, to convey a sense of the density of pipework evident in many compartments. The geometric nature of the majority of the objects within the submarine was kept as simple as possible, again relying on textures to create immediately recognisable features and locations. Lighting effects were kept constant throughout the boat and no sounds were in evidence.

## HYPOFIDELITY EXAMPLE

An interesting example relating to the notion of *hypofidelity* (see Section 3.3) was noted when presenting *SubSafe 1* to instructors and officers for the first time. When boarding the virtual submarine, comments regarding the static nature of the vessel's flags and the water surface were often made, despite the fact that these features bore no relevance to the delivery of instructional material relevant to spatial awareness. However, as this was not the only time background contextual features played quite a significant role in the early acceptance of simulated scenarios (see also Case Studies 4 and 14), the comments were noted and revised in a subsequent iteration of *SubSafe* (see case Study 9)

Figure 33:  *SubSafe* Modifications for HMS *Tireless* Coroner's Court of Inquiry Animation

Figure 34:  *SubSafe* "Mobile" - Small Interactive Sections of theVirtual SSN on *iPod Touch* (Left) and *iPad* (Right)

## OUTCOME

The first *SubSafe* demonstrator was delivered in the form of a first-person walkthrough simulation, although the software did possess two or three "gaming"-like implementations, including a "treasure hunt" mode, where trainees were presented with a target item to find and time limits in which to find it. These modes were never used during the classroom evaluations of *SubSafe 1*, as the walkthrough mode was found to be more than adequate for the purposes of SMQ instruction. Another option took the form of a short simulation illustrating the importance of donning emergency breathing apparatus to evacuate a smoke-filled compartment. On being surrounded by smoke in the weapons stowage compartment, trainees had to locate an Emergency Breathing System (EBS) mask from a nearby container, "don" the mask and then, by pointing and clicking, locate ceiling-mounted low-pressure air connectors to replenish their virtual air supply in order to evacuate the compartment safely.

A statistical analysis of knowledge transfer data, collated over a year of experimental trials undertaken in collaboration with the SMQ (South) personnel at HM Naval Base Devonport, revealed that use of the simulation during classroom training significantly improved the final "walk-round" performance of students (onboard an actual submarine) when compared to that of a control group. Further experiments have investigated the optimum presentation times for *SubSafe 1*, comparing a single exposure of the simulation to SMQ students at the end of their 6-week training régime to course-specific exposures during weeks 2 to 4. Significant attitudinal changes have also been recorded, with participants responding more positively to the notion of using games-based simulation in mainstream RN training after exposure to *SubSafe 1*.

In addition to the experimental trials with this first version of the *SubSafe* trainer, the simulation was modified to provide an animation sequence for a UK Coroner's Court of Inquiry in 2009 relating to the HMS *Tireless* SCOG incident, mentioned earlier (Figure 33). In conjunction with a narrative presented by an RN senior officer, the animation demonstrated the location of the explosion, the subsequent smoke propagation throughout the forward sections of the boat and the activities of the crew in attempting to rescue casualties within the Forward Escape Compartment. The *SubSafe 1* real-time simulation was also used during the Courtroom proceedings, to help familiarise attendees with the layout of a *Trafalgar* Class submarine.

Interest in *SubSafe* has also stimulated the development of other concept demonstrators, including the simulation of a submarine rescue scenario, where the user has to rendezvous and dock a rescue submersible with a disabled *Kilo* Class submarine using a typical gaming hand controller whilst viewing simulated underwater images through the submersible dome and external CCTV cameras (see Case Study 10). Another safety-related demonstrator focused on the deployment of $CO_2$-absorbing Lithium Hydroxide "curtains" within the Forward Escape Compartment and the constraints these curtains impose on available crew space. These additional projects demonstrate how the *SubSafe* simulation can be re-used for design and ergonomic evaluation purposes, as well as training.

At the time the first iteration of the *SubSafe* demonstrator was being delivered, interest was being shown throughout the Royal Navy in the possibility of exploiting small, hand-held mobile computing platforms for educational purposes, such as the Sony *PSP*, or the Apple *iPod Touch* and *iPad*. With this in mind, *SubSafe Mobile* was developed, mainly as an exercise to demonstrate the important Human Factors issues associated with hosting i3D media on small delivery platforms. Some of the recommendations from this informal investigation (based only on *iPod Touch* and *iPad* implementations – Figure 34) have been provided in Section 3.4.6 of this booklet. Needless to say it was impossible to host all of the 3D geometry on the devices and this limitation led to a rethink as how best to allow users to access the important training-related material (again summarised in Section 3.4.6). It was clear that the effective use of training material on platforms such as these was not simply a case of reproducing Virtual Environments previously hosted on more powerful computers. Limitations in screen size, interactive styles and devices and platform performance all play a role in defining what kind of material should be exploited, should such devices be considered for individual or small-group training applications.

Finally, and again following the the delivery of the first *SubSafe* demonstrator, information exchanges with the Canadian and Australian Navies have supported those countries' attempts to launch their own *SubSafe* equivalents, for the *Victoria* and *Collins* Class SSKs respectively. In the UK, consideration is, at the time of publication, being given to exploiting the lessons learned from the *SubSafe 1* project to early concept designs for the future submarine, *Successor*.
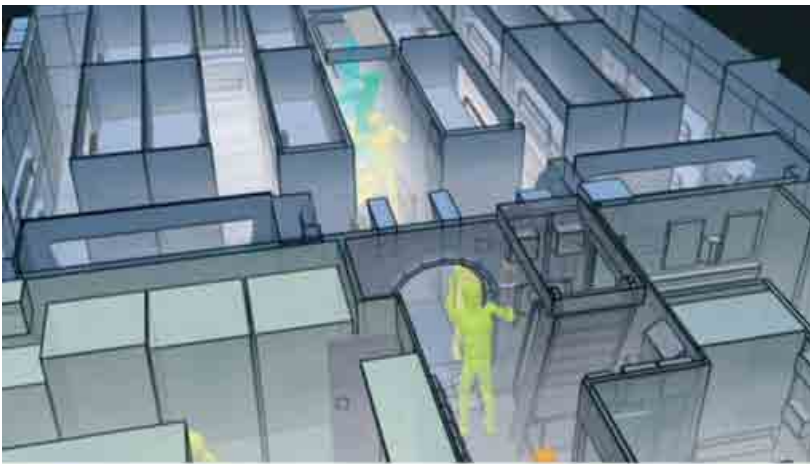
**Figure 33**



**Figure 34**

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# CASE STUDY 9: SubSafe 2

**(Stakeholder: Submarine Qualification (South), HMS Drake; 2009-2011)**

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

In order to incorporate many of the student and instructor comments and usability issues arising from the *SubSafe 1* evaluation programme, a decision was made in 2009 to "transfer" the digital assets collated during the early part of the project – 3D models and textures – into a more flexible 3D toolkit and advanced rendering engine. As with many concept demonstrator projects, once an initial prototype has been developed, this "triggers" a range of "what if?" questions from stakeholders – current and new – relating to how the simulation could be extended to meet the needs of other training and development applications. In the case of *SubSafe*, such applications included maintenance training, damage control rehearsal, submarine escape and abandonment, compartment modification planning, future submarine design, and so on.



**Figure 35**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

As a result of the *SubSafe 1* evaluations, a number of additional features were requested in order to enhance the SMQ learning process, from dockside (Figure 35) to submarine interior. For example, requests to provide important dockside "staging" features for a safe and efficient approach to the vessel included hazard warning boards at the top of the walkway, the presence of a casing sentry avatar (at the entrance to the trot box and main access hatch), more casing detail (i.e. the presence of a more detailed service tower) and animated masts (Figure 36). The animated masts – raised and lowered using a series of virtual slider bars – were requested to support recognition training. In *SubSafe 1*, all masts were constantly raised, which was not indicative of an alongside state, when just the diesel induction and exhaust masts are typically evident.

Many of the other navigation and interaction features remained similar to *SubSafe 1,* although there were some key changes and additions to the use of the mouse for navigation and object selection. With *SubSafe 1*, the circular screen marker, always in the centre of the user's field of view, had to be slewed onto an object of interest to establish whether or not it could be animated or "extracted" for further examination. This proved on occasions to be quite frustrating, as the movement of the marker meant that other, potentially important objects in the scene fell outside of the field of view. To overcome this in *SubSafe 2*, the mouse view-slaving persisted, but interaction with objects was

developed into a separate cursor-controlled activity, actuated by right-clicking the mouse button and moving the cursor in an otherwise static field of view. Another motion-related function requested was the ability to crouch. Certain key valve and safety item locations, particularly on No. 2 deck, were on, or just above deck level. If one approached these locations in *SubSafe 1*, it was not possible to view them in their entirety. Consequently, assigning the 'C' key to a "crouch" function was implemented. Another function key, 'F1', was assigned to an external-internal toggle function, thereby saving time by allowing users to "teleport" into and out of the vessel instantly, thus removing the need to walk onto the submarine every time the simulation was started. The simple plan view, showing the user's current deck and compartment location, was also removed, as this feature did not prove useful during the *SubSafe 1* evaluations (the plan and current position marker were also found to be inaccurate).

## FIDELITY ASSESSMENT

The very act of transferring assets developed during *SubSafe 1* to the new rendering toolkit was accompanied by a step-change in visual quality. The toolkit was able to support some of the hypofidelity issues (flag-waving and water motion) with ease, even though those features bore no relationship to the training content of the simulation. The internal spaces were able to benefit from improvements in the lighting simulations that accompanied the toolkit and brightness, contrast and colour levels could be altered as required.
Display effects, such as screen emissivity, when implemented together with darker lighting on No. 21 Deck and in the vicinity of the Control Room (Figure 37), added a significant degree of realism, as did the use of background sound effects and alarms (although, on occasions, the recorded sound samples did not match the activity in visual scene – another example of hypofidelity, similar to the subdued crowd activity described in Case Study 4). In addition to the standard environmental rendering effects, the opportunity was




**Figure 36**

Figure 37: *SubSafe 2* Control Room with Bulkhead and Screen Lighting Effects
Figure 38: *SubSafe 2* Flooding (Upper) and Smoke (Lower) Effects on No.2 Deck (Bulkhead 29)



**Figure 37**



**Figure 38**

taken to illustrate extreme conditions, such as compartment flooding and smoke (see Figure 38; the smoke effects were achieved in a very similar manner to that described for the Helicopter Brownout investigation described in Case Study 22).

## OUTCOME

Unlike its predecessor, which required significant amounts of additional software to be installed on the host computer prior to running the simulation, the *SubSafe 2* environment can be distributed as a single, relatively small executable file (license-free) and has delivered a much higher-fidelity visual and auditory virtual world than its predecessor. From an experimentation and usability evaluation perspective, *SubSafe 2* also supports a much wider range of interface modifications than before (such as a variable first-person field of view, control over through-boat motion speed, object interaction styles, multimedia and performance metrics integration and the use of numerous forms of interactive hardware technologies). The software also allows end users to edit the 3D environments, adding new objects, labelling others and hyperlinking objects to additional forms of informative media. *SubSafe 2* was installed on the training computer suite of HM Naval Base Devonport's Waterfront Learning Centre in April, 2011. Consideration is still, at the time of publication, being given to exploiting the lessons learned from the project to feed early concept designs for the future submarine, *Successor*. However, *SubSafe 2*, as with its predecessor, remains only "half" a submarine, in that no decks or compartments currently exist within the aft section of the boat (for reasons outlined in Case Study 8). Whether or not this situation will change in the near future is uncertain.

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# CASE STUDY 10:
# Submarine Rescue ("Virtual LR5")

**(Stakeholder: SMERAS Project Team; 2008)**

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The "Virtual *LR5*" concept demonstrator study (Figure 39) was conducted at the request of the Submarine Escape, Rescue and Abandonment Systems (SMERAS) Project Team at DE&S, Abbey Wood, following earlier exposure to the *SubSafe* project (Case Studies 8 and 9). The *LR5* manned submersible (Figure 40), at the time part of the UK Submarine Rescue System (UKSRS), was designed to rendezvous with a disabled submarine (DISSUB), create a watertight seal between the hatch to the submarine's escape tower and a special transfer "skirt" on the bottom of the submersible, and then transfer survivors to the safety of a support ship on the surface equipped with appropriate hyperbaric and medical facilities. The system was also designed to provide life support for 16 rescued submariners and three crew for — worst case — up to 96 hours whilst underwater. The SMERAS team felt that a cost-effective opportunity existed for a games-based simulator to provide an early ("pre-wet") form of pilot training, emphasising the critical components of approach and mating with a Disabled Submarine (DISSUB) under a variety of subsea conditions, including high levels of turbidity, poor lighting, strong currents and extreme submarine resting angles.



**Figure 39**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

Human Factors observations were undertaken onboard the *LR5* during a short, three hour dive in Lamlash Bay, just off the coast of the Scottish Isle of Arran. Additional experiences during a dive undertaken prior to this — onboard the submersible's sister vessel, the *LR2* — were also referred to during the subsequent simulation design process. On the occasion of the *LR5* dive, no trials support submarine was present (the UKSRS team often work with Dutch or Norwegian diesel (SSK) submarines, as these are easier to place on the seabed than British nuclear attack submarines (SSNs)). Instead, a large "mating target" — essentially a circular hatch-like plate on four legs — was placed on the seabed.

The *LR5* was launched by crane from the Royal Maritime Auxiliary Service vessel *Salmoor*, a mooring and salvage platform, and spent a total of three hours submerged. During this time, the submersible conducted two "mock" dockings with the underwater target and the crew conducted simulated evacuation and emergency surface procedures. Recordings of the dive and mating attempts were captured using a small video camera clamped to a panel within the *LR5* pilot's forward command module.

Whilst most of the footage was too dark to discern any detailed pilot activities, once the submersible's external lights were switched on (just before starting an approach to the docking target), sufficient detail could be seen to enable appropriate external fidelity conditions to be defined for a games-based simulator. However, the key development challenges were (a) the simulation of a view of a disabled submarine through the submersible viewing dome (with appropriate visual distortions), and (b) the provision — for the trainee pilot — of additional simulated CCTV views from those external cameras mounted within and behind the transfer skirt. These views are exploited by the submersible pilot once the escape tower hatch (or the mating target in the case of the *LR5* exercise witnessed) had passed under the main viewing dome, outside of his immediate field of view.

**Figure 40**


**Figure 41**

## FIDELITY ASSESSMENT

The subsea environment was based on a scenario created for another games-based simulation project, the *Virtual Scylla*, in which a 3D model of the ex-RN *Leander* Class Frigate was developed for the National Marine Aquarium in Plymouth, to support climate change and marine ecosystem education (Case Study 23). However, the *LR5* simulation demanded greater attention to visual and functional fidelity as a result of the environment being viewed (in the main) by the virtual submersible pilot *in situ*, as opposed to via a basic camera mounted onboard a remotely operated vehicle, as was the case for the *Virtual Scylla*. A virtual *Kilo* Class Submarine (based on a bought-in 3D model – the submarine fin and masts can just be seen beyond the virtual; viewing dome in Figure 41) and seabed environment were rendered using a high level of exponentially increasing fog density. Secondly, a particle effect was linked to the virtual camera position that represented the end user's viewpoint, such that particles were emitted at relative velocities to the camera's movement only. A Gaussian blur filter was added to approximate focusing imperfections through the submersible viewing dome. Another effect used a special form of texturing to simulate the image refraction caused by the Perspex viewing dome. Also, and for early illustrative purposes, an additional particle effect was implemented for escaping air bubbles from the casing and a damaged mast well. When in contact with the virtual *LR5*, these particles endowed the simulated submersible with positive buoyancy. Implementing these effects endowed the DISSUB scenario with a realistic appearance especially given the possible real-world lighting and turbidity conditions submersible pilots might experience. A low-fidelity submersible interior was created to simulate the pilot's viewpoint. The cockpit contained an additional two simulated CCTV displays, relaying real-time virtual views of the cameras mounted externally (Figure 41). This solution was based on earlier work, simulating real-time video feedback from

bomb disposal vehicles, as described in Case Study 16. For the purposes of this early demonstrator, flying the virtual submersible and looking around the cockpit area were made possible by the use of controls provided on an *XBox* gamepad.

## OUTCOME

Although the simulator concept was not taken any further by the SMERAS team, the research undertaken and the effects achieved have stood the test of time and have been used to guide developments in subsequent simulated underwater scenarios (e.g. Case Study 12). The work also stimulated discussions raising the possibility of developing the simulator into a dive planning tool, such that deployment, safety, approach and mating procedures could be defined and rehearsed whilst the DISSUB rescue team was in transit to the site of the incident. Case Study 13 shows a related (and later) outcome of these discussions, albeit with a new set of stakeholders. The UKSRS has now been replaced by the new NATO Submarine Rescue System (NSRS), which has been designed to deliver a rescue capability not only to the partner nations of France, Norway and the UK but also to NATO in general. *LR5* remains in service with the Royal Australian Navy.

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# CASE STUDY 11: Initial Warfare Officer Performance Capture Tool & Rules of the Road

## (Stakeholder: Maritime Warfare School, HMS Collingwood; 2005-2012)

### SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The principal role of the Royal Navy's (RN) Junior, or "Initial" Warfare Officers (J/IWOs) is to apply navigational knowledge and observational skills relating to the application of naval "rules of the road" (ROTR), thereby ensuring the safe passage of their own vessel and the safety of others. To achieve this whilst onboard, they are required to undertake regular bridge poloris bearing checks of known man-made and natural geographical features (including features indicated on supplied Admiralty charts), to correlate events presented via the radar display with the outside world scene, to check heading and to monitor other displays (including the rearward-looking closed-circuit television camera). J/IWOs are also required to check the type and motion status of other vessels (from small sailing craft to other RN assets), using binoculars when necessary. Any close-proximity vessels or potential threats must be reported to the senior officer or captain (who may be located off-bridge).

Unpublished historical performance data generated in 2004 by J/IWO instructors based at the Maritime Warfare School, HMS Collingwood, indicated that the simulator-based training methods in place at that time were not consistently producing the required levels of competencies expected of RN Officers Of the Watch (OOW). Further anecdotal evidence suggested that a limited number of trainees appeared to be unable to correlate navigational data presented in essentially two-dimensional form (e.g. from charts and bridge radar screens) with their simulated out-of-the-window counterparts. The RN instructors were also concerned that some trainees tended to display very poor spatial awareness, visuospatial, cognitive and basic numeracy skills whilst undertaking simulator training and assessment sessions and that these problems were not being detected and subsequently addressed until J/IWOs were well into their training programme.
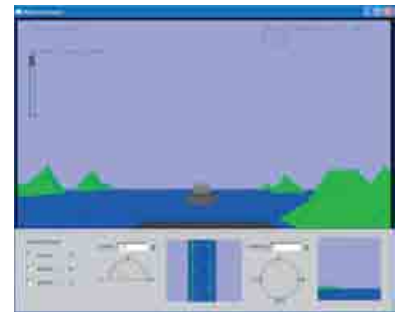


**Figure 42**

consideration were taking the form of those used in a very early (1984) – and very popular – commercial multitasking space trading game called *Elite* (Figure 43). Briefly, *Elite* required players to fly between galaxies, collecting and trading assets en route, avoiding renegade spacecraft in the process and rendezvousing with rotating space stations. The design of the user interface proved to be one of the long-enduring features of this interactive 3D classic. The *Elite* spacecraft "cockpit" view (shown in Figure 43), required a number of skills similar to many of those observed during the HMS Collingwood Human Factors analysis, including interrogation of a 360° "situational awareness" radar-like display (bottom centre of screen in Figure 43), collision avoidance, and the monitoring of spacecraft status and resources histograms (either side of the radar-like display). Another key skill was the need to control the approach speed and match the rotation of one's own craft with that of the target space station to effect a successful dock. Different cockpit views (side and rear) were selectable via specified function keys. These design features drove the original thinking behind the J/IWO Performance Capture Tool, namely a single-screen, multitasking interface, displaying – to a relatively low level of fidelity - a primary navigational task (including collision threat detection and prioritisation), with secondary task elements, including the monitoring of different digital readouts (including the virtual "radar"), rear-view target detection and numerical calculation, as shown in Figure 42.

### HUMAN FACTORS ANALYSIS & KEY ISSUES

The original Human Factors observational sessions took place within the RN's Endeavour Building simulator suite at HMS Collingwood in June 2005. The observations were made during an end-of-course examination period for the J/IWO candidates and access to the simulator bridge area was permitted at all times. An additional navigational observation opportunity was also taken in October 2005 onboard HMS *Roebuck*, one of the RN's oceanographic survey vessels, during a return journey from a Minigun firing trial in the English Channel to a mooring just inside Plymouth Breakwater. During the observations, data were captured relevant to a range of subsequent simulation design activities, including those features that defined the multi-tasking elements of the J/IWO on the

bridge, together with those that would be influential in defining the appropriate levels of internal and external task and context fidelity in any future simulation tool. Finally, a short observation of channel navigation procedures was undertaken onboard the Type 42 Destroyer HMS *Gloucester* in Plymouth Sound in May 2010.

### FIDELITY ASSESSMENT

Based on the original Human Factors observations, the conclusions of the original J/IWO project drove the decision to implement a relatively low level of visual fidelity within the simulation, but to develop tasks that would enable the end user's multitasking skills – perceptual, reaction time, decision-making, and so on – to be tested to the full. During the early design and storyboarding phases of this simulation, it became evident that the tasks under
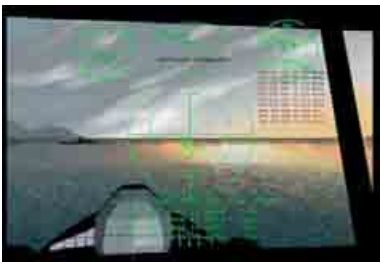
**Figure 43**



**Figure 44**

Since 2010, however, and with the availability of efficient and cost-effective games development tools, it has been possible to introduce a degree of enhanced fidelity into the bridge and external context simulations, although the *Elite* interface design philosophy has remained very much constant (Figure 44). Greater attention has been placed on endowing some of the external objects (or "agents") with levels of Artificial Intelligence (AI), enabling the scenarios to take on a much more realistic, dynamic and uncertain quality. In addition, the present version of the ROTR simulator features greater enhancements to such aspects as the implementation of a collision radar system, higher quality ship and environment simulation, ship collision effects, simulator session logging and after action review.

### OUTCOME

The first version of the J/IWO Performance Capture Tool required the trainee to follow – using keyboard speed and direction inputs – a computer-controlled vessel representation, whilst maintaining a specified stand-off distance as its speed increased and decreased at random. Distance management was achieved by simulated "out-of-the-window" viewing and by monitoring a vertical bar chart display, located close to the left-hand edge of the main window. Two secondary tasks were included. The first required trainees to answer a number of "cognitive questions", one mathematical, one relating to situational awareness (own ship, other vessels, land features) and one demanding string recognition. The second task required the candidate to monitor both the simple "radar" and rear-view "camera" screens for other vessels. When another vessel appeared, the candidate was required to identify it by pressing a specified key on the keyboard. Early feedback from HMS Collingwood subject matter experts (SMEs) indicated that the performance capture system would be compatible with existing RN training schemes and the next step was to determine the viability of this approach as part of the RN training and assessment programmes. Support for this was forthcoming from the SMEs, who offered to install the final version of the prototype tool within the classroom facilities at the base and to expose the tool to J/IWO students pre- and post- their sea training phases. Unfortunately, and due to a perennial problem in defence research (the promotion or change in role of key military stakeholders, requiring them to move on), the implementation and evaluation of this early tool within classrooms at HMS Collingwood did not occur.

However, the situation for the more recent simulator has been much more positive. Working closely with the Collingwood SMEs, not only has it been possible to provide an extensive list of ROTR scenarios, the software has also been accredited for installation on the computers in place within the Collingwood Technology-Based Training Unit and is, at the time of writing, awaiting its first exposure to real J/IWO trainees. Interest has also been shown from the Royal Navy Submarine School, with regard to providing a submarine fin representation for similar ROTR activities. The latest (at the time of writing) application starts by displaying a menu offering scenario selection. For example, the trainee can select a head-on collision scenario. The application randomly will select a collision scenario where the trainee's own vessel faces an AI-controlled vessel either head on, or to port or starboard. The trainee default view is from the bridge of the Type 23 frigate, although other views are selectable. A head-up display shows the trainee's actual and target heading, speed and signals, together with that of the AI-controlled vessel. The trainee turns to port and speeds up, which results in a rule violation. The simulation suspends and a window appears with a training report form consisting of a 2D overview map, a detail of rules broken and some fields where the player justifies his decisions. This training record is stored as part of the trainee's records for later review by the instructor. The simulation then returns to the main menu.

The ROTR simulator was exposed to 14 J/IWOs as part of their training at HMS Collingwood in January 2011. They were invited to use the simulation tool in groups of two or three for approximately 20 minutes, during which time they provided verbal feedback on their experience. After each session, the J/IWOs completed a questionnaire which included ratings of the usefulness of various components in the simulation. The questionnaire responses indicated that the J/IWO students appreciated the use of 3D graphics to gain spatial awareness (with particular reference to vessel physics and sound effects) and the opportunity for reflection provided by a 3D After Action Review (AAR) system.

### KEY REFERENCES

**Stone, R.J. & Flannery, T.** (2007). "Initial / Junior Warfare Officer Performance Capture Tool: Research Milestone Summary". Unpublished Human Factors Integration Defence Technology Centre Report; HFIDTC/WP4.7.2/1; February, 2007. Available from: http://www.hfidtc.com/research/training/training-reports/phase-1/4-7-2-1-i-jwo.pdf

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# CASE STUDY 12:
# Defence Diving Situational Awareness Trainer

**(Stakeholder: Defence Diving School; 2011)**

Figure 45:   Trainee Divers at the RN Defence Diving School
Figure 46:   Virtual *Astute* (Top) and *QE* Class (Bottom) Defence Diving Scenarios
Figure 47:   DDS Trainee (Left) and Instructor (Right) View of Seabed Artefact for Exploration and Identification

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

From forensic lake-diving to the identification and recovery of defence materiel, personnel or lost munitions, defence divers (Figure 45) find themselves exploring some of the most hazardous environments known to man, often in conditions of severely degraded visibility, strong currents and low temperatures. Following a presentation to the UK Joint Service Defence Diving School (DDS) at Horsea Island, interest was expressed in the potential offered by simulation to help train – in a classroom setting – the procedures and recording processes that need to be undertaken during the investigation of artefacts that may be attached to the hull of a vessel or on the seabed. In particular, the challenge was to provide some form of simulation that would help trainees master the process of *mentally* recording (i.e. without note-taking aids) and reporting such features as artefact size, shape, markings, condition, location and the nature and condition of the immediate seabed area.



**Figure 45**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

The Human Factors observations were conducted during a very short visit to the DDS, which included a briefing from diving instructors on the procedures undertaken for detecting and reporting on underwater ordnance. Information and training videos were also provided by the DDS. One key issue noted was the lack of awareness training for tasks involving hull inspections on *specific* vessels. Divers qualifying from the DDS with minimal experience might be expected to dive on new (and unfamiliar) vessel types, including *Astute* Class submarines, Type 45 Destroyers, and the *Queen Elizabeth* Class aircraft carrier (see Figure 46). Another, perhaps more serious issue was the lack of appropriate methods for analysing and reporting on underwater artefacts, with DDS personnel commenting on frequent inconsistencies from divers reporting on the same object underwater. Consequently, it became apparent that the simulation solution would not be as "straightforward" as some of the others reported within this booklet. For example, the simulation tool would need to provide instructors with a means by which vessels, artefacts, debris, plants and other features could be pre-programmed into scenarios and saved for subsequent presentation to trainees (much like that developed for *EODSim*, described in Case Study 17).

The ability to change scenarios whilst a simulation was running – to alter visibility, for example, or trigger some form of underwater incident – was also necessary, as was a means by which the instructor could monitor a trainee's progress from a



**Figure 46**

different screen. Detailed after-action review (AAR) was also essential, especially for 1:1 reviews between instructor and trainee.

It was stressed from the outset that, despite the extent of its capabilities in the classroom, any simulation would not (indeed could not), under any circumstances, be designed to *replace* wet training. Instead, the goal of the project was to assess whether or not simulation could, during classroom briefing and individual "hands-on" sessions, help improve defence diving trainees' performance when recording and memorising features of artefacts they found during their underwater investigations and how these features are then relayed back to the dive supervisors for the assessment of threat and the formulation of render-safe procedures. An additional feature that was added, again based on early briefings from DDS personnel, was that of a simple "eyeball" (inspection) remotely operated vehicle (ROV), based on the commercially available *VideoRay* system, used also in previous simulations (e.g. *Virtual Scylla* - see Case Study 23).

**Figure 47**

## FIDELITY ASSESSMENT

The fidelity assessment for this project stimulated much discussion. Whilst it was accepted that many of the activities undertaken by defence diving teams occurred in underwater conditions of high turbidity and low lighting (often forcing divers to focus on tactile exploration rather than visual), it was accepted that there was still some value in providing a simulator that could present underwater scenarios in a reasonably clear form, but could also support progressively degradable conditions. The ability to train defence divers to be aware of what features they should take note of during a mission, including prominent hull and seabed visual features, locations of buddy divers and so on would also be of value. Also, and as has already been emphasised, trying to simulate all conditions associated with underwater diving was not the aim of this project. Apart from being totally unnecessary, a realistic diving simulator would be highly costly, if not impossible,

given current-generation wearable and haptic feedback (see Section 3.4.4) technologies. Consequently, a medium fidelity approach was taken, exploiting subsea environments of relatively simple geometric and texture features and allowing instructors and trainees to visualise underwater scenarios on separate screens (Figure 47). Lessons learned from other underwater games-based simulation projects (e.g. Case Studies 10 and 23) were taken into account during the development of this concept demonstrator, although new techniques were necessary to enhance the variable lighting and turbidity effects, in addition to the disturbance of seabed material, by the diver or ROV, or as a result of an underwater incident. Virtual vessels (e.g. Figure 46), mines, non-ordnance items, subsea features and so on were based on modified bought-in assets, supplemented where necessary with bespoke models and textures.
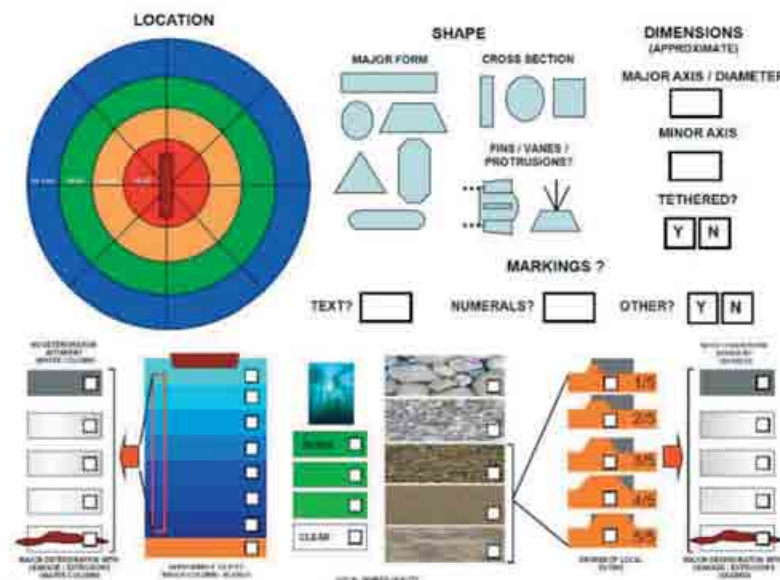
**Figure 48**



**Figure 49**

## OUTCOME

In its most basic form, the simulation presents trainees with two scenarios (additional scenarios are, at the time of writing, being added). Both require early attention to surface preparation procedures before the dive takes place. One scenario is based on an incident in October 2010 when HMS *Astute* ran aground off the Isle of Skye, triggering fears of damage to sensitive areas of the ship such as the rudder, aft planes and propulsor. Building on these events, the simulator enables trainees to undertake an underwater search for ordnance, around the propulsor area, within nearby water columns and on the seabed in the immediate vicinity of the submarine. A second fictional scenario involves the *Queen Elizabeth* Class aircraft carrier, which plays host to a hull inspection and search of surrounding seabed for any potential threats to the ship.

Throughout the simulation, the trainee is presented with a range of challenges, each of which requires careful and thorough navigation of the virtual environment and the identification of ordnance. To mimic real-world conditions, the virtual environments contain representations both of real ordnance and "distraction objects". These include a wide range of objects, including general junk, oil barrels, wooden boxes, small wrecks, downed aircraft and so on (placed by the instructor using the simulation's dedicated editing toolkit – see Figure 48). All objects can be endowed with differing states, such as the degree of silting, deterioration (rusting, leaking) and position in the water column. During each dive, trainees must contend with low visibility and differing levels of turbidity.

The AAR runs in parallel with the simulator and both captures and analyses the trainee's performance, ready for post-session presentation and review. The AAR system captures the trainee's virtual position location and orientation throughout the simulation session, together with dwell times on all underwater artefacts, objects identified as ordnance (and time of identification) and the

HIT ITEMS:[]
INCORRECT HITS: ['tyre', 'Cube.016', 'mk5']
SIMULATION TIME: 660
OBJECT HIT: OBtyre AT 609

**Figure 50**

trainee's on-screen view when identifying an object. These data are then analysed to extract AAR-relevant measures, such as:

- all objects identified as ordnance by the user in the virtual environment,
- the percentage of correct versus incorrect objects identified,
- the dwell times on all underwater ordnance in the scenario,
- the dwell times on all incorrectly identified items, and
- deviation from the ideal search path (pre-set by the instructor).

At the request of DDS instructors, and unlike other examples of military AAR, the present replay system has not been fully automated. The instructors expressed a preference to have full control over the replay/review process, thus being able to impart their task-specific knowledge to enhance the AAR session. To support this, the system allows – in real time – the selection of one of a number of camera views of the virtual scenario, the highlighting of particular items of interest and the "scrolling" forwards and backwards through the scenario at various step speeds using the mouse wheel.

A short pilot study investigating the effect on performance based on the provision of this unique form of AAR was conducted using student and staff participants at the University of Birmingham. In summary, simulated diving trials with AAR were associated with a significant increase in performance when compared to those without AAR with respect to the number of correct seabed items identified and a decrease in the number of incorrect items identified. Simulated diving trials with AAR were also associated with a significant increase in the reporting scores for underwater ordnance (based on the accuracy with which participants complete a reporting sheet for each correctly identified object in the simulation – see Figure 49). Finally, simulated diving trials with AAR (an example of which is shown in Figure 50) were not accompanied with significant increases in search path accuracy (although the results only marginally failed to reach the stated level of significance).
At the time of publication, subsequent investigation and exploitation opportunities are being sought with the DDS and the demolition diving section of the Defence Explosives, Munitions and Search School

(DEMSS). Additional demonstrators have been built, including wreck exploration, ROV intervention and conservation.

## KEY REFERENCES

**Snell, T.** (2011). "MCM Diver Training in Virtual Environments with AAR System & Analysis"; Unpublished MEng Final Year Report, School of Electronic, Electrical & Computer Engineering, University of Birmingham; June 2011.

# CASE STUDY 13: Integrated Subsea Visualisation Concept

**(Stakeholder: Flag Officer Sea Training, Hydrography, Meteorology and Oceanography – FOST HM; 2009)**

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

This project, whilst having a strong future potential role in training, was more of an exercise to evaluate the capabilities of current gaming technologies to deliver a real-time, multi-source/multi-screen 3D visualisation capability for subsea situational awareness. The interest from Flag Officer Sea Training Hydrography, Meteorology & Oceanography (FOST HM) related to the development of an intuitive visualisation tool that could be used by future Mine Countermeasures Vessel (MCMV) personnel to help foster a strong spatial awareness of the "arrangement" of the seabed and various artefacts – targets, debris, wrecks, mines and the like – and to plan the deployment of appropriate countermeasures processes and assets. This was based on a future RN plan (under discussion) which aims to bring together, on a single naval platform, the survey functions of current hydrographic and coastal survey vessels, with those of MCMVs. Another application for this concept was the provision of a planning tool to support subsea interventions for Disabled Submarine (DISSUB) incidents (see Case Study 10).
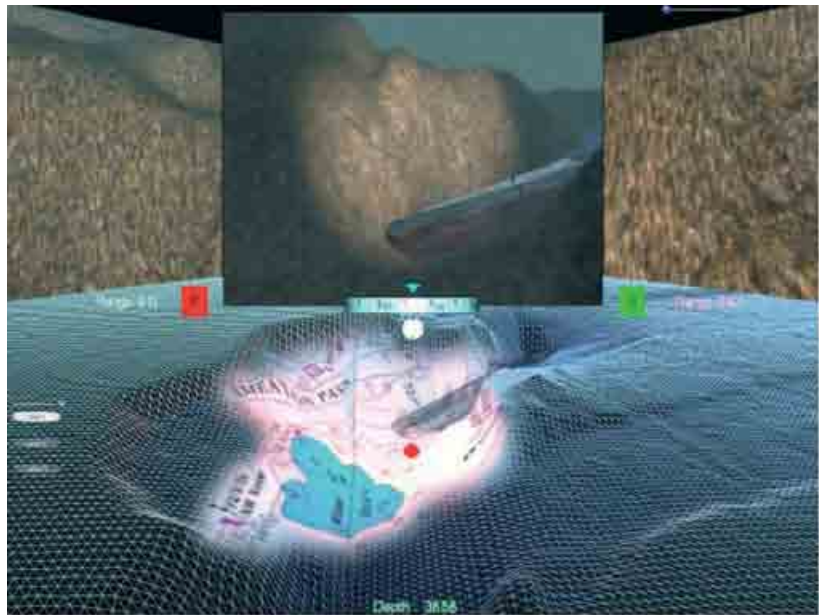


**Figure 51**

### AIMS AND HUMAN FACTORS ISSUES

The driving aim of this project was to design and develop a "unified" planning human-system interface and visualisation tool for enhancing end user spatial awareness in the planning of (initially) subsea intervention tasks, based on the conversion of actual bathymetric data, enhanced with appropriately coded representations of underwater features and man-made artefacts. Secondary aims were to investigate the optimum "blend" of real-world and abstract data, at varying levels of fidelity, and to investigate the most appropriate interactive COTS technologies (display and data input) and interaction "styles" in relation to supporting the simulated planning task.

### THE DEMONSTRATOR

A process to support the rapid conversion of bathymetric data into a format suitable for real-time exploration using a modified games engine has been developed. The conversion takes high-resolution greyscale height map images derived from *Fledermaus* bathymetric survey datasets (in this case data from surveys in

Plymouth Sound) and uses the brightness levels to generate a topographical map in 3D, using an industry-standard modelling package. This map is then converted into a polygonal representation, suitable for import into a real-time games (or rendering) engine and development toolkit where it can be enhanced using a variety of visualisation techniques, added to (using other 3D models, for example) and interacted with using a range of data input and display technologies. In addition an early concept human-system interface has been developed around the converted bathymetric data to demonstrate a multi-window interface format, depicting close-proximity seabed topography and simulated views from port-, front-, starboard- and downward-pointing virtual cameras onboard a deployed probe, or ROV, which is itself controlled using an *Xbox* hand controller (Figures 51 and 52). The underwater fidelity and effects underpinning these views were based on techniques developed for the *Virtual Scylla* project (Case Study 23) and for a submarine rescue demonstrator (Case Study 10). In addition, the demonstrator has been further developed to show how
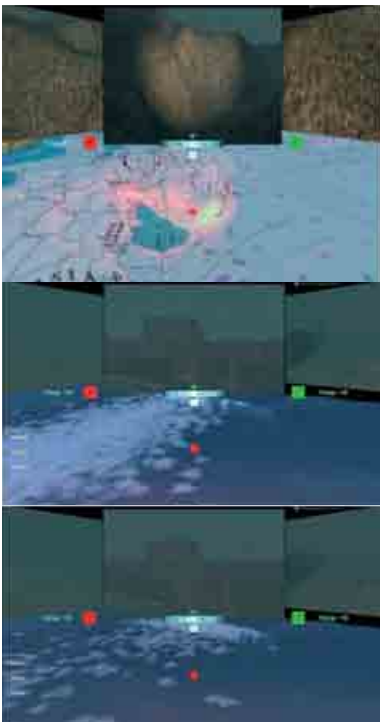
**Figure 52**



**Figure 53**

UK Hydrographic Office Assets (Maritime Foundation Data, MFD), in this case a navigational chart of Plymouth Sound, can be digitised and overlaid onto the converted bathymetric scan data. It is also possible to vary the transparency of this digital chart, thus allowing the end user to visualise the seabed and any virtual artefacts that have been modelled in 3D.

An investigation has also been completed to address alternatives for visualising dynamic virtual environment properties. One promising technique involves the use of video textures displaying the results of particle models representing such processes as silting over time, subsea currents or tidal streams, pollution fields and so on.
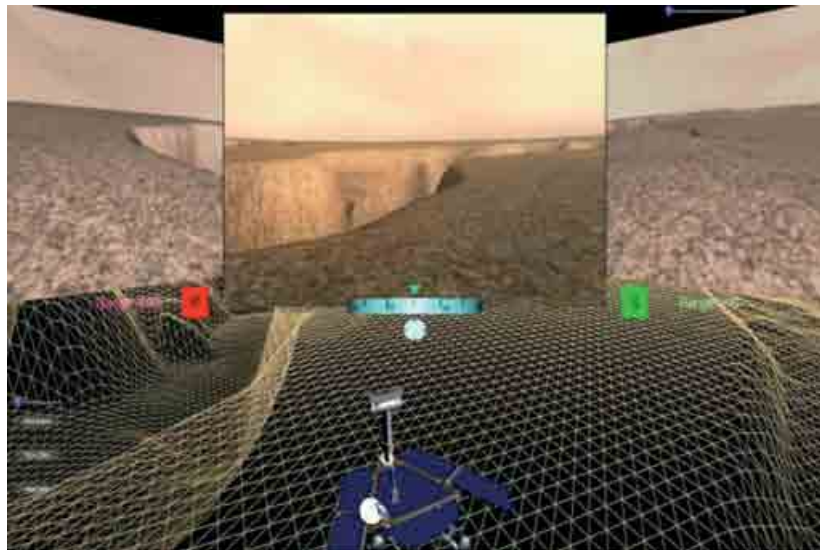
## OUTCOME

Potential applications exist in other areas of robotics and autonomous vehicle high-level supervision and task planning, including planetary roving and supervisory control (see Figure 53) and underwater heritage (e.g. wreck location classification and visualisation). In addition to FOST HM, this project has developed additional collaborative links with the UK Hydrographic Office (UKHO) and Plymouth Marine Laboratories.

## KEY REFERENCES

**Stone, R.J.** (2010). "Serious Games – the Future of Simulation for the Royal Navy?". *Review of Naval Engineering;* 3(3); March 2010; pp.37-45.

# CASE STUDY 14:
# Type 26 Design Review

**(Stakeholder: Naval Design Partnership/DE&S Ships; 2010-2011)**

## SUMMARY & KEY REQUIREMENTS

The Type 26 Global Combat Ship (GCS; or, originally, the *Future Surface Combatant* (FSC) – Figure 54) Project Team was tasked with procuring a class of vessels to replace the Type 22 and Type 23 frigates currently in RN service. The project was launched in April 2008 within the MoD Surface Combatant Directorate and, as the vessel's functions and budget priorities have been under regular review, a number of changes in direction regarding concept designs have been evident over recent years. The Naval Design Partnership (NDP) – an MoD/pan-industry grouping, has been leading the concept design phases, and was tasked with the development of a range of concepts defining the Type 26, taking into consideration through-life cost-capability trade-offs and the adoption of appropriate technical solutions. One such solution was the development of a "living" virtual model of the vessel, capable of rapid change (based on the output of computer-aided design (CAD) systems used by the NDP and other contractors) and presentation to senior MoD representatives for such purposes as design review and the making of decisions relating to the size and accommodation needs of the ship's complement.



Figure 54



**Fig 55**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

The main Human Factors issue relating to this particular project focused on usability and interactivity, particularly with regard to the navigation of the virtual vessel and supporting immediate location awareness on the part of the end users. Historically, and in the opinion of the author, the import of unmodified or "raw" CAD data into real-time rendering software packages has met with end user dissatisfaction and project failure. In order to exploit early CAD datasets relating to the Type 26, a different approach to one based purely on a first-person (or egocentric [G1]) viewpoint was deemed essential from the outset. Lessons learned during the modification of the original *SubSafe* data to support the development of the HMS *Tireless* Self-Contained Oxygen Generator (SCOG) explosion animation (Case Study 8) were influential in the final presentational solution.

## FIDELITY ASSESSMENT

The levels of fidelity achievable at this stage of the Type 26 project were, of necessity, relatively low, given the state of development with the source CAD data and the absence of a real vessel from which appropriate textural material could be obtained. However, in order to make the concept review process as engaging and meaningful as possible, it was deemed necessary to supplement the converted CAD geometry with basic textures (from other naval simulation projects) to endow a small amount of realism and to help with features such as distance and motion perception (using patterned flooring), way-finding, and so on. Another feature deemed essential, as not every deck within the vessel geometry provided by the NDP was populated with accommodation modules at the time this project was undertaken, was the provision of deck number and direction signs (port-red, starboard-green colour codes and forward-aft directional arrows – Figure 55) because of a lack of specific features/cues to aid with waypoint navigation.

In terms of interactivity and exploration, again the lack of detail in the supplied CAD data proved challenging, and a totally first-person perspective was ruled out at an early stage. An attempt was made to support a *SubSafe*-like "walk-on" scenario by re-using that simulation's naval base wharf model (see Figure 56). However, the lack of vessel fidelity did not do this first-person scenario any justice, due in part to the visually impoverished model and the length of time taken to navigate before any meaningful compartment model was arrived at. Consequently, a more exocentric style of exploration was developed, such that each individual deck

**Figure 56**



**Figure 57**



**Figure 58**

of the Type 26 model, endowed with a texture generated from that deck's original 2D plan, could be selected "from a distance". Once a deck had been "extracted", and its "active" (i.e. explorable) compartments had appeared (Figure 57), the user could then position him/herself within a specific walkway or compartment by pointing and clicking using a mouse-slaved red ball cursor, as first used in the *EODSim* project (Case Study 17) for time-saving, long-distance exploration. A subsequent double left-click would take the end user to the selected location; a double right-click would return him/her to the exocentric viewpoint. Once at the selected location, first-person ("egocentric") navigation could occur using the W-A-S-D (forward-left-back-right) or arrow keys.

## OUTCOME

The accommodation geometries for key locations on three of the vessel's decks were delivered from an architectural practice commissioned to provide the basic 3D concept modules for review. These were incorporated into the Type 26 virtual shell, for exploration and interaction as described above (Figure 58). For conceptual illustration, one of the recreation spaces was equipped with a whole-wall video screen concept, providing a video texture showing a conceptual example of a virtual environment for restoration during long missions at sea (see Case Study 5). The work undertaken here has, in addition to lessons learned from *SubSafe* (Case Studies 8 and 9), been exploited during early concept stages of the design of BAE Systems' Future Submarine, *Successor.*

## KEY REFERENCES

None as of date of publication (February, 2012).

# CASE STUDY 15:
# Counter-IED "Rural"

**(Stakeholder: Defence Explosive Ordnance, Munitions & Search School, South; 2007)**

Figure 59:  Simulated Rural Scene with Incident Command Post and Wheelbarrow EOD Vehicle

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

Counter-IED/EOD (Improved Explosive Device / Explosive Ordnance Disposal) training, including threat assessment training for both operational (Afghanistan) and homeland security applications, has become an urgent operational priority, and establishments are under increased pressure to "process" new IED/EOD trainees quickly, but without compromising the delivery of course content. It can take many years for trainees to become experienced operators, particularly given the skills required to conduct thorough route searches, handle the range of equipment necessary to conduct such searches and operate Remotely Controlled Vehicles (RCVs), manipulators and associated effectors. In addition, there is a growing concern that current generations of EOD/IED specialists are failing the training courses provided by the Army. Part of the reason for this may lie in potential "disengagement" on the part of the trainees, resulting from the style in which training material is being presented and the legacy media with which it is being delivered.

## HUMAN FACTORS ANALYSIS & KEY ISSUES

The following five games-based simulation projects have benefited from the considerable support of specialists at the North and South Defence Explosives, Munitions and Search Schools (DEMSS). These organisations have contributed to the research by providing access to training programmes in which simulated route searches have occurred using a variety of assets, from dog handlers and Army search personnel to subsequent neutralisation teams deploying a variety of remotely-controlled vehicles. For this first investigatory project, early Human Factors observations were undertaken on a 1-mile Army training route in the southeast of the UK. The rationale behind the early focus on predominantly rural terrain was that search teams trained in such environments are more likely to be aware of the wide variety of natural and manmade features associated with IED placement, regardless of the operational setting in which they ultimately find themselves. In addition, there is a recognition that "fourth generation warfare" is not confined to the battlefields of the Middle East or Afghanistan, and route searches could occur in any part of the globe — rural or urban, desert or jungle. A comprehensive database of terrain photographs was developed as a result of this survey,

including images deemed suitable for subsequent texturing activities. Additional observational exercises were undertaken at DEMSS South, focusing on search patrol activities, including dog handling, detection equipment types and specific activities (e.g. searching culverts, ditches, overgrown areas, etc.).

## FIDELITY ASSESSMENT

The observational activities were crucial to defining the level of graphical detail delivered in this first rural C-IED demonstration and the results indicated that this project was to demand the highest level of visual fidelity of those conducted up to this date (Figure 60). For example, using flat textures to create areas of grass or simple billboard representations of linear features such as fences and hedges was judged to be highly inadequate, given the typical placement characteristics of IEDs. Consequently, a more convincing three-dimensional effect had to be devised, such that IED components could be "hidden" in a way that made the simulated search and detection procedures more realistic. Examples of "disturbed earth" had to be subtle, as opposed to simple geometric "mounds" which would be easy to detect from a distance. Grass and plants had to be implemented in 3D (bearing in mind the processing limitations of the host computers), such that very fine IED elements, such as command wires, were also realistically hidden. Attention also had to be paid to realistic lighting effects, and this particular aspect of virtual environment fidelity has been a driving feature of all counter-IED projects ever since. Without accurate lighting effects, even the most subtle of geometric features can become visually very evident. Considerable attention was also given to the development of 3D assets (Figure 59), especially as models of contemporary British Armed Forces equipment and personnel were nowhere near as available to download from the Web as those for the US. Such assets included support and command vehicles, human avatars and EOD detection and robotic removal systems. First-person exploration occurred via W-A-S-D keyboard inputs.
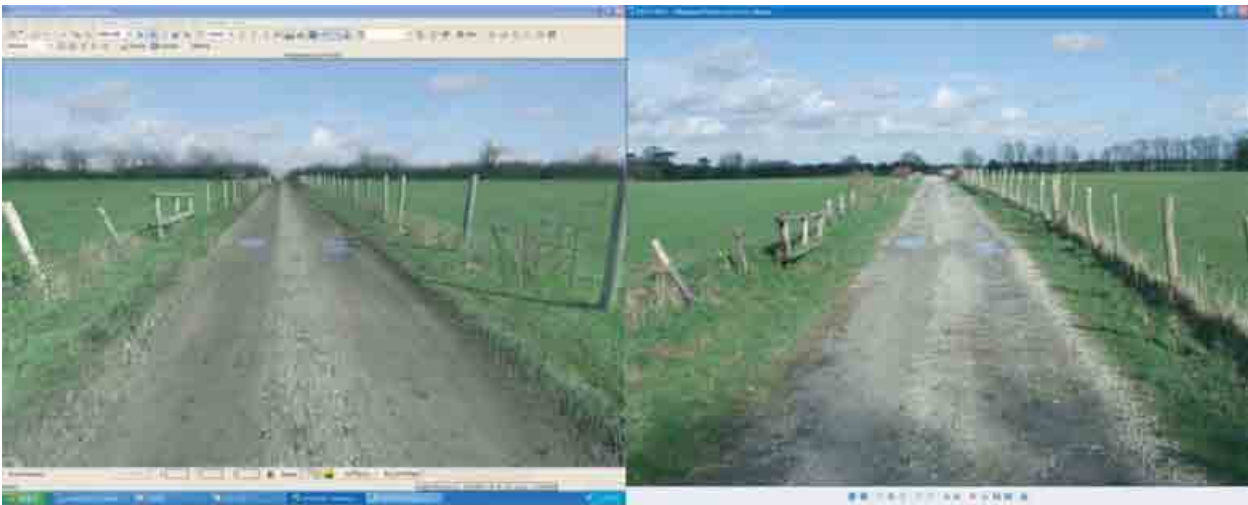


**Figure 59**

**Figure 60**



**Figure 61**

## HYPOFIDELITY EXAMPLE

An example of the effects of *hypofidelity* (Section 3.3) similar to those seen with the first version of *SubSafe* (Case Study 8) were in evidence – distracting "omissions" or unrealistic effects bringing the potential to lose the engagement of end users far too early. Figure 61 shows a 3D model of a Springer Spaniel "sniffer" dog, as deployed by British Army patrols when conducting early route searches for explosive ordnance. Even with the extent of "rigging" achieved (the process by which the 3D model is endowed with a virtual "skeleton" that defines the level of detail achievable for animation purposes), the animal's motion patterns – based on video footage of a dog participating in a mock explosive ordnance location exercise – were not of an acceptable quality. Consequently, it was decided to render the dog with minimal moving features, some distance away from the main part of the simulation. In this way, the credibility of the game-based simulation was preserved from the outset, the static dog being less likely to distract the end user or damage the credibility of the simulation from the outset.

## OUTCOME

With an early design emphasis placed on the need to demonstrate acceptable levels of fidelity suitable for C-IED training, this particular demonstrator was not endowed with any significant educational content and was, therefore, not originally destined for classroom use. The demonstration was successful in helping to engage additional Armed Forces stakeholders and in setting the baseline for levels of fidelity in subsequent C-IED projects, such as those described in Case Studies 15 to 18.

## KEY REFERENCES

**Stone, R.J.** (2008). "Simulation for Future Defence Applications – How Serious are Serious Games?" Defence Management Journal; February, 2008.

# CASE STUDY 16:
# Counter-IED "Urban 1"

**(Stakeholder: Defence Explosive Ordnance, Munitions & Search School; 2008-2009)**

Figure 62: Virtual *PackBot* Approaches Suspect Package in Waste Bins
Figure 63: Police, Witness and Incident Command Personnel Avatars

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

Further to the delivery of the Rural C-IED demonstrator described in Case Study 15, the increased Armed Forces stakeholder pool expressed a desire to move more towards simulation tools that were able to support MACP training (Military Aid to the Civilian Power) scenarios, in particular those relating to the placement of suspect packages and similar incidents in and around typical urban conurbations. The ability to exploit a real-time 3D context to help visualise the outcome and potential impact of a trainee's decisions relating to device Render-Safe Procedures (RSPs) was considered to offer a significant step forward from current training practices. Again, trainee potential "disengagement" resulting from the style in which current training material was delivered was giving cause for concern. Another issue raised by stakeholders related to the need to include different forms of media, embedded within any virtual setting, effectively adding to the educational power of the simulation and enabling instructors to continue using material developed previously (videos, images, booklet/manual contents, procedures, etc.).



**Figure 62**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

Constructing a virtual town environment was not a problem in this instance, as many assets were available from Web sources. The modelling tools used meant that additional content could be developed quite easily. The key to this simulation was the way in which instructors anticipated its use in the classrooms at the two UK Defence Explosives, Munitions and Search Schools (DEMSS). Early briefings with the instructors (plus exposure to classroom lectures and hands-on sessions with remotely-controlled vehicles) indicated that they did not expect the tools to be used on a 1:1 trainee-to-computer basis. Rather, they anticipated using the simulation as a form of "digital sandbox", projecting the virtual scenarios onto a screen at the front of a classroom and actually playing the roles of the "actors" normally encountered during an incident (police, public witnesses, EOD personnel). To support this style of classroom presentation, attention had to be given to the provision of additional forms of teaching material, from video records of incidents and other types of evidence (e.g. witness statements, sketches, prior intelligence) to multiple choice questions,

designed to focus discussions on a step-by-step basis as the lesson progressed. In addition, instructors were keen to be able to select the most appropriate "technology" (protective suit, one of a number of remotely-controlled EOD vehicles) for intervention at the end of an RSP decision-making exercise and deploy that technology to the location of the suspect package. To support this, it was necessary to be able to simulate the deployment of the selected intervention technology from the location of the Incident Command Post (ICP), including the remote control of, and receipt of images from, disposal telerobots such as *Wheelbarrow* — originally designed in the 1970s to support bomb disposal activities in Northern Ireland — and *PackBot*, a much smaller system designed by iRobot in the US.

## FIDELITY ASSESSMENT

The initial observations and briefings drove the level of fidelity evident in the early MACP town scenario. The town, which was of quite a simplistic geometric make-up, took the form of a series of small areas — railway station, industrial plant, school, shopping centre and terraced housing — each area offering locations for the placement of suspect packages (benches,

litter and "wheelie" bins, vehicles, etc.).
Although the fidelity of the town (Figure
62) was lower than that achieved in the
Rural C-IED demonstration described in
Case Study 15, it was still possible to
achieve a level of "believability" through
the use of textures, lighting, sound and
even rainfall effects. In the end, the
background sound effects were turned off,
as the distant sound of emergency
vehicles, plus rain and thunder claps
became both repetitive and annoying.
Although a small selection of avatars was
included in this concept demonstrator,
they were effectively animated
"placeholders" (Figure 63), their
contributions to the RSP decision-making
process being "represented" (in terms of
information imparted to students) by
instructors whilst playing out the scenario
in the classroom. Avatar believability in
real-time simulations, especially for
face-to-face contact and information
exchange, is still at a very immature level
of development and, based on the guidance
given in Section 3.2.1, their use in the
development of appropriate context
fidelities needs to be given very careful
consideration.

Additional media – text, illustrations and
video sequences – did not interfere with
the real-time 3D scenarios until their use
was required, at which point they were
launched in drop-down menus actuated by
a mouse click. The other key achievement
with this demonstrator was the simulation
of video displays in the back of the ICP
vehicle, fed by real-time images relayed
from virtual cameras mounted onboard the
RCVs (Figure 64). Using keyboard inputs, it
was also possible to actuate the
extendable boom arm on the *Wheelbarrow*
vehicle and each joint of the *PackBot*
manipulator system. Driving these vehicles
was achieved via W-A-S-D keyboard inputs,
or via an *Xbox* controller. First-person
exploration was achieved using mouse
("head movements") and arrow key inputs.



**Figure 63**



**Figure 64**

## OUTCOME

This first urban C-IED training tool was
presented to numerous stakeholders
throughout the MoD and to members of
EOD teams including DEMSS. Although a
formal training evaluation of the software
was not undertaken, the demonstrator
provided an excellent means of eliciting
feedback from SMEs, thereby enabling a
second iteration of the tool to be developed
with much greater functionality and more
focus on opportunities for classroom
delivery and evaluation (Case Study 17).
The ability to relay virtual images in real
time from a remote vehicle to a virtual
control station has also proved highly
useful in other demonstrators, including
one developed to show the potential of
games-based training for submarine
rescue planning (Case Study 10).

## KEY REFERENCES

None as of date of publication
(February, 2012).

# CASE STUDY 17:
# Counter-IED "Urban 2"
# (*EODSim*)

**(Stakeholder: Defence Explosive Ordnance, Munitions & Search School; 2010-2011)**

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

Further to the delivery of the Rural and Urban C-IED (Counter Improvised Explosive Device) demonstrators described in Case Studies 15 and 16, the Armed Forces stakeholder pool conducted a review of their specific needs for classroom-based Military Aid to the Civilian Power (MACP) simulation and training and reached two key decisions. The first was that a simulation of a typical homeland scenario *would* be of benefit to the training of threat awareness, intervention planning and the formulation of Render-Safe Procedures (RSPs). However, the success of such a training system would depend on providing instructors with an adequate number of scenarios with which to "expose" trainees to a broad spectrum of potential incidents. The second decision was to play down the dual-use of this type of simulation for the training of threat awareness *and* remotely-operated systems skills (driving, manipulation and remote tool/weapon use). It was felt that, unless (a) the simulated vehicles and subsystems behaved accurately with regard to their physics-based interactions with objects, surfaces, inclines, steps and so on and (b) the simulated remote system could be



**Figure 65**

operated using the same interface devices as were in use with the real-world vehicles (or closely-matched replicas), then there was no need to include them in the urban threat simulator. However, it was accepted that the inclusion of the less realistic vehicle models would be beneficial, but only as a means of illustrating the deployment of a remotely-controlled vehicle (RCV) at the end of a threat awareness and RSP process. Consequently, the second version of the MACP simulation focused on expanding the functionality of the virtual town scenario, improving the user interface to support pre-lesson configuration of the town and virtual EOD assets (Figure 65), and to provide new graphical assets to assist the instructor in developing the lesson in an engaging fashion.

## HUMAN FACTORS ANALYSIS & KEY ISSUES

Early briefings with DEMSS Subject Matter Experts (SMEs) were essential in the process of defining the main improvements necessary to take what was being referred to as *EODSim* forward. A comprehensive storyboard was developed, partly using screen captures of the original simulated MACP Town (as described in Case Study 16) embedded within a sequence of PowerPoint charts. The development of the new user interface was an iterative

process, consulting with DEMSS SMEs at regular intervals. One major difference between this demonstrator and that described in Case Study 16 was the opening view of the virtual town. This was now exocentric in nature (Figure 66), providing an "at-a-glance" appreciation of the town layout and the location of additional vignettes that were developed to increase the number of simulated incident contexts. These included a multi-storey car park – shown in Figure 66 - a petrol station and a "vivisection laboratory" (which doubled up to provide a hospital scenario).

The interface shown in Figure 66 is the result of two major iterations, resulting from early classroom deployments of the *EODSim* tool and feedback from the instructors. Amongst the functions added included:

- "Rapid transit" point-and-click function. In order to reduce the time in which the on-screen view could be changed rapidly between exocentric and egocentric (first person), and to support instructors in their locating of virtual assets during the lessons themselves, a mouse-slaved red ball cursor indicated the point to which the instructor could "jump" (via a mouse double left-click). A double right click would return the instructor to the exocentric viewpoint. Once at the selected location, first-person ("egocentric") navigation or RCV driving are governed by W-A-S-D or arrow key inputs.
- Mouse-controlled pick-and-place of key assets from drop-down menus (ICP vehicles, RCVs, avatars, devices and triggers), with the ability to reorientate said assets during scenario construction.
- Camera selection. The term "camera" refers to the available viewpoints in a given scenario, which include first person, view from an avatar's location and views from camera positions onboard RCVs.
- Full slider control over time-of-day and shadowing.
- A circular cordon range tool – basically a simple red circle, the diameter of which could be set by the instructor (by mouse-dragging), depending on the location and "size" of the device under consideration. Familiar yellow strip cordon "tapes" could also be located when in first-person view, to add to the realism of the incident.
- A range marker (essentially a click-and drag "rubber band" tool to help trainees estimate distances).
- A red "marker pen" to highlight key features during lessons (the red marks disappear immediately following the instructor's next movement).

**Figure 66**

### FIDELITY ASSESSMENT

One of the major changes to the *EODSim* town scenario (in comparison to the version described in Case Study 16) is the inclusion of time-of-day effects (ambient lighting and shadowing). The version of the rendering engine used for this particular concept demonstrator had been upgraded to support real-time lighting effects, and this finally supported a hitherto unfulfilled aspiration to be able to endow scenes with a greater degree of visual realism than before. As was noted during patrol and RCV observations, ambient lighting and shadowing play a significant role in the identification of cues and ground markers relating to the placement of IEDs, command wires and other features. This is especially the case when viewing a scene remotely, via the remote camera system of an RCV, for example, where subtle environmental features can be missed altogether, due to issues such as bandwidth, display resolution and image quality and interference when using a wireless link. Indeed one option programmed into the camera views selectable for RCVs was a "video degrade" function, simulating picture break-up and interference (a quality observed all-too-often during RCV trials in the field and at DEMSS). The lighting techniques – and their control by end users – have been re-used in other demonstrators, including the

Afghan Village model described in Case Study 18.

In addition to the extended database of new scenarios and objects, new foliage models (trees, plants) were added to increase the level of visual realism throughout the town. The tube train was also animated and could be started and stopped via a single mouse click. This may sound trivial, but ensuring that public transport in the area has been included in the evacuation procedures (and hazards such as electric rails have been isolated) are also key decision points in building up the threat awareness picture.

As with Case Study 16, a small selection of avatars was again included in this concept demonstrator, although, once again, their "presence" simply took the form of animated "placeholders" due to ongoing concerns with the potential negative impact of current-generation avatars when used in real-time training scenarios.

### OUTCOME

At the time of writing, *EODSim* is undergoing a further evolution, again based on feedback from SMEs at DEMSS and elsewhere. New scenarios are being developed, including a remote runway apron and aircraft, a transport intersection (road and rail), a sports stadium and a small rural area, similar in scope to that described in Case Study 15. In addition, the


**Figure 67**

database of 3D device models is being significantly expanded in order to allow instructors to cover a wide range of scenarios in future lessons.

As with the *SubSafe* investigations based on *iPod* and *iPad* technology (see Case Study 8), *EODSim Mobile* was developed to investigate the Human Factors issues associated with hosting i3D media on mobile computing platforms. Again, the general recommendations from this informal investigation have been provided in Section 3.4.6 of this booklet.

Although the fidelity of the *iPad* demonstrator was low, in comparison with the PC-based *EODSim* system, it was possible to explore a version of the virtual town in real time, using virtual thumb controllers located in the bottom corners of the *iPad* screen. It was also possible to simulate a two-camera view from a simplified model of a *PackBot* RCV, viewed through a virtual representation of a basic control panel (Figure 67).

### KEY REFERENCES

None as of date of publication (February, 2012).

# CASE STUDY 18:
# Afghanistan Market / Village Scenario

**(Stakeholder: Defence Explosive Ordnance, Munitions & Search School; 2010)**

Figure 68:   Two Scenes from the Virtual Afghanistan Village Demonstrator
Figure 69:   Effect of Time-of-Day and Shadowing on Ground Marker Visibility

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

As stressed in Case Study 15, effective Counter-IED/EOD training for both operational and homeland security applications is placing considerable pressure on specialist schools to deliver new IED/EOD specialists quickly to front line units. Although the Afghanistan Village demonstrator (Figure 68) was originally requested to provide urgent resource for a new C-IED "Destroy" course to be staged at the IEDD (Improvised Explosive Device Disposal) Wing of the Defence Explosives, Munitions and Search School (DEMSS), the project also demonstrated how quickly such a resource could be developed – in less than four weeks from the time of the original request. The demonstrator was designed to be used as a pre-deployment awareness-training tool, including many features – ground signs, building anomalies, threat indicators, unusual objects and the like – that might be experienced or observed whilst on a routine patrol in Afghanistan.



**Figure 68**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

As with other C-IED Case Studies, the initial Human Factors assessments for this project were based on briefings from military personnel, with the aim of identifying the scope and specific features that were required to meet the training aims of the C-IED "Destroy" course. These briefings, together with pictorial and video information culled from Web sources and operational reports, enabled a simple plan-view sketch of a generic Afghan village to be developed and used as a "storyboard" to define the typical approach routes and items that were likely to be found whilst transiting those routes. In addition to the layout of the village, consideration was also given to the technologies necessary to deliver the virtual material. Again, emphasis was placed on instructor delivery, as opposed to 1:1 computer hands-on on the part of the trainees. In order to help the instructor engage with the trainees, whilst having full control over movement through the virtual world, an *Xbox* game controller was selected and configured such that it would support walking through the village and, when necessary, "flying", to enable an overview of the virtual village to be presented for global awareness and discussions relating to insurgent surveillance locations, escape routes, and so on. A simple "binoculars" function was also deemed necessary, so that patrol vulnerability from high or distant insurgent vantage points could be demonstrated. The demonstration was also operable using a mouse and keyboard, if an *Xbox* controller was unavailable.

**Figure 69**

## FIDELITY ASSESSMENT

One of the key driving features behind the level of fidelity specified for this demonstrator was the need for realistic and effective variable daylighting. As was discovered during the development of the urban C-IED demonstrator described in Case Study 17, when training fine observation skills, time-of-day effects, plus associated ambient lighting and shadowing are all essential features of a simulation of this nature. These features, when correctly implemented, can help render crucial IED components and cues – command wires, disturbed earth, small markers – almost invisible, It is often these near-invisible markers that can make the difference between a safe patrol and one at risk of casualties from IED explosions. Furthermore, strong shadows are capable of concealing even the most obvious (under other lighting conditions) of markers, such as the small rock circle shown adjacent to a distant walkway gate in Figure 69. If the walkway shown in Figure 69 had to be used during a rush exit from part of the village, the shadowing at a particular time of day might well lead to such a cue being missed altogether.

In addition to the lighting effects, attention was paid to the fidelity of other markers and contexts, such as the poppy and wheat fields, both of which required similar levels of plant fidelity (including gentle swaying in the breeze) to that demonstrated previously in the original rural C-IED demonstrator (Case Study 15). In addition to the main village and market buildings, discarded items, ditches, junk piles, ISO containers, oil cans and many other 3D features were included within the scenario to quite high levels of fidelity. As well as the ability for instructors to "fly" to different elevated parts of the village, collision detection with all buildings was deactivated, thus allowing them to enter buildings rapidly in order to illustrate views through windows and cracks and other possible vantage points for insurgents.

## OUTCOME

Although the Afghan Village demonstrator was not used during the IED "Destroy" course (due to issues with instructor availability and pre-training time), the simulation was developed and delivered within the four-week timescale imposed by the stakeholders. The demonstrator is currently being shown to a variety of potential future military stakeholders as a generic virtual environment in which to train a wide range of activities, including the deployment of RCVs, perception of intent (via the use of village avatars, for example), urban UAV deployment and the illustration of new tactics in the concealment of IEDs and associated markers. Consideration is also being given to the expansion of the scenario to include a longer patrol route, approaching the village from a distant helicopter insertion point, with intervening hills, ditches, culverts and other vulnerability points.

## KEY REFERENCES

None as of date of publication (February, 2012).

# CASE STUDY 19:
## *Cutlass* Manipulator Familiarisation Tool

**(Sponsor: Dstl; Stakeholder: Defence Explosive Ordnance, Munitions & Search School; 2011)**

### SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The first and second MACP (Urban) C-IED demonstrators included basic remote driving and manipulation examples associated with a range of remotely-controlled vehicles (RCVs). However, as described in Case Study 17, it was generally accepted that these vehicles were included in the simulations for completeness, illustrating the culmination of a Render-Safe Procedure (RSP) decision-making process, rather than as an element supporting the development of remote driving and manipulation skills. The challenge faced with the development of a part-task simulator for the new *Cutlass* RCV system (Figure 70) was to develop an affordable portable trainer, potentially for multi-site deployment, with accurate physics-based representations of remote functions.



Figure 70

### HUMAN FACTORS ANALYSIS & KEY ISSUES

One of the major concerns expressed by RCV instructors during observations undertaken at the Defence Explosives, Munitions and Search School (DEMSS) in September 2010 was the regularity with which more recent classes of vehicle (i.e. more recent than, and more sophisticated than the long-running *Wheelbarrow* system) may be damaged. Many instructors felt that there was a potential for damage as a result of possible limitations in "hands-on" access to the vehicle. Current classroom training may not, they feel, equip RCV trainees with adequate skills and system awareness to help them appreciate the capabilities and limitations of the vehicles they are about to operate. Nor may it help trainees to adapt to the notion of controlling vehicles and manipulators *remotely*, especially in the case of multi-axis manipulator systems (such as that fitted to *Cutlass*), where each one of six joysticks (see Figure 71) controls a different function and movement of the manipulator, depending on which of a number of joint-by-joint or multi-axis ("resolved" motion) control modes has been selected. Consequently, early hands-on opportunities can sometimes be characterised by trainees pushing the remote systems to their limits and failing to appreciate those limits when approaching obstacles, such as steep ramps or stairways, narrow corridors, or platforms that may look mountable from a remote camera viewpoint, but in reality are not.

Vehicle damage would have a knock-on effect in that a reduction in the size of a RCV fleet may mean fewer opportunities for hands-on training, or significant delays when trainee groups have to share limited resources. Delays may also have an impact on skill fade – the fewer the systems (and this is a particular concern as RCVs become more sophisticated), the greater – potentially – the remote operations skill fade. With future RCVs such as *Cutlass*, the cost per vehicle will undoubtedly restrict the number of systems that are made available for training, and the impact of this on basic training, let alone skill fade and

refresher training, could be immense. An additional concern, brought about by observations at early *Cutlass* trials, related to the remote manipulation behaviours of some of the RCV users. Some – particularly those with *Wheelbarrow* experience – were seen to extend the *Cutlass* manipulator outwards, past the front of the vehicle chassis, and leave it in this position, changing the position of the end effector by driving the vehicle forward and backward (mimicking the *Wheelbarrow* boom), and turning left and right when necessary (a classic case of "old habits die hard"). They would then operate the wrist and gripper functions when in close proximity to the target object. This indicated that the RCV users may not be taking full advantage of the 9 degrees-of-freedom the system possesses, thereby compromising its overall performance. A part-task simulator will allow future *Cutlass* users to experience the full range of capabilities of the manipulator system.

## FIDELITY ASSESSMENT

The fidelity requirements for this project closely parallel those originally established for the mid-1990s Minimally Invasive Surgical Trainer project described in Case Study 1, in particular recommendations for the use of realistic input devices, tools or specialist items of equipment in order to help train appropriate skills and enhance the simulator's "believability" whilst presenting low fidelity virtual images. However, unlike the case for *MIST,* the *Cutlass* manipulator familiarisation trainer also demanded a high level of simulated functional fidelity in order to foster the correct remote operation skillsets. Consequently, detailed attention was given to the design of a virtual environment which would not only provide an adequate introductory training scenario for the end users, but would also accurately represent the physics-based qualities of the *Cutlass* manipulator, including fine detection of contacts and collisions, grasping, object friction, grasped object slippage and release (falling under gravity). An early physics-based prototyping simulation was developed for this very purpose and, once refined, the effects were programmed into the Virtual Environment designed for use with the simulator. The virtual scenario takes the form of a room with a cupboard. The cupboard door, when opened, exposes shelves with numbered cans, each of which has to be carefully manipulated into a floor-mounted tray using a range of manipulator control modes and selectable remote camera views. A replica (physical) *Cutlass* console was also designed and constructed (Figure 72). Whilst this console did not possess all of the controls evident with the real system (as shown in Figure 71), it contained accurate representations and locations of the key components, including the manipulator mode selection areas on a touch screen.



**Figure 71**



**Figure 72**

## OUTCOME

At the time of publication (February, 2012), the *Cutlass* simulator is still at a prototype stage of development and is being exposed to a range of stakeholders and potential exploitation supporters. Refinements are still in progress, including running the simulator in parallel with an actual *Cutlass* console system, in order to check the accuracy of the software manipulator model. Early feedback from SMEs has identified key additional functions that, again at the time of writing, are being developed. These enhancements also include improvements to the physics-based qualities of the virtual *Cutlass* and an accurate simulation of vehicle roll-off and roll-on. Additional switch functions (particularly with regard to the panels just above and below the monitor) and software capabilities have been specified following recent trials with end users. For demonstration purposes, the simulation can also be hosted on a laptop using an *Xbox* gamepad.

## KEY REFERENCES

None as of date of publication (February, 2012).

# CASE STUDY 20:
## *Tornado* F3 Avionics Maintenance Trainer

**(Sponsor/Stakeholder: RAF Marham; 1999)**[8]

### SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The Avionics Training Facility (ATF), based at RAF Marham, originally consisted of three key components – a selection of instrumented mock-ups relating to the *Tornado* GR4 strike aircraft, an F3 Avionics Ground Training Rig (AGTR) and an F2 rig, modified using F3 and GR4 components, including Line Replaceable Units (LRUs) and wing pylons. The modified F2 rig was essential for activities such as health and safety training associated with weapons loading and the manipulation of heavy LRUs. The ATF replacement project arose not only as a result of limited access to airframe hardware, but also as a requirement to reduce training times and costs. The £14 million AGTR facility had, at the time of the project, been in existence for a year and had enabled instructors to reduce course times from 13 to 11 weeks. However, only two students plus one instructor could be present on the rig at any one time. Furthermore, in order to simulate avionics faults, the LRUs provided with the rig had to be removed and inserted into a nearby bench unit, the wiring and functions of which resembled that of an old telephone exchange. As a result of these limitations, each and every student experienced a downtime totalling nearly 3 weeks (i.e. time in which waiting students did nothing).



**Figure 73**

### HUMAN FACTORS ANALYSIS & KEY ISSUES

The virtual *Tornado* F3 was developed on the assumption (confirmed by Subject Matter Experts) that, by the time technician trainees undertook the avionics simulation course, they would already possess the basic manual skills and knowledge necessary to select and use the correct tools to remove LRU cover panels and the LRUs themselves. It was decided, therefore, that the simulated maintenance task would not benefit from a Virtual Reality-like interface that attempted to reproduce the use of spanners, screwdrivers and other common tools. Not only was this level of technology unacceptable from a cost and reliability perspective, its use would probably focus the trainees' attention more on interfacing with the virtual *Tornado* through what would have been quite cumbersome and unreliable wearable equipment than on performing the task. Consequently, LRU panel opening, LRU extraction and inspection operations were achieved using "point-and-click" mouse inputs, combined with simple drop-down task sequence menus. This approach has since been exploited in the *SubSafe* submarine safety/spatial awareness demonstrator (see Case Studies 8 and 9). Navigation around the external shell was achieved by mouse motion, coupled with a simple on-screen directional cue.

### FIDELITY ASSESSMENT

Figure 73 shows the extent of the virtual components and LRUs and simulated test equipment that made up the virtual *Tornado* F3. Each LRU was geometrically accurate and possessed high-definition textures to aid in recognition and fault detection (some even featuring bent connector pins). The external shell of the virtual aircraft was rendered to a medium level of fidelity, with greater detail included only when it was deemed necessary to provide trainees with location recognition cues relating to a specific panel and its underlying LRU. All external moving surfaces were present, including removable and hinged panels, flight control surfaces and radome. The cockpit areas (pilot and navigator positions) were endowed with the highest level of visual and functional fidelity, including active head-up and navigator displays, together with fully operational controls, actuated by mouse click and/or drag, with directional cues for linear and rotary functions offered by the cursor when over the virtual control in question. Joystick functions were an exception to the point-and-click/drag rule, due to the distribution of the multifunction controls around the joystick handgrip. Consequently, physical pilot and navigator joysticks were provided on each trainee workstation. In order to accommodate the effective learning of virtual and real control inputs and their effect on the aircraft's avionics functions, a triple-screen interface was developed that supported the display of a full-length representation of the virtual aircraft, specific cockpit locations, or combinations of the two.

[8]Original project conducted by VR Solutions Ltd.

**Figure 74**

## OUTCOME

The ATF system was hosted on a high-specification Windows PC and, uniquely (for the time of installation), featured three screens per workstation, each displaying different working views of the aircraft, avionics bays, over 450 LRUs and 50 items of virtual test equipment (Figure 74). Ten such workstations were produced, fully networked, allowing a minimum of eight students to be trained and supervised by two instructors in basic and advanced *Tornado* F3 avionics maintenance routines, with collaboration between students supported over the local area network as necessary. Soon after its operational debut in 1999, the ATF simulator was instrumental in helping Marham instructors reduce training time from 13 to 9 weeks and downtime from 3 to zero weeks. Indeed, the instructors believed the course could be shortened even further, but were reluctant to do so, choosing instead to increase course content, to promote retention through "consolidation breaks" and to introduce extramural self-paced refresh trials. Further feedback from the instructors suggested that, in contrast to previous courses, ATF students "grasped the concept" (i.e. gained enhanced spatial and procedural knowledge of the aircraft and LRU distribution) up to 40% faster than achieved by previous non-ATF students. The modified (physical) *Tornado* F2 rig, as used by the GR4 course students, was retained in order to deliver health and safety training associated with lifting procedures for some of the heavier LRUs. Of particular interest was the cost of the ATF. In total this amounted to just over one-tenth of the cost of previous non-VR set-ups.

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# CASE STUDY 21:
# Helicopter Voice Marshalling

**(Stakeholder: RAF Shawbury, Valley & St Mawgan; 2001 to 2004)[9]**

Figure 75: The RAF Shawbury Voice Marshalling Trainer
Figure 76: Rear-Door Helicopter Marshals - *Bell Griffin* (Upper) and *Sea King* (Lower)



**Figure 75**





**Figure 76**

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

The term "voice marshalling" refers to the actions of a member of the aircrew of a military or civilian multi-role helicopter, whose responsibility is to monitor the position of the aircraft vis-à-vis the external environment through the rear cabin door and to relay important (verbal) flight commands to the pilot. These actions help to expedite an accurate and safe ascent or descent, with or without load, from and to a specific location. The RAF was keen to adopt a low-cost simulation solution in order to improve the quality and efficiency of pre-flight, ground-based training, and to provide a more cost-effective mode of *remedial* training. Their particular aspiration was to help novice rear-door aircrew master the style and content of their voice interaction with the helicopter pilot. Legacy training techniques, based on scale dioramas and model helicopters, had proven inappropriate for this type of training. Deploying aircraft for remedial training was (and still is) a major problem, due to increased flying restrictions, dwindling personnel resources and, of course, the actual cost of flying (which, at the time of this project, was in excess of £2500 per flying hour).

## HUMAN FACTORS ANALYSIS & KEY ISSUES

The Human Factors analyses focused on identifying the limitations of current ground and in-flight helicopter voice marshalling (HVM) training methodologies. The analyses were conducted at RAF Valley (Search and Rescue Training Unit, SARTU) and RAF Shawbury (the Central Flying School), both bases flying Bell HT-1 *Griffin* helicopters over a period of three days. A later, similar analysis was conducted onboard a 203(R) Squadron Sea King HAR3 helicopter during a short coastal flight out of RAF St Mawgan.

During reconnaissance of a potential landing or search-and-rescue (SAR) hovering area, both the pilot and voice marshal agree on important features of the terrain (the "5 Ss" – size, shape, surround, surface and slope). They then identify man-made or natural markers for a controlled and safe final approach, including all-important monocular depth/distance cues, such as size and shape constancies, linear perspective, texture gradients, interposition and parallax. Commonly used markers include telegraph poles, isolated ("NATO Standard 40ft") trees and bushes, dwelling features (10ft and 20ft to the tops of a typical house first and second floor windows) and hangars (30ft to top of hangar door). HVM trainees are expected to be able to "halve" the distance repeatedly between their helicopter and target, thereby ensuring a smooth, rhythmical vocal countdown and, thus, a steady rate of approach on the part of the pilot.

When at sea, voice marshals often use breaking wave patterns as markers. As the helicopter approaches the target or landing area, the voice marshals make regular head and torso movements – both outside *and* inside the aircraft – in order to maintain a strong situational (and, therefore, safety) awareness of the dynamically changing situation.

[9]Original project conducted by VR Solutions Ltd.

Figure 77: Examples of Virtual Environment Fidelity Provided in the Voice Marshalling Simulator

**Figure 77**

## FIDELITY ASSESSMENT

Of paramount importance to the levels of virtual environment fidelity provided in this simulation were representations of the key markers exploited by voice marshals during the reconnaissance and approach procedures. Given the range at which these features would exist in the real world, highly detailed 3D assets (such as trees with individual branches, ground vehicles and marine vessels with fine structural detail, etc.) were considered inappropriate (Figure 77). Consider, for example, in the case of training *backdrop parallax* – instantly judging the altitude of the helicopter based on the extent to which familiar objects, such as trees, are occluded by or visible over other familiar objects, such as buildings. The trees used in the simulation took the form of simple billboarded texture pairs [G1], the buildings simple flat-shaded structures. The provision of real-time shadowing (highly difficult and expensive to achieve at the time this simulation was developed) had already been discounted, as they are only useful in the judgement of altitude if the helicopter is active over artificial surfaces or is involved in load lifting and depositing. A similar decision was made with rotor downdraft effects (also a complex feature to deliver at the time of development – contrast this with the effects achieved in Case Study 22). Downdraft for SAR applications only provides a useful cue in confined areas (e.g. generating foliage movement) and is influenced by prevailing winds - a 10-15 knot wind will move the downdraft effects aft of the helicopter.

From an interactive technology fidelity (data input/display technology) perspective, in addition to scene scanning, the regular head and torso movements noted during the in-flight observations were interpreted as a means of obtaining parallax cues, either by using external physical features of the helicopter, or by lining up visually with features in the external environment. These behaviours, along with the requirement for the voice marshals to make regular head-up motions to view the horizon and even look under the helicopter on occasions (supervising under-slung loads, or monitoring very uneven terrain), drove the conclusion that a helmet-mounted display (HMD) and head-tracking solution was desirable in this instance. However, in order to enhance the simulation experience and with operational health and safety in mind, a non-face-enclosing HMD was chosen, affording the end user peripheral views of their arms and of the immediate real working environment (see Section 3.4.2). Furthermore, given the ranges over which marshalling target procedures are active, not to mention the limitations in HMDs in presenting reliable and consistent stereoscopic images, the need for 3D viewing was judged unnecessary. Consequently, the virtual imagery was presented *biocularly* (the same rendered image being presented to both eyes). Finally the in-flight movement analyses of the aircrew suggested that a simple wooden framework would suffice as a representation of the rear door of the 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 (see Figure 75).

Figure 78:   Virtual Griffin Helicopter over a Coastal Gulley



**Figure 78**

## OUTCOME

The HVM facilities have been used by the RAF training teams at Shawbury (2 sets) and Valley (1 set) since their installation in 2002. Their capabilities were extended in 2007, when a dynamic winching simulation was added to complement the rescue scenarios being trained (Figure 78). The RAF has recorded a number of successful training results with the systems, particularly with the remedial training of close-to-failure trainees. The cost of all three simulator systems, including development, hardware and installation of all three systems equated to roughly 96 flying hours. This project also provided valuable Human Factors information relating to voice marshalling, which was used to good effect during the early stage of a later helicopter brownout simulation study (see Case Study 22).

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# CASE STUDY 22:
# Helicopter Brownout

**(Sponsor: Capability, Joint Training, Evaluation and Simulation (Cap JTES), 2010)**

Figure 79:  RAF Chinook Generating Dust Cloud on Landing
Figure 80:  Simulated Dust Cloud Effects Noted at RAF Benson

## SUMMARY & KEY TRAINING REQUIREMENTS/GAPS

Helicopter brownout refers to a rapid onset of dust or sand clouds brought about by a variety of aircraft and environmental factors. Such clouds often envelope the cockpit and can drastically reduce the pilot's visibility, leading to a serious deterioration in spatial and situational awareness. Concern was raised that current-generation helicopter mission training simulators, particularly those featuring desert areas (e.g. at the Medium Support Helicopter Aircrew Training Facility (MSHATF) at RAF Benson), were not providing trainees with appropriate fidelity representations of brownout (see Figure 79). As well as understanding the key Human Factors issues relevant to simulation design for brownout training, this project was designed to evaluate three popular games engine/sandbox/interactive media products to assess their suitability for developing a more comprehensive brownout simulator, should this future capability be demanded by stakeholders.


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**Figure 79**



**Figure 80**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

The Human Factors Analysis was based on an extensive briefing at Joint Helicopter Command and participation in a series of simulated Chinook sorties at MSHATF. From a Human Factors perspective, the key training issue relates to what is known as "Three-Crew Patter" – similar in importance to the verbal instructions relayed from the helicopter voice marshal to the pilot described in Case Study 21. In the case of the Chinook, the status of the helicopter "cycles" verbally from the Handling Pilot to the Non-Handling Pilot to the Rear-Door Crewman and back to the Handling Pilot. Any break in the patter on the part of one of the crew indicates a problem and is challenged by one of the other two. The circular patter gets tighter as the final approach progresses.

The "Handling Pilot" maintains a heads-out view as the aircraft makes its approach, fixating on the horizon for stabilisation cues in order to avoid heavy or asymmetric touchdowns through excessive rolling, yawing and vertical motions. The Handling Pilot also looks for closer fixed "markers" (such as a bush, rock or other distinct natural features, even huddled groups of ground personnel). Ground texture and constancy effects are important at this stage. The "Non-Handling Pilot" relays information to the Handling Pilot from Doppler Ground Speed and Radar Height instruments during approach and hover, together with trim and, importantly, any lateral drift or rotational motion. The (Rear-Door) Crewman will, again as observed with the helicopter voice marshals described in Case Study 21, conduct normal marshalling procedures as well as monitoring the progress of the dust cloud as it approaches the aircraft (usually) from the rear. He will provide cloud "catch-up" information to the cockpit team members, including stating when the cloud has reached the tail and door and when it is about to engulf the cockpit region (Figure 80). About a second or two after the dust cloud covers the cockpit, the Handling Pilot attempts to select another, more close-field visual marker to effect a safe touch-down.

Figure 81:  Simplified Particle Count vs. Rendering
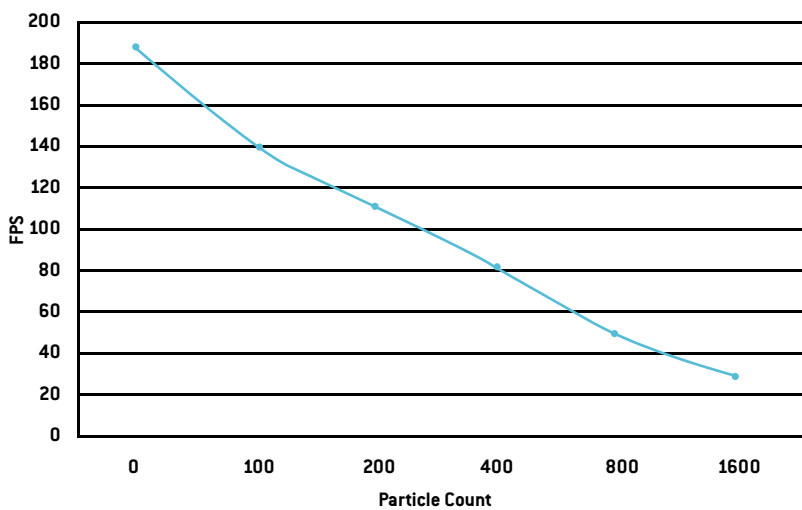Performance (Frames per second)
Relationship



Figure 81

## FIDELITY ASSESSMENT

From a simulation design perspective, helicopter brownout is dictated by a range of parameters, including aircraft type, weight and blade configuration (e.g. flat-blade, paddle, etc.), number of aircraft in sortie, aircraft flight profile and loading, "off-aircraft" effects (e.g. wind speed and direction, type of dust and surface material), and ambient weather conditions. None of the products tested provided an editing tool (or the means to develop such a tool) capable of developing or experimenting with variations in these parameters. Therefore, in order to approximate the simulation of dust or sand in motion, the particle physics modules of each product were investigated to judge their performance in generating dynamic brownout effects of acceptable visual credibility. The products investigated were *CryEngine 2* (Crytek), *VBS2* (Bohemia) and *Quest3D* (Act-3D). Semi-transparent textures were applied to billboards to create the effect of a dense particle field, whilst bearing in mind the computational cost of rendering these billboarded "particles" – in other words their effect on the rendered image frame rate (the number of frames "drawn" per second – Frames Per Second (FPS) in Figure 81).

**Figure 82**

## OUTCOME

With *CryEngine 2* (Figure 82, Upper), aircraft particle effects are governed using scripts and source code. However, the source code is not available, thereby limiting the alterations that could be made. Basic changes could, however, be made to such features as particle count, colour and size/shape – the movement path of the particles could not be changed. Additional particle effects could not be added without access to the source code. *CryEngine 2* only supports very limited flight dynamics.

With *VBS2* (Figure 82, Lower), aircraft particle effects are governed using scripts. However, the main particle script 'helidust' is not directly accessible to the developer. Whilst it was not possible to adjust the standard particle effect, additional particle-like effects could be added. By writing new scripts a trailing dust effect was introduced that would follow the aircraft when close to the ground. However, from a visual perspective, this effect looked very unrealistic. *VBS2* only supports limited flight dynamics.



**Figure 83**

With *Quest3D* (Figure 83), there is no limitation on scripting. Greater access to code allows for detailed multi-level particle effects. A three-stage particle effect was created to approximate the movement of the particles. Furthermore, particle effects could be created at any stage of the rendering process, allowing for post-processing effects to give a more realistic, "softer-blurring" effect. *Quest3D* does not include flight dynamics as standard. However they can be implemented with relative ease.

## KEY REFERENCES

None as of date of publication (February, 2012).

# CASE STUDY 23:
## *Virtual Scylla*

**(Stakeholders: National Marine Aquarium, FOST HM, 2006 to 2009)**

Figure 84:  HMS *Scylla*
Figure 85:  Reconstruction of Bathymetric Survey Data of *Scylla*, showing Damage to Aft Helicopter Hangar Area
Figure 86:  Original *CryEngine* Model of the *Virtual Scylla* (Top), with a More Realistic Real-Time Rendering Quality

## SUMMARY

The *Virtual Scylla* "Case Study" is included here for completeness, in that the lessons learned and the outcomes of the project have helped to drive developments in a number of the other case studies described herein, from submarine rescue (Case Study 10) and subsea visualisation tools (Case Study 13) to defence diving (Case Study 12). The last of her type to be built at Devonport in 1968, the ex-Royal Navy Batch 3 *Leander* Class Frigate, HMS *Scylla* (Figure 84), was deliberately scuttled on 27 March, 2004 by the National Marine Aquarium (NMA) to become Europe's first artificial reef. Today, resting on the sea floor in Whitsand Bay at a depth of 24-26m, the *Scylla* provides a venue for sports divers and marine conservationists alike. *Virtual Scylla* was not developed to provide any specific form of training. Instead, the simulation was designed to provide a means of attracting the attention of a range of end users – from schoolchildren to members of the public – to a more scientific demonstration relating to climate change and underwater ecosystems. Also, during the course of developing the *Virtual Scylla* scenario, considerable assistance was provided by FOST HM, particularly in making hydrographic survey results of the *Scylla* wreck site available. Throughout the early stages of the *Virtual Scylla* project, survey missions using the Aquarium's *VideoRay* ROV were undertaken to monitor the declining condition of the vessel and to chart colonisation cycles of various forms of marine life. Using the survey information provided by FOST HM (e.g. Figure 85), it was possible to maximise the data collected during the short times available at the dive site (due to the tide-linked deterioration in visibility and current condition).


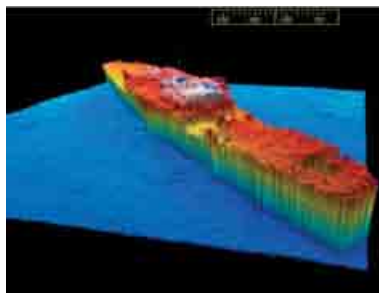© UK MOD/ Crown Copyright 2012
**Figure 84**


**Figure 85**

## HUMAN FACTORS ANALYSIS & KEY ISSUES

No early formal Human Factors assessment was undertaken in support of the *Virtual Scylla* project, although lessons were drawn from other, prior case studies. In order to create a realistic environment with which to educate end users about the environmental conditions, both current and future, in which the vessel would now be experiencing, video records were taken of the ROV camera system after each mission. These videos were used to help recreate a realistic underwater scene, both with regard to visual qualities of the wreck and water, and of the motion qualities of the *VideoRay*. An early decision with regard to the use of an *Xbox* hand controller was driven by the anticipated familiarisation of end users with this form of input device. This single controller would govern the orientation and dive/surface functions of the virtual ROVC, plus additional functions, such as simulated forward lighting and single-frame image capture.

## FIDELITY ASSESSMENT

Only the external areas of the ship were modelled, based on images and models of her pre-scuttling condition. Early experiments with one particular games engine (*CryEngine*) produced quite stunning representations of the *Scylla* wreck on the seabed (Figure 86, top image). The realism inherent in this virtual scenario was quite low, particularly with regard to ROV lighting, subsea turbidity and the placement of convincing underwater fauna. Consequently, the 3D *Scylla* model assets were imported into a second simulation toolkit (*Quest3D*), where it was possible to experiment with rendering and particle effects (Figure 86, bottom image and Figure 88). Indeed, the particle and fogging effects described in Case Study 10 (submarine rescue) were originally developed for the *Virtual Scylla* project, as was the effect that simulated remote image distortion brought about by the curvature of the ROV's Perspex dome.
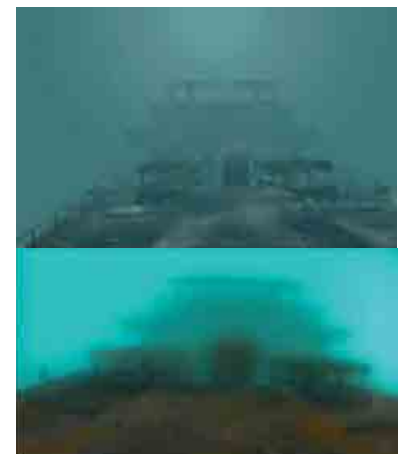

**Figure 86**

Figure 87: Virtual "Aquatheatre" (Object at Bottom
of Image is the Simulated VideoRay
Gripper)
Figure 88: Additional Realistic Real-Time Rendering
Quality Images of *Scylla* Bow (Upper)
and Helicopter Hangar (Lower)



**Figure 87**



**Figure 88**

## OUTCOME

As already mentioned, the early research efforts underpinning the development of the *Virtual Scylla* were also influential in the execution of subsequent projects described earlier in this document. As for the *Scylla* simulation itself, the system has featured in numerous exhibitions and events both at the NMA and elsewhere. The project provided the basis for a postgraduate research project addressing the use of Artificial Life techniques relating to the simulation of underwater colonies and the effect on said colonies of sea temperature changes. It is still hoped that the project can be resurrected and updated in the future, in collaboration with the NMA. Building upon lessons learned during the *Virtual Scylla* project, an additional interactive underwater "serious game" was designed as a research tool to capture basic remote control skills of visitors to the NMA. The game was based on a virtual reconstruction of the Aquarium's "Aquatheatre" – in essence an underwater "assault course" for mini-ROVs, housed within a large tank (Figure 87) and supported research into issues such as visual fidelity, simulation of underwater physics (e.g. ROV buoyancy caused by bubble "stacks"), differing control input devices and the effects of input-output time delays.

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# ABBREVIATIONS

| | |
|---|---|
| 2D | Two Dimensions / Dimensional |
| 3D | Three Dimensions / Dimensional |
| | |
| AAR | After Action Review |
| ABC | Airway-Breathing-Circulation |
| AFV | Armoured Fighting Vehicle |
| AGTR | Avionics Ground Training Rig |
| AI | Artificial Intelligence |
| AR | Augmented Reality |
| ATF | Avionics Training Facility |
| | |
| Cap JTES | Capability, Joint Training, Evaluation and Simulation |
| CAVE | Cave Automatic Virtual Environment |
| CAD | Computer-Aided Design |
| CCTV | Closed-Circuit Television |
| CDM | Context-Dependent Memory |
| CGI | Computer-Generated Imagery |
| C-IED | Counter Improvised Explosive Device(s) |
| COTS | Commercial Off-The-Shelf |
| CRWS | Close-Range Weapons System |
| | |
| DARPA | Defense Advanced Research Projects Agency |
| DARWARS | DARPA Wars (also DARPA WARfighter training) |
| DDS | Defence Diving School |
| DE&S | Defence Equipment & Support |
| DEMSS | Defence Explosives, Munitions and Search School |
| DISSUB | Disabled Submarine |
| DPM | Disruptive Pattern Material |
| DTC | Defence Technology Centre |
| DTED | Digital Terrain Elevation Data |
| | |
| EBS | Emergency Breathing System |
| ECEHH | European Centre for the Environment & Human Health |
| ENT | Ear, Nose & Throat |
| EOD | Explosive Ordnance Disposal (Device) |
| EU | European Union |
| | |
| FOST | Flag Officer Sea Training |
| FOST HM | Flag Officer Sea Training Hydrographic, Meteorological and Oceanographic |
| FPS/fps | Frames per Second |
| FSC | Future Surface Combatant |

| | |
|---|---|
| GCS | Global Combat Ship |
| GDP | Gunner Director Platform |
| GPMG | General Purpose Machine Gun |
| GPS | Global Positioning System |
| GUI | Graphical User Interface |
| | |
| HMCS | Her Majesty's Canadian Ship (Submarine) |
| HMD | Head-Mounted Display |
| HMS | Her Majesty's Ship (Submarine) |
| HF | Human Factors |
| HFI DTC | Human Factors Integration Defence Technology Centre |
| HM | Her Majesty('s) |
| HVM | Helicopter Voice Marshal(-ling) |
| | |
| ICP | Incident Command Post |
| IED | Improvised Explosive Device |
| IEDD | Improvised Explosive Device Disposal |
| i3D | Interactive 3D (Three Dimensions / Dimensional) |
| I/ITSEC | Interservice/Industry Training, Simulation and Education Conference |
| ITT | Interactive Trauma Trainer |
| IWO | Initial Warfare Officer |
| | |
| JWO | Junior Warfare Officer |
| | |
| LCD | Liquid Crystal Display |
| LRU | Line Replacement Unit |
| | |
| MACP | Military Aid to the Civilian Power |
| MCMV | Mine Countermeasures Vessel |
| MIST | Minimally Invasive Surgical Trainer |
| MFD | Maritime Foundation Data |
| MoD | Ministry of Defence |
| MSHATF | Medium Support Helicopter Aircrew Training Facility |
| MTS IPT | Maritime Training Systems Integrated Project Team |
| | |
| NASA | National Aeronautics and Space Administration |
| NATO | North Atlantic Treaty Organisation |
| NDP | Naval Design Partnership |
| NMA | National Marine Aquarium |
| NPC | Non-Playable Character |
| NSRS | NATO Submarine Rescue Service |

| | |
|---|---|
| OLED | Organic Light-Emitting Diode |
| OOW | Officer of the Watch |
| | |
| PC | Personal Computer |
| PLP | Phantom Limb Pain |
| PSP | Play Station Portable (Sony) |
| PTSD | Post-Traumatic Stress Disorder |
| | |
| QEHB | Queen Elizabeth Hospital, Birmingham |
| | |
| RAF | Royal Air Force |
| RAVE | Reconfigurable Advanced Visualisation Environment |
| RCDM | Royal Centre for Defence Medicine |
| RCV | Remotely Controlled Vehicle |
| RN | Royal Navy |
| ROTR | Rules of the Road |
| ROV | Remotely Operated Vehicle |
| RSP | Render Safe Procedure(s) |
| | |
| SAR | Search and Rescue |
| SARTU | Search and Rescue Training Unit (RAF) |
| SCOG | Self-Contained Oxygen Generator |
| SE | Synthetic Environment |
| SME | Subject Matter Expert |
| SMERAS | Submarine Escape, Rescue and Abandonment Systems |
| SMQ | Submarine Qualification |
| SSK | Ship, Submersible, (Hunter-) Killer/Attack (conventional submarine classification) |
| SSN | Ship, Submersible, Nuclear |
| | |
| TRL | Technology Readiness Level |
| | |
| UAV | Unmanned Air Vehicle |
| UK | United Kingdom |
| UKHO | UK Hydrographic Office |
| UKSRS | UK Submarine Rescue Service |
| US | United States (of America) |
| USB | Universal Serial Bus |
| | |
| VCASS | Visually-Coupled Airborne Systems Simulator |
| VE | Virtual Environment |
| VR | Virtual Reality |
| VRET | Virtual Restorative Environment Therapy |
| | |
| WDV | Weapons Director Visual |

# ABOUT THE AUTHOR



**PROFESSOR BOB STONE** holds a Chair in Interactive Multimedia Systems within the College of Engineering and Physical Sciences at the University of Birmingham, where he is also Director of the Human Interface Technologies (HIT) Team. He graduated from University College London in 1979 with a BSc in Psychology, and in 1981 with an MSc in Ergonomics. Bob also currently holds the position of Visiting Professor of Simulation Psychology within the University of Plymouth, his home town, and was made an Honorary Professor of the South Russian State Technical University (Novocherkassk) at that University's 100th Anniversary in 2007.

After 9 years of ergonomics research at British Aerospace in Bristol, where he specialised in military Human Factors and remotely operated systems (conducting applied research and consultancy for the Department of Energy, the nuclear industry and the European Space Agency), Bob was involved in the launch of the UK's National Advanced Robotics Research Centre (NARRC), funded by the Department of Trade & Industry. Bob was the first European to experience the NASA *VIEW* Virtual Reality (VR) system in 1987, following which he established the UK's first industrial VR team at the NARRC. Over a number of years, his team undertook numerous telerobotics and VR consultancy and research projects for commercial and government clients (including developing the world's first tactile feedback glove for VR applications, *Teletact*). Following an appearance on the BBC's *9 O'Clock News* in January, 1993, he brought together (initially) 12 companies to fund the world's first industrial collaborative project addressing the commercial uses of VR. The success of this initiative enabled Bob's group to be launched as VR Solutions Ltd in the mid-1990s, a company he remained a Director of until 2002.

In May 1996, Bob was elected to become an Academician of the Russian International Higher Education Academy of Sciences in Moscow and was, in 2000, accredited by General Klimuk, Director of Russia's Gagarin Cosmonaut Training Centre as responsible for "introducing VR into the cosmonaut space programme". Bob was the Research Director of the UK Human Factors Integration Defence Technology Centre (HFI DTC) for over 6 years, and it is from within the DTC that many of his team's projects originate, covering human-centred design and evaluation methodologies for applications as varied as close-range weapons training and support for surgical and mental health therapies to submarine safety awareness, IED search and disposal training and unmanned vehicle control. Bob and his team adopt a very pragmatic approach to Human Factors research and he regularly spends time conducting observational studies in the field with subject matter experts. This has taken him from Royal Navy vessels conducting close-range weapons and missile trials to underwater operations onboard submarines and rescue submersibles; from oil and gas support platforms in the North Sea to remotely operated vehicle trials in the waters around Scotland; and from search-and-rescue helicopters over the mountains and coasts of Wales and Cornwall to operating theatres and medical units throughout the UK, US and South Africa.

Indeed, Bob's pioneering surgical task analysis efforts in the mid-1990s led to the development of a suite of simulated perceptual-motor tasks for a unique keyhole surgery VR trainer (*MIST*), still marketed today by Mentice of Sweden. From 1999 to 2002, Bob sat on a working party on behalf of the Royal College of Surgeons' Joint Committee on Higher Surgical Training (JCHST) investigating the assessment of surgical training and competence and, in January 2000, passed the Royal College of Surgeons of England's Basic Surgical Skills course. Today, he works closely with the Royal Centre for Defence Medicine and the new European Centre for Environment and Human Health, is an Honorary Consultant in Human Factors & Simulation within the UK's Hollier Medical Simulation Centre and was a

Human Factors consultant to the US Office of Naval Research-funded *Pulse!!* Virtual Healthcare Project (led by Texas A&M University Corpus Christi). Bob also represents the UK on a NATO Research & Technology Group (HFM-215 - *Advanced Training Technologies for Medical/ Healthcare*).

His work has received numerous awards, including, in 2003, the Laval Virtual Trophée d'Honneur for his "service to the European Virtual Reality Community" since 1987. In the same year, was made an Honorary Cossack at a ceremony in Starocherkassk, the former Don Cossack regional capital, recognising his decade of VR collaboration with the Russians. In 2007, he was awarded the UK Ergonomics Society's Sir Frederic Bartlett Award, the highest award given by that Society to an individual (and the first time ever that an individual had been awarded by the Society three times in their career). In 2011, he received an MoD Chief Scientific Adviser's Commendation for his contribution to Defence Science & Technology – one of only four individual; recipients in the UK. Later that year, his HFI DTC Serious Games Team received the BAE Systems Chairman's Silver Award for simulation research contributing to front line safety. A member of the UK Government's Simulation & Synthetic Environments National Technical Committee, Bob lectures to audiences of all backgrounds and ages across the world on the subject of VR, serious games and Human Factors.

MINISTRY OF DEFENCE

[dstl]

BAE SYSTEMS

Cranfield
UNIVERSITY

LOCKHEED MARTIN

MBDA
MISSILE SYSTEMS

sea

UNIVERSITY OF
Southampton

UNIVERSITY OF
BIRMINGHAM