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ABSTRACT.
The use of real time 3-D computer graphic models for preparation and support of remote handling operations on JET has been in use since the mid 1980 s.

A complete review has been undertaken of the functional requirements and benefits of virtual reality (VR) for remote handling (RH) and a subsequent market survey of the present state-of-the-art of VR systems has resulted in the implementation of a new system for JET.

The VR system is used in two discrete modes:

- In on-line mode the remote handling equipment Electro-mechanical hardware is connected to the VR system and provides input for the VR system to update a real time 3-D display of the equipment inside the torus. This mode supplements the video camera system and assists with camera control and warnings of impending or potential collisions.
- In off-line mode the operator manipulates the VR system model with no connections to the remote handling equipment. This mode is used during preparation of RH operational strategies, checking of operational feasibility and operations procedures.

Various VR systems were evaluated against a detailed technical specification that covered visualisation function and performance, user interface design and base model input/creation capabilities. The cheapest of those systems that satisfied the technical requirements was selected.

1. INTRODUCTION

This paper discusses the experiences gained in the selection and use of a Virtual Reality system for the support of remote handling operations on JET.

Recently, a complete review has been undertaken of the functional requirements and benefits of VR for remote handling and a subsequent market survey of the present state-of-the-art of VR systems has resulted in the implementation of a new system.

2. MODES OF USE OF VR FOR REMOTE HANDLING AT JET

To understand the rational for implementing a new approach to the use of VR for JET, it is necessary to briefly review the Remote Handling philosophy for the maintenance and upgrade of the JET machine.

The JET Remote Handling System employs a man in the loop approach with the robotic Boom and Mascot manipulator system providing the operator with a pair of remote hands inside the JET Vessel. All remote handling tooling and installation components are designed to be handled by the remote hands in a manner similar to an operator actually working within the JET Vessel. Overly complex electro-mechanical remote tooling and equipment is avoided, with a preference for hand tools which offer proven reliability.

Such an approach requires a high degree of operator skill and training, together with proven methodologies for remote operations task development, tooling and component validation.

To date, the JET In-Vessel Training Facility (IVTF), which is a full size mockup of inside the JET Torus has provided the testing ground for remote task development and an ideal environment for operator training and familiarisation. This does however require the manufacture of elaborate full size prototype components and tooling at an early stage to allow mockup work to proceed. This is complicated by the ever growing range and diversity of remote handling tasks for each new JET shutdown, from cleaning tasks to installation of major new diagnostic systems, each requiring a different configuration of the IVTF. The next JET shutdown planned for 2004 presently has around 100 remote tasks.

There is considerable demand on use of the IVTF both in terms of the cost of mockups for the many configurations and booking of operations development time within the facility. It became evident that a new approach was required which would allow multiple operations tasks to be developed simultaneously within tight budgetary and time constraints.

A further consideration involved improvements required to the on-line monitoring of the remote handling Boom during operations by the VR system. The existing system provides a real time 3-D display of the Boom & Mascot within the Torus but has limited automatic collision detection and lacked sufficient detail to properly support the operators.

3. REQUIREMENTS FOR A NEW VR SYSTEM

The main requirements of the new remote handling VR system were defined as:

- Should provide adequate detail to accurately simulate remote handling equipment within the JET Vessel and IVTF, allowing thorough validation of new tooling and component design within tight timescales. (Virtual mockup).
- Enable simultaneous remote operations task development by 5 people.
- Enable real-time monitoring of an 18 degree-of-freedom robot including collision detection.

In parallel with research into a new remote handling VR system, a paper-less remote handling Operations Documentation System was being planned and developed. A further requirement was added for the new VR system, in that it should:

- Integrate with the RH Operations Documentation System (ODS).

These main requirements were translated into a detailed technical specification, which fell into two categories:

1. Essential Functions – incorporating all of the main requirements.
2. Preferred Features – identifying capabilities, which would be useful, such as the ability to customise Graphics User Interface (GUI), provide animation facility, accurate lighting etc.

It was recognised early on that a major failure of the existing VR system was its inability to easily access the database of over 70,000 JET 3D CAD models from which the configuration control model of the JET machine is built. Therefore one of the prime essential functions was defined as be able to accurately translate JET CATIA models.

Our experiences with VR and 3D CAD models also suggested that the size and complexity of simulation we were intending to build would place considerable demands on both VR software and hardware. The existing VR software ran on Silicon Graphics hardware and maintenance/upgrade costs were high. With the advances being made in personal computers (PCs) and low cost/high performance graphics cards (driven by the gaming industry), we started with the premise that we would specify PCs running Windows NT software, unless proven otherwise. An acceptable refresh rate for the displayed VR simulation was established as 5 frames per second (fps).

4. VR SYSTEM SELECTION

A market survey was initiated and a short list of four companies generated, who seemed to offer products that satisfied our requirements with an established and proven product.

We then entered a stage of product demonstrations and evaluations with each of the four companies. Site visits occurred with existing customers to give an unbiased view of product and company.

Each company was sent a selection of JET 3D CAD models prior to product demonstration for translation into their VR environment, with further models supplied during the demonstration. This allowed optimum use of time but still allowed the evaluation panel to witness the translation process.

The translated VR models were then used to create a simulation within the VR package, which demonstrated:

- Methods and tools within the VR software for constructing simulations.
- Level of Detail Reduction algorithms (LODs) to produce acceptable performance (fps) for a JET Vessel simulation.
- Navigation of the simulation (Zoom, rotate, translate & Fly-through).
- Kinematics for creation and manipulation of a robotic device.
- Real world communication between the VR software an external network to facilitate real time monitoring of robotic devices.
- Collision detection within the simulation without loss of fps.

Evaluation sheets were produced prior to the demonstrations for use by the evaluation panel, which together with site visits and product documentation, provided the input for a process of benchmarking and decision analysis. This resulted in two companies who were able to meet all our Essential Functions and many of our Preferred Features, being asked to provide competitive tenders. The selection of PTC Division Mockup 2000i[2] as the outcome.

5. IMPLEMENTATION AND BENEFITS OF USE

Product demonstrations had been carried out using twin processors PC s with 500Mb to 1Gb of system RAM and large CRT monitors running Windows 2000/NT, so these were selected as the JET RH hardware platform. The choice of graphics cards was wide, with price ranging from a few hundred pounds to thousands. A new generation of low cost/high performance graphics cards promised good level of performance and were selected by one of the VR product demonstrators. A choice was made to purchase one of these low cost gaming cards together with a professional OpenGL (high cost) card for comparison. In use, the low cost cards have provided higher fps but with less visual quality, while the professional Open GL card provides a stable, high visual quality image. Based on this experience, the optimum graphics card for use with VR PCs for JET applications are low to medium cost (£300–£700) offering high fps with hardware based OpenGL providing good to high visual quality.

The supplier of the software was commissioned to install the software and provide initial product training over a two-day period. Installation of the CATIA translator proved challenging as it required direct access to a CATIA licence (JET drawing office) and PTC DIVISION Mockup2000i[2] licence (RH control room) across two firewalls and three networks. Optimum translation of the models required the correct setting of many parameters within a recipe file within the translator program. This involved considerable experimentation. The software supplier performed this task.

5.1 CREATING JET VESSEL VR SIMULATIONS

An early decision was made that all models used in the JET Vessel simulation should be provided by the JET Configuration Control officer (drawing office) to ensure an accurate, up to date simulation. This person operated the CATIA translator, providing models as requested.

The JET Vessel is a Torus, constructed in Octants with major sub-systems located on the walls allowing the plasma to occupy the central volume.

The VR simulation was therefore constructed in a similar manner, with a single generic octant being built then copied to form the torus. The major sub-systems were then overlaid in each octant (poloidal limiters, divertor, diagnostics etc) to form the complete vessel.

The VR simulation object tree was structured to allow the top half of the vessel to be turned off, providing the operator with the option of viewing the remote Boom operating inside the vessel simulation. (See Figure 1.)

All major remote handling systems that interface with the JET vessel have been simulated with kinematics used for robotic systems. Many tools, jigs and specialised equipment have also been simulated. (See Figure 2.)

5.2 MODES OF USE

Three configurations of simulation are produced for use by remote handling operators:

- JET Vessel with high detail – used in off-line mode for operations development and on-line during operations (vessel shutdown) where detailed information is required.
- JET Vessel with Low detail – used in on-line mode for operations during vessel shutdown for Boom monitoring .
- High detail Bench models – used for operations development and design evaluation. (See Figure 3.)

5.3 BENEFITS

The following benefits have been obtained so far with the use of VR simulations:

- Rapid validation of new component and tooling design.
- Thorough analysis of planned major new vessel sub-systems (new diagnostics, first wall components etc) using simulated remote systems and tooling.
- Early recognition of design/installation problems saving costly changes late in the design cycle.
- Reduced need for physical prototypes, lowering project costs and reducing timescales.
- Operations staff able to develop remote operations tasks in offices without the need to access central facilities such as the RH Control Room or the IVTF.
- Reduced reliance on the IVTF.

6. FUTURE DIRECTIONS

Investment is on going with people training and software/hardware purchases.

Improvements to visual realism of the simulation are being achieved using 3rd party software to re-work original CATIA translated models. (See Figures 4 and 5.)

Animated sequences together with the use of low cost viewers are being used allowing distribution to a wider audience for design/installation discussions and for use alongside operations documentation.

Experimentation with importing 3D scanned images obtained remotely into simulations are ongoing with initial results proving promising. These allow the JET Vessel simulations and Configuration Control model to be up-dated to an accurate (<1mm) as-built condition. Integration with the new RH Operations Documentation System has yet to be implemented.

CONCLUSION

The benefits obtained by investing in VR have been tangible and positive. Remote operations development within the remote handling group has been re-structured to take advantage of these and other improvements enabling the group to respond quickly to ever increasing demands.

With the move away from dedicated workstations to high performance/low cost PC platforms and the availability of a wide range of VR and Visualisation software available to meet different needs, the ability to create effective simulations is now a cost effective option for even the smallest of companies or organisations. The availability of low cost viewers further allows wide dissemination of these simulations.

ACKNOWLEDGEMENTS

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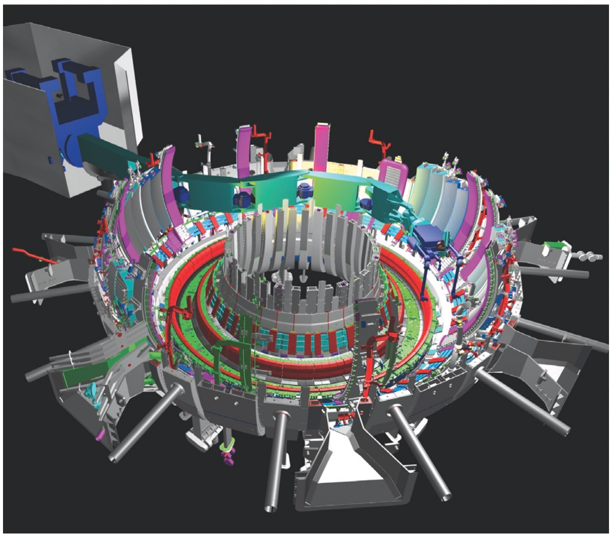

Figure 1: Boom in JET Vessel with top of vessel removed.

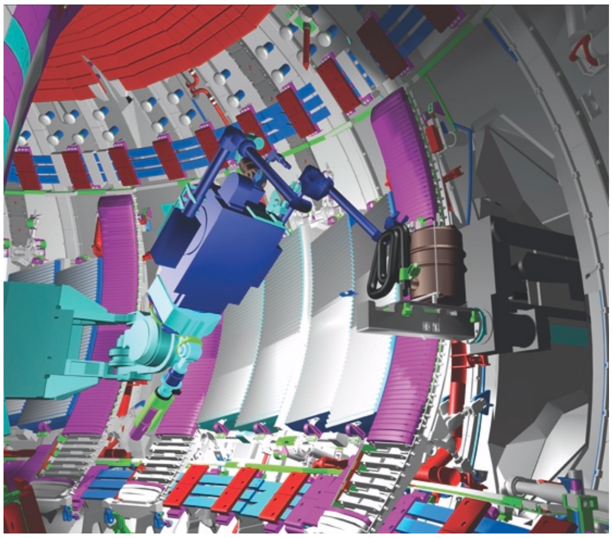

Figure 2: Mascot and Short Boom in JET Vessel.

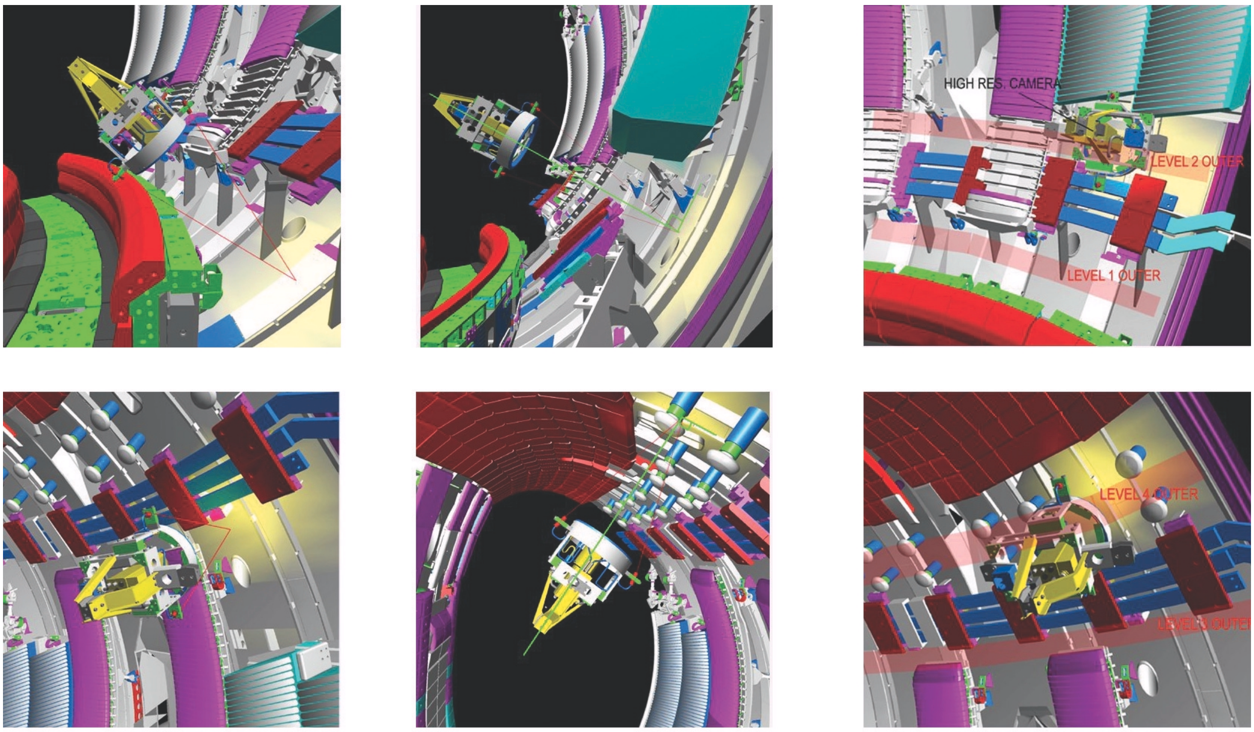

Figure 3: Operations task development for use of high res. camera in JET Vessel.

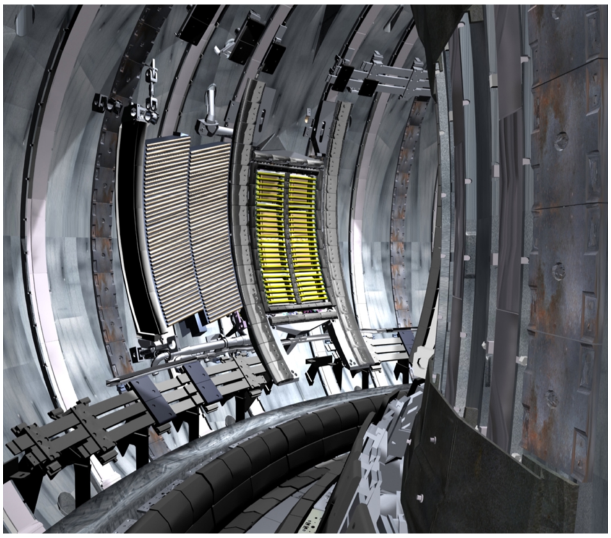

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Figure 4: Photo-realistic image of JET Vessel.

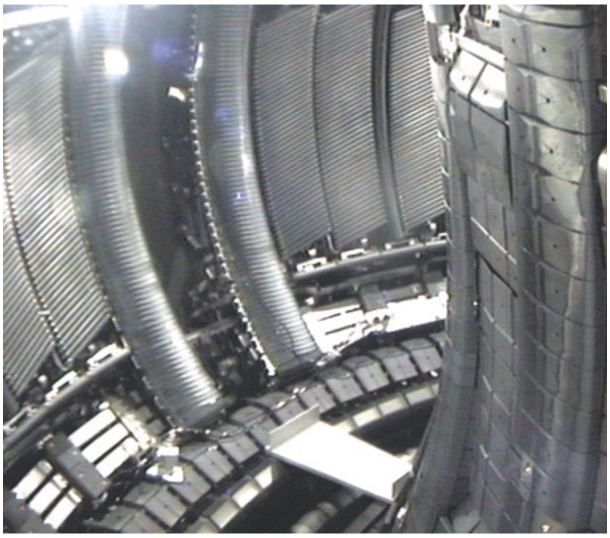

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Figure 5: Photograph of JET Vessel.