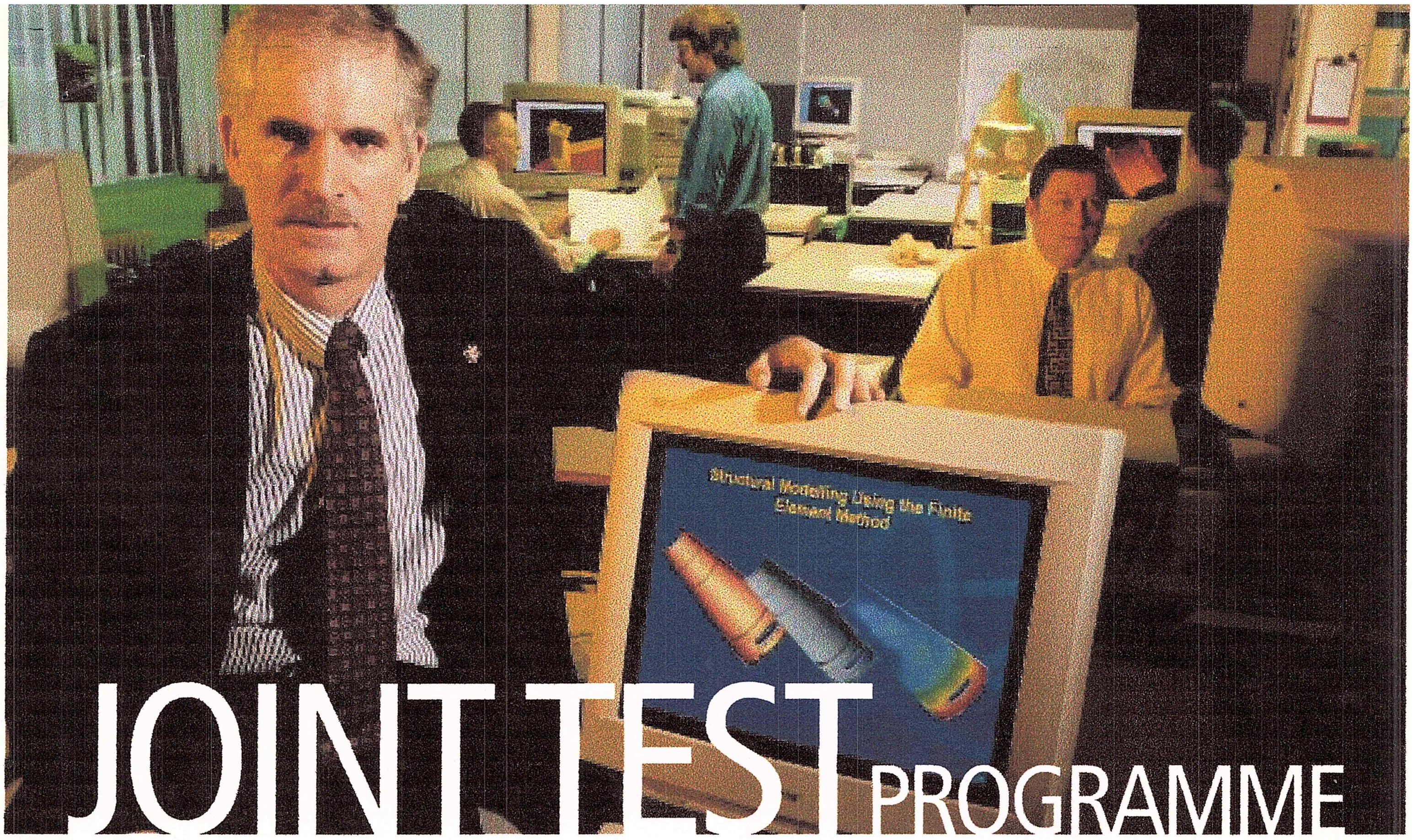

JOINT TEST PROGRAMME

Model Based Assurance

In the past AWE has used Underground Nuclear Tests (UGTs) to provide information on warhead safety, reliability and performance. Now that underground tests are no longer permitted, there is a drive towards what has been called 'Model Based Assurance' as an approach to the underwriting of warhead safety and performance. An important aspect of model based assurance is being able to predict the structural dynamics and response of a warhead throughout its life and also through the environments it could experience during deployment.

The UK has joined US nuclear warhead laboratories in a programme called the "Joint Test Programme" which has the objective of furthering the combined understanding of the basic science of structures and their responses, and then to incorporate the enhanced understanding into an improved modelling capability. This paper details some of the work being undertaken in delivering these aims.

Two of the main areas of work in the Joint Test Programme are developing structural models of the UK Trident Re-entry Body, which are to be verified by undertaking low excitation experiments to underwrite these models. In addition, two inert trials bodies have been manufactured for testing in the US at higher impulse levels to provide further data for model validation.

Model Based Assurance

It is worth trying to put into context the need for, and benefits of, structural analysis as a part of the model based approach to assurance of warhead safety and performance. As already stated, an important aspect of model based assurance is being able to predict the structural dynamics and response of a warhead throughout its life and also through the environments it could experience. Such environments are included in what are known as Factory-to-Stockpile and Stockpile-to-Target sequences. These sequences cover all aspects of normal and foreseen abnormal environments experienced during manufacture, transport, storage, submarine patrol and eventual retirement and disassembly. During deployment all phases need to be considered from launch through to exo-atmospheric flight and eventually re-entry and flight to target. Also needing to be addressed during the deployment phase are the effects of any defence systems that may directly or indirectly affect the warhead and its ability to perform.

The understanding of the structural behaviour in all of these environments is key to underwriting the safety and performance of a warhead. With a characterised structural response, a design can be continuously refined to 'engineer' the desired safety and performance characteristics when modifications are required. Greater confidence in the ability to model accurately allows a more cost effective assessment of changes to a warhead

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throughout its life, which are inevitable as materials age and components need to be replaced. The ability to model accurately and to simulate the effect of changes will minimise the need for expensive large scale trials.

Structural Model Development

The first stage in gaining an improved understanding of the structural response, was the production of an updated Finite Element (FE) model of the UK Trident Re-entry Body (RB). The original Trident designs were completed and recorded on a now outdated 2-Dimensional CAD (Computer Aided Design) package. These drawings were converted into 3-Dimensional 'Solid Models' or "Virtual Models" on our current generation of CAD systems (Unigraphics). This solid model now provides a common virtual model for all design and analysis work on the Trident RB, reducing the risks of error in transcribing aspects of the design into different specialist analysis packages. It will also provide a more robust and traceable link between the baseline design and assessments made.

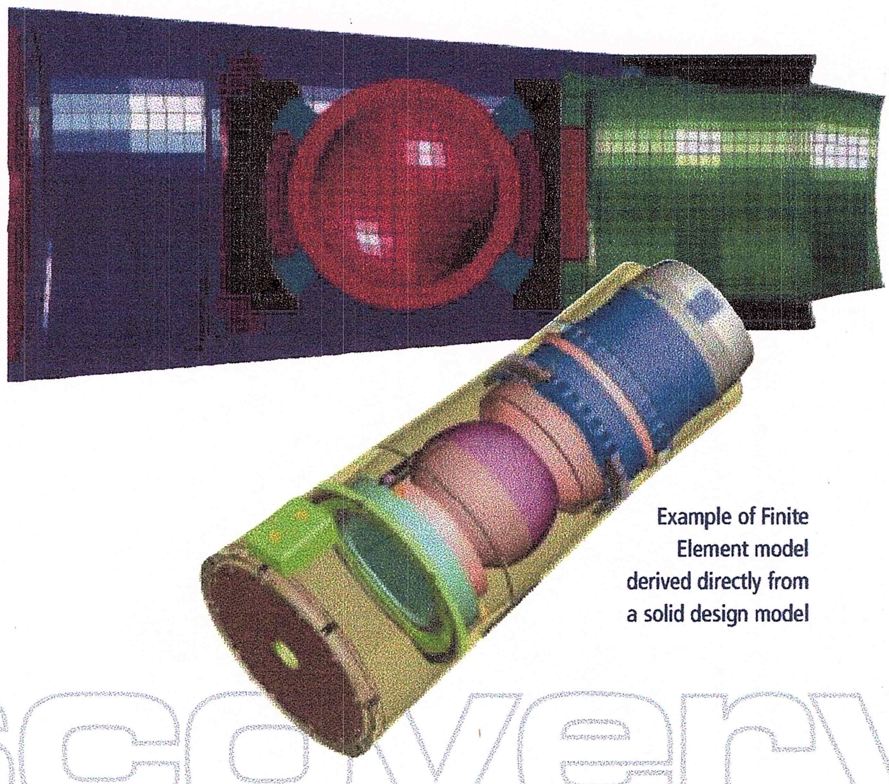
Finite element modelling is a well known and widely practised technique. Much development has had to be undertaken to refine the basic FE models to represent better the reality of the materials and structures found in a Trident RB. Previous FE modelling did not adequately represent some of the more extreme behaviour of materials, for example non-linear behaviour, and a large amount of work has been done to expand the materials database to provide this enhanced information.

Work must continue in understanding the behaviour of materials at molecular and even atomistic levels to ensure that the "science" behind the computations remains valid.

Existing models of assemblies had assumed ideal interactions of component parts and thus did not fully reflect what is found in reality. In particular the way components are joined to each other and how a joined sub-assembly responds to stimuli needed addressing. The new models benefited from research into modal coupling that was described in the AWE Journal of Achievements, which was a forerunner of this Science and Technology Journal, in the article on modal correlation techniques.

To build a validated model of the full Trident RB, each component and sub-assembly was created in turn as a solid model and then the response was predicted and verified against existing experimental data from low level excitation techniques such as modal testing. With each sub-assembly verified, the next level assembly could then be verified and so on until the whole Trident RB was created as a complete FE model. This model was incidentally the largest FE model created to date at AWE of the Trident RB and it is able to run successfully on the recently acquired Silicon Graphics Origin 2000 supercomputer. Future advances in computer technology will continue to enhance model based assurance capabilities.

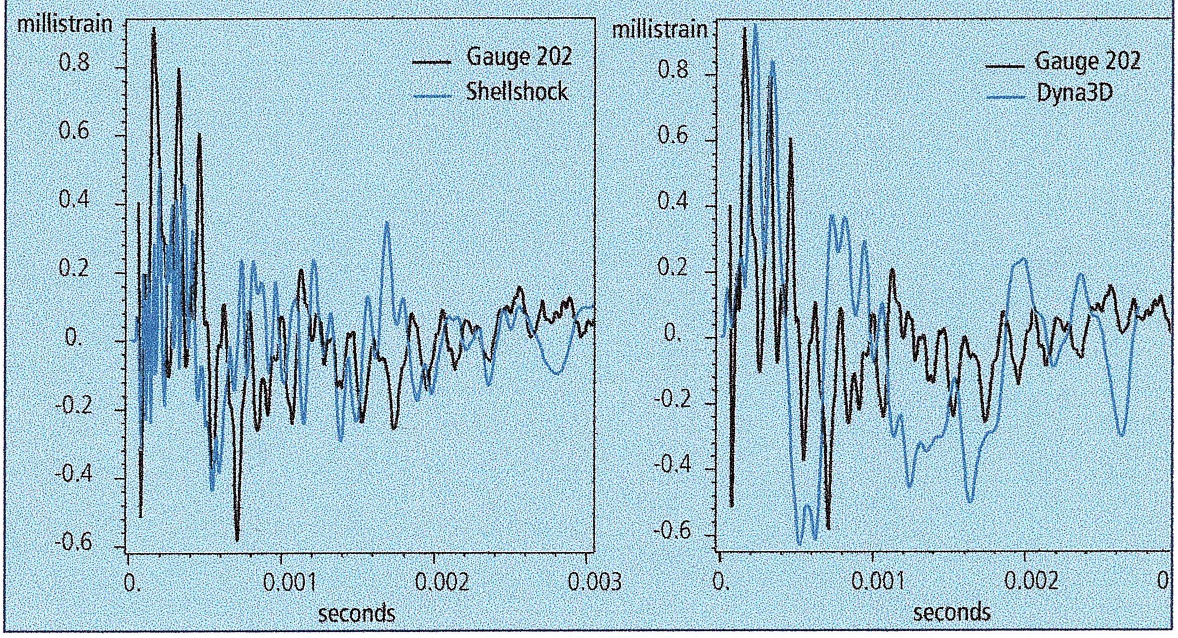
The complete RB model was finally validated against the results from an instrumented impulse trial carried out at AWE during the 1980s. The correlation of the 1980s predictions with one of the actual results can be seen in Figure 1 (overleaf).



Example of Finite Element model derived directly from a solid design model

Figure 1: Correlation achieved in the 1980s between a strain gauge result (black curve) and a prediction (blue curve) for an impulse test.

Figure 2: Correlation between a 1980s experimental result (black curve -same as figure 1) and the current predictive standard (blue curve).



The predictions (blue line) are significantly underestimating the strain seen during the early time shock. The prediction was made at the time of the test using a linear elastic 2-D axi-symmetric code called 'Shellshock' (Reference 1). Figure 2 shows the correlation now achieved between the same data and using the updated FE model of the Trident RB, with a more modern non-linear 3-D code called Dyna3D (References 2 and 3). The amplitude correlation at the beginning of the strain/time history is greatly improved, which is important for structural performance considerations; these early high magnitude strains are the most damaging to a structure.

The Joint Test Programme

The UK has joined with a number of US parties under the banner of the 'Joint Test Programme' to undertake some more high level impulse trials to develop the knowledge of RB response to such environments and to contribute further to model validation. Two inert experimental bodies have been designed and manufactured in the UK which have been shipped to the US to be subjected to high impulse experiments, at a unique facility there, in the near future. A number of challenges were faced by the team in delivering these test items to the US to schedule which was a tribute to the teamwork of the multi-disciplinary group who designed, manufactured, tested and managed the whole project. The two bodies are both heavily instrumented, one body with some 90 high level shock accelerometers and the second with about 180 low level vibration accelerometers. The design of the bodies and their instrumentation was a difficult balance between obtaining the maximum quantity of data from these experiments without compromising the integrity and response of the trial bodies through excessive instrumentation.

The second body, with 180 low level vibration accelerometers, was subject to preliminary modal and transfer function tests at various stages of assembly providing valuable information in developing the RB model. This represented the most comprehensive application of modal testing to date within AWE. Figures 3 and 4 illustrate the difficulties in running and splicing the cabling for all of the instrumentation to avoid obstructing the behaviour of the internal components.

Prior to the shipping of the bodies to the US, a series of simulations have been completed using the UK model to predict the behaviour of the bodies under the high impulse loading of the proposed tests. All involved in the Joint Test Programme await the results of these trials and the opportunity to correlate the predictions against the actual experimental results.

Summary

The work described is an important waypoint towards improved model based assurance. Work continues to improve materials data and modelling approaches to further refine the capability. The results of the Joint Test Programme will deliver another iteration in improving the ability to make predictions; lessons learned from this programme will further refine the modelling assumptions.

Approaches followed in the work described here have provided a new baseline solid, or virtual, model of the UK Trident design and the opportunity has been taken to review how we undertake future assessments of the Trident warhead. The work completed to date now provides a more robust and traceable link between the baseline design and assessments made. A new updated 3D finite element model of the UK Trident RB has been developed that has been verified against component level modal test data and validated against experimental data from an impulse test carried out during the 1980s at AWE. In this model, the interfaces between sub-systems have been addressed more rigorously than previously.

Many challenges were overcome in providing the instrumented test bodies to our US partners in the Joint Test Programme. The challenges were met and the bodies delivered to the US to schedule, which was a tribute to the teamwork of the multi-disciplinary group involved in the project.

Advances in computing technology, both hardware and software, will continue to enhance model based assurance capabilities. Similarly, improved understanding of material properties at molecular and even atomistic levels must be gained to ensure that the 'science' behind the computing power remains valid.

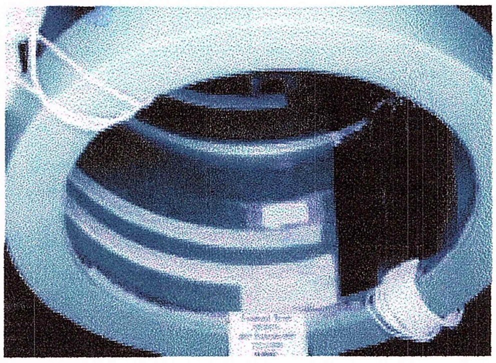


Figure 3

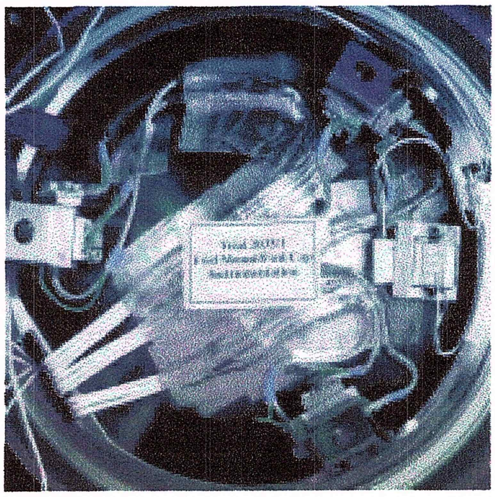


Figure 4

References

1 Shellshock Structure Code (Fourth Edition), JE Grant and VK Gabrielson, SAND83 - 8011.

2 LS-DYNA, a Program for Non-Linear Dynamic Analysis of Structures in three Dimensions, Livermore Software Technology Corporation.

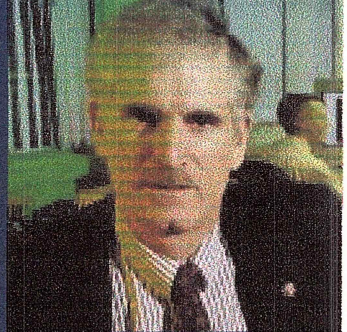
3 DYNA3D, a Non-Linear Explicit Three-Dimensional Finite Element Code for Solid and Structural Mechanics, Lawrence Livermore National Laboratory.

- US Codes.

Author Profile

Charles Kernthaler

Charles has a first class degree in engineering science from Oxford University and is a Chartered Engineer and Fellow of the Institution of Mechanical Engineers. After completing a student/graduate apprenticeship at AWE, he has remained here ever since, largely within what is now the Systems Engineering Directorate, specialising in the structural analysis and performance assessment of re-entry vehicles. Particular highlights of his career have been periods as Technical Assistant to the Director of AWE, designing the UK Trident storage and transport container system and managing the UK's underground nuclear testing programme. He is currently the Engineering Science Authority with the Design Authority Department of SED, with technical oversight of engineering analysis, computing, environmental testing methods and design processes.



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