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Demonstrating the Potential Use of Virtual Prototype Modelling Techniques for Future AFVs

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Abstract/Executive Summary

The need to provide light weight armoured fighting vehicle (AFV) structures while maintaining or increasing the survivability of these structures has increased the need to develop new materials and design processes. One way to address this requirement is to use composite materials to increase the structural and ballistic efficiency of the hull. Composite materials offer a number of advantages including weight reduction by the elimination of the spall liner and integral stealth protection leading to signature reductions. QinetiQ in partnership with Vickers Defence Systems, have produced a full-sized composite demonstrator AFV called the Advanced Composite Armoured Vehicle Platform (ACAVP).

To obtain the maximum benefit from new materials new modelling techniques are being developed by QinetiQ. These techniques will increase the accuracy of the structural analysis used in the design of future AFV structures and also provided additional information to assist in the design and integration of sub components which include the main armament and vehicle suspension systems. The developed modelling techniques have also been applied to gun systems and a range of vehicle components. In effect a virtual prototyping tool has been developed.

This paper provides a description of the ACAVP demonstrator, which was subsequently used as the test bed vehicle to validate the virtual prototype modelling. The paper describes the testing procedure and compares the results generated from the vehicle and those produced by the model. It is shown that good agreement can be achieved between the model and test vehicle.

Introduction

The need to provide light weight armoured fighting vehicle (AFV) structures while maintaining or increasing the survivability of these structures has increased the need to develop new materials and design processes. One way to address this requirement is to use composite materials to increase the structural and ballistic efficiency of the hull. Composite materials offer a number of advantages including weight reduction by the elimination of the spall liner and integral stealth protection leading to signature reductions. QinetiQ in partnership with Vickers Defence Systems, have produced a full-sized composite demonstrator AFV called the Advanced Composite Armoured Vehicle Platform (ACAVP).

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This paper provides a description of the ACAVP demonstrator, which was subsequently used as the test bed vehicle to validate the virtual prototype modelling. The paper describes the testing procedure and compares the results generated from the vehicle and those produced by the model. It is shown that good agreement can be achieved between the model and test vehicle.

Paper presented at the RTO AVT Symposium on "Reduction of Military Vehicle Acquisition Time and Cost through Advanced Modelling and Virtual Simulation", held in Paris, France, 22-25 April 2002, and published in RTO-MP-089.

Advantages of Composite Materials

The advantages offered by composite materials over metallic materials are now quite well known in terms of their mechanical properties when measure on a weight for weight basis (Table 1). It is worth reiterating that the main driver for the utilisation of composite materials in military vehicles is the ability of composite materials to reduce vehicle hull and armour weights. One way that this can be achieved is by the elimination of parasitic mass in the form of a separate spall liner, from a composite vehicle. This is achieved by the composite hull acting both as a spall liner material and as a structural material capable of carrying all the operational loads associated with the vehicle. However, a major design problem preventing composite materials from significantly reducing hull weight is the opposing needs to provide the vehicle with both ballistic protection and mechanical structural performance. The level of ballistic protection provided normally correlates to the weight of the vehicle's hull and armour. Consequently, reducing hull weight can lead to a reduction in ballistic protection, unless the weight reduction is put back as additional armour mass.

Other advantages of composites : GRP composite is a poor transmitter of sound, its damping capacity being attributed to the fibre matrix interface. A reduction in radiated noise leads to lower crew fatigue [1], and a lower acoustic signature for the vehicle. Further work is required in this area before the full advantage offered by composites can be quantitatively assessed, and this is a subject that is being actively tackled by the modelling being conducted at Chertsey and will be described later in this paper. A summary of the additional advantages of composite materials compared to traditional materials used for AFVs are:

- increased ballistic protection against small arms;
- reduced behind armour damage;
- reduced parts count.

As discussed above, the use of composite materials in military vehicles is not new to the British army, since it already operates the CAV 100 and the Bv206 vehicles. However, in both these vehicles a metal chassis carries the structural loads from the running gear, whereas in the case of ACAVP the composite hull carries all these loads.

ACAVP Demonstrator Design

Vehicle description: The ACAVP demonstrator is based on a future scout reconnaissance vehicle with a battle weight in the range of 18 - 25 tonnes (figure 1). The engine is situated at the rear of the vehicle, which, together with radar absorbing materials and IR paints, reduces the vehicle's signature. The vehicle has mobility at least equal to Warrior IFV and the hull has been designed to allow for transportation in a Hercules aircraft. The demonstrator is designed to accommodate a mission module in the centre of the vehicle and two men sitting abreast at the front. The vehicle has demonstrated complete electro-magnetic compatibility including radio and EMI features.

Metal appliqué armour appropriate to meet typical light armoured vehicle ballistic threat requirements has been designed together with the required armour fixings The ability to rapidly deploy an AFV has been addressed in the ACAVP vehicle by using the armour in combination with the composite hull. The appliqué does not form part of the vehicle's load bearing structure and can be easily removed to allow the vehicle to attain the weight limit imposed by the load carrying capacity of a C130 aircraft.

Vehicle design: Solid modelling design tools were used extensively throughout the development of the demonstrator vehicle providing an efficient means of managing changes in geometry and vehicle configuration. Finite element analysis techniques were used to evaluate the performance of alternative structural concepts and materials with geometry from the solid models being used directly in the creation of finite element models resulting in close integration between the design and analysis tasks.

Three primary requirements were responsible for determining the design of the vehicle hull structure, ballistic performance, mechanical properties, and manufacturing process. The hull is required to perform as a ballistically efficient component in the overall armour system, any compromise to the efficiency of the system at the threat levels seen by the vehicle would have had a dramatic impact on vehicle weight. The structure must have sufficient strength and stiffness to carry all automotive loads in both armoured and un-armoured conditions. The design must also take full consideration of the strengths and weaknesses of composite materials unique material properties and the range of available manufacturing processes.

The primary hull structure consists of two large e-glass/epoxy composite mouldings joined around the lateral line of the vehicle. The upper moulding forms the roof, glacis, upper sides and rear of the hull. The roof is one of only three areas of the vehicle not covered by metal appliqué in the fully armoured configuration and is designed to defeat artillery fragments. Two layers of specialised materials are incorporated in to the material lay-up of the upper moulding. Under the outer surface there is a layer of radar absorbent material to reduce the vehicles signature, while under the inner surface there is a layer of EMC shielding to protect the vehicles radios and other vulnerable equipment. The glacis plate at the front of the vehicle is inclined at an angle of 60 degrees to take full advantage of the increased ballistic performance offered by plates at obliquity. The side plates and rear are inclined at 5 degrees to minimise the vehicles radar signature.

Internal bulkheads are used to isolate the crew from the noise and fumes of the powerpack and compensate for the reduction in vehicle stiffness caused by the large appetures in the roof.. Stiffness was a major consideration in the vehicles development as the composite materials considered for the hull generally had very low stiffness compared to traditional materials such as steel or aluminium. The composite hull of the demonstrator vehicle provides the same vehicle stiffness as Warrior. Two large composite transverse bulkheads are positioned in front of the engine bay and behind the crew compartment, in addition to increasing the stiffness of the vehicle these also help support the weight of the turret on the roof. Longitudinal bulkheads run down the length of the vehicle closing of the sponson area. Standard Warrior running gear was used for the demonstrator vehicle as it was readily available and has proven reliability. The standard equipment was originally designed to interface with the vertical lower sidewalls of an aluminium hull so was not suited to attachment directly onto a composite hull. The demonstrator vehicle employs interface plates to provide a suitable mounting surface for the equipment and transfer load the composite hull. The standard Warrior suspension units employ torsion bars, which traverse the entire width of the vehicle. These torsion bars are protected by composite torsion bar covers, which also help react the bending loads induced at the suspension attachments.

The lower moulding forms the floor, lower sidewall, rear, and toeplate. The composite floor offers broadly equivalent mine protection to existing in service vehicles, with extra protection provided in the crew compartment by a secondary floor. The lower sidewall includes a draft angle of to aid extraction from the mould during the manufacturing process and forms part of a spaced armour system which employs the skirt plate as its outer element. The obliquity of the toeplate is limited by practical considerations such as space required for the driver and ability of the hull to support the idlers during severe load conditions such as terrain impacts. The design of each area of the vehicle structure is a balance between a number of different, often conflicting requirements.

Analysis Design Tools – Virtual prototype modelling

Structural design of ACAVP: An extensive programme of component and material testing supported the structural analysis of the demonstrator hull. Material tests were carried out at the end of each development phase of the manufacturing process to ensure the properties used in the finite element models were as close a s possible to those of the final hull. Testing of larger components such as sections of the composite hull and hull joint were undertaken as soon as they became available.

The highest risk to the accuracy of the structural analysis results was the absence of reliable load data defining the worst conditions the vehicle structure would be likely to see in service. Loads used in the analysis were derived from standard conditions used in the development of Warrior. Measured trials data and results of ride models suggested that these conditions were over conservative although experience also shows that the maximum loads experienced by a vehicle is also dependant on the skill and motivation of the driver and crew.

Traditionally the absence of accurate load data has not been a problem in AFV design as the hulls consisted of thick steel or aluminium armour plates whose thickness was driven by ballistic rather than structural requirements. However, the constant development of the weapons used to attack AFV's has led to the situation where sophisticated new armour system are required if the weight of modern vehicles is to be maintained at a practical level. These armour systems employ a combination of different materials and air gaps to achieve mass efficiencies of two to three times traditional armour systems. The drawback of using these systems is that many of the elements of the system do not lend themselves to performing the role of vehicle structure.

Glass and carbon composites take advantage of the fact that most of these systems employ a spall liner backing to catch fragments and prevent them entering the vehicle, composite materials have been proven to be the most weight efficient materials for performing this role. Increasing the thickness of this spall liner to the point where it can be used as an effective structure provides the opportunity of integrating highly efficient armour systems with vehicle structure for future AFV's. The key to designing these systems is minimising the deviation away from the optimum ballistic configuration which requires that the areal density of the composite hull structure be kept as close as possible to that of the spall liner in the optimum system. To do this effectively it has been necessary to develop a range of modelling techniques capable of accurately predicting the loads on each element of the running gear during simulated worst case operational conditions. These techniques have now been developed to include representation of the structural flexibility of the hull, which provides the opportunity of using tem to predict vibration and provide data for studies into vehicle noise.

Virtual prototype modelling: The techniques developed extend the capabilities of ADAMS mechanical system simulation software produced by MDI which is widely used by the automotive and aerospace industries to model complex systems. The development and analysis of system models, often referred to as virtual prototyping, offers many benefits to the designers and sponsors of new systems. They increase understanding of the physics of the mechanical system leading to more efficient lighter systems, and help the designer to make critical design decisions earlier in development. As the project progresses the simulations become more refined leading to greater accuracy and reducing the need for expensive testing by getting the design right first time.

The techniques developed for the analysis of tracked vehicles consist of two modules. A pre-processing module which automates creation of the complex models, assembling the many components of the system, and creating the constraints and forces which define the interaction of components with each other and the environment. And an analysis module which supports the ADAMS solver in performing the simulation, providing specialised functions for complex conditions such as interaction of the track with the sprocket or the terrain.

The track system is modelled in detail with the mass and inertia of each individual track link and definition of connections and impacts with other track system components represented. The non-linear characteristics of a number of different suspension units including Warrior and Challenger 2 have been defined and successfully simulated in the many models created to date.

Simulation of tracked vehicle systems undertaking extreme manoeuvres in truly three-dimensional environments has now been conducted. The simulations provide detailed information on almost any aspect of the system including position, velocity and acceleration of each component or the time history of the forces at connections and points of impact between components. The force information generated can be used to undertake detailed finite element analysis of components or aid our understanding of mechanisms such as the variation in track tension at different positions around the track.

It is also possible to simulate the behaviour of subsystems such as the gun control system of a main battle tank as it interact with the vehicle. This is achieved by attaching a subsystem model to the vehicle model and solving the model concurrently with a control package such as Matlab. Virtual prototyping offers to opportunity of investigating the performance of new equipment such as weapon systems and identifying any potential problems such as levels of recoil force transmitted to the hull at the design phase.

These techniques have now been successfully validated using data obtained from physical testing of the demonstrator vehicle. Peak loads at the wheel stations were found to be within 10% of measured values for a wide variety of different operational conditions. Figure 3 shows the predicted loads on each wheelstation as the model traverses a gap at 10 kph. A comparison between predicted and measured at the front wheel station is presented in figure 4.

Confidence in the accuracy of predicted values is very dependent on the type of simulation being conducted and the quality of the data used to define the systems components and their behaviour. Work undertaken on light artillery guns has shown that errors of less than 5% are achievable if extensive trials data is available and the behaviour of individual subsystems is validated through testing.

A new facility in the ADAMS software now makes it possible to use a finite element model of the hull structure to produce a flexbody representation of the vehicle structure in the ADAMS simulation that deforms and vibrates in a similar fashion to the physical hull structure. Work on the validation of the vibration predicted by models employing flexbody hulls is continuing. Modal testing of the demonstrator hull shows good agreement with results of the finite element and flexbody models.

Current research is focussing on the detailed characterisation of the parameters that define the interaction of the components in the running gear and their influence on the overal vehicle characteristics. A longer term aim is to evaluate the use of the flexible hull to characterise vibration input into the hull at each source such as suspension and powerpack and feed this information into specialised software for predicting internal and external noise. Noise is a major problem in military vehicles both in terms of the effect it has the crew and from a vehicle signature perspective.

Summary

In view of the findings of the ACAVP programme to date, it is possible to state that composite materials can offer a weight saving over conventional vehicles for future armoured fighting vehicles. Further reductions in weight could be achieved by the use of carbon fibre composite materials and by the ability to accurately model and predict the loading regimes encountered by AFVs.

The ability to model the structure of tracked AFV concepts and in service vehicles has been demonstrated. The successful testing of the produced models compared to the ACAVP vehicle has demonstrated the applicability of using these techniques. The successful modelling of gun systems has also increased confidence in their accuracy. These modelling tools have the potential to lead to increased accuracy in the design load cases for future AFVs leading to optimised structural designs and reductions in vehicle weight. The ability to model the flexibility of the hull and attached components will allow the AFV designers to identify vibration problems at a much earlier stage in the design process. This will help to prevent vibration related crew problems from occurring in the finished vehicle and should increase the performance of subsystems influenced by hull vibration.

Future

The future design of armoured fighting vehicles is difficult to predict but there is a strong desire to reverse the ever increasing weight of AFVs, though predictions of a twenty tonne vehicle operating in the same role as a conventional sixty tonne MBT will be difficult to achieve. Any approach that reduces vehicle weight is obviously of great interest. Composite materials can help to reduce weight but composites are not the answer to every question posed by the already diverse and ever increasing requirements predicted by military doctrine. Composite material solutions must be combined with synergistic vehicle designs and the tools to accurately design the vehicles to meet the anticipated performance characteristics and associated loading regimes. Modelling tools to predict structural loading in vehicles have been developed and studies to identify vibration are on going. The studies have also demostrated that the loads generated by gun systems can also be accurately modelled. By combining theses techniques and investigating the potential to identifying noise both within the vehicle and external to the vehicle would complete the toolset required for a truly virtual vehicle. This is the ultimate aim of the current study.

Acknowledgements

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Table 1 : Properties of engineering materials at 20°C					
Material	**Density**	**Tensile Strength**		**Young's Modulus**	
	kg/m^3 (ρ)	Absolute MPa (σ_t)	Specific (σ_t/ρ) MPa/(kg/m^3)	Absolute GPa (E)	Specific (E/ρ) MPa/(kg/m^3)
Steel RHA	7850	775	0.10	210	26.8
Aluminium 7017	2750	425	0.15	70	25.5
Titanium (6Al-4V)	4400	800	0.18	110	25
GRP Vf 0.55 Quasi-isotropic (0/-45/90/+45)	1902	300	0.16	22	11.6
CRP Vf 0.55 Quasi-isotropic (0/-45/90/+45)	1520	350	0.23	42	27.6

Vf = the volume fraction of fibres in the composite material. (The numbers in brackets indicate the principal fibre angles)

Figure 1 ACAVP Demonstrator Vehicle

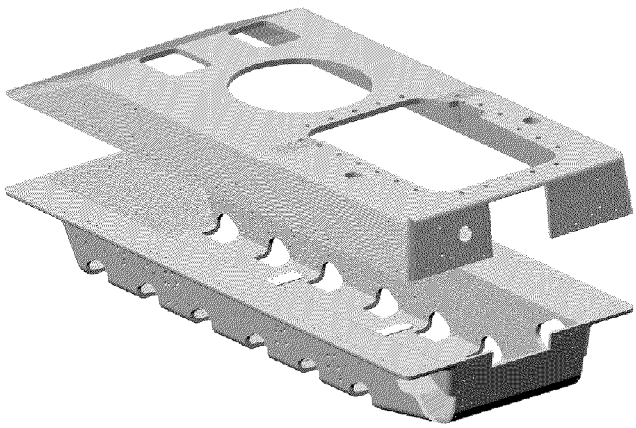

Figure 2 ACAVP Demonstrator Mouldings

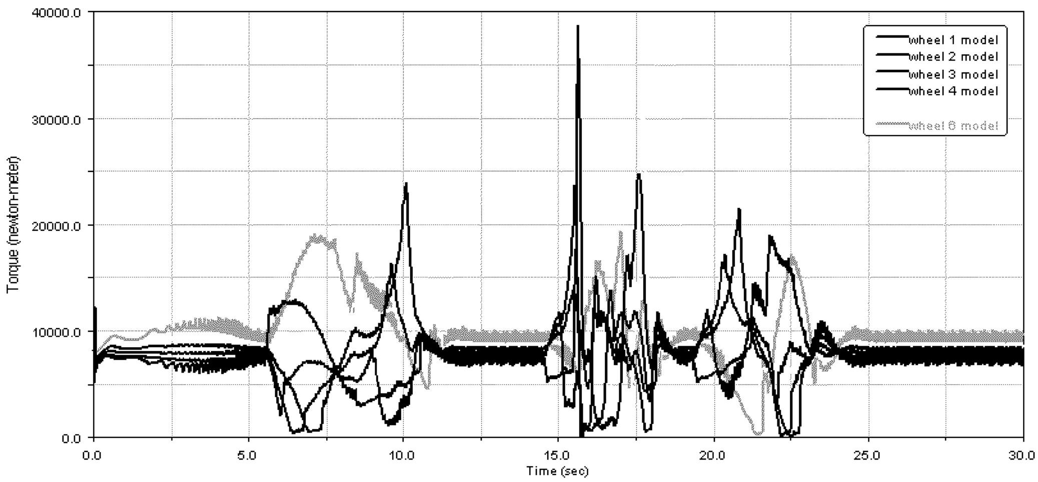

Figure 3 Predicted suspension torque over obstacle

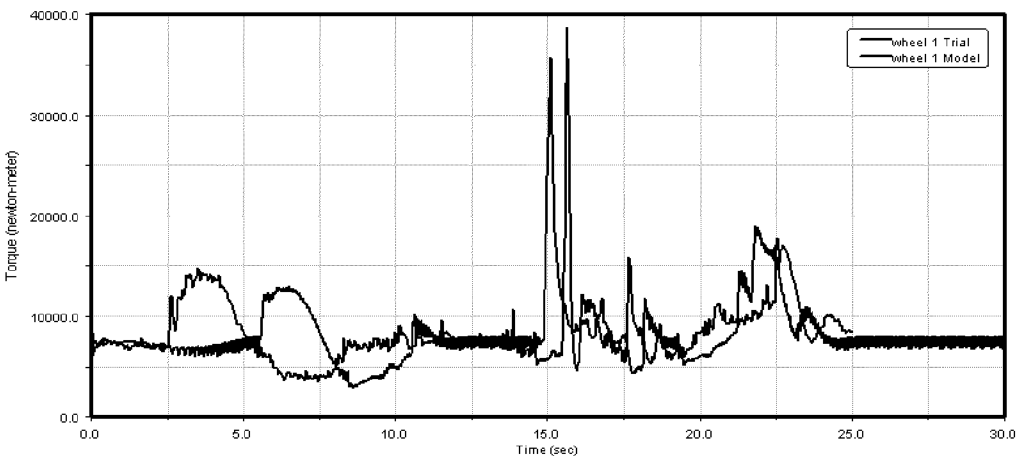

Figure 4 Predicted versus measured torque at front wheel station