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Technical Report

Success Story of Armored Multitask Vehicle Design “New Combatant on Terrain: GEKKO”

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Abstract- In this study; an armored vehicle design including whole process from preliminary studies to armor design is presented in order of defining requirements depending on the multitasking performance, selecting armor threats for different parts of the fuselage, preliminary design stages for different arrangements, procurement phases and performance tests. Ballistic evaluation of main areas depending on the vulnerability capabilities are studied by means of no add-on protection for personnel is necessary excluding outer gunners. Compact arrangement enabling personnel transfer, carrying attached heavy weapons or suitable for mission modules is possible by design flexibility. Additionally, pictures and drawings are attached to show this innovative design.

Keywords- Armored vehicle; Combatant; Ballistic protection; Multitask effectiveness.

1. Introduction

It is essential to specify the initial and boundary conditions to start a new design, even for truck or sport car. These preliminaries have to be determined before pre-design activities. Mostly resident comfort, engine performance, maximum speed are the major initial conditions for a commercial vehicle, however payload and operational performance are the major factors for military vehicle designers. Consequently, spaces for engine, guns, crew and electrical requirements are critical to define boundaries for designers.

Bespoke solutions for dedicated problems force designers to solve real problems at the intersection of initial conditions and boundary problems. It is a must to understand how to balance vehicle “protection”, “performance” and “payload” through an integrated survivability approach that starts with occupant protection, against the evolving threat and requires rapid response to urgent operational requirements. Moreover, responsible design team never has additional time for developments and design reworks even for confirmation of new chassis which can take up years.

Protection and payload are always major factors pushing the designers against performance consisting of vehicle speed, maneuverability, and operational range effecting of fuel consumption which means light weight materials or effective partition of body parts. GEKKO Design Team (GDT) preferred the mixture of these solutions.

Modern composites have created a revolution in lightweight body armors. Their advantages relative to conventional materials such as high strength to weight and stiffness to weight ratios, superior resistance to environmental conditions, design flexibility also known as tailoring the material for desired application, make them attractive for a wide range of applications at different threat levels and environment (Swanson, 1997 and Jones,1999).

Sutherland and Soares (2006) noted the importance of difference between impact resistance, which means the resistance of the material to impact damage and impact tolerance, which defines the performance of the material once a given impact has occurred. Furthermore, the amount and the type of failure mechanisms activated depend on some factors: Mass, velocity and geometry of the impacter, geometry of the structure, type of fiber and/or matrix used for manufacturing of the composite plate, stacking sequence of the plies. Final damage is sensitive to even small changes in the fiber/resin type, ratio, architecture, interface and laminate production method. Therefore it is important to realize that a laminate that performs well in one area may not perform well in another. So, further information shall be considered during and after experiments as to how well plate resists de-lamination, fiber damage, perforation, plunging, bushing, crater shape and how the stiffness is effected by damage.

Armored vehicles can be designed to have separate body parts to provide "*form-fit-function*" as detailed at the following areas: *i*) Vehicle Main Areas (MA) which are the relatively uniform armor panel areas that provide protection coverage against the specified ballistic threat levels, *ii*) Localized Weak Areas (LWA) where main armor systems are constructed from a combination of materials or rely on geometrical effects to defeat the threats, the protection provided may not be fully consistent over the full armor area, *iii*) Structural Weak Areas (SWA) where are the larger main armor panel discontinuities that are potentially ballistically weak zones. Finally, there may be no prior evidence for the size of the SWA that exists at the target boundary or around bolt holes, an assumption has been made for the size of this zone. The nominated area around such features, initially excluded for the purposes of MA testing, is designated the Excluded Zone (EZ). This zone shall be tested to validate if the EZ is ballistically resistant or if it is a Vulnerable Area (VA) (Mukasey et al., 2008).

GDT has preferred to use this partition of vehicle body to reduce total weight and optimize mutually balanced design by VA assessment which is leading to simplification that the protection system should perform to ensure that in %90 of occurrences no projectile could enter the occupant compartment of the vehicle.

2. Design Preliminaries

Concept design studies have begun with identifying the occupants' cabin inside the vehicle and the empty areas for personnel transportation or guns.

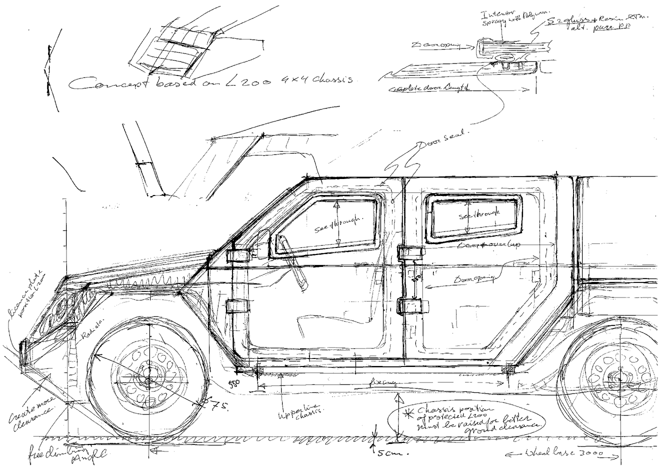

Fig.1. First step: Defining the main compartment.

Main compartment has been defined as leading the forward chassis and locations of axles while informing about the preliminary decisions for ground height, forward angle of the frame which constraints the climbing capability as a foresight. While setting the preliminary concept, GDT tried to localize possible problems such as window and door connections. Additionally, main dimensions are tried to be estimated at this first stage.

Weight estimation which leads the engine power and vehicle performance is also a major issue at the beginning. Therefore, protection levels have to be agreed to estimate the weight of armor panels which should be effective especially for the main compartment as defining the failure of the protective system. GDT decided to use Kinetic Energy (KE) projectiles and artillery threat to choose correct protection. Main criteria for protection of main compartment are; behind armor debris test (i.e. fragmentation) arising from penetration of the armor by a KE projectile, or from damage such as back spall produced by a non-perforating projectile. Depth of penetration (DOP) test was chosen for engine cover, where a homogeneous semi-infinite backing is placed behind a tested component or material target and scoop depth measured.

Choosing the right technology for armor panels gives GDT the opportunity of weight consideration and procurement expenses. Table 1 indicates the benefits and drawbacks of different materials.

Partition of body parts gives the chance to define different armor materials for different parts which has unequal protection levels.

Table 1. Comparisons of Armor Materials.

Technology	Benefits	Drawbacks
High hardness steel	Low cost, low volume, good multi-hit performance	Heavy
Perforated steel	Lightweight, robust, good multi-hit performance	Large volume demands
High strength metal alloys (titanium, aluminium)	Machinable, moderate cost, good all-round	Larger volume than steel, increased behind armor effects
Alumina ceramic	Lightweight, low volume	Difficult to get good multi-hit
Silicon carbide ceramic	Effective against highly Armor Piercing(AP) ammunition	Very expensive, poor multi-hit
Glass reinforced plastic	Lightweight, low cost	Not effective against AP ammunition
Aramid	Lightweight	Poor against AP ammunition
Polyethylene	Very lightweight	Expensive

3. Concept Design

Concept Design (CD) stage normally consists of defining power requirements, engine selection, general arrangement, weapon and command control equipments, electrical needs, etc. However the main issue of this study is presenting the base design stages of the vehicle, main design studies are presented in the following figures for the brevity of presentation.

Normally design steps are; pre-design, concept design, contract design and detail design, however this vehicle does not have a contract as being a concept design. GDT has agreed to catch design details at concept stage. It is finalized defining main dimensions and part separations consisting of armor materials at pre-design stage.

4. Armor Design

The ballistic materials used by armored vehicles have similarities with the hard molded armor being used by military personnel for body armor. Therefore there are instances where the soldiers have used armor material specified for one particular situation in an entirely different situation. As the vehicle being forged ahead, different threats should be covered depending on the situation surrounding it.

As materials are evolving and getting lighter, the test standards and specifications are also evolving. However, some of the vehicle armor standard written for molded panels of woven aramid prepreg materials can be used for new materials. This is achieved by fine tuning the fabrication process based on the chemistry of reinforcing fibers and prepreg resin (Figure 2-5).

Fig.2. Concept Design: The main part separation and personnel cabin details

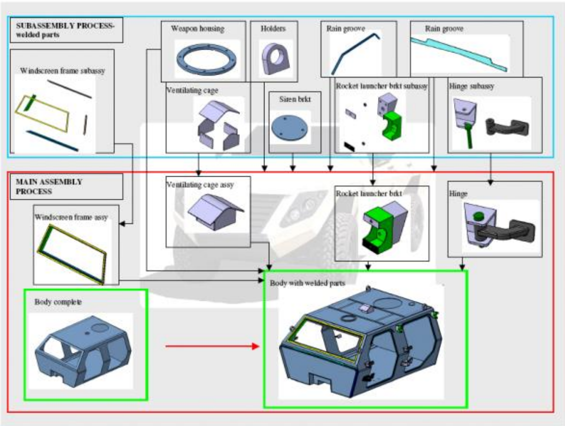

Fig.3. The main compartment.

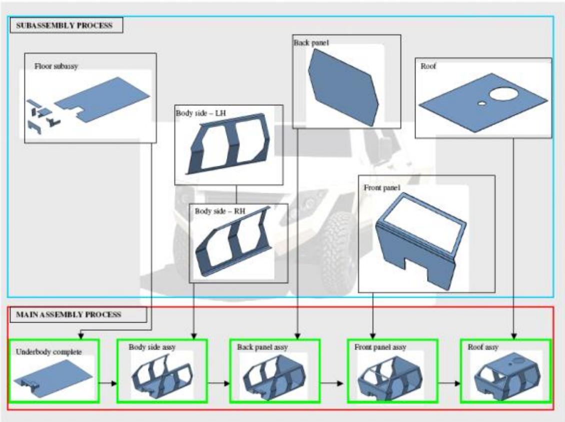

Fig.4. Main compartment parts.

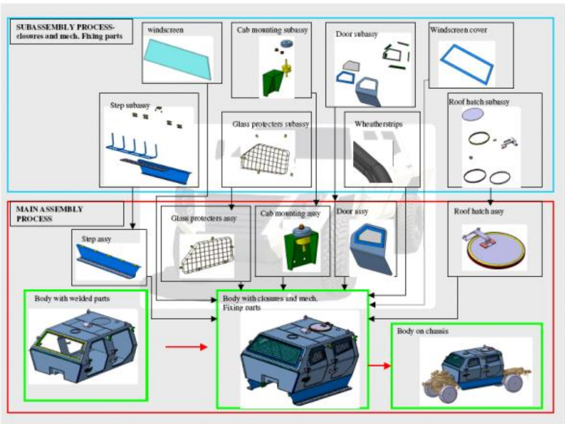

Fig.5. Main compartment chassis interface.

Laminated composite plates are made up of two or more layers of materials bonded together to form a new material. The properties of the laminate can be tailored for a desired application. However, the analysis of composite laminates brings additional difficulties to the analyst such as the inter-laminar or transverse shear stress due to mismatch of material properties among layers, bending-stretching coupling due to asymmetry of lamination, and in-plane orthotropy. Extra complexities arise by the necessity of the satisfaction of the prescribed boundary conditions. Therefore all these advancements and design requirements place a premium on an in-depth understanding of the response characteristics of such structural components (Figure 6).

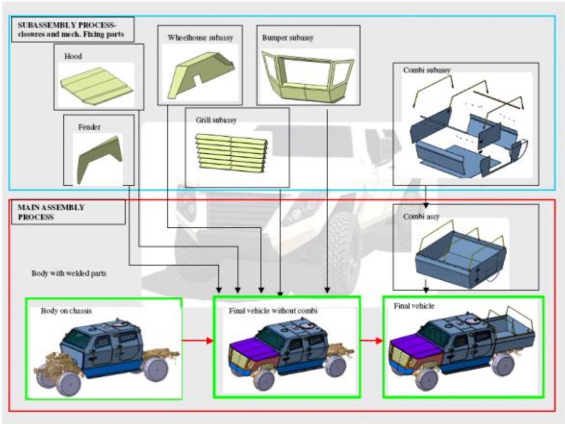

Fig.6. Engine cover and backstage design.

The structural analysis of laminated composite plates is performed generally by approximate numerical methods, such as finite element methods (FEM), boundary element methods (BEM), and more recently developed meshless “Petrov-Galerkin” methods. Derivation of analytical (e.g., Fourier series) solutions for the problems of laminated plates fabricated with such advanced composite materials as graphite/epoxy, Kevlar/epoxy, boron/epoxy, graphite/PEEK, etc., is, however, fraught with many complexities as briefly mentioned above. Notwithstanding; Karakuzu et al (2010) defines that, the numerical evaluation of impact with a linear static finite element analysis is not very accurate, but it gives a meaningful insight on the major mechanisms of failure. However, it is required by contractors that the armor shall be proven by real shots to define impact damage (Figure 7).

Fig.7. 3D Artistic view of GEKKO.

Additional complexities occur while composite material resists to the impact loads. Impact loads are classified into three categories by Naik et al. (2004); low velocity impact, high velocity impact and hyper velocity impact, because of the differences on energy transfer between projectile and target, energy dissipation and damage propagation mechanisms undergo drastic changes as the velocity of the projectile changes. In low velocity impact regime; the support conditions are crucial as the stress waves generated outward from the impact point have time to reach the edges of the structural element, causing its full-vibrational response. In high velocity impact, which is known as ballistic impact; the response of the structural element is governed by the local behavior of the material in the neighborhood of the impacted zone, the impact response of the element being generally independent of its support conditions. Hyper velocity impact involves projectiles moving at extremely high velocities such that the local target materials behave like fluids and the stress induced by the impact is many times the material strength.

When a penetrator impacts to a composite armor plate; instantaneous stresses produced and immediately transmit to remaining parts of the plate. However, the stress distribution depends on the material properties and the thickness or structural design of the armor. Naik et al (2008) presented that; if the deformation behavior along the thickness direction of the target is same along the entire thickness, the wave propagation through the thickness direction is not considered therefore it shall be accepted as thin target. Conversely, wave propagation along the thickness direction shall be considered for thick targets, therefore deformation and the induced stress behavior of the target would be different at various locations along the thickness direction.

Sutherland and Soares (2006) defined the damage mechanism of composite plates and reported that the most important variations seen were between the responses of thin and thick composites. Thin plates suffered internal de-lamination but this was not seen to affect the response significantly. High deflections gave a membrane stiffening effect until at high incident energies back-face fiber failure led to perforation. Thick plates showed both significant shear and indentation deformation. A bi-linear force-displacement response as de-lamination led to a significant stiffness reduction was seen, followed by front-face initiated fiber failure leading to perforation and/or shear failure.

For the analysis of thick targets, the wave propagation along the thickness direction shall be considered. The wave propagation through the thickness direction causes different failure reactions inside the target depending on the contact force, mass and velocity of the impactor, which designates the impact kinetic energy. The dominant damage mechanisms of composite laminates are determined as de-lamination and fiber failure by Johnson et al. (2009). Tita (2008) defines these failure mechanisms by two modes. Intra-ply failure which damages at fibers, polymeric matrix and/or interface between fibers and matrix. Secondly, inter-ply failure mode that consists of delaminations between plies.

Furthermore, the amount and the type of failure mechanisms activated depend on some factors: Mass, velocity and geometry of the impacter, geometry of the structure, type of fiber and/or matrix used for manufacturing of the composite plate, stacking sequence of the plies. Final damage is sensitive to even small changes in the fiber/resin type, ratio, architecture, interface and laminate production method. Therefore it is important to realize that a laminate that performs well in one area may not perform well in another. So, further information shall be considered during and after experiments as to how well plate resists de-lamination, fiber damage, perforation, plunging, bushing, crater shape and how the stiffness is affected by damage.

Military operations are dependent on support from armored ground vehicles, cargo planes and helicopters. A number of vehicles take part transporting soldiers and ammunitions. Specially designed vehicles can battle the enemy along armored tanks and military helicopters.

Current high performance ballistic materials used in armored ground vehicles are limited to spall liners inside the battle tanks to catch any spall generated when an enemy hits the vehicle. However, there is a major accord to develop lightweight, highly mobile, all composite load bearing armored vehicles with state-of-the-art ballistic materials. Such systems are in the early stages of design and evaluation for ground fighting vehicles, armored helicopters and other military planes (Bhatnagar, 2006).

GEKKO is protected by an armor system sufficient to withstand heavy machinegun fire and overhead artillery fire. Armor design contains the following parts;

- Exterior: Modular expandable armor panels made with ceramic faced woven aramid.
- Roof-interior: Molded woven aramid reinforced composite panels.

- Interior side: Molded S2 fiberglass reinforced composite panels.
- Door glasses: Polycarbon reinforced glass panels.

The tests of the vehicle are conducted as a system which includes the outer material of the vehicle plus the composite armor. A main criterion is to reduce behind the armor damage inside the vehicle leading to increased crew survivability.

Additionally, composite panels should provide other benefits to have capabilities of procurement such that easy to machine, easy to maintenance and easy to supply.

5. Performance Tests

An armored vehicle should be tested according to related publications (AVTP-1, 1991) for the performances of *(i)* Steering and maneuverability, *(ii)* Gradients and side slope, *(iii)* Braking, *(iv)* Speed and acceleration, *(v)* Dynamic stability, *(vi)* Lateral guidance force, etc.. Unfortunately, the details of the tests such as the criteria and the results can not be presented due to the confidentiality of the information. However the vehicle is pointed out as satisfactory and accepted at the end of performance tests (Figure 8-9).

Fig. 8. Climbing performance test of GEKKO.

6. Conclusion

Whole design process of an armored vehicle is presented considering the armor and structural integration with preliminary studies. Initial design stages while balancing the requirements, suitable materials and technology are detailed. Manufacturing the prototype as final step with performance tests can not be provided in details since belonged information is commercially confidential and trade marked. However this study is presented as an innovative design guide of the beginning pre-design for multitasking vehicles with complicated requirements.

Fig. 9. Side slope performance test of GEKKO.

Acknowledgement

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Disclaimer

The views and conclusions contained herein are those of the author and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied of any affiliated organization or government.

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