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LATEST TRENDS IN DESIGNING SPECIAL VEHICLES

Abstract. The paper presents new trends in design, particularly in the design of military vehicles. The idea of mechatronic design, which is a synergy of research methods in order to achieve optimal product, is outlined. The method of designing special vehicles which is the combination of both virtual and real models of selected vehicle components is described. Additionally, trends in development of military vehicles are analyzed.

Keywords: mechatronic design, military vehicles, armour.

1. INTRODUCTION

Technological progress, observed over the last few decades, is closely related to the rapid increase in innovation in the field of new manufacturing technologies as well as design methods and tools.

Integrated design methods, using the latest achievements in material engineering, supported by physical and simulation research using virtual models, are becoming standard practice in the process of product creation and manufacture. Further development of these methods, particularly in relation to the design of mechatronic systems, requires meeting many challenges related, among others, to the multidisciplinary nature of this type of systems and their simultaneous coupling with control systems. An important aspect is therefore to make use of the synergy effect of research methods in order to obtain optimal dynamic features and ensure the given operational parameters (Fig. 1).

The first challenge for project teams is related to the fact that almost all simulation tools that were implemented in the last 20 years to support product design engineering (including: finite elements method, modelling of multibody systems), refer mainly to the selection of geometrical features of the structure. Further integration of hydraulic, electronic, electromechanical and other systems, each with complex functionality and physical nature, is carried out by independent groups of design engineers using other specialized software. However, a modern approach to design requires the application of new simulation methods that go beyond traditional CAD and FEM tools [3].

Another challenge is connected with the integration of physical systems and control systems. Non-optimal combination of the various subsystems: (mechanical, electronic, computer and control) generates problems in the integration process and fails to make use of the synergy effect, extends the duration of the design and construction process, increases costs, or even interrupts the process due to the failure to achieve the goal (Fig. 2) [3].

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Fig. 1. Advanced methods of design and modelling applied in the ANDERS project

Optimal combination of systems of diverse nature, including control systems, at all stages of the design process results in the emergence of new research paradigms. This may be exemplified by: Hardware In the Loop (HIL), Software In the Loop (SIL) and Model In the Loop (MIL) (Fig. 2).

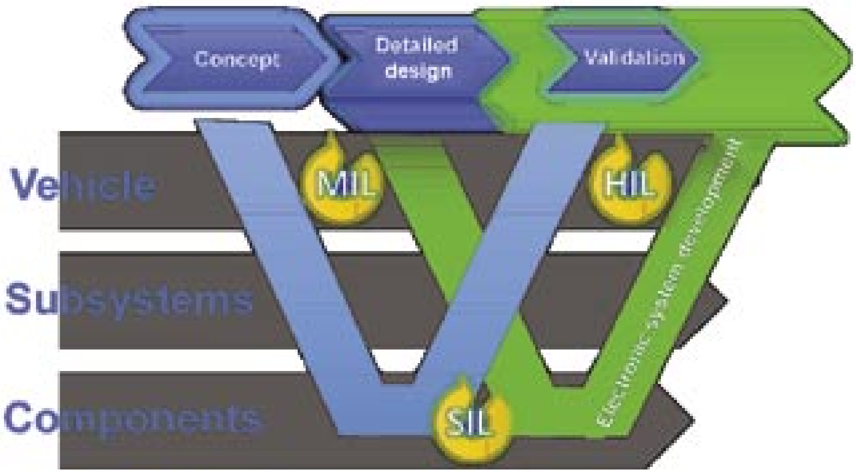

Fig. 2. Model of research methods synergy [3]

The fundamental changes that are taking place in the areas of state security and defence rely primarily on the increasing number of electronic and mechatronic systems. Performance optimization, integration of subsystems, control of parts of subsystems must become an integral part of the product engineering process. Numerous studies have shown that the discussed (mechatronic) approach to design, where virtual models and real objects are used in co-simulations, in real time, contributes to achieving the goal by providing solutions at both levels: mathematical model (including the dynamics of the real object in co-simulation) and integrated control system.

In order to construct mechatronic systems, it is necessary to build a number of physical models of the individual subsystems. It is also necessary to carry out many simulations, and to validate the models developed. For instance: modelling of electrically-assisted steering requires a combination of mechanical and electrical system models, and the braking system requires the development of models of the mechanical, hydraulic and electrical systems. Multidimensional physical models built for the purposes of simulation and validation must also take into account the increasing diversity and complexity of sensors and components that are used in mechatronic systems, taking into account the environment in which the system is to operate. The integration of such models of different physical nature is a great challenge for the design engineer, especially in the case of tracked vehicles. Changing the conditions of the use of modern military equipment confronts the constructors of military vehicles with completely new tasks, both in the application of modern solutions that provide the desired tactical parameters, as well as a new systemic approach to design and manufacture issues, with significant involvement of computer technology. Complexity of the systems, large number of mechatronic systems, as well as high costs of conducting research and development and implementation works require the use of the most modern mechatronic design methods (Fig. 3).

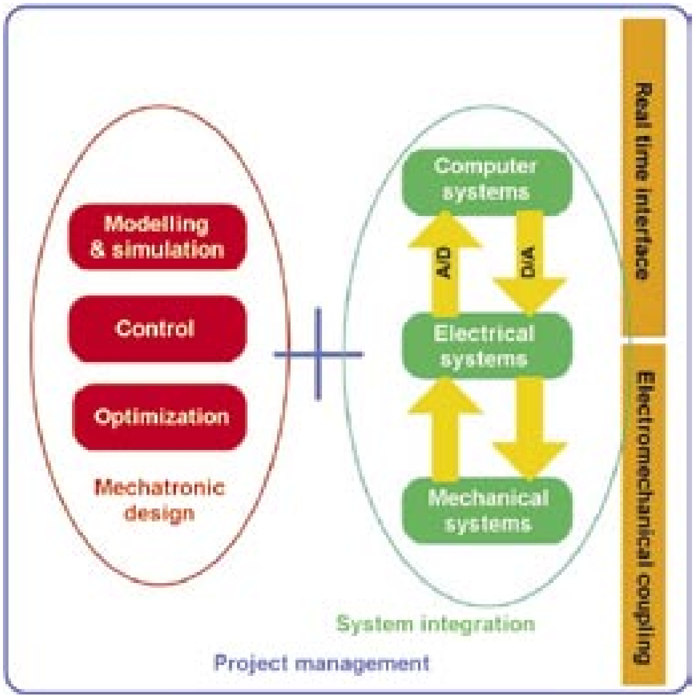

Fig. 3. Mechatronic approach to project realization [3]

The need to integrate many technical systems into a vehicle means that nowadays, during the design process, it is not enough to perform static calculations and to create a constructional record of the system, and then verify the documentation based on the prototype experimental tests. It is necessary to use computer aided design methods and virtual modelling, numerical simulations or rapid prototyping methods. Vehicle documentation is created not only in the design office, but also in the microprocessor laboratory and software laboratory. Mutual communication between mechanical engineers and electronic and IT engineers is getting increasingly important. An example of such approach is to support the design process with the results of numerical calculations in the field of modelling, sensitivity analysis and optimization of dynamic features of the system (Fig. 4).

Many possibilities in this field are provided by the finite elements method software. However, the specificity of the method of loading the structure of the vehicle (e.g. penetration of the armour with a projectile, analysis of the impact on the hull of shockwave from mine explosion, etc.) causes that traditional static stereomechanical calculations are not sufficient. Such calculations must take into account large strains, pulse loads and fast-changing processes. Specialized software that uses FEM, e.g. LS-Dyna, MSC.Marc, etc., features such possibilities.

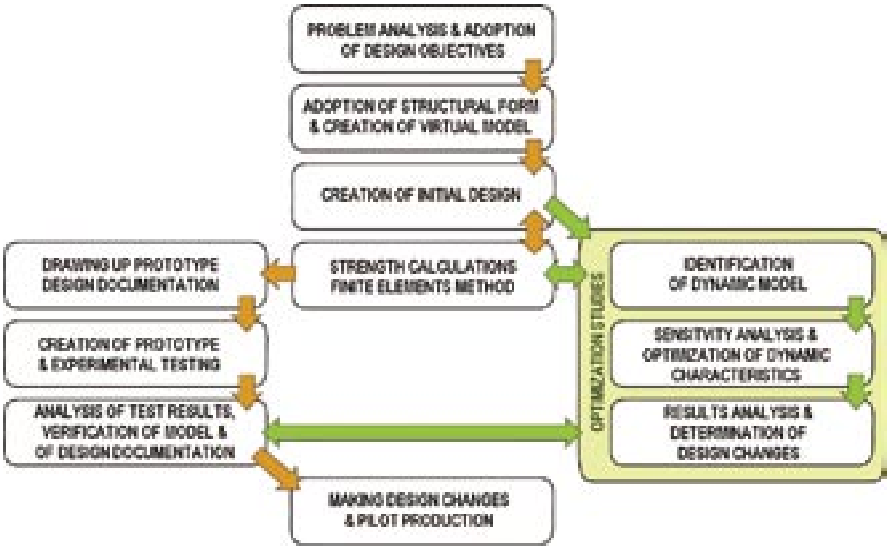

Fig. 4. Flowsheet of a mechatronic process design [3]

Commercial software for computer-aided design and numerical calculations enables carrying out many steps in the process of designing special vehicles.

When developing design objectives and prototype documentation, the structure of the system and its geometrical features are determined. On this basis, it is possible to identify the model and to estimate its parameters, and at the further stage of the work also to optimize for the purpose of providing the desired dynamic properties. In this context, the mechatronic approach to design issues, often supported by rapid prototyping methods, enables significant time and cost reduction of the production process of a technically complex product (Fig. 4). In mechatronic terms, the design process should therefore include the following steps:

- problem analysis and determination of project objectives;
- development of a project management system;
- virtual modelling of mechatronic systems;
- numerical calculations of stereomechanical and dynamic models;
- optimization of the mechatronic system with account taken of internal interactions,
- drawing up design documentation;
- integration of systems and construction of a prototype;
- prototype testing.

The individual stages of design are not implemented in sequence, they rather overlap or are effected in parallel (e.g. within individual subsystems), and in addition, in many points there are interactions between them.

2. CHALLENGES

Until the end of the last century, there was a distinct transfer of technological knowledge from military to civilian areas, but changes in the geopolitical situation, reduced threat of military conflict and economic changes and increased competition on global markets caused a rapid expansion of civilian research and development projects and reduced expenditure on military programs. The results of civilian research and development work often create opportunities for their simultaneous military applications - dual technologies or dual-use technologies. In recent years, especially in technologically advanced countries, a large part of technological solutions applied in the production of military equipment is derived from civilian research and development. The direction and scope of technology flow between the civilian and military spheres depends on the subject area, but most often the army implements civilian technological solutions in the field of electronics and information technology. However, it should be emphasized that many specialized research areas are and will be strictly reserved for military laboratories (e.g. new weapon systems, stealth technologies, etc.).

The involvement of civilian technologies in the development of military-oriented products changes the approach to the manner of design, manufacture and operation of military equipment, and at the same time enables achieving high tactical and technical parameters. The use of complete components developed for civilian applications cuts short the research and development cycle of new equipment, reduces the costs of developing and launching production of the final product, and reduces manufacturing and operating costs due to the use of much cheaper subassemblies and components produced in series. Particularly important is the participation of the Polish scientific thought in the co-creation of global and national trends in the development of products for military use. Taking into account the forecast of world markets for military equipment by 2022 (based on the Defence IQ survey), one may believe that Poland is among countries with a significant share of purchases of military equipment and weapon systems.

3. SIMULATION TECHNOLOGY IN THE CONTEXT OF CONCURRENT ENGINEERING

The development of computer techniques in recent years has given new possibilities in the field of modelling and analysis of machines and parts. These techniques are a great convenience when designing devices that set new standards in the areas of safety, usability and production economics.

In the past, many design works were based on the assumption that a system is composed of rigid bodies, or that elastic strains that arise as a result of dynamic interactions are minimal or even have no significance at all. External or internal forces generated during motion cause component vibrations that are superposed on the motion of the mechanism. This effect is particularly distinct in highly precise mechanisms.

The correctness of numerical calculation results depends on proper identification of dynamic models. The key point is the estimation of the model parameters, especially the energy dissipation characteristics.

The problem of estimating model parameters can also be solved by creating hybrid models, which consist in coupling the real object installed on the dynamic testing stand with a mathematical model, and by performing real time simulation.

As part of the work at the Institute of Theoretical and Applied Mechanics of the Silesian University of Technology a method was proposed and implemented for modelling a selected class of mechanical systems as a combination of models developed in virtual environments with real elements of such systems (Fig. 5) [6, 18, 19, 20, 21, 29]. The combination is effected in the so-called real time using a real-time environment and *dSpace* signal processor board. The developed methodology for modelling mechanical systems is an alternative to traditional modelling methods. In addition, in the representation of dynamic phenomena it takes into account the actual elastic-damping characteristics of the elements of the mechanical system being modelled. Its undeniable advantage is the ability to simulate the operation of a mechanical system taking into account the real component of this system, which leads to a shorter marketing time of the product and to the reduction of the cost of constructing system prototypes. During simulation it is also possible to take into account the control quantities necessary for the proper functioning of the system under design.

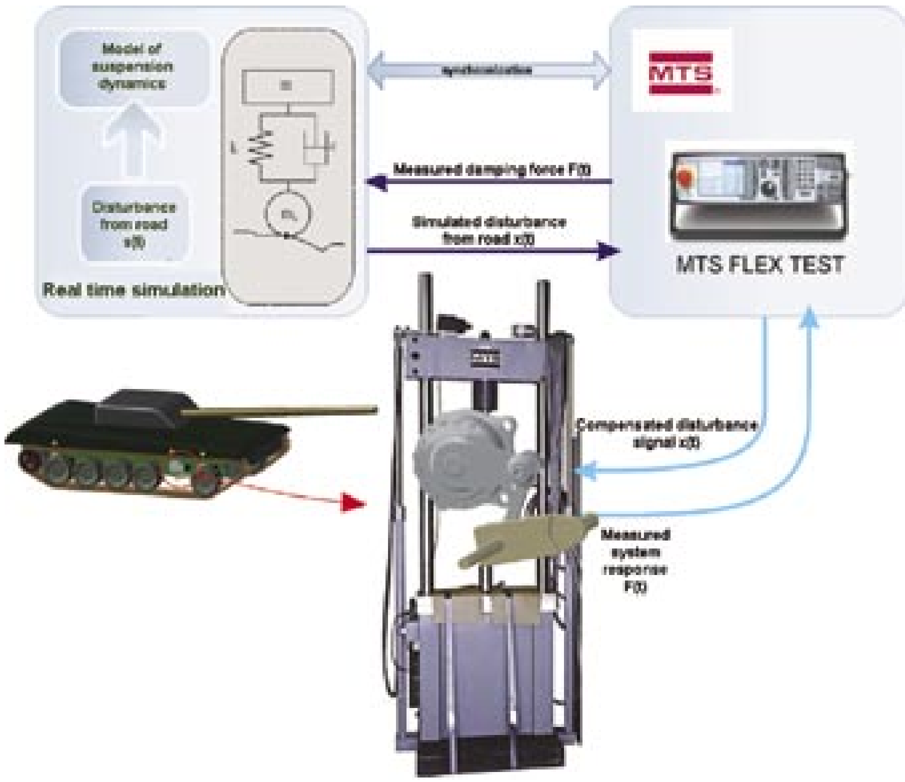

Fig. 5. Example of a flowchart of a hardware in the loop simulation [3]

The model developed by this method (Fig. 6), which describes the dynamic phenomena occurring in a real object, implemented in a virtual environment by applying, among others, the so-called *Real Time* modules, is processed into a source code in the *C* programming language. This code is transferred to the effector system. By using *dSpace* boards the entire program load and execution process is done on the on-board processor outside of the computer, which significantly increases the efficiency and capabilities of the entire process. The relieved computer may generate better graphical representation of the process. The computer only serves as a communications tool between the user and the computation environments. Fig. 6 shows a flowchart of a hardware in the loop simulation using a *dSpace model DS 1104* board.

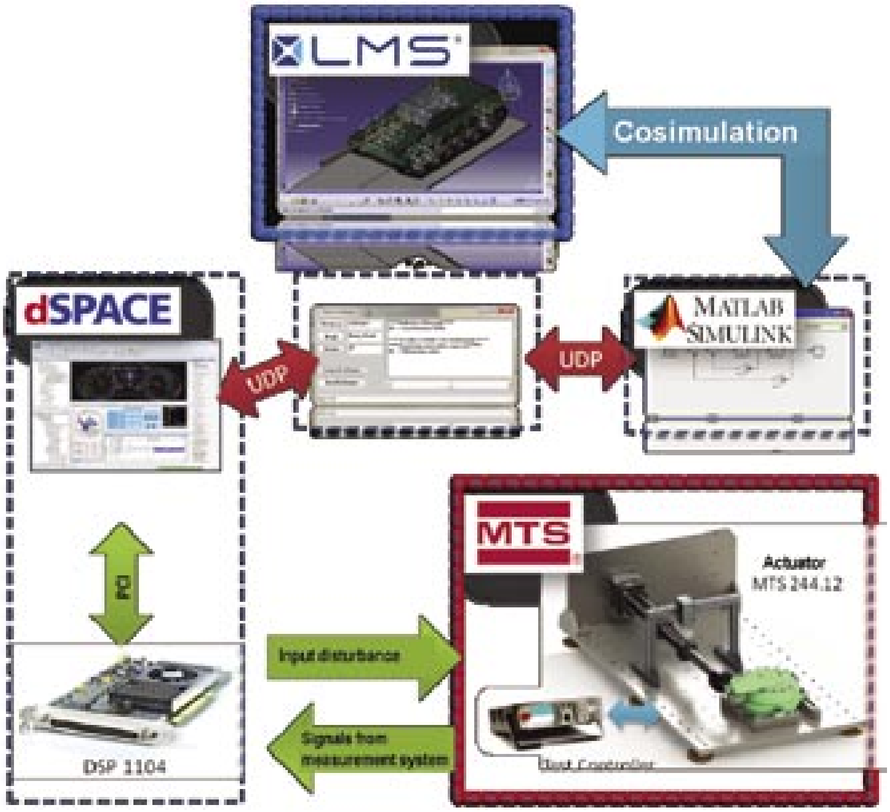

Fig. 6. Hardware in the loop simulation using a dSpace Real Time board [3]

The simulations conducted can be monitored and their parameters can be modified on the run.

4. TRENDS IN THE DEVELOPMENT OF MILITARY VEHICLES

The hitherto prevailing design concept of military vehicles intended to participate in conflicts where the opponent forces are similarly armed and equipped in the form of a regular army, meant that the main focus was on fighting enemy armoured assets and on increasing the resistance of the possessed equipment to the impact of such assets. This resulted in the expansion of the armour on the front and on the sides of the vehicle, as well as in the increased calibre of the main gun, leading to an increase in the weight of the vehicle. Less emphasis was put on increased mine resistance and on vehicle protection against assaults from above. Such vehicles were suitable for manoeuvre operations, but in asymmetric conflicts, where guerrilla activities prevailed, all their imperfections were exposed. Heavy armament of tanks and other combat vehicles is of little use when a fighter is encountered armed with an antitank grenade launcher or with an improvised explosive device (IED). The USSR's participation in the Afghan conflict, and operations of Russian troops in Chechnya, where guerrilla warfare was conducted in mountainous or urbanized areas, showed the ineffectiveness of the basic weapons and the lack of resistance of the armoured equipment and vehicles to close distance attacks from below or from above. Similar problems were encountered during the missions of allied forces in Iraq and Afghanistan. A characteristic feature of current armed conflicts is the use of improvised IEDs as the main means of combat. Despite the technological domination in equipment and armament, NATO troops taking part in armed operations in Afghanistan and Iraq suffer relatively large losses resulting from the explosions of landmines and IEDs. Over the course of several years of fighting in Iraq and Afghanistan, the number of landmine and IED incidents against the coalition troops has been growing at a high rate.

Military vehicles used in current armed conflicts should therefore provide adequate ballistic protection, appropriate to the new threats (Fig. 7). The level of ballistic protection of NATO vehicles is specified in the STANAG 4569 standard. The criterion applied in that standard for determining the level of protection of military vehicles is the assessment of the threat to the life of the vehicle crew members.

The most deadly weapons currently used in asymmetric armed conflicts are landmines, improvised explosive devices (IEDs), explosively formed projectiles (EFPs) and high explosive anti-tank projectiles [41-43]. After the detonation of an explosive device, depending on the mass of the charge and the type of initiation, the impact of the shockwave and the formed fragments generate pulsed loads on the vehicle hull [5, 22]. After a few milliseconds this pulse results in significant acceleration, which causes injuries or even death of the crew members [1, 2, 5, 7].

Fig. 7. Threats to military equipment in current armed conflicts

Providing adequate protection against various types of threats and explosive devices becomes the basic goal in the design of modern military vehicles. The proper level of crew protection is attained by using modular shields and add-on armour, selected and installed on the vehicle depending on the type of threat. A diagram showing the complexity of vehicle passive protection systems is presented in Fig. 8.

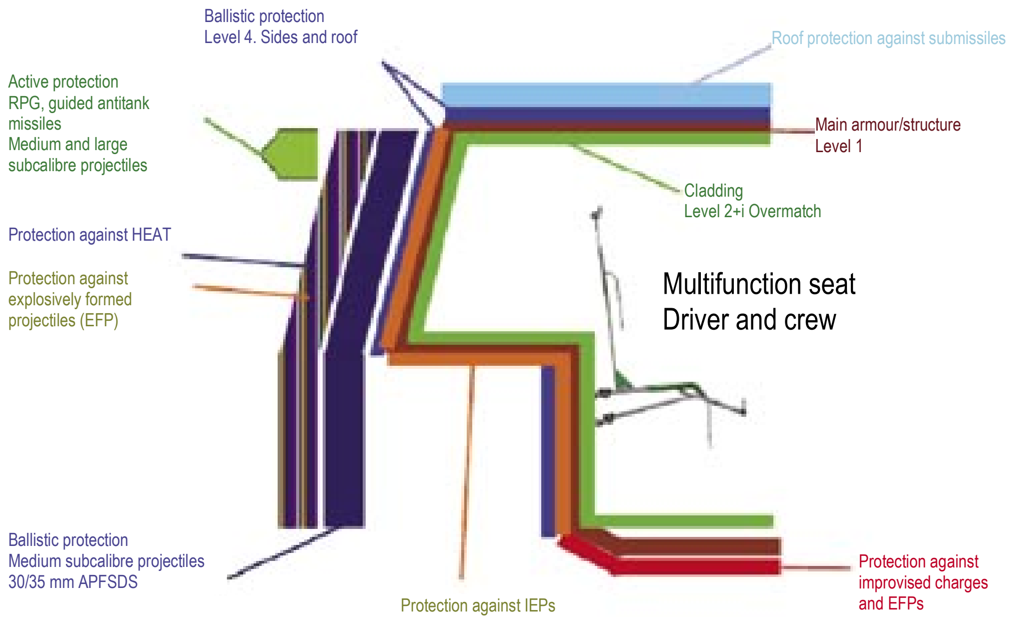

Fig. 8. Cross-section of the hull of a special vehicle equipped with a complex system of additional armour shields

Development of methods and means of protection against mines depends mainly on proper characterization of the impact of the shockwave on the structure of the vehicle and on its crew. Information on overloads from the impact of landmine explosions on humans is hardly available or insufficiently detailed, therefore it is acquired in the course of experimental tests and model studies, and the provision of an appropriate level of protection against mines becomes a standard for the design of future military vehicles [4, 8, 34, 41-43].

Although much attention is given to threats occurring during military missions, work is done on versatile equipment that meets the requirements of the traditional symmetrical conflict. Full intercompatibility and modular vehicle design is sought. This will provide full flexibility in vehicle configuration depending on the nature of the mission performed. An example of this are the vehicles designed under the Swedish SEP program. Both the wheeled vehicle and the tracked vehicle consist of 3 basic modules: crew module, chassis and interchangeable functional module designed to perform defined combat tasks. The modules are fully interchangeable between the wheeled and the tracked vehicle (Fig. 9) [10-15].

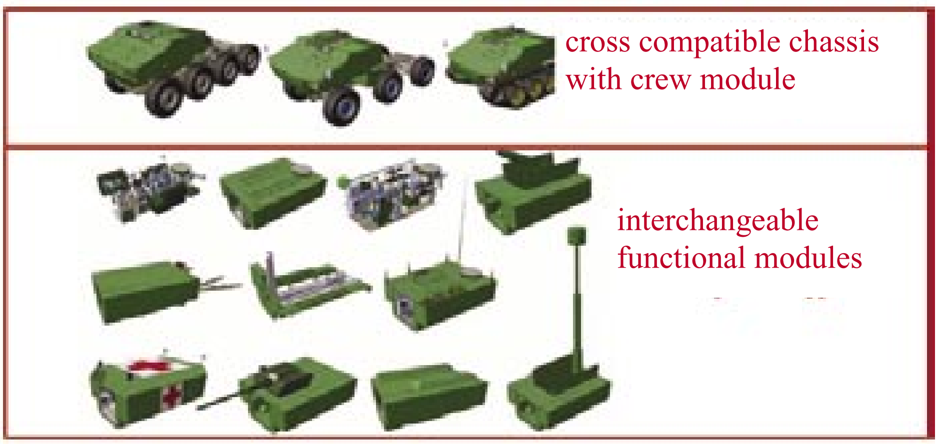

Fig. 9. Modular SEP vehicles

A new generation of wheeled armoured personnel carriers and infantry fighting vehicles is being developed that will also meet the requirements of asymmetric conflicts. An example of the application of this approach is the AMV Patria, manufactured in Poland under the codename KTO Rosomak. The vehicle has demonstrated a high level of crew protection in numerous attacks suffered during the Afghan mission, and it is now considered one of the best vehicles in its class. There is now much discussion about the future of tanks. Current research and development projects carried out across the world indicate the emergence of a concept of a main battle tank (MBT) that could be air-lifted to any place in a short time. The priorities in the design of such tank include relatively low weight and large firepower. An example of such a vehicle may be a new generation 33-ton tank developed at OBRUM in Gliwice, which is air-transportable, armed with an autoloaded 120-mm gun (Fig. 10) [27, 31].

Fig. 10. Virtual model of a new generation tank developed at OBRUM

Advances in materials engineering enable maintaining high resistance to threats while using armour of similar weight to that of conventional solutions. For example, while providing the same ballistic resistance to the vehicle, thanks to the use of nanostructured materials, the armour weight can be reduced by up to 30% (Fig. 11) and its resistance to multiple hits increased (Fig. 12) [23].

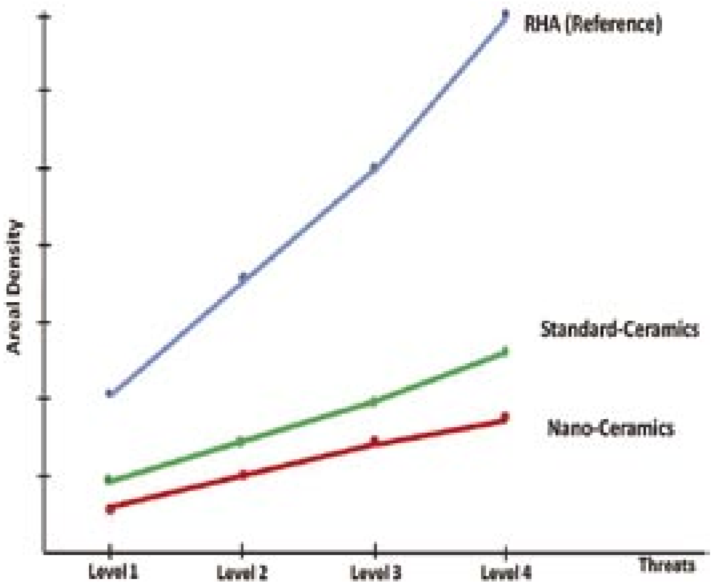

Fig. 11. Comparison of the unit weight of armour made of RHA steel, ceramic armour and nanostructured ceramic armour in relation to the level of ballistic protection (STANAG 4569)

Other factors that reduce vehicle weight are progress in the field of power unit design and automation of ammunition feeding to the guns. Increasing the speed of combat vehicles is, however, limited by the characteristics of the suspension. In the case of military vehicles, it is necessary to provide variable suspension characteristics for different traction conditions (road, off-road, field conditions, etc.). Modern semi-active suspension systems will enable further development of the new generation of high-speed military vehicles and increase the mobility of modernized machines. The solutions being developed are part of NATO's research strategies and follow the trends in the development of modern armour and automotive technology.

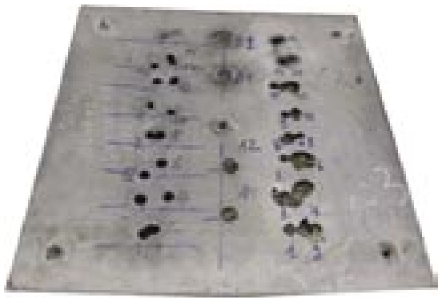

Fig. 12. Testing of steel armour resistance to multiple hits: left – nanostructured steel, right – RHA armour steel

The introduction of vehicles providing soldiers with adequate protection against the effects of detonation of mines and IEDs became the main issue to be solved for the troops participating in the missions in Iraq and Afghanistan. Similar threats occurred in Africa during combat operations conducted in 1972-1980 in Rhodesia (now Zimbabwe) and South Africa. At that time, the concept of vehicles with increased resistance to mine explosions [9] was developed. This concept has now been applied again in MRAP (Mine Resistant Ambush Protected) vehicles (Fig. 13).

a) b)

Fig. 13. Examples of MRAP vehicles:
a) Cougar in an IED explosion,
b) RG 31 after an IED attack (crew survived) [8, 11]

The main feature of these vehicles is a V-shaped bottom of the hull, which allows the shockwave to dissipate and thus reduce the impact on the crew. This configuration, however, causes a significant increase in the vehicle silhouette. MRAP vehicles have already saved the lives of many soldiers, but they are mainly intended for patrol, evacuation and auxiliary tasks carried out under the conditions of present missions. The usefulness of this type of equipment in typical army military operations is debatable, because the vehicle is heavy, has poor field performance and a high centre of mass. A solution to this problem is sought by developing a new generation of multi-purpose special vehicles for patrol, reconnaissance and combat tasks with wheeled and tracked chassis.

5. REQUIREMENTS SET FOR MODERN SPECIAL VEHICLES

According to some military experts, protection and counteracting IEDs are the areas of development in the field of special vehicles, for which the largest funds will be allocated up to 2033 (Fig. 14.) [27].

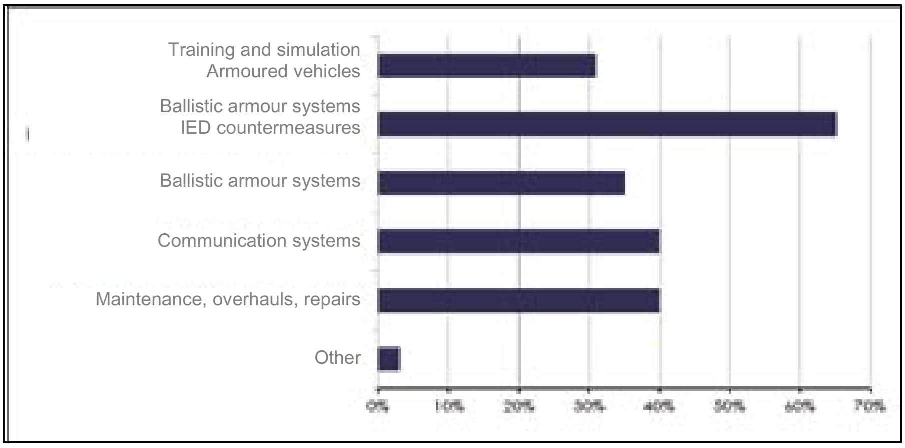

Fig. 14. Predicted areas of special vehicle development up to 2033

The most important problem in the design of modern military vehicles is to provide a high power to weight ratio, which increases vehicle mobility and improves traction characteristics, while improving the protection of health and life of soldiers. The priority in this case is a relatively low weight and large firepower while ensuring maximum crew survivability in the battlefield [30]. The interrelations between these three parameters are shown in Fig. 15.

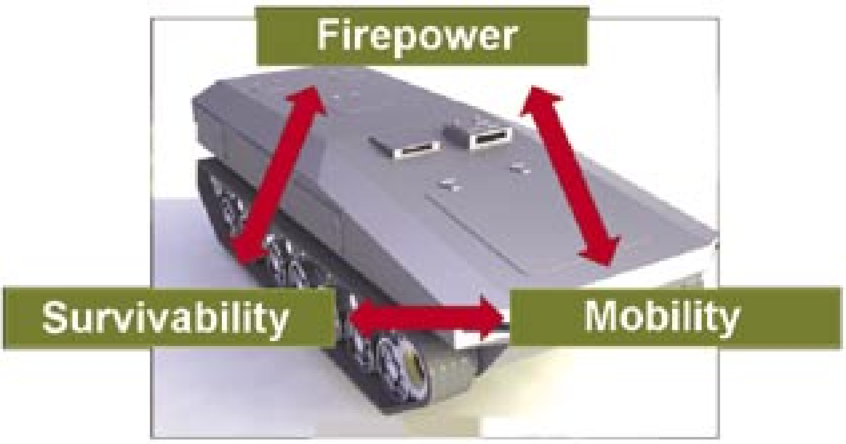

Fig. 15. Initial requirements set on the design of modern military vehicles [3]

In view of the quest for solutions that warrant high survivability of the crew as well as of the vehicle itself in the battlefield, the demand for solutions using innovative materials, particularly composite materials, for the additional armour is increasing.

Until recently protection to special-purpose vehicles was traditionally provided by means of steel armour. However, the on-going retrofitting of vehicles with standard steel armour caused a significant increase in the weight of vehicles, even making it impossible to transport them by air to operation sites [32].

6. SUMMARY

The application of advanced technologies and modelling methods and numerical simulations in the research on and development of new generations of special military vehicles is becoming indispensable. The creation of numerical models, as well as the design and optimization of systems at an early stage of design is made possible by modern computer technology. However, the degree of complexity of problems and the need to use advanced computational techniques require close cooperation between scientists and industry, both in the field of basic and applied research, as well as in introducing new manufacturing technologies.

Effective cooperation between scientists and industry is made possible due to the creation of appropriate tools and procedures. Joint implementation of practical projects, the results of which can be applied in industry, stimulates scientists to focus their efforts on the most desirable research areas, the outcome of which will be a product featuring the highest technical parameters and performance characteristics. Moreover, the problems reported by the industry may inspire new trends in research activities. The industry, on the other hand, thanks to such cooperation, gains access to the most recent advances in a given field of technology, supplemented with expertise and research experience of partners from the scientific circles. One of the ways to make cooperation between scientists and the industry more efficient is by establishing consortia for the implementation of joint projects. Project activities contribute to the integration of communities, as well as to a better understanding of the aspects, needs and problems of each of the partners in scientific and industrial cooperation.

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