# Compendium

by armada

# Armoured Vehicle Protection

## 2013

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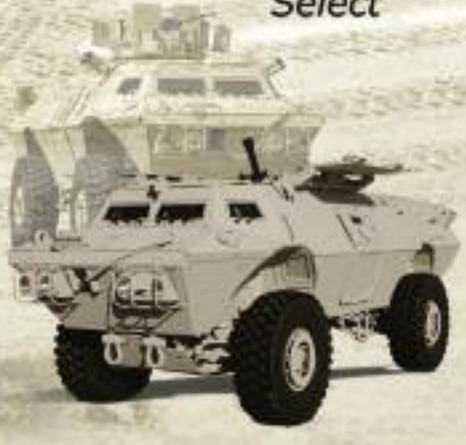

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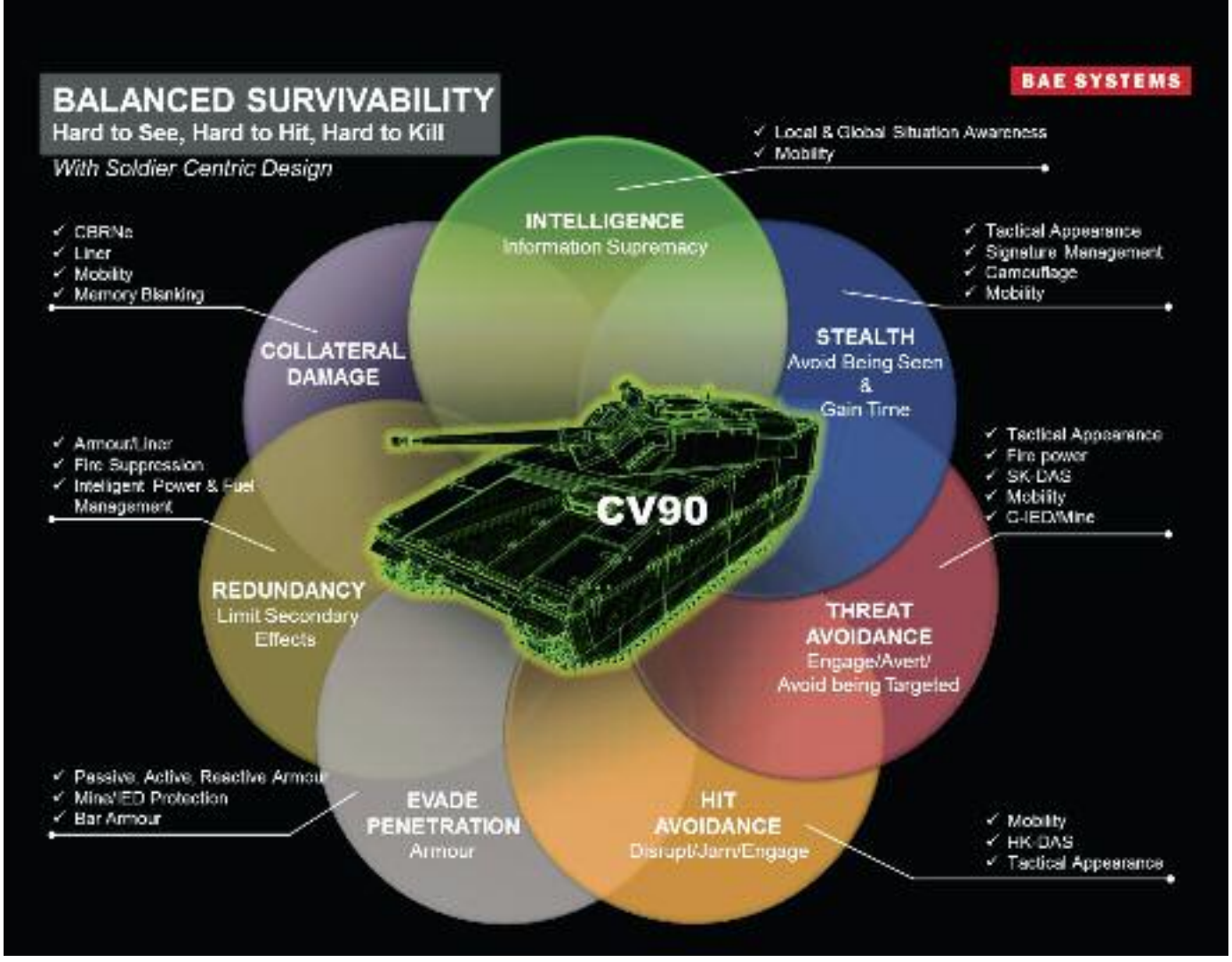



# Vehicle Survivability, A Holistic Problem

**The survivability of a vehicle is not the sum of the various protection systems available, but more the smart integration of all those components to use the quintessence of their characteristics, as illustrated in this BAE graph. While the "survivability onion" concept remains valid in terms of sequence if seen from the attacker's standpoint, see – acquire – hit – penetrate – kill, looking at survivability from the defender's standpoint brings in other elements that are not necessarily linked to the vehicle, such as intelligence and training, while many others may impact survivability in different ways.**

Paolo Valpolini

A good case study for an integrated survivability approach is that of the CV-90 developed by BAE Systems. Compared to the original vehicle the current CV-90 Mk3 is entirely new in terms of mobility and protection, but most of all in terms of digitisation, allowing to easily add new sensors and systems to improve crew situational awareness. BAE Systems aims at providing the crew with the tools needed to see first, understand what happens, and possibly infer what will happen. Stealthiness is another key factor, and includes not only hardware, from evolved camouflage systems to rubber tracks, but also training, since specific tactics can help in avoiding detection. If one is seen, soft-kill systems are key to evade the threat. Hard kill active defence systems can intercept the approaching round at a distance. Then comes the armour in its various forms, reactive or passive the latter being normally


*This close-up of the CV90 displayed at DSEi in 2011 reveals the shape of the thermo-variable tiles that compose the Adaptive camouflage. (Armada/Eric H. Biass)*

the current choice for avoiding perforation. Reducing the perforation effect is the responsibility not only of liners and fire suppression systems, but also of an appropriate design that allows to decouple dangerous materiel from the crew.

Dealing with the whole set of systems and concepts involved in vehicle protection and survivability would exceed the boundaries of a Compendium. Hence we shall try to depict the current state of the art in some of those fields, such as evolved camouflage, soft and hard kill and passive armour, knowing perfectly that when approached on the subject of protection most companies are not that talkative. Other systems, such as 360° situational awareness sensors, have already been discussed in recent articles while others, such as transparent armour, will be the subject of forthcoming articles.

## CAMOUFLAGE AND DISGUISING

The best way of avoiding detection is to merge the vehicle with its background, in all spectra. Passive systems, such as camouflage painting, camouflage nets, infrared painting and radar absorbing coatings work to some extent. However, with the increase in technology on the battlefield a comprehensive approach to camouflage has to be taken. In the visual field, Polymer Light-Emitting Diodes (PLED) and Liquid Crystal Display (LCD) are among the most promising technologies. A recent example of a "camouflaged" vehicle was seen when a car manufacturer launched an advertisement in which its car was made "invisible" thanks to the use of several mats of light-emitting diodes on the driver's side, while on the opposite side a video camera was used to pick the background to be mimicked by the diodes. Defence companies are working on similar solutions, with the addition of the considerable challenge of providing an all-spectrum camouflage, not only in the visual one.

How much adaptive systems will completely take over from current systems is open to discussion. According to officials from Saab Barracuda, one of the leading companies in camouflage, many situations can still be covered with current "static" systems: thermal or infrared can be handled by systems in 90 per cent of the cases, the remaining 10 per cent being definitely better treated with active systems. Currently Saab Barracuda's top product for vehicles is the Mobile Camouflage System (MCS), intended primarily for protection during movement and in combat. The MCS can be applied in a number of configurations and provides stealth capability in the visual, near-infrared, thermal infrared and broadband radar wavebands. It consists of interlocked panels, attached using a variety of techniques, none of which require modification to the vehicles. Saab Barracuda is, however, already looking at the future and with 20 per cent of its turnover devoted to R&D, a lot of work goes into the field of new materials, new solutions in chemistry, and nanotechnologies. The company thinks that in the mid-term new systems will emerge allowing real-term adaptable camouflage systems both in the visual and in the thermal fields.

Intermat of Greece, known for its Chameleon camouflage painting, has recently introduced a self-adhesive visual and infrared camouflage system known as Chameleon Skin. A new camouflage layer can be rapidly installed by non-specialised personnel at the lowest echelon allowing to quickly adapt the vehicle pattern to the landscape.

Some companies have already started to reveal some new products. In 2006, United States-based BAE Systems Land & Armaments requested a patent for an all-spectrum camouflage system based on a series of reflective layers controlled by applying different voltages. What happened to that programme and how much it might have impacted other programmes within the company is unclear, but BAE Systems is definitely involved in active visual

*Adaptive camouflage systems are still far from being a practical reality, but in the meantime Saab Barracuda offers the Mobile Camouflage System, which according to the Swedish company covers most current needs in the infrared spectrum. (Saab Barracuda)*

*These infrared pictures show the Adaptive non activated (left), in operation to blend into its backdrop (centre) and, supreme refinement, in operation to mimic an ordinary saloon car. (BAE)*

camouflage, and has recently confirmed that a multispectral camouflage system will be available "in some years".

Where work appears to be most advanced, however, is in the field of infrared. At DSEI 2011 the company unveiled the Adaptive, a fifty-fifty investment between industry and the Swedish military: hexagonal tiles based on a semi-conductor that acts as a heat pump are each linked to a computer that also receives the data from a thermal sensor looking at the background (in other words 180° away from the face of the tiles), enabling adapting each tile temperature to optimise the merging of the vehicle thermal signature into that of its own background. The tiles are roughly 150 mm across. Some 450 are thus required to cover the side of a CV90. The time needed to vary the tiles' temperature affords a "camouflage on the move" capability of up to 30 km/h. Dimensions are optimised for obtaining an IR stealth effect from 500 meters hence. To disrupt the opponent's intelligence cycle Adaptive can also be used as a deception system, as it allows to show an IR shape of a wholly different type of target. According to BAE Systems the IR Adaptive also embodies good radar absorbing features.

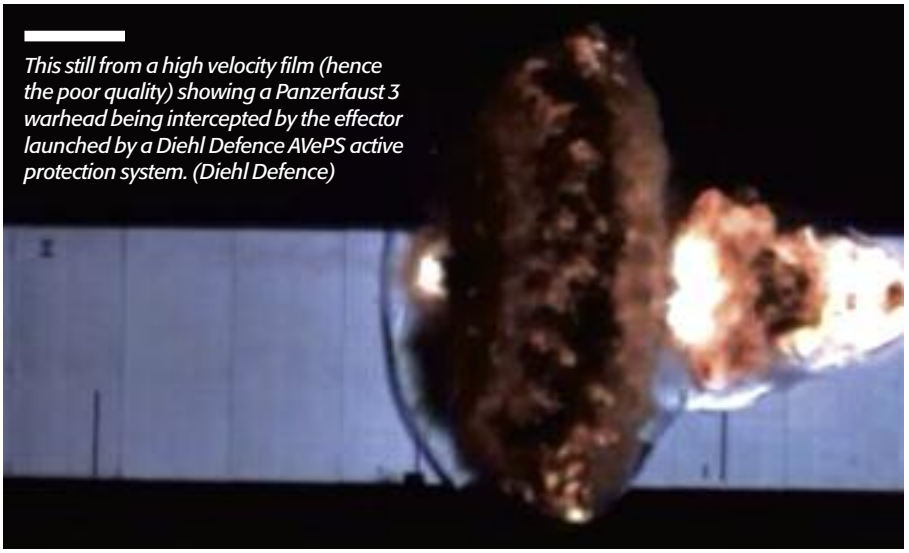
Another company active in infrared active camouflage is Eltics of Israel. Its Black Fox multi-spectral stealth technology is now mature and the company was granted two patents, while some more are on the way. The Black Fox sensor suite is based on two cameras which scan the surroundings on 360° providing the thermal scenario to the computer which in turn provides the correct

orders to the rigid panels installed on the vehicle in order to merge its signature with the background. Each panel acts as a pixel canvas surface, temperature being set for defeating thermal imagers working both in long- (8-12 µm) and mid-wave (3-5 µm) infrared. Eltics underlines how much mimicking other vehicles, in order to deny intelligence to the enemy and confuse its intelligence process, might be even more important in terms of overall survivability, the company having developed a network centric stealth and deception system that allows the HQ to control and monitor the camouflage pattern of friendly vehicles on the battlefield to optimise the deception effect.

Eltics also developed a technology that allows one to obtain the same effect of stealth panels on transparents to ensure view from inside – something quite useful for wheeled armoured vehicles with large armoured glass surfaces. The company is not very forthcoming about its programmes as it is in the process of moving from laboratory stage to marketing. Several possibilities are envisaged, such as establishing a partnership with a major international company with production and marketing capabilities, or by selling the technology to a major company.

Noise is another important issue, sound signature being able to give away the presence of a vehicle that managed to escape all other sensors. Engine noise can be limited but not wholly suppressed, while wheeled vehicles are inherently less noisy than their tracked counterparts. For the latter, rubber tracks are being developed, Soucy of Canada being the leading company, providing as it does CV90s with such a solution. Norway was one of the first countries to explore the rubber band option, initially with M113s and then with CV90s. Rubber tracks are being developed with increasing gross weight allowances: 28 tonnes CV90s are fielded in Afghanistan and trials are underway at 35 tonnes. Not only do they reduce noise signatures (currently by 10 dB), but they also cut down vibrations by 65 per cent, and thereby increase crew endurance and subsystem lives. They also play a major role in the effectiveness of seismic sensors.

Although it will be impossible to make a vehicle completely invisible, reducing the distance at which the enemy will track it will reduce the opponent's reaction time and hence increase chances to engage him before he even noticed the threat.



*This still from a high velocity film (hence the poor quality) showing a Panzerfaust 3 warhead being intercepted by the effector launched by a Diehl Defence AVePS active protection system. (Diehl Defence)*

# Actively Keeping Threat at Bay

**Killing the round before it hits the vehicle is still the best way of protecting a crew. The control over the newest versions of the most lethal antitank weapons has gone astray due to many recent events in North Africa and the Middle East. Kornet AT-14 missiles were used in Libya and are being supplied to Syrian rebels. The latter looted Syrian Army depots capturing quantities of RPG-7s, RPG-29s and Kornets, and the number of MBTs and IFVs of Russian origin destroyed daily in that war is considerable.**

The fact that those will sooner or later be used against western nations' vehicles engaged in some operations is only a matter of time. Passive solutions have been adopted to counter the threat and only Israel uses an active protection system on its Merkavas, as western armies await to have full certainty that such systems do not cause any collateral damage even in the most remote opportunity. The feeling is that nations' legal systems tend to be more cautious about collaterals than about the protection of their own troops.

A few years ago active protection systems, or APSs, were in their infancy, but nowadays some of them have been optimised and reached sufficient maturity to allow their integration on current and future armoured vehicles. A formal evaluation of active protection systems by the US Army is awaited for 2013, the German Bundeswehr also awaiting to take a decision, as well as many other forces. This year might thus mark a definite step forward.

The Raytheon Quick Kill, the development of which was part of the Future Combat Systems programme, is the only one to employ vertically mounted effector launchers. It is based on a multifunction electronically scanned radar array installed over the vehicle ensuring detection and tracking of the incoming missile. The computer establishes the speed, trajectory and intercept point and cues the effector. This is ejected using a soft-launch method that allows its installation on light

vehicles. The 480 mm long effector then pitches over and accelerates towards the point of impact against which it fires its warhead that generates a focused blast destroying the incoming missile in mid-air. The vertical launch system provides a 360° coverage and ensures multiple hit capability because launchers are not assigned a specific sector. The Quick Kill demonstrated its multi-threat capability by defeating simultaneously two incoming missiles, multi-tracking and multi-engagement being part of the core system. The latest testing campaign was conducted in December 2012 and involved an extended set of threats, including one of the most lethal RPGs which was destroyed in mid-flight.

With the acquisition of 51% of Virginia-based Artis, Plasan Sasa not only increased its footprint in America, but also entered the active protection system business. Artis is the leading company in the development of the Iron Curtain under the auspices of the Darpa and is teamed with the Mustang Technology Group that provides the C-band low-cost radar that, with innovative signal processing, determines range, range rate, angle and timing for each incoming projectile. It works as follows: the radar activates the system to a ready state, optical sensors classifying the threat and determining the aiming point with a 10 mm accuracy: one of the countermeasures modules is then activated, the system firing it downwards in order to minimise collateral damage to the vicinity. The Iron Curtain programme is aimed at US use only, and the Darpa as well as the two companies involved decline to comment on its status. What is clear is that it has been merged with the Crosshairs acoustic threat detection and countermeasures system, and that the resulting system should have been deployed to Afghanistan as a prototype during 2012. This has however not been confirmed by any official source.

In 2011 Rheinmetall's stake in ADS Gesellschaft für aktive Schutzsysteme

*A pictorial of the Crosshair – Iron Curtain system that puts together an active defence system and an acoustic location system, developed under the auspices of the Darpa. According to some information the system has been tested in Afghanistan. (Darpa)*

*Operating sequence of the Raytheon Quick Kill. The company carried out a further series of successful tests in late 2012. (Raytheon)*

*A German Fuchs equipped with the Diehl AVePS active protection system, the launcher of which is seen standing on the roof of the vehicle. The system, currently at prototype stage, is awaiting a decision from the German Bundeswehr. (Diehl Defence)*

increased to 74%, the remaining shares being held by IBD Deisenroth. Its Amap-ADS (Advanced Modular Armour Protection - Active Defence System) is based on ladar sensors connected via optical fibre to an electronic control that provides data to the effectors located around the vehicle. With a system response time of less than a millisecond it can react to weapons launched from less than two metres, less than the average warhead activation distance. Effectors generate "focused blades of concentrated energy" intercepting the incoming round at 1.5 or 2 metres from the vehicle. If installed with overlapping arcs they provide multi-hit capacity. Quick replacement of effectors allows to rapidly re-establish the vehicle protection after an attack. The system can intercept approaching missiles travelling at 2,000 m/s, which means that it can also be effective against 120 mm KE long-rod rounds providing the actual armour can withstand the residual kinetic energy. As for collateral damages the company states that these will be contained within a radius of 5 metres around the vehicle. The latest version shown in 2012 was integrated on a truck cabin and is known as ADS CAB; the number of sub-system is changed to achieve the desired protection solution, this capability being known as Plug & Safe. The costs are estimated at a four-zero € figure. Such a solution has a weight of 70-90 kg and a power consumption of 150 W. Those values increase to 100-200 kg and 250-300 W for a light vehicle, 200-350 kg and 350-600 W for a medium vehicle, and 400-600 kg and 600-800 W for a heavy vehicle. Of course cost can differ by one order of magnitude from the simplest configuration to the most complex solution. The ADS is now fully qualified and in series production for undisclosed customers. Deliveries are already underway to one customer while others are working on system integration on their platforms for qualification purposes. The ADS is being qualified against a broad spectrum of antitank shoulder-launched rockets and guided missiles, and in general terms showed its ability to handle up to three hits on the same spot and more than one threat at a time.

Diehl Defence has concentrated on developing active stand-off protection systems. Today´s launcher-based AVePS prototype comprises a radar/infrared sensor system, a fire control computer, a multiple launcher including a fragment-free effector as well as safety electronics. Sensors provide threat detection and tracking up to a distance of several hundred metres and enable to pinpoint the opponent's firing position, data of which, fed to an RCWS, allows immediate firing reaction. The AVePS provides hemispherical 360° and top-attack protection for the carrier vehicle as well as vehicles in its vicinity, whish is a quite unique feature amongst active protection systems. Even if the same part of the vehicle is targeted repeatedly, no gaps in protection occur. By employing fragment-free blast effectors, collateral damages are largely ruled out. The safety concept provides high reliability and optimal protection against random triggering. The AVePS can engage the entire range of RPGs and modern anti-tank missiles, including the tandem hollow charge variety. Likewise, the effectiveness of large-calibre KE penetrators can be reduced decisively. The AVePS can be integrated on a variety of platforms, from light to heavy. The prototype is available in two system configurations: a single launcher version (< 350 kg) for light armoured vehicles and a twin-launcher configuration (< 500 kg) for heavy vehicles. Diehl is awaiting a decision on APS by the German Army.

One of the latest entries in the active protection system field is Krauss-Maffei Wegmann whose Aktives Schutzsystem was unveiled at AUSA 2012. Sensors come in the form of radars operating in the 25-35 GHz band, which is the optimal frequency to obtain the ±10 cm accuracy required to

# Saving soldier's lives: Protection systems by RUAG.

Photo Carl Schulze

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*Israel is the first nation to deploy an active protection device in the form of Rafael Trophy-H, which has been installed on Merkava 3 and 4 MBTs. (Rafael)*

properly activate the effectors. A typical layout on a Dingo would see one radar at each corner and one on each side. Optical sensors may also be used to further improve the system. Thirty centimetre-wide effector modules are arranged around the vehicle's roof. Upon detection of the threat three such modules are detonated directing a blast downwards to intercept the warhead. The effectors have an effective range of between 4 cm and 2.5 metres and contain a minimal charge and no metal. Dismounted infantry safety range around the vehicle can thus be evaluated at about three metres. KMW developed the basic elements of its system, work having started over eight years ago, and AUSA was the opportunity to get feedback from potential customers before investing in a full technology demonstrator and system qualification. According to KMW about two years would be needed to mature the Aktives Schutzsystem to production level.

Another company awaiting a decision from Germany is Cassidian, which developed the Muss (Multifunktionales Selbstschutz-System). For the time being the company does not communicate on this multispectral soft-kill system aimed at neutralising laser guided missiles. The Muss is based on the Cassidian Electronics AN/AAR-60 P-Milds missile warning system and on Colds laser detection system, installed on a same sensor head, four of which are mounted on the vehicle to provide 360° coverage. Effectors come in the form of grenade launchers, either 76 or 81 mm, able to fire IR obscurant grenades, and of an active IR jammer. How much recent eye-safe dazzling systems might be integrated into the Muss remains unclear. In its current form the Muss has been integrated into a Leopard 2A4 tank and demonstrated over ten years ago.

Oto Melara is working on the Scudo, and is looking at ways of installing its sensors linked to a data gathering system onto vehicles that are deployed downrange. Discussions are underway with the Italian MoD regarding this new approach: the company would like to install its sensors – sans actuators – probably on a few Freccia 8x8s in order to obtain real-life data about false alarm rates and sensor effectiveness. The Scudo features four continuous wave dual frequency radar sensors that cover 90° in azimuth and 60° in elevation, with a detection range in excess of 600 metres against antitank threats. They each weigh five kilos. They are installed around the vehicle or turret, or on a column over the turret. Alert level and non-active arcs of fire will be dynamically established thanks to the integration with the Soccona C2 and navigation system and the Forza-NEC digitised battlefield system data. As for the actuators Oto Melara has already developed a two-layer system consisting of grenades for 100 to 250-metre engagements on the one hand, and of active tiles mounted on the vehicle with a 6 to 15-metre range on the other. Their respective engagement times

*An IDF Merkava 4 equipped with the Rafael Trophy-H active protection system is here seen during training manoeuvres. The Trophy has successfully proved its worth in real-life action. (Rafael)*

*The Trophy-L has been developed to answer the protection needs of light vehicles, and its effectors bear no resemblance with those used in the heavier versions of the system. These pictures offer a clear view of the sensors installed at the four corners of the roof and of the downwards-looking (and firing) effectors. (Rafael)*

are of 350 and 150 milliseconds. Upon completion of sensor evaluation the company will consider various options including the integration of third-party actuators, should the latter prove to be more effective than in-house developments.

Known in the past as the Aspro, the Rafael APS family for armoured vehicles now comes under the Trophy brand name and includes three versions, namely the HV (Heavy Vehicle), MV (Medium Vehicle) and LV (Light Vehicle). The first two use the same technologies while the light version maintains algorithms and logics of the heavier systems, but with threat neutralisation based on a wholly different physical principle. The Trophy-HV is fully qualified and in service with Israeli Merkava 4s and Merkava 3s. Declared operational by the Israeli Defence Forces in 2009, it was proven in combat in several engagements from March 2011. It weighs 850 kg and is based on a radar, two launchers equipped with an automatic reloading system and associated electronics. Key to the system is the IAI/ELTA ELM-2133 WindGuard pulse Doppler aesa radar that provides incoming missiles cueing. Four bullet and fragment-proof antennae each covering 90° are located on the vehicle ensuring full 360° upper hemisphere coverage. Maximal accuracy in tracking, identifying, classifying and verifying the incoming threat are needed as the effector adopted does not use explosive energy to neutralise the incoming warhead. Known as MEFP (Multiple Explosive Formed Penetrators) it generates a limited number of EFPs that are aimed at specific points of the warhead in order to disintegrate it without detonation at a range of 30 to 60 metres with a 90 per cent kill probability. Safety, collateral damages and legal issues were among top priorities during development, and it took four years to obtain the safety certification. Lessons learned led to increased attention to radiations, fragments and software design, though software development with a view to improving the system is a never-ending process.

The Trophy HV was successfully tested in the US where it was considered for its low collateral damage features and maturity. Currently three Merkava battalions are equipped with the Trophy, which according to Rafael proved to be very reliable in terms of MTBF in three years of operational life. The company is ready to satisfy a UOR with a relatively short delivery time should a customer choose the Trophy HV.

The MV version leverages recent trends in miniaturisation, tipping the scales at 520 kg. Rafael is awaiting a launch customer to complete qualification, which requires additional investments. It remains to be

*In this still from a high speed film of the Trophy-L in action, one can see the blade of energy that is directed downwards to neutralize the incoming RPG. (Rafael)*

seen, however, whether the company will propose this version for the new round of testing by the Israeli Defence Forces in view of the selection of a next-generation active protection system.

The LV version, finally, comes in the form of a roof-mounted system with a main alert sensor also mounted on the top of the vehicle. Further sensors around the vehicle, probably electro-optical, are used to accurately evaluate the position and time of impact of the incoming warhead, those data triggering the activation of the concerned energetic blade effector focused downwards to intercept and neutralize the round. With a weight of 200 kg for a Hummer-class vehicle, the Trophy-LV is optimised for countering RPG-type threats. The LV version has successfully passed the test phase and is now awaiting a launch customer before undergoing the final qualification.

First shown in 2006 at Eurosatory by Israel Military Industries, the Iron Fist has evolved into a soft/hard kill system that can be installed onto vehicles of different tonnage, from light to heavy. Laser jammers can counter antitank missiles guidance systems, instantaneous smoke screens can impede target acquisition or tracking, and a hard kill system can neutralise the incoming threat. The main sensor is the RPS-10 software-defined compact hemispheric radar developed by Rada, This provides a 120° coverage in azimuth and 90° in elevation and was developed from the ground up as an armoured system, its antenna being protected against gunshots and splinters. An all-in-one system weighing 17 kg, three such units allow full 360° coverage. Infrared sensors integrate the data provided by the radar. The active element comes in the form of a twin-tube launcher using soft-launch techniques to deploy a fin-stabilised canister which, to minimise potential collateral damage, generates only blast (the case is fully combustible). Triggered by a proximity fuse, it destabilises the incoming round – RPG fired at short range, missile or even a KE round alike. A full system normally includes two turrets, although a light solution for smaller vehicles based on a single turret is also available. (A recent Bright Arrow version, with two launchers and IR sensors also carries a 7.62 mm machine gun with optronics, merging the functions of the APS with those of an RCWS for a weight penalty of 250 kg without weapon and ammo).

In mid-2011 the Iron Fist was successfully tested in America on board an MRAP using both soft- and hard-kill capacities against missiles and KE rounds, while previously testing were also conducted in Germany. In the United States IMI has teamed with General Dynamics Armament and Technical Products to act as "prime" for the national market. The Iron Fist was selected by Israel for its Namer infantry fighting vehicle, based on the Merkava 4 MBT chassis.

Saab Electronic Defence Systems is promoting its Leds (Land Electronic Defence System), which consists of a sensor suite, a central active defence controller, high-speed directed launchers and countermeasure options (featured on our cover). The Leds-50 laser detection system ensures 360° coverage using four LWS-310 sensors while the addition of an LWS-500 top-attack and anti-reflection sensor ensuring full hemispherical coverage. Sensors are linked to the Active Defence Controller (ADC) that provides the cueing of the potential threat associated with the laser emission allowing the crew to take action.

The first reaction normally comes in the form of soft-kill solutions, exploiting the Leds-100 that integrates infrared jammers and high-speed directed launchers loaded with fast multi-spectral smoke ammunition that deny acquisition, tracking, ranging and guidance. This however works only against laser-guided threats. To counter other types of threats such as RPGs Saab developed the Leds-150 that includes active (radar) and passive (IR) sensors and a hard-kill effector in the form of Saab Avitronics Moongoose 1 mini-missile.

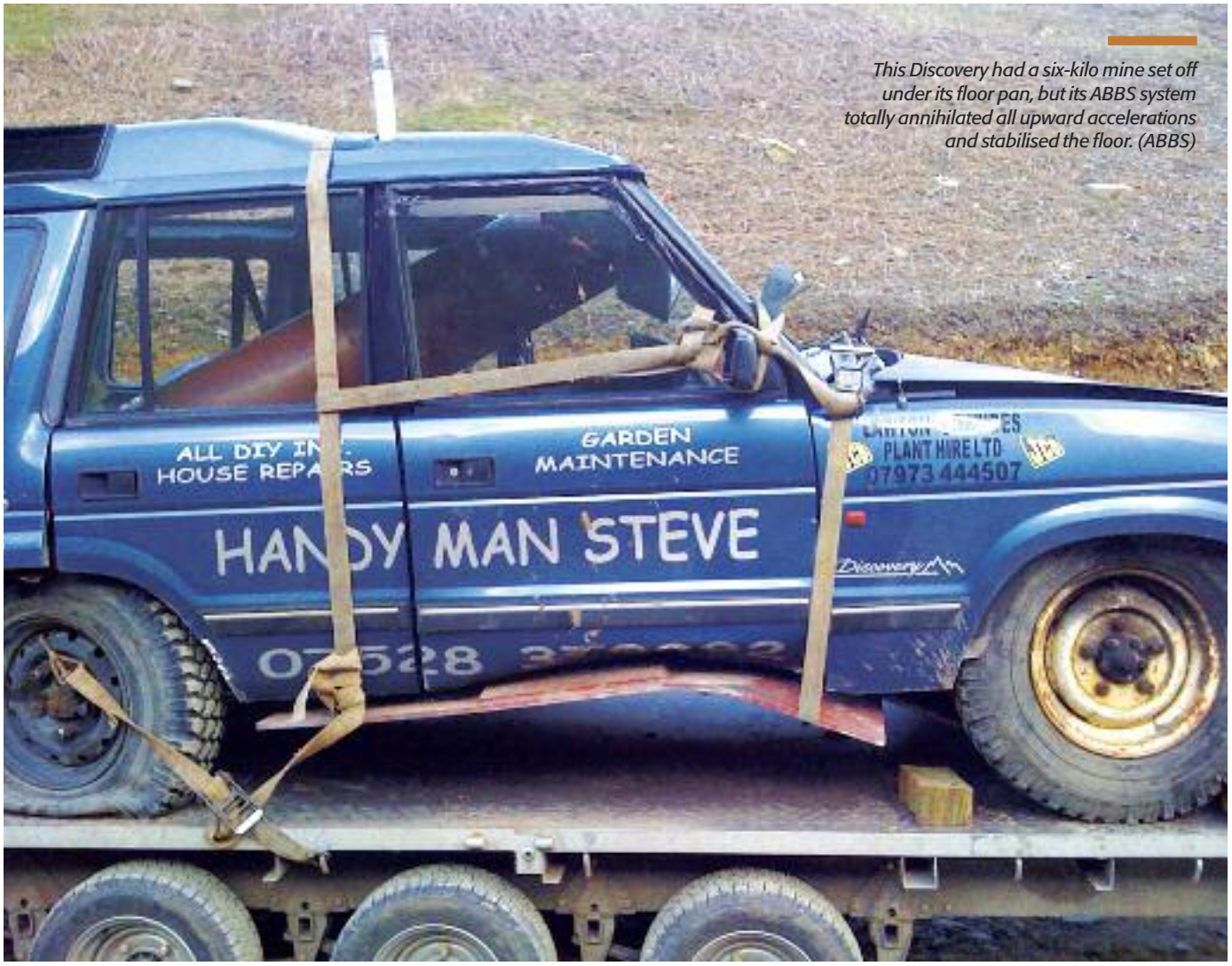
The main sensor is the Reutech Radar Systems frequency modulated continuous

*A CV90 prototype equipped with Saab Leds sensors. The protection device's hard-kill effector is the Saab Avitronics Moongose 1 missile. (Saab)*

*Seen here during testing, the Leds-150 uses a 81 mm calibre missile that neutralises an RPG launched from a range of 20 metres, six metres away from what should have been its point of impact. (Saab)*

wave staring array radar. This is able to detect an RPG within 5.2 milliseconds from launch, providing an accurate tracking within 14.3 ms. Knowing that an RPG will take some 190 ms to reach a target at 20 metres and considering the systems reaction time, that RPG can be neutralised at a distance of six metres from the vehicle. In March 2012 Saab underwent further testing with a new launcher known as DSL-306 developed in co-operation with Curtiss-Wright Antriebstechnik of Switzerland. This was designed in order to ensure full hemispherical coverage and multiple-shot capacity, while reducing weight, size and power consumption. Apparently Saab EDS is looking at further developments of its Leds family, capable to deal with multispectral threats as well as with kinetic energy antitank rounds.

Currently marketed by Ukraine Microtek, the Zaslon is based on models containing two effectors each under the form of a telescoped grenade launcher. Each warhead is equipped with a Doppler radar sensor covering 150 to 180° in azimuth and −60° to +20° in elevation. The radar continuously emits and has a range of 2.5 meters. When an incoming round is detected the relevant shaped charge warhead is detonated and neutralises the hostile warhead. The Zaslon technology allows to shorten reaction time down to a few milliseconds. Once the first ammunition is fired the second is readied. To ensure maximum protection a main battle tank requires up to six modules, however three of them can already be sufficient. The Zaslon is effective against RPGs, antitank missiles and anti-armour rounds up to 1,200 m/s. A light version known as Zaslon-L is also available for light armoured vehicles integration.




*This Discovery had a six-kilo mine set off under its floor pan, but its ABBS system totally annihilated all upward accelerations and stabilised the floor. (ABBS)*

# Underbelly Protection Going Active?

**One of the main threats to military vehicles comes from underneath. An explosion under the vehicle belly can have two types of effect: the first is to perforate the vehicle's floor, thus killing the occupants, or to damage it to a point that serious injuries occur even without penetration, the second being the tendency to lift the vehicle from the ground leading to the so-called "drop down effect", often more dangerous than the explosion's own induced acceleration.**

Put in simple words, actively countering the effects of a mine or of a buried explosive would mean that the protective system would have to a) deny penetration, b) limit deformation, c) reduce the accelerations inflicted to the crew and d) minimise the height at which the vehicle is raised.

Passive systems can cope with an underbelly blast but implies a number of penalties, the main one being an increase in ground clearance, since maximal pressure decrease proportionally with the square power of that distance. Another factor is the shape, the typical "V" allowing to deflect blast and pressure. Energy-absorbing armour located under the vehicle also comes to the rescue in reducing the blast effect, a trade-off between thickness and weight being the norm in order to avoid cumbersome

solutions. To maintain a good ground clearance while combining those three solutions leads to an overall height increase, which in turn means greater visibility and a higher centre of gravity that impairs stability.

If upwards and downwards forces on a sheet of metal are equally balanced this would not budge nor deform. Putting this theory into practice is no easy task, especially when the up-thrust is caused by a mine explosion that leaves virtually no time to react. However, to Roger Sloman, managing director of Advanced Blast & Ballistic Systems (ABBS) in Britain, "no time" was wrong as he understood while watching a slow motion video of a blast. He found that the 5 to 6 milliseconds that elapsed between the moment the shockwave hit the vehicle's bottom and the moment the vehicle started to move and lift-off were sufficient to trigger a reaction force – basically apply sufficient downforce. With weight and dimensional factors in mind, energetic solutions had to be found, either based on recoil systems or rocket motors, the latter being the preferred solution. With Ministry of Defence funding, ABBS started developing a diversified family of products, including the VGAM (Vehicle Global Acceleration Mitigation) and the VAFS (Vehicle Armoured Floor Stabilisation).

The number of effectors varies according to vehicle type and the desired effect. Pressure and acceleration sensors provide the computer with all needed parameters to ensure that every motor is activated at the right moment, with the right thrust and for the right period of time, to cope with the blast level and impulse duration, and with the position of the explosive under the belly. Weight and volume are both sensible issues. However, according to ABBS, the VAFS technology would permit reducing the "V" angle allowing to lower the floor and thus the centre of gravity, and thereby reduce vehicle profile or conversely increase internal volume, an overall positive trade-off for the presence of the columns containing or supporting rocket engines and redistributing forces on the floor. The VAFS may also allow to crush the floor in order to avoid contact with occupants' feet and reduce loose objects' acceleration, honeycomb material being added between the V underbelly and the floor. All energetic material used is insensitive munition (IM) grade and rocket bodies are bullet proof. Initial testing confirmed the system's principles and ABBS is now seeking partnership for shifting from concept to production. The company is planning to demonstrate the technology's capability in an 8kg under-belly test involving a Jankel Jeep 8 with near production-standard motors and control system around the time these lines are printed. ABBS expects the three-tonne armoured SUV-type vehicle to stay either on, or very close to, the ground with minimal or nil internal floor deformation.

TenCate Advanced Armour developed together with ABDS A/S of Denmark the Active Blast Defence System (ABDS). Development started in 2010 and in March 2011 first tests were carried out. In late 2011 TenCate acquired all the shares of ABDS A/S giving birth to TenCate Active Protection ApS. Not many details are known, but ABDS should be based on two mobile masses that are accelerated downwards to reduce the vehicle's upwards acceleration, thus reducing the transfer of blast energy to the occupants. The system is installed under the vehicle belly and includes a purposely designed Trigger and Activation System (TAS). This provides a stable, secure, high speed, automated fire command to actuate the proprietary countermeasures and yield a precise programmed structural and biomechanical response mode. A thorough test campaign was carried out including testing on an 15-tonne M113. According to TenCate the ABDS can increase anti-mine protection up to Level 5 and 6 and be retrofitted to a wide range of light, medium and heavy platforms.

*This picture clearly shows the smoke column emerging from the central pipe and that the vehicle neatly remains very close to the ground, which demonstrates how the downwards thrust allows to crush global upwards acceleration. (ABBS)*

A different solution was developed by Drehtainer of Germany. Its Zero Shock System is based on a second floor that hangs up on steel cables within the vehicle or shelter; the floor is located 200 mm from the armoured floor, considered sufficient to decouple it from main floor deformation. Upon explosion, sensors activate airbag-like pin pullers that react in less that 0.4 milliseconds, the floor "floating" for a time sufficient to considerably reduce accelerations. According to Drehtainer the forces on the floor are 20% of what is accepted by Stanag, and this allows not only to avoid injuries but also to install seats on the floor itself rather than hanging them on walls. The system was tested in German, British and Canadian military centres, while the Netherlands tested an M113 equipped with the second floor, exploding an antitank mine under its belly. The Zero Shock System has been installed in transport containers delivered to the Swiss Army as well as in casualty transport containers that are being delivered to the German Bundeswehr in 2013. Drehtainer is currently working on a new solution that would allow to neutralise the global acceleration on the vehicle itself.

## PASSIVE UNDERBELLY

Turning to passive systems, Oto Melara worked on underbelly protection exploiting two financed research programmes, one multinational and one national, developing a new protection package aimed at neutralising high blast and EFP threats. The EFP threat was taken into consideration by a multinational development programme that included Italy, the Netherlands, the Czech Republic and Spain; it involved defence agencies and industry, Oto Melara being the "Single Leader Industrial Entity". A surrogate TRMP-6 antitank EFP formed by a 5.2 kg TNT explosive charge and a 174 mm diameter liner weighing 773 grams yielding an impact velocity of 1,850 meters per second, was the standardised threat. This is capable of penetrating a 400-Brinell high-hardness steel at 0.8 metres standoff. Simulation allowed to carry out initial testing, with a step-by-step increase in both threat efficiency and armour panel dimensions. About twenty different solutions were tested by simulation, panels dimensions varying between 600x600 mm and 1,500x1,500 mm. Mass and volume are the two leading elements needed to defeat the threat, a compromise being required to allow armour packages to be added under the vehicle belly. The optimal solution would have the highest mass and volume efficiency, that is minimal mass and volume for a given protection level. However the two notions are

normally somewhat antonymous. Solutions developed within the testing phase had unique mass and volume efficiencies. One of those was tested in June 2012 on an Italian Army M113, the charge being positioned at a 410 mm stand-off distance. The floor was not perforated by the EFP while the two fully instrumented dummies installed on energy absorbing seats showed loads much lower than tolerance values. Exploiting a national research funding Oto Melara carried out a similar programme aimed at neutralising the blast threat. The next phase saw the "merging" of the results obtained in order to develop a solution against both threats. This had to be cost-acceptable, its mass had to be compatible with troop transport vehicles, and it should be installable on new combat or tactical-logistic vehicles as well as on existing vehicles. Oto Melara did not follow the hardness and mass path, but studied the interaction between blast and protection, and blast propagation in non-homogeneous armour, which behaves in a nearly acoustic way, in order to obtain high protection levels with limited mass. The aim was to maintain 100 per cent protection compared to the two separate solutions, while reducing mass as much as possible. A series of simulations and real-life tests, also verifying the behaviour on non-plane surfaces with discontinuities were carried out, the result being an armour package with a weight only slightly higher than single protection solutions.

*A number of companies have in recent years come up with a variety of underbelly protections, often based around open-V absorption boxes. General Dynamics Land Systems for its part, has developed what it calls a "double-V hull" for its latest iteration of the Stryker. No details have been given but the Army first acquired a first batch of 450 thus equipped Strykers, followed by a second of 292 vehicles. An upgrade package for the LAV II (seen here) is now offered as the upgrade still costs 40% less than a new-build vehicle.*

## JAMMING

Eric H. Biass

While there isn't much else one can do against a rocket that is already on its way than using some of the devices described in this Compendium, a lot more could be said of so-called improvised explosive devices. Some extremely clever, and pretty impressive – if not slightly frightening – solutions are also described here, but as fixes rather than pre-emptive measures, in other words when the aggressive action is already underway.

What about preventing the aggressive action from starting, then? One very first measure is to avoid getting into habits or routines. That's where, or when, the enemy starts to wait for you. But sometimes there is no alternative, in which case intelligence derived from surveillance systems should prevail to spot bomb "planters". But as we know, we already find it difficult to prevent clandestines and smugglers from crossing our well-defined borders, so let alone trace the presence of insurgents burying bombs at night on a desert trail!

Unlike RPGs however, buried or roadside bombs are triggered from a distance, either by television controls or telephones, meaning that some vehicles in a convoy, for example, could be equipped with jammers. This is more easily said than done, because jammers can adversely affect one's own radios, weapons and other systems (not to mention a vehicle's own electronics!), particularly at a time when soldiers are being equipped with a proliferation of electronic paraphernalia. Jammers, like countermeasures, therefore always need to be updated not only against a potential threat, but also against one's own systems to make sure they don't get frozen or put out of commission.

A recent development comes from Cassidian and requires quite a lot of processing for the reasons explained above. Known as the Smart Scout and here shown mounted on a G- Wagen, it continuously analyses the electromagnetic environment and adapts the required countermeasures. In Cassidian's own words, the jammer "features the new, ultra-fast Smart Responsive Jamming Technology to substantially enhance the level of protection. This system detects and classifies radio signals intended to ignite roadside bombs. It then transmits jamming signals in real-time, which are tailored exactly to the hostile frequency band. Thanks to the new digital receiver and signal processing technologies it is thus possible to achieve reaction times of well below a millisecond".

# A FULL SPECTRUM OF CAPABILITIES

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*A damaged cage armour fixed onto a Danish BV206. Cage armour are a statistic protection system, the average probability being around 60%. (Danish MoD)*

# RPG Shields

**Approximately 40 countries are using RPGs, which are manufactured in a number of variants by nine countries, the estimated overall production being in excess of nine million systems. It is thus hardly surprising it became one of the most frequent threats posed by rogue armies and terrorists in both urban and open terrain situations.**

One of the most widely used protective solutions is to equip vehicles with systems that allow to mitigate or as much as possible distort the jet generated by the shaped charge. This can be done either by deforming or destroying the liner or by increasing the stand-off distance, although in the latter case much work will be left to the original armour of the vehicle. Some programmes aimed at adapting main battle tanks to urban warfare have shown that even the best Cold War era tanks were not that well protected against RPGs on their sides, the main protection being concentrated on the frontal arc. Two kinds of solutions are currently adopted, "cage" or "bar" armour that physically decouple the incoming round from the hull surface, while "net" variants, and "energetic" armour use some form of low burning rate materials to defocus the jet.

But here too, there's no panacea. Cage armour considerably increases vehicle width, generating mobility problems in some urban scenarios. Being a statistical system, its effect depends very much on the point of impact and aspect of the incoming round. Most systems have a high probability of neutralising or consistently reducing the effect of an incoming RPG, and some of them can even withstand very close multiple impacts. Non-metallic solutions in the form of nets are also available, as well as mats which consistently tend to stop the round while avoiding initiation, although even those remain probabilistic items. The energetic solution, being based on armour modules fitted to the hull, is a non probabilistic solution as any place hit by an RPG will react in the same way. Moreover, it contributes to the protection against KE rounds. On the other hand, it remains to be seen how much of the energetic armour surface is damaged when hit and how much of that now vulnerable surface is exposed. The energetic solution generates a much lesser width increase, while the weight balance has to be considered case by case.

Ruag Defence of Switzerland proposes two different versions of its SidePro armour systems conceived for protecting vehicles from RPGs. The best known is SidePro-Lasso, a net system made of 4 mm diameter high tensile steel wire that adds a mere 6 kg/m2 to the vehicle weight and 250 mm per side. Steel was chosen versus fabric due to its resistance to environmental influences and its much longer operational life. According to Ruag the optimized size and shape of the mesh provides multi-hit capacity, as well as minimal decrease of the protection level

*The Ruag SidePro Lasso, here mounted on an Eagle, is designed to preserve maximum accessibility to the vehicle. It has been adopted by Denmark, Slovenia and Estonia. (Ruag)*

when the RPG reaches the net at an elevated angle, 1% less coverage at 30° angle of attack being negligible compared to that of bar armour. The first customer was Denmark, which used it on its upgraded M113s deployed to Afghanistan. Lessons learned have led to the development of an integral flexible mounting system and to that of a curtain system that improves access for maintenance purposes. The 92% transparency of the Lasso allows its use in front of windshields with minimal effect on drivers. In Fall 2012 Ruag scored another two orders, one from Slovenia, which installed it on its Skov 8x8 Svaruns (the local designation of the Patria AMV), and the other from Estonia which will equip its XA188. Both nations intend to field their vehicles downrange in early 2013.

The second Ruag option is the SidePro RPG: still a statistical system it is based on an undisclosed technology and ensures a higher protection compared to the Lasso,

*Developed in a new much lighter version, the Ruag SidePro RPG ensures a higher protection probability than the Lasso, and has recently been adopted by an undisclosed customer. (Ruag)*

reaching over 80% against all types of RPG-7s, roughly the efficiency of a reactive armour but at a fraction of the weight and with no collateral damage. A fully passive solution, the prototype system weighs 45 kg/m2 but was never sold. Further developments allowed to reduce weight down to 30 kg/m2 (10% that of a reactive solution). Qualified in 2012, this version triggered a first contract from an undisclosed customer, implying deliveries this year. Interestingly the two Ruag offers are "mergeable" into a comprehensive solution on the same vehicle.

In 2012 Nexter unveiled its RPG protection system in the form of a cage armour known as the PG-Guard. It weighs 11 kg/m2 and its layout has rectangular voids arranged like a brick wall. Elements are produced according to the vehicle shape. The design preserves vehicle accessibility: panels swivel together with doors, while quick-removable panels are used where maintenance hatches are located. Designed to neutralise PG-7 V, VL and VM rockets, its effectiveness varies between 50-65% according to the rocket type. With multi-impact capability, the PG-Guard can withstand between two and four firings per square metre. Time needed to design and install a prototype system on any vehicle is estimated at two months by Nexter, with mass production following at a rate of 50 kits per month.

To deal with the dreaded RPG threat BAE Systems developed the L-ROD bar armour system, an aluminium alloy solution that reduces weight by more than 50 per cent compared to steel-based systems. Over 50 live-fire tests were carried out by the US Army during validation. Bolted onto the vehicle, its panels are therefore easily replaceable in the field. L-ROD kits have been installed on numerous variants of primarily US military vehicles, and are standard issue on all US Army Buffalos. Currently over 1,100 L-RODs are installed on ground vehicles deployed in Afghanistan. Overall more than 3,000 L-ROD kits have been delivered. BAE Systems is currently working on further reducing the L-ROD weight.

Based in the Netherlands Falanx Armour Systems is a small company founded by Cyril Wentzel, aimed at the development of net-based protection against RPG7. The

*Nexter has developed its own RPG bar armour system known as PG Guard, here mounted on the company's VBCI (left), and Aravis (right). Its effectiveness is rated at 50 to 65 per cent depending on the type of RPG warhead countered. (Armada – P. Valpolini)*

*Seen at a defence exhibition, this set up shows an RPG attacking an opaque version of the Falanx Armour System. Falanx is awaiting a launch customer and is open to co-operation. (Falanx)*

Falanx concept consists of a very lightweight net as a basis for high dud-rate. The carefully designed and manufactured combination of high-performance fibres ensures that the RPG nose cone is crushed within a very short distance, disabling the warhead. The main armour then stops the rocket, which disintegrates. Available in transparent net form, the company advises its integration through an opaque flexible panel, a solution offering several benefits maintaining a low installed weight. The Falanx is considered to provide at least the same protection as a cage system at less than 10% of the weight, areal density being between 5 and 10 kg/m2 while width increase remains around the standard 250-300 mm. Baseline Falanx net design is frozen and available since 2009. Development work is in progress to offer a very high-performance net at an acceptable cost.

Truly high performance nets pose a manufacturing and cost challenge, and Falanx is solving that issue for a novel net type. The development is enhanced by advanced simulations and also involves an improved diagnostics methodology to objectively assess statistic performance. This approach will enable tailor-made solutions for customers with a particular RPG7 threat mix as part of their requirement. Starting from a performance indicator of over 50%, the company aims at getting as close as possible to 90%. Although a large-scale live firing evaluation of a specific Falanx product is still lacking, Falanx Armour states that its technology is based on hundreds of experimental results of variable complexity, ranging from simple live firings to elaborated laboratory ballistic experiments on actual RPG hardware. No products are operational yet as the company is looking for a launch customer or a partner. Falanx Armour Systems also offers its services as a consultant on net technology for industrial parties.

Leveraging experience in weight-sensible

*Montage shows the Falanx solution installed over a Mowag Eagle with both the net and opaque options used to provide full protection of the vehicle, while the graphical representation of the system over a Piranha depicts its effectiveness. (Falanx)*


*The Tarian RPG-net installed on an FNSS PARS 6x6; the net, used on British Army vehicles under a recent contract, is also produced as a gap-filler to quickly replace missing bar armour. (Armada/P. Valpolini)*

textile aviation restrain systems, AmSafe exploited textiles with high mechanical strength to develop an RPG protection system known as the Tarian (shield in Welsh). To this end the American-British company worked with the British MoD – the British Bridport facility being in charge of the product and production entrusted to a Phoenix facility in Arizona. Initially the material used allowed to cut down the weight of a protective system to 50% of that of an aluminium-based cage armour and to 15% of a steel one. The Amsafe homogeneous fabric can be printed with camouflage patterns. The latest version is a net-type system installed over a metallic frame; its mesh is sufficiently thin to capture the RPG and stop it at a distance from the actual hull, the latest breakthrough in material allowing the company to claim a saving of 94% and 98% respectively versus aluminium or steel cage armour. The latest development from AmSafe is Tarian QuickShield, which provides a quick-fixing solution to replace damaged or missing slat armour. The net element is similar to the Tarian's and is provided in 1000x440 mm or 1700x1000 mm sizes and is quickly installed on the remaining metal cage armour. Deployed in Afghanistan since May 2009 on British Army Heavy Equipment Transporters (HETs), the Tarian won a further £10 million contract in early 2013 for the supply of several hundred systems. In late 2011 the Darpa tested a further variant of the Tarian, with the protection integrated into a Textron Defense Traps (Tactical RPG Airbag Protection System). The original Traps developed for the JLTV programme, was based on a series of cots radar sensors that identified the incoming threat sending a signal that activated an airbag module in the area of impact with a reaction time of about 50 milliseconds. One module has a weight of about 15 kg and can be replaced within minutes. The inflated airbag creates the required stand-off to defocus the shaped charge jet. This system allows minimum width increase and avoids interference with

*A close up of the Tarian, the net anti-RPG system produced by AmSafe in Britain, exhibited at IDEX; the stand-off distance is of about 250 mm, which is typical of those systems. The actual net was made of a fake fabric to avoid industrial intelligence. (Armada/P. Valpolini)*

vision systems.

Another non-metallic solution comes from QinetiQ North America in co-operation with the Darpa and the Office of Naval Research. The Kevlar based Q-Net is a net with embedded metal nodes that, according to the company, ensure higher performances than standard bar armour while being 50 to 60% lighter. Supported by a frame that maintains it at stand-off distance from the hull, it ensures all-round protection (in can be roof mounted). It has been installed on over 11,000 vehicles, including the French VBCI and the Polish Rosomak deployed in Afghanistan. In early 2012 QinetiQ NA unveiled Q-Net II, which features a 15% higher effectiveness and a 10% lower weight according to company data, a further weight saving being made in the system used to attach the frame to the vehicle, which decreases between 35 and 50% compared to that used in Q-Net I.

Plasan Sasa of Israel developed the Ultra Flex Family (UFF) that includes three different solutions: one is an opaque non-metallic stand-off protection, the second is a non-metallic semi-transparent used in front of armoured glass windows aimed at providing crew situational awareness, and the third is a metallic solution for use in front of the driver's windows. The last, known as SlatFence, is currently provided in steel with an optimised cross-section that reduces its weight to a minimum. Plasan Sasa considers that a rigid solution has to be adopted in front of the driver, as non-rigid ones such as the LightFence would float in front of him making driving impossible. To further reduce the SlatFence weight and ease maintenance tasks, the company is currently developing a Hybrid version that will allow over 30% weight reduction. It should be available soon. The LightFence appears as a net with lozenge holes, the vertical ribbons zigzagging at each step, and is installed at the same 160 mm standoff distance as the FlexFence, the opaque technology of the family. Plasan Sasa aimed at reducing as much as possible the RPG effectiveness by avoiding to initiate the warhead both in its semi-transparent and opaque solutions: this means short-circuiting the piezoelectric ignition system upon impact, avoiding the explosion of the warhead or, in case of crash, causing only a secondary explosion that spoil the generation of the shaped charge jet.

According to Plasan Sasa ballistic performance results after over 250 live rounds firings with PG-7M, PG-7V and PG-7L rounds and extensive modelling and analysis using the GSS (Gesamt-Schutz-Simulation) software developed by Condat of Germany have shown a defeat rate of up to 80%, 90% of which being silent neutralisations (the remaining 10% being

*French Army VBCI operating in Afghanistan are equipped with QinetiQ North America Q-Net, a net system with embedded metal nodes. (Armada/P. Valpolini)*

*A Renault Trucks Defense VAB Mk3 exhibited at Eurosatory 2012 modelled the various elements of the Ultra Flex Family, an RPG protection system developed by Plasan Sasa. (Armada/P. Valpolini)*

violent neutralisation causing secondary explosions). The FlexFence has an inherent multi-hit capacity and each square metre can withstand the impact of up to six rockets. A damaged panel can be replaced in approximately five minutes. The FlexFence has evolved and the current version has a weight of 10 kg/m2, improvements having resulted in a slight weight decrease and in much greater durability. Design to cost was one of the imperatives during development, with savings not only generating from weight reduction, but also from secondary properties: Plasan Sasa is currently finalising the testing protocol to verify the benefits in terms of IR reduction signature, something that has been emphasised in late 2012 following the first feedbacks from a customer that uses the UFF in Afghanistan. This allows to obtain multiple benefits such as IR signature reduction and insulation-isolation system, thereby reducing air conditioning operating times and hence fuel consumption.

Protecting the upper surface of vehicles is becoming a common request due to RPGs being used from building tops. The opaque surface is available in a selection of camouflages, while it is fire resistant and provides ultraviolet protection. The FlexFence mat that constitutes the ballistic module is 50mm thick, and the standoff required is 160 mm, which leads to a 210mm addition per side to the vehicle. The system can be integrated on the platform in a number of different ways, using existing frames, attaching the module with Velcro

*The back of the VAB Mk3 shows the Light Fence's transparent elements that are being used in front of windows with the exception of the windscreen. (Plasan Sasa)*

and/or cables or using non-ballistic supportive panels and straps. The UFF was seen installed on a VAB 4x4 at the Renault Trucks Defense stand at Eurosatory 2012.

The Israeli company is not sleeping on its laurels in terms of RPG protection. According to company officials Plasan Sasa will soon unveil its next-generation of bar armour. No details are given, but the new system should solve many of the current problems, not the least being the vehicle becoming a soldier death trap following a roll-over.Company sources said that work is quite advanced and that results are encouraging.

Among the latest addition to the cage net armour world is the TenCate Armour stowable bar armour. Seen at IDEX 2013, the system was based on vertical steel cables with horizontal bars that can be easily fitted to any frame and rolled up when not needed. TenCate Armour is ready to develop the concept according to customers specifications, adopting ad hoc materials to meet specific weight and cost requirements.

Stronghold Defence in the US approached the RPG problem in a totally different way by developing the Phalanx Armour, which is based on the strategic integration of geometric and material properties. The system combines spherical geometries and composite materials, taking a novel view on the prevention of casualties from projectile threats. The specific combination of geometries and materials was developed to minimize weight while ensuring blast and radiation shielding.

In Italy Oto Melara worked on the RPG problem leveraging a national defence technology R&D programme. A surrogate RPG threat was used for simulations and testing, this being considered more efficient than the average RPG round. An energetic solution was adopted to contain mass issues. The material, contained within the sandwich armour, reacts with the melted dart when this tries to penetrate. Effectively "defocusing" it, the energetic material spreads the warhead energy over a wider area, dramatically defusing its aggressiveness. A mathematic model providing six degrees of freedom to simulate the possible orientations of the dart helped to define and developed the required metals and energetic materials. Numerous types of grenade and missiles warheads were taken into account, leading to a patented solution, which according to an Oto Melara R&D official is "very competitive" in terms of weight effectiveness.


# Passive Armour: The Final Barrier

**Armoured vehicles hull structures are still mostly made of steel, to which add-on armour packages are bolted. However, the more the basic structure can provide in terms of ballistic and blast protection, the higher the final level of protection will be. Moreover when adopting active defence systems that disrupt the incoming projectiles before impact, fragments still hit the vehicle with a high energy content, commanding a good basic protection.**

SSAB of Sweden is one of the world specialists, its family of armour steel being known as Armox. It includes six different types, the number indicating their average Brinell Hardness. While hardness goes in parallel with ballistic protection, toughness is needed to guarantee good blast absorption capacities – two features that won't naturally live together. Formability strengthens the disagreement, as high hardness steels tend to be less formable and often give rise to welding problems.

SSAB steel ballistic performances steadily increased in time: in 1990, 9mm of Armox 500T were needed to stop an M193/SS92 round travelling at 937 m/s, but ten years later, using Armox 600T, only 6mm were needed. Add another ten years, and 4.5mm of Armox Advance did the same although it has to be unnumbered as its hardness is beyond the Brinell system scale!


*Iveco's MPV exploits the latest IBD Deisenroth armour developments, mostly based on nanotechnologies. (IBD)*

From an initial 70.7 kg/m2 SSAB cut down the weight to 47.1 kg/m2 in ten years, with a further reduction to 35.3 kg/m2 in the following decade. According to SSAB experts no further dramatic reduction is to be expected in the coming years though, a credible goal for 2020 being 30 kg/m2. The company's R&D department is working more on improving toughness and formability of existing materiel rather than pushing on hardness, especially that blast is now the main threat. Its Armox 440T, 420-480 HBW, is the "energy eater" of choice, and besides its toughness it can be easily formed to obtain, for example, a single-piece hull bottom. Even the harder Armox 500T, 480-540 HBW, is considered for blast protection applications.

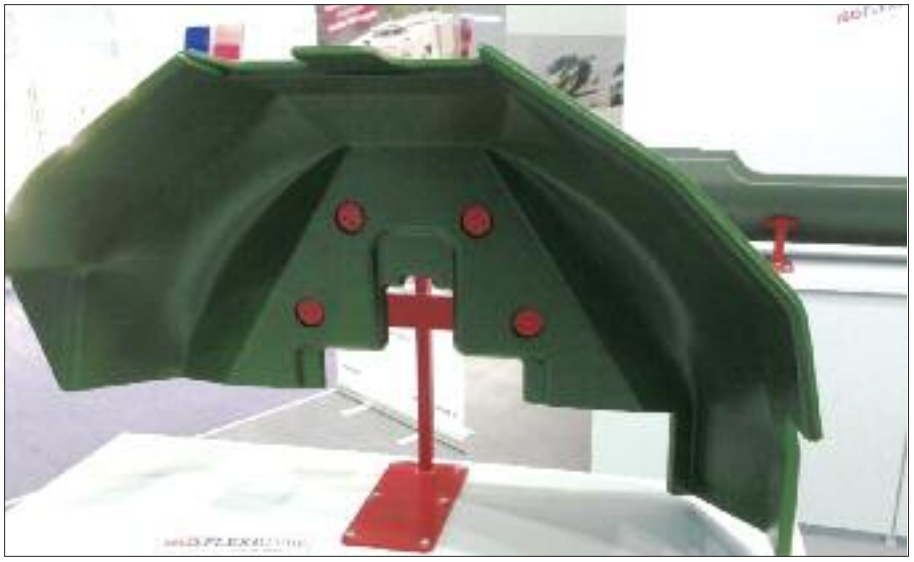
As hinted above, the Armox Advanced's main characteristic is hardness, and this material is almost considered by SSAB as ceramic. The company thus strongly advises not to form it or weld it, as it must not be heated above 100°C if its hardness is to be preserved. How much similar levels of protection and weight might be obtained in the future with more formable materials is the current challenge.

Among new armour steels is of course the Super Bainite introduced in the fall of 2011. Developed by Defence Science and Technology Laboratory in Britain, the new material is produced by Tata Steel UK at Port Talbot and has shown much better performances than standard armour steel. These characteristics do not only result from

*Aardvark Perroc makes large use of SSAB Armox 500 steel, which shows that even that a hard product is able to absorb good quantities of energy. (Armada – P. Valpolini)*

*A complex shape element made with SSAB Armox 440T steel, often dubbed the "energy eater" and thus particularly suite for countering IEDs. (Armada – P. Valpolini)*

*SSAB is currently working on ways of making its armour steel solutions more formable. Here is an example of Armox 500 formability. (Armada – P. Valpolini)*



*The use of IBD FlexiComp allows to produce 3D armour elements reducing weak points in the overall protection system (IBD)*

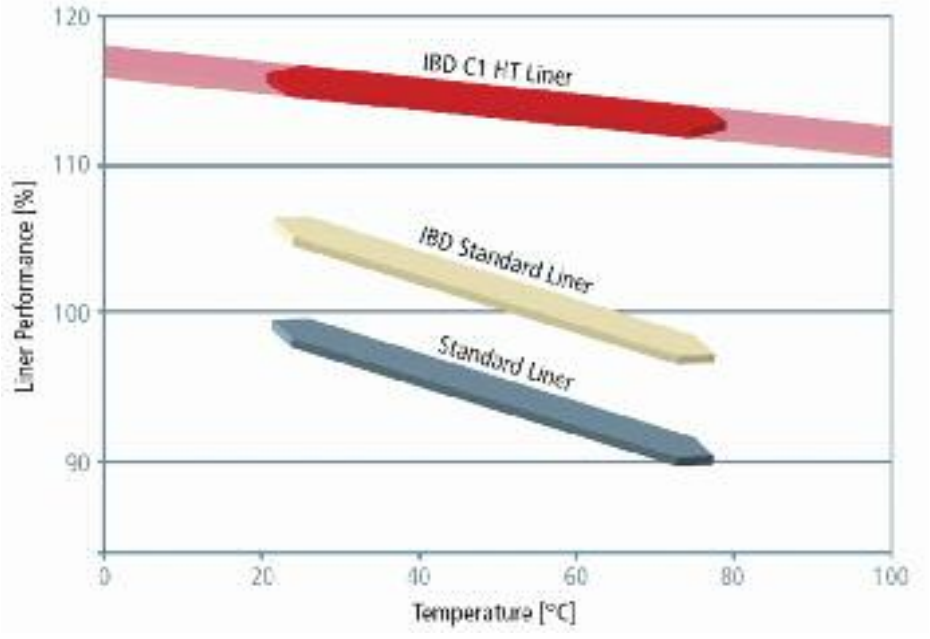
chemical composition but also from processing, particularly its thermal treatment with air and molten salt as part of the coolants, with the end product offering ballistic performances that are twice those of RHA.

In December 2012 Lockheed Martin UK and the University of Surrey announced a new lighter-weight method of improving the protection and survivability of armoured vehicles. Scientists developed a method of treating ceramic materials to improve the bond strength of both alumina and silicon carbide ceramics to the composite backing, greatly enhancing armour robustness. Connecting ceramic plates to their backing has always been the Achilles' heel of that technology. Results have shown that the new technique leads to increased bond strength. Tests revealed that when a 14.5mm armour piercing incendiary was fired at the panel it remained intact.

Technology development remains the core business of IBD Deisenroth Engineering while the production of passive solutions is now the responsibility of Rheinmetall Chempro, owned to the tune of 51% by Rheinmetall Defence and 49% by the Deisenroth family.

With the aim of reducing weight while maintaining protection level, or conversely increasing protection for a given weight, the fourth generation of armour technologies developed by Dr. Ulf Deisenroth applied to different types of materials promise savings of over 40%. These are based on the most recent breakthroughs in the domain of passive protection related to nano-materials, which include nano-cristalline ceramics, nanometric steel and high strength fibres. In co-operation with steel manufacturers, IBD managed to develop high-strength nanometric Nitrogen steels yielding almost the performance of standard ceramic materials. Those new types of steel can be employed for structural elements, allowing for even greater weight savings if their use is part of early design stages. As for high-strength fibres, such as IBD C1 HT Liner, those not only provide performances nearly 20% higher than standard liners and 10% higher than IBD liners, but their performance degradation with temperature is also slower, an important feature considering the extreme temperatures of current theatres. Besides nanometric steels and nano-ceramics, adopted in recently developed vehicles, IBD also developed new composite solutions that allow to manufacture complex curved geometry elements permitting to achieve a high coverage of the protected area with almost no ballistic gaps. This solution applies particularly to under-belly elements where the slightest gap can thwart the whole protection.

IBD also succeeded in developing nano-composite laminates with such a dramatically improved strength that they can replace structural parts of a vehicle and simultaneously serve as high level ballistic protection. Thanks to their low areal density the overall weight of the protection is thus significantly reduced. Those composite materials are based on the aforementioned IBD Nanotech-materials. Special gluing processes were developed to produce nano-composite structural laminates, known as IBD FlexiComp, with significantly improved structural strength and ballistic performance. While having a 10% lower density than standard laminates their elastic properties are twice as high. This gives them




*A diagram showing the behaviour of IBD liners over temperature, a key issue when vehicles are deployed in hot areas. (IBD)*

the necessary strength to be integrated into the vehicle structure, while their ballistic performances allow to deal with high threat requirements, with potential for weight savings. Their application can follow two different approaches. The straightforward approach is to use them as add-on armour for mine and IED protection in wheel houses, on fenders, as mine plates and decoupled inner floors. When formed as 3D-parts they can replace other solutions that need to be assembled by welding or bolting. A new type of application is the integration of the composite parts as roof hatches, engine hatches and rear doors and ramps. These add up to a large portion of the total vehicle surface, therefore the absolute weight reduction is significant. For STANAG 4569 Level 4 this saving reaches 1500 kg on an 8x8 vehicle as shown in the table. As for production cost, the processes developed by IBD allow manufacturing composite parts without using autoclaves, ensuring considerable cost savings especially for large dimensions components, costs being comparable to those of elements manufactured with standard technologies.

Those elements are now being produced by Rheinmetall Chempro, whose role is to take IBD Deisenroth Engineering technologies, develop them into the production process to obtain competitive prices, and then develop customers' tailored solutions, following the process down to vehicle qualification. Delivery of elements produced with the latest advanced technologies will start in early 2013, to the benefit of vehicles like the KMW-Rheinmetall AMPV and the Iveco DV-KMW Medium Protected Vehicle. According to Rheinmetall's Business Unit Protection Systems over 10 OEMs (Original Equipment Manufacturers) around the world will soon get components that will allow them to truly decrease the curb weight of their vehicles, thus increasing payload capacity and decreasing life cycle costs.

Rheinmetall Chempro passive protection catalogue includes numerous versions of the Amap (Advanced Modular Armour Protection) family that exploit the latest technologies developed by IBD. Amap products are normally combined to obtain the desired protection against various threats. Among the various opaque products we find the Amap-B ballistic solution providing protection from small arms to medium calibre rounds, the Amap-M blast protection against mines, Amap-IED developed when improvised devices became a major threat, Amap-L liners that protect the fighting compartment absorbing secondary fragments, the blast wave, the fireball and reduce acoustic pressure, Amap-SC against shaped charge rounds, and Amap-X protecting against threats typical to the urban environment.

It is to note that within the Rheinmetall Group another company deals with passive protections, Rheinmetall Ballistic Protection GmbH, that acquired that name on 1 January 2013 being formerly known as Rheinmetall Verseidag Ballistic Protection GmbH. Based


*A new bonding technology developed by Lockheed Martin UK and the University of Surrey may considerably improve the protection level of armoured vehicles, like this Warrior. (Lockheed Martin UK)*

*Ruag further developed its SidePro KE/IED, here seen in a photo montage, to counter those new devices that generate multiple fragments. (Ruag)*

in Krefeld and now fully owned by Rheinmetall, the company specialises in the development and production of armoured solutions for light military vehicles using materials like ceramics, advanced metals and special fabrics.

Although Ruag Defence still has reactive armour solutions in its portfolio, they no longer very trendy in customers' eyes to improve the survivability of medium and heavy vehicles. The Swiss company has thus turned its attention to improving fully passive solutions to cope with both kinetic and hollow charges. The SidePro-ATR fits well beyond the spectre of RPG-7 aggressiveness, as it can cope with shaped charges used in a symmetrical threat scenario, while the base version ensures a Level 5 ballistic capacity. First shown in public trials in 2012 the SidePro-ATR is scalable, and can thus be adapted to personnel carriers and tanks alike. In its basic version it is 400mm-thick while its weight is comparable to that of a reactive solution (i.e. around 300 kg/m2), and was qualified on a Leopard 2A4. Ballistic level can be considerably increased to deny 120 mm Long Rods any success, although no data were provided.

The SidePro-ATR scalability allows it to fit both symmetric or asymmetric warfare needs. Another solution against kinetic energy and IED weapons, the SidePro-KE/IED has been used on the Fennek armoured reconnaissance vehicle in service with Germany and the Netherlands. Mostly ceramic based, it was conceived to counter first-generation IEDs. The new roadside bombs used in theatre generate thousands of very high-speed fragments, thus a very high multi-hit capacity was needed. Ruag has since redeveloped the KE/IED doing away with ceramics and calling in a sandwich package of undisclosed nature. Made available in 2012 the new SidePro-KE/IED provides Level 4/Level 5 protection against KE weapons and an extremely high multi-hit denial. Assuming a 7mm ballistic steel chassis, a 30 mm thick panel would be used to provide the required protection, the KE/IED retaining the lowest weight option depending on the vehicle. The solution is under consideration by several manufacturers.

Plasan Sasa remains one of the major players in the field of passive armour. No technological details are provided in this field, the company being active both in add-on armour solutions as well as in kitted hulls. The latter approach has been adopted in the development of both the Navistar MaxxPro Mraps and the Oshkosh M-ATV. "This allowed us to ramp-up production using manpower that was not skilled in welding procedures, as we adopted a Lego-approach based on boxes containing all components that could be assembled in minimum time," a company source told the author. Part of the company's 200+ engineers are working on new solutions that might come either from new materials or innovative geometrical design, the systemic approach remaining at the core of the protection cycle.

IMI has recently developed a series of solutions in both the passive and reactive disciplines to cope with the most recent types of so-called improvised explosive devices involving EFPs or SFFs (Self Formed Fragmentation) and the most recent RPG models. The Iron Wall is the passive solution proposed and is based on a compound of metal and composites complemented by slat armour. Depending on the required protection level, thickness can vary between 110 and 150 mm and weight between 200 and 230 kg/m2. The Iron Wall is currently under operational evaluation by the Israeli Defense Forces.

IMI also proposes its slat armour solution as a stand-alone system. The L-VAS, for Light Vehicle Armour System is aimed at protecting armoured personnel carriers. To save on weight the system is based on composites and reactive elements, the latter containing a minimum of energetic materials. This limits collateral damage, and the type of material used avoids the risk of sympathetic detonation of neighbouring elements. According to IMI the L-VAS also protects against 14.5 mm AP rounds and artillery fragments. The system has been fully qualified in Israel for the M113 APC and weighs about 200 kg/m2.

The heavier system proposed is Breakwater, a reactive armour that includes metal and composite elements aimed at defeating the three major threats, RPGs, SFFs and EFPs. IMI carried out a thorough testing campaign and is now proceeding with qualification to see the 350 to 400 mm and 430-450 kg/m2 solution being available for production in late 2013.

Ceradyne is another major player in the passive armour field. According to Marc A. King, Ceradyne President, steel will remain

## EXAMPLE OF WEIGHT REDUCTION FOR AN 8X8 VEHICLE WITH IBD FLEXICOMP COMPONENTS

Weight in Kg

| | Standard Solution | Composite Solution | Weight Reduction | Reduction |
|---|---|---|---|---|
| Crew Hatches | 640 | 280 | 360 | 56.25% |
| Engine Hatches | 468 | 222 | 246 | 52.56% |
| Ramp Door | 542 | 284 | 258 | 47.60% |
| Ramp (complete) | 1400 | 675 | 725 | 51.79% |
| Total | 3,050 | 1,461 | 1,589 | 52.10% |

*An M113 armoured personnel carrier equipped with Israel Military Industries Iron Wall passive anti-RPG system – a mix of passive and bar armour. (IMI)*


*Ceradyne and Cellular Materials International developed an underbelly protection system based on CMI MicroTruss, an aluminium cellular material that allows to absorb about one third of the energy generated by the explosion. (Armada/P. Valpolini)*

a major player in the armour business, the aim being to improve performances and reduce costs. "In the US the driver is still mostly the vehicle acquisition cost rather than the life cycle cost, and this goes against improvements," King told the author at AUSA 2012. The reduced number of vehicles acquired by European armies led to greater investments in protection, while in the US the emphasis was on numbers, which according to King led European armour specialists to be ahead of the American ones. However, King underlined how America is making progresses, mostly focusing on blast underbelly solutions, as ballistic protection is considered a problem solved. The renewed interest by the US Army to address the problem of bottom protection for vehicles such as the Humvee ($20 million for development alone) is considered positively by King, Ceradyne being one of the companies that will certainly compete for the Recap contract. The requirement calls for maximum protection at much lower weights than now to reduce impact on vehicle performance.

Ceradyne developed a solution based on Cellular Materials International Inc's (CMI) MicroTruss, an aluminium-based periodic cellular material which has a density of 58 kg/m2 compared to the 112 kg/m2 of an equivalent monolithic metal solution. The solution features a "V" angle of only 5°, sufficient to deflect the blast while limiting ground clearance reduction, and has a weight of 300 kg. MicroTruss ensures an absorption of up to 30% of the blast energy, which not only limits the impulse in the crew cell, but also mitigates the vertical lift of the vehicle. Ceradyne is also fully involved in the Flyer Gen.2 armour solution aimed at the Socom's GMV 1.1 programme. To maintain the V-22, CH-47D and CH-53E internal transportability weight and width had to be kept under control, the company having developed a kit providing B6 ballistic level (.357 Magnum) on doors and roofline.

Ceradyne is also involved in the Marines Personnel Carrier programme in co-operation with Lockheed Martin and Patria for the proposal based on the Patria AMV. It is to note that on 28 November 2012,

*Polaris Defense and M9 Defense Armor Technology have developed a hybrid steel-composite integral structural armour that allows to considerably reduce the Humvee's curb weight for a similar protection level. The prototype seen here has a curb weight of only 3,400 kg, which is nearly 50% lighter than Level 3 Humvee. (Polaris Defense)*

*Protection also means not to remain stuck on the battlefield due to a tyre puncture. Polaris Defense Non Pneumatic Tires ensure much greater durability than standard tyres and can withstand a 12.7 mm shot. Currently available for vehicles up to Hummer class, those tyres are being developed for the much heavier Mraps. (Polaris Defense)*

Ceradyne was acquired by the 3M Group, which gives the Costa Mesa-based company a greater strength to carry on R&D and to find innovative solutions.

Integrating structure and armour is a viable solution for light vehicles. At AUSA 2012 Polaris Defence unveiled a Humvee-based prototype that featured a new concept developed by the company together with M9 Defense. The aim is to reduce curb weight while maintaining or enhancing protection levels. To do so the Polaris-M9 team swept appliqué armour aside to look into a structural armour concept. The vehicle was thus stripped to its bare rolling chassis, then dressed up with a lightweight hybrid steel-composite structure. This structural armour can provide a Level 3 protection at around 70 kg/m2 while at 83 km/m2 it is able to withstand 12.7x99 mm ball ammunition, though Polaris-M9 are confident to reach Level 3+ (12.7 mm AP). The abovementioned weight includes the vehicle structure, the Polaris-M9 solution allowing also to protect the engine. While the standard up-armoured Hummer tips the scales at about 6,350 kg, the proposed solution does it at 3,400 kg. The hybrid structural armour uses available non-exotic material, thus according to Polaris-M9 the cost is comparable to current solutions. Moreover the material can be moulded in complex shapes, which allows to obtain, inter alia, seamless underbody V shapes. Shaping is obtained by hydroforming, a high-speed process contributing to cost reduction. According to the Polaris-M9 such technology allows to shrink weight by 40 per cent.

Another mobility aspect is part of the protection equation: following the acquisition of Resilient Technologies, Polaris Defence is now offering non-pneumatic tyres (NPTs). Tyre consumption and reliability is one of the major logistic problems in theatre and NPTs can solve it in many cases. According to Socom data in Afghanistan, a conventional tyre lasts about 1,300 km while NPTs can cover six times that distance. Also, Polaris has demonstrated that an NPT hit by a 12.7 mm round can run over 8,000 km and thereby wave farewell to spare tyres, while apparently improving ride. Prototype NPTs for Hummers have been produced, the current target being a set of NPTs for a 7.7-tonne vehicle, which is nearly the objective gross weight of the JLTV General Purpose variant. According to company representatives, modelling shows that weight capacity could reach 18 tonnes, in other words, bearing the weight of an Mrap. While increasing the payload the technology remains the same, and the modelling software developed by the company allows very accurate forecast. What changes is the material, which has to be adapted to the weight to be borne.

## INDEX TO ADVERTISERS




**ON THE COVER:** The best way of curing a cold is not to get one. This motto could apply to armoured vehicles and to the active protection systems being devised to keep lethal bugs like RPGs at bay. Many methods are described in this compendium, one of them being the Leds system seen on our cover and devised by Saab.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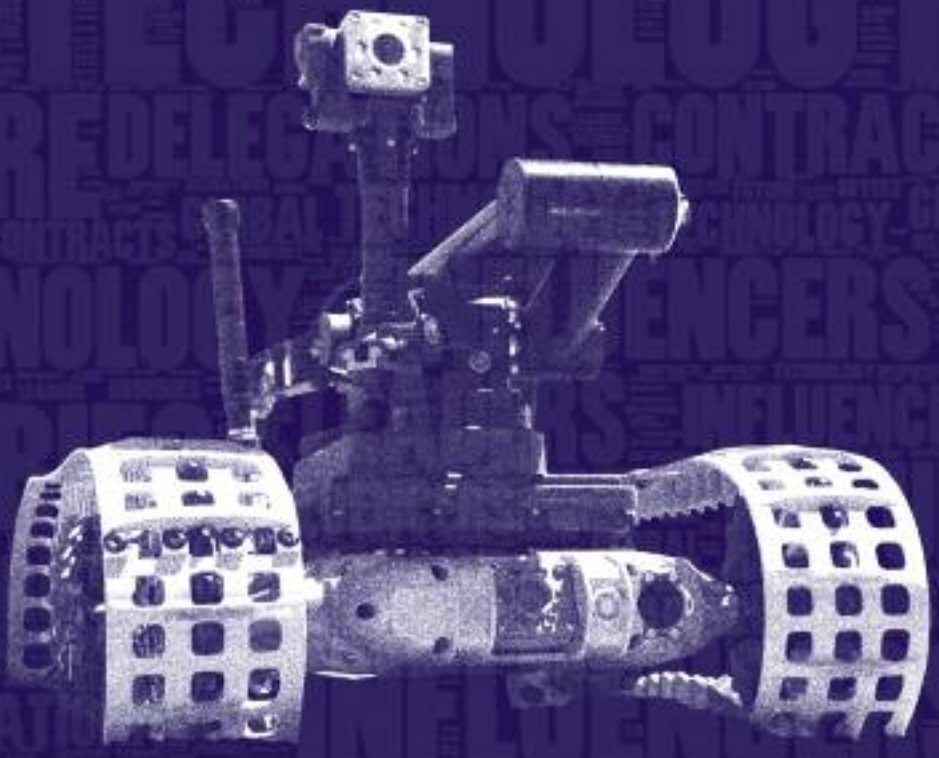

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