Protection of Soldiers — Concepts and their Test Methods

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When looking at the events of day-to-day politics the observer is being made keenly aware of the threat potential the servicewomen and servicemen are exposed to in their missions abroad. That these missions are anything but routine is shown by the mere fact that reports of attacks against national and international armed forces can be found daily in the media. The requirement to ensure an effective protection from dangers by appropriate safety precautions is therefore embodied in, inter alia, diverse basic documents (Federal Ministry of Defence, Sub-Concept "Protection of Forces and Facilities in Operations", 2006; Sub-Concept "Conduct of Bundeswehr Operations", 2005).

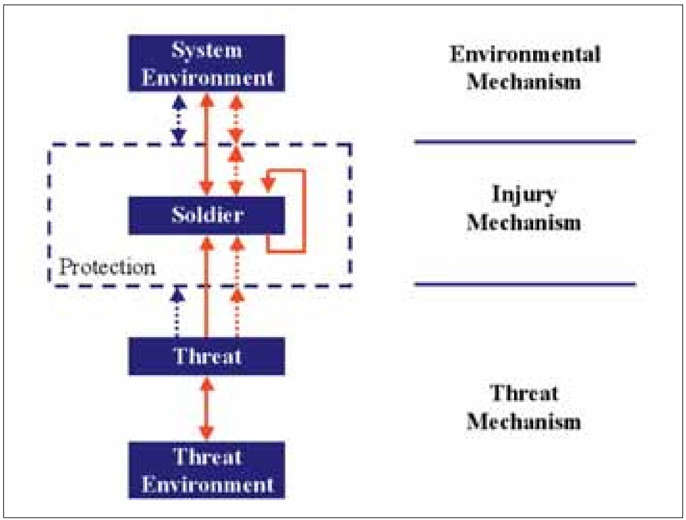
In interpreting the protection, particular attention was focused on the threat spectrum. The past has shown that a large number of the attacks was carried out by means of partly most primitive, homemade explosives or, comparably, with technologically more sophisticated means. These explosives are subsumed under the technical term "Improvised Explosive Devices (IED) and, in consequence, they reflect a continuing, rapidly changing threat spectrum. Special feature of the protection concept should therefore be a proportionate balance between competitive requirements. For instance, against the background of extreme climatic conditions, ergonomic aspects play a considerable role for the soldier's mission accomplishment.

In addition, it is essential to find out which strains on the passenger can be tolerated at all. Do all human beings act and behave the same way under the effect of external loads or is it necessary to apply individual criteria as a standard? Is it possible at all to ensure one-hundred-percent protection?

Threat and Mechanisms of Action

In assessing the protective effectiveness and the criteria to be applied it is necessary to make an advance analysis of the chain of action. For the purpose of explanation we take an exemplary look at the soldier of a protected vehicle who is exposed to threat. Assumed as a scenario is an explosive, which is detonated outside of the protected vehicle. During the detonation, the expansion of the partly toxic reaction products leads to a locally enhanced pressure as well as to an acceleration of fragments. Both fragments and pressure wave have a direct effect on the external vehicle structure. The effect is decisively influenced by the interaction of the explosive with the direct threat environment. To be mentioned in this context are e.g. the laying depth in the ground or a tamping of the demolition charge. Following the chain of action it is possible that the threat can now affect the passen-

The Threat by IEDs (Improvised Explosive Devices) Exists in every Mission. Picture: ES-Archive



Load Transfer Model. Grafic: WTD 91

ger directly — a burst vehicle shell lets the pressure wave or fragments partially through without hindrance — or even indirectly.

An indirect impairment is given, if parts of the interior (for instance mission equipment such as radio communication sets) come off e.g. due to shock discharge (primary acceleration-based effects) or if portions of the armour plating spall on the inside of the vehicle which again can harm the passenger as so-called secondary fragments. Moreover, the vehicle body will be indented due to the pressure wave (secondary acceleration-based effects) so that the passenger can, resulting from that, get in contact with the interior of the vehicle.

Aside from the local impairment of the vehicle structure the vehicle will also experience a global dislocation. This means that the vehicle can be accelerated to the side or upwards. Consequently, the passenger must more or less follow this forced movement. In order to rule out a contact with the interior or the mountings, the passenger should be properly fixed by appropriate restraining systems (belts and seat systems) so that he can follow this global movement of the vehicle.

In principle, the human body cannot be regarded as an individual rigid body, however. Rather, the human tissue stands out for a complex biomechanical behaviour. In addition, the human being has a large number of joints. This means that by this inherent "flexibility" and due to mass effects of inertia the passenger is set in a relative motion, which can also vary from body part to body part. Even if the passenger is well fixed and if there is no direct contact with the interior beforehand, serious injuries by blunt or pointed impact can be the result in this tertiary acceleration phase. This example of an oriented representation of the chain of action may have made the reader more sensitive to the fact that the vehicle crew can be exposed to diverse impacts resulting from:

- Excessive pressure (pressure wave of a detonation)
- Accelerations (shock, indent of the vehicle structure, inertia effects of the passenger)
- Fragments (primary and secondary fragments)
- Heat
- Toxic gases and substances.

Soldiers who fell victims to an attack with explosives will have come to terms with the psychical effects in addition to the physical ones. These rather hardly qualifiable traumatic injuries, which are heavily conditional on the psychical shape of the individual, can lead to acute and long-term impairments. In extreme cases this can result in immediate, complete combat ineffectiveness. The following will exclusively deal with the aspect of the physical condition, however.

The aforementioned explanations have deliberately put the human being in the center of interest. It is just not enough to focus the attention on the resistance of the hardware only, because as far as technical systems are concerned their effectiveness depends ultimately on the readiness of the operator after the event. Therefore it is essential that protection systems be assessed from especially that point of view.

How can Protection be Generated?

The question that immediately arises is: what measures can be taken to ensure that the strain and load of the passenger stays in the tolerable range. It is certainly extremely effective, not to get hit at all. Particularly in MOUT (Military Operations in Urban Terrain) scenarios the distance between lateral threat (e.g. by IEDs) and vehicle may only be a few meters in terrorist acts. Besides, friendly forces in such scenarios are often forced to pass through bottlenecks, which significantly increase the vulnerability of the vehicles.

Now, there are two starting points to effectively minimize the load on the passengers. The first one aims at minimizing the effect at the interface between environment and vehicle. This immediately requires that the vehicle protection, i.e. the vehicle structure/body including the armour plating, must remain intact so that fragments or shells cannot penetrate, and spalling effects cannot occur on the inside, and/or installations cannot fly off. Moreover, temporal distortions in the discharge of pressure shouldn't be too high.

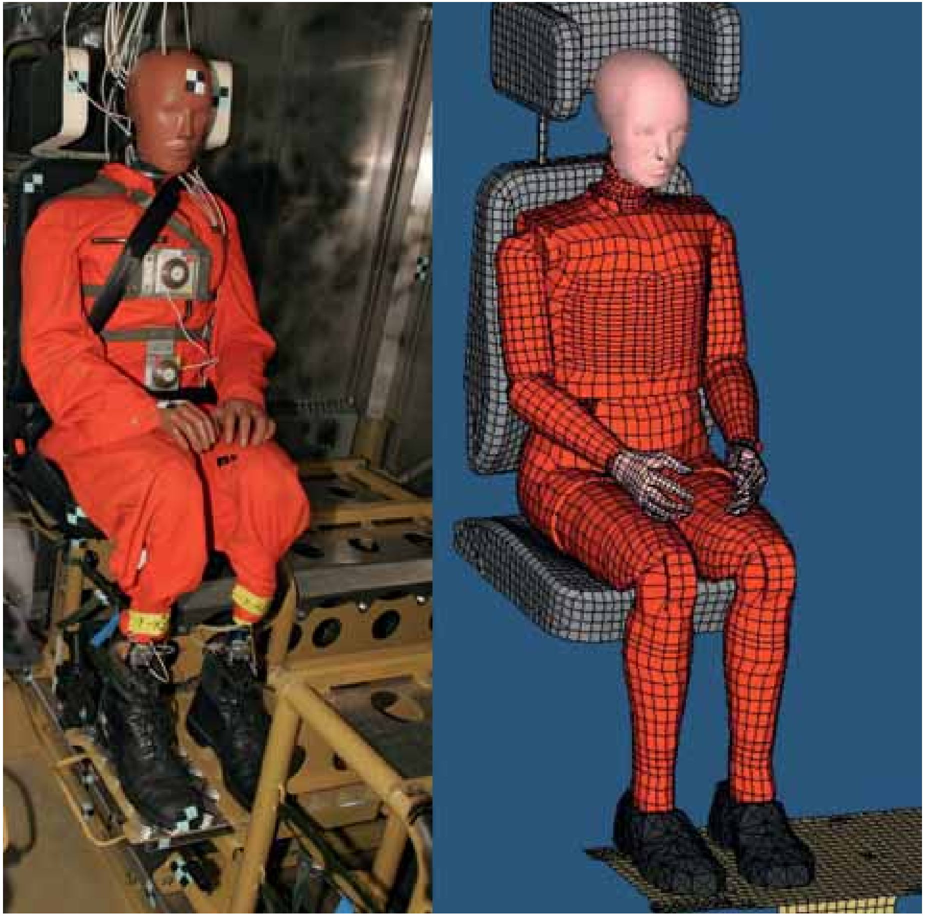
At this point it should already be pointed out, however, that there couldn't be a hundred percent protection. It is rather necessary to develop a protection concept based on the result of a threat analysis which must additionally meet many and diverse parametric conditions. The following are to be mentioned here:

- Maximum permissible gross vehicle weight to ensure strategic deployability
- Maximum exterior and minimum interior permissible allowances to meet the requirements for the railroad loading gage and to get sufficient space for the vehicle crew and the load
- Vehicle silhouette in respect to a low signature.

In the light of the constantly changing threat situation and the types of employment of the vehicles it is mandatory, of course, that this concept has still a certain improvement potential to avoid having to make a technically expensive and completely new construction.

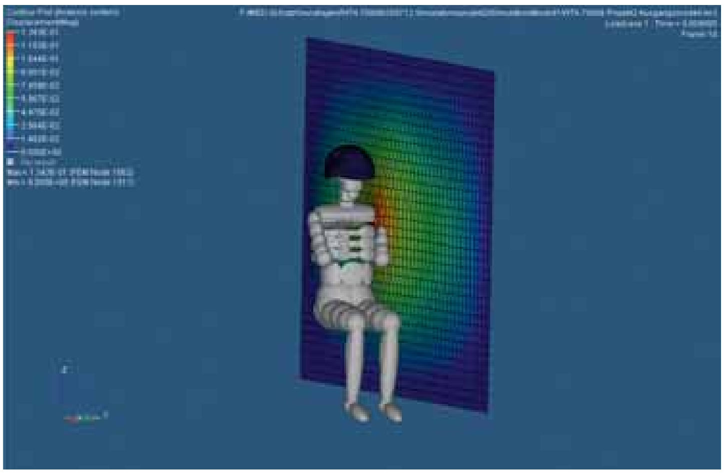
The second approach concerns the maximal decoupling of the passenger from the vehicle structure. Seat systems that are fixed at the roof of a vehicle — where accelerations are often many times lower in comparison with the floor area — are not always realizable. In such cases one has to fall back on solutions, which provide for a connection on the vehicle floor or at the sidewalls. The connecting points should be possible to be decoupled by a combined spring and absorption system or crash elements to effectively reduce the strain/load on the passengers. As it is customary in civilian road traffic, belts are an essential element of this protection concept.

It should be heeded, however, that the correlated protection system is effective only to the extent in which it is correctly used. Classical crash tests in the automobile sector clearly show what can happen, if the passenger is not buckled up. In these scenarios even the airbags can no longer guarantee sufficient protection. Here, the protection concept is configured for a closely correlated interaction of belt and airbag.



Test Configuration in a Real Vehicle Demolition (Contact Explosion) and the Projection as Computer Model. Grafic: WTD 91

Another important element of the protection concept is the individual protection. Among other things it comprises ballistic protective vests, protective helmets and visors. Their relevance gets the higher the more the vehicle-specific protection is left. Within the scope of the MOUT scenarios, vehicle patrols during which crewmembers operate the mounted weapon through a hatch are not an exceptional phenomenon. Eventually the chest, the arms, and the head are directly exposed to possible attacks. During patrol or combat missions conducted with dismounted squads this naturally applies all the more.



Computer Model of a Passenger with Helmet Shown in Lateral Contact Explosion of the Vehicle (Detail: Passenger and Indenting Lateral Wall). Grafic: WTD 91

How are the Tests Run?

In the project-planning phase during which a completely developed vehicle including the protection system is normally not yet available, the protection experiments are basically organized into two phases and geared to the "threat-protection-passenger" action chain. Tests accompanying the development are frequently conducted — also for financial reasons — on (sub) demonstrators. However, for the final protection qualification of a vehicle integrated tests in mine and IED protection will always be made on the overall system in order to allow the entire action chain to be presented as real as possible. Vehicle protection tests deal mainly with the question as to how the integrity of the vehicle body can be maintained covering the field of the impulse injection from the threat onto the protection and the vehicle structure.

According to the NATO Standardization Agreement (STANAG) 4569, defined test methods and procedures have to be complied with and standards for the ballistic protection, shielding against mines and protection from fragments have to be met. Protection classes for IED protection, which also take the Explosively Formed Projectiles (EFP) into account, are presently in preparation.

The passenger protection represents the area of impulse transmission from protection and vehicle structure, respectively, up to the human being. Primary focus is directed to identifying what ultimately arrives with the human being as physical strain and how this eventually reacts in biomechanical ways. It is obvious that in this type of test recourse has to be taken to suitable surrogates, which are highly similar in their behaviour to that of man (biofidelity). Anthropomorphic Test Devices (ATD) have proven to be very effective testing instruments or colloquially "crash test dummies". These ATDs which originally stem from the automobile sector have been adapted to specific passenger protection aspects according to stipulations of the Bundeswehr Technical Center for Weapons and Ammunition and are equipped with a large number of measuring feelers/sensing elements which can detect the force, acceleration, and impulse at diverse parts of the body. In a mine explosion during which the vertical forces are dominant in comparison with the lateral portion, special attention is given to the legs and the spine. The test method and the underlying criteria in mine protection tests are specified in NATO Document TR-RTO HFM 90. Here, the Bundeswehr Technical Center for Weapons and Ammunition was already able to successfully bring in its many years of experience. The requirements for the field of IED protection are in preparation.

Aside from the real demolition tests, the numerical simulation has established itself as an efficient method for protection tests. The advantage is obvious: demolition patterns are expensive and cannot be provided in larger numbers. Moreover, demolition tests require high expenditures in terms of personnel and material resources. It is therefore desirable to limit them as far as possible, but to be able to make sound statements about the protection effectiveness on the other hand.

Computer simulation is a remedy here. The total scenario consisting of environment and threat such as a mine buried in the ground as well as the vehicle including the protection and passengers can be simulated by use of special software. The computer calculates the lapse of the mine detonation, the reaction of the vehicle, and the strain/load put on the dummy. If the ascertained passenger loads/strains do not meet the criteria, it is possible to determine the optimal solution by calculation. The result could, for example, come in the form that either the seat must be given a softer cushioning or that the seat position has to be adjusted. Therefore, the optimisation of the best protection for the service personnel should nowadays not be made without computer assistance.

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One of the frequently asked questions concerns the individual protection. Does it, for instance, make sense to wear ballistic protective vests or protective helmets in a protected vehicle according to the motto "much helps much"? If operational requirements such as combat readiness do not necessitate this and the vehicle protection maintains its integrity, this question must be clearly answered with a "no". By means of computer simulation it is possible to graphically show the negative effect of additional masses — helmet approximately 1.5 kg and protective vest up to 15 kg. If the passenger sits in a protected vehicle, helmets and vests induce significant supplementary forces in primarily the vertebral region.

Can Man be Expressed in Code Numbers?

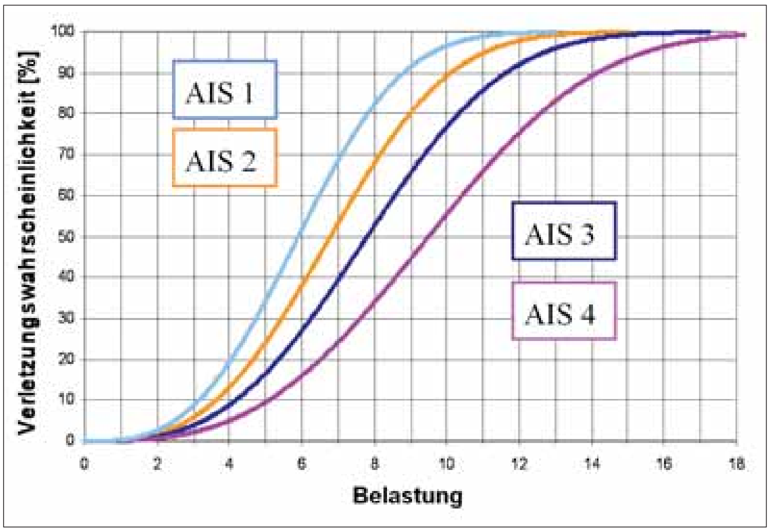
So far it was referred to biomechanical limiting values without being more specific as to what these represent in detail. In contrast to material characteristics of mechanical engineering — steel can be described relatively simple in its material behaviour — the theme becomes all the more complex as soon as the human being is the subject of the tests. Here one has to consider that the individual constitution (among other things, the size, physique, weight, sex, age, fitness) has decisive influence on the load/strain limits. And the structure is many times more complex, too. A steel beam, for example, can be modelled in its geometry and its structure — keyword homogeneity — with manageable expenditure. In the human body, however, bones, tissue, joints, and organs with different material characteristics are arranged in a complex combine.

This variation width with humans can be comprehended only with the aid of statistical procedures. Analogous to the diversity of the individual physical condition the load limits are subject to a large spreading range as well, with the load limits referring always to a defined injury level. In the Abbreviated Injury Scale (AIS) for example there are six injury levels defined: minor (AIS 1), moderate (AIS 2), serious (AIS 3), severe (AIS 4), critical (AIS 5), and maximal (AIS 6) (currently untreatable). The biomechanical limiting values, which are taken as a basis in protection tests, represent the injury level AIS 2+. Life-threatening injuries or damages must be excluded; however, in respect to extremities, for example, a low probability for a simple fracture — in contrast to an open fracture — can be accepted. According to the current state of technology a tightening-up of the limits would generally require protection solutions that would evade the operational and technical parameters.

Generating Maximum Protection

The current missions and operations show that the soldiers need effectively protected vehicles in order not to suffer serious injuries in terrorist attacks. For a protection qualification it is insufficient, however, to test the vehicle only. In order to get reliable statements it is rather necessary to represent the passenger in a suitable form in the tests and to be thus able to comprehend his biomechanical load.

The real, resource-intensive tests are meanwhile assisted be efficient computer-aided simulation procedures. The consistent pursuance of both approaches allows generating the best possible protection for the soldiers in operations. ■



Correlation Between Networking Probability and Loads for Different AIS Levels.
Grafic: WTD 91

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