## Chapter 5.

# The protection of vehicles and plant equipment against mines and UXO

### Summary

*Three principles can be incorporated into the design of vehicles and equipment to render protection against the blast effect of mines: absorption of energy, deflection of blast effect away from the hull and the distance from detonation point.*

*A simple and cost-effective manner to absorb energy is to fill the tyres of wheeled vehicles with water. This increases considerably the protection of light and medium vehicles against the threat of blast anti-tank mine detonating underneath a wheel.*

*The effect of blast against the hull of a vehicle can be reduced considerably by incorporating steel plates at an angle to the direction of blast. Reflected pressures are generated when the blast direction is at a 90° angle to the plate. This approach has lead to the introduction of V-hulls, which have been successfully used in the protection of light- and medium-sized vehicles against mines.*

*The protection level of all vehicles can be further increased by use of four-point safety belts, good seating design and footrests (not attached to the floor), and "good housekeeping" (not having loose items in the car).*

## Introduction

This chapter discusses the threat posed by landmines and UXO to vehicles and plant equipment operating in the field and offers guidance on appropriate ways to minimise the damage to vehicles and injuries to their occupants in the event of an explosion.

The design, construction and testing of mine-protected vehicles and systems are conducted within a framework of military standards and specifications. Most of the design and testing detail is considered confidential information. Some military standards and specifications have, however, been de-classified for use by commercial and humanitarian deminers; where this has occurred, they have been included.

Similarly, construction methods are regarded as intellectual property by the various companies and entities involved within the industry. It has therefore not been possible to include exact detailed mechanical design and manufacturing criteria as well as test data.

This chapter does not provide the last word in the protection of vehicles in demining. It represents sensible principles, distilled over years of practical field experience. The information provided is especially useful for organisations intending to adapt commercial vehicles for demining purposes.

## Assessing the mine and UXO threat

### Classification of mines and UXO

It is assumed that the majority of humanitarian and commercial demining operations are conducted in a stable or semi-stable political environment. Hostilities have ceased and deminers, vehicles and equipment are not exposed to direct or indirect fire or the threat of command detonations. The threat of hostile fire (direct or indirect) as well as that of command-detonated mines or devices are therefore excluded from the study underpinning this chapter.

It is common to classify mines according to their intended use and purpose. This classification is used throughout the demining world today and will be used here to provide a framework for further discussion. While clearing mines dominates the overall demining effort, items of UXO also need to be located and rendered safe. UXO poses a threat to operators, vehicles and plant equipment during clearance operations and items of UXO are therefore included in this classification.

**Fig. 1. Classification of mines and UXO**
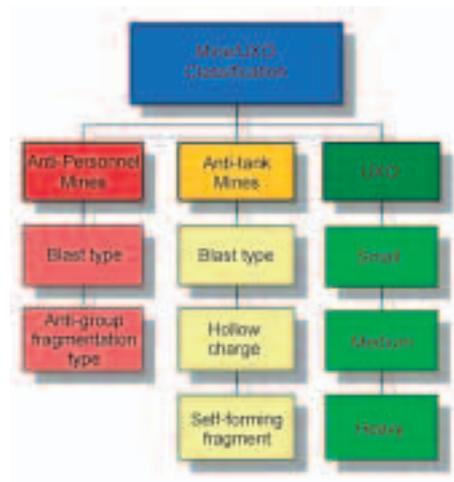


### Anti-personnel mines

Anti-personnel mines are designed to incapacitate or kill personnel on foot through blast or fragmentation effect.

#### Blast mines

As their name suggests, anti-personnel blast mines rely primarily on the blast effect from the explosive charge to incapacitate personnel. Such mines are usually initiated by direct pressure on top of the device, i.e. by stepping on them. Detonation results in a combination of shock and blast effects that destroy human

tissue with severe localised maiming of flesh and limbs in the lower body region. If the victim is not killed outright, amputation of the lower limbs — feet or legs — is usually required.

Secondary blast effects can also include severe damage to the lungs in the upper torso, depending on the size of the explosive charge and the position of the victim's body relative to the mine. The detonation and resulting blast effect also creates secondary fragmentation in the form of soil particles, stones and mine debris that can cause wounds and lacerations to the lower limb region as well as the upper torso and arms. Eyes are particularly vulnerable to the secondary fragmentation effect. Hearing is normally impaired as a result of the blast.

Smaller blast mines contain less than 100 grams of high explosive as their main charge. Their primary objective is to incapacitate the victim by causing severe localised damage to the feet and lower limbs. Secondary effects, aside from the threat of fragmentation to eyesight, are usually less severe than those encountered with larger blast mines.

Larger blast mines contain between 100 and 250 grams of high explosive. These mines not only cause severe damage to lower limbs and tissue, they also have greater and more severe secondary effects on the upper torso, which include severe lung damage and secondary fragmentation effects. The loss of upper torso limbs, such as fingers and hands, is not uncommon when victims encounter these larger anti-personnel blast mines.

### Fragmentation mines

#### *Omni-directional mines*

These mines rely on the fragmentation effect to incapacitate personnel. This type of mine usually consists of a cylindrical metal sleeve that surrounds an explosive charge. The metal sleeve produces fragmentation with velocities up to 1,500 metres per second when the explosive charge is detonated and is lethal to people up to 50 metres.

Two types are encountered: the first is stake-mounted on the surface and activated by pull-switch and tripwire; the other is referred to as the "bounding mine". Bounding mines are buried underneath the surface and activated by either pressure or tripwire. Activation of the fuse initiates a black powder charge that expels the mine from the ground to detonate at a height of approximately 1.5 metres to optimise the fragmentation effect against personnel.

#### *Directional mines*

These mines restrict the projection of fragmentation within a 40° to 60° arc in front of the mine. They are commonly used to initiate ambushes where they are command detonated (usually electrically) or for perimeter protection and early warning. In the last instance they are initiated by tripwire.

### *Anti-tank mines*

These mines rely on blast effect to incapacitate vehicles. Self forming fragment (SFF) and hollow charge (HC) mines (discussed below) use the "platter charge" effect or the "Munroe" or "hollow charge" effect to penetrate steel in order to incapacitate vehicles, especially heavy armour.

## Blast mines

These mines rely on the blast effect from the main explosive charge (normally 5-7 kilograms) to incapacitate vehicles. The charge is usually initiated by a pressure mechanism that activates the mine. While the blast effect is devastating to light, soft-skinned vehicles, damage to medium-size armoured vehicles is usually contained to the wheel stations or tracks. The shock effect transferred to the hull can cause injury to occupants, especially if the hull is penetrated.

Anti-tank blast mines can either be boosted with additional explosives placed underneath the mine or by more than one mine being stacked on top of the other, as depicted in Figure 2. This results in a main explosive charge of 15-20 kilograms that enhances the blast effect. (So-called triple mines are not uncommon in certain regions). This configuration is usually used against armoured personnel-carriers, mine-protected vehicles and medium to heavy tanks.



*Fig. 2. Double mine located in Angola. The bottom mine is a metallic TM46 anti-tank mine with a low-metal-content Type 72 anti-tank mine on top.*

Another tactic is to position the mine to allow for a centre blast underneath the vehicle's hull. The blast is contained underneath the hull and causes greater damage to the vehicle. The mine is positioned in the middle of the road with a second mine located in the wheel track. These mines are linked with detonating cord as depicted in Figure 3. This configuration is known as the "goggle mine".



*Fig. 3. Two linked mines located in Angola. The TM57 anti-tank mine in the centre is linked by a detonating cord to a low-metal-content PTMI BA3 anti-tank mine in the track on the right of the picture.*

## Hollow charge mines

These mines use the "Munroe" or "hollow charge" effect to penetrate armour and allow the blast and shock effect of the accompanying explosion to incapacitate the vehicle and occupants. The explosive charge is cone-shaped and provided with a metallic liner (usually copper) with the open end of the cone pointed upwards towards the target. Upon detonation, the Munroe effect causes a focused blast effect that turns the metallic liner into a high-speed copper slug capable of penetrating the steel due to its very high kinetic energy. Once the steel has been penetrated, the blast effect enters the vehicle interior and incapacitates the occupants. These mines are used against armoured and mine-protected vehicles.

A number of mines are included in this category because they create more damage to vehicles than the conventional anti-tank mine relying on blast alone, even though they are not, strictly speaking, HC mines. For example, although the South African

No. 8 anti-tank mine does not use the Munroe effect optimally (as it does not have a metallic liner), the focusing effect of the explosive charge causes the resultant blast effect to be more effective than some other conventional blast anti-tank mines. Similarly, the British MK 7 anti-tank mine is fitted with a heavy metal fuse array on top of it. This fuse forms a high-speed metal slug that penetrates steel up to a certain thickness. This mine is also more effective than some other conventional blast anti-tank mines.

### Self forming fragment (SFF) mines

SFF-type mines rely on the "Miznay Shardin" or "platter" effect to incapacitate vehicles and its occupants. The mine contains a hollow dish-shaped metal liner facing towards the target. Upon detonation, this dish (with a mass of 0.73 kilograms) forms a high-speed metal slug that is projected towards the target at velocities up to 2,500 metres per second. This slug is capable of penetrating armoured steel, allowing the ensuing blast effect to enter the target vehicle and incapacitate the occupants and cause damage to the vehicle.

The Miznay Shardin effect causes greater damage to vehicles than the Munroe effect. The formed slug is bigger and thus causes greater damage to the vehicle's hull. The ensuing hole in the hull is larger, with the result that the blast effect that enters the hull is considerably larger, causing more damage to occupants and the interior of the vehicle. These mines are usually used against medium and heavy armour and mine-protected vehicles.

Less effective SFF mines can be improvised by positioning a circular metal plate (10-20 millimetres in thickness) on top of a conventional blast anti-tank mine. While detection of the mine is easier, the resulting effect is far more devastating than that of a conventional blast mine alone.

## *Unexploded ordnance*

UXO can be classified as small, medium and heavy according to their explosive content. While most items of UXO rely on a combination of blast and fragmentation effect to incapacitate personnel and vehicles, more sophisticated devices include HC effects, thereby posing a greater threat.

### Small-size UXO

Small-size items of UXO contain an explosive charge of less than 500 grams and rely on a combination of blast and fragmentation effect to incapacitate personnel and vehicles. Examples include the following:

- ➢ hand grenades,
- ➢ rifle grenades,
- ➢ 40-millimetre aircraft rounds, and
- ➢ submunitions.

### Medium-size UXO

So-called "medium-size" items of UXO contain an explosive charge of between one and 20 kilograms and rely on a combination of fragmentation and blast effect to incapacitate vehicles and personnel.

### Large UXO

These items of UXO consist mostly of aircraft bombs with explosive charges of up to 500 kilograms. They rely mostly on their blast effect to incapacitate vehicles, equipment and personnel.

### *Definition of mine threat levels*

The threat that mines and UXO pose to vehicles, plant equipment and their occupants is defined according to severity in Table 1 below. These levels will be used to determine required protection levels to counter this threat.

**Table 1. Definition of mine threat levels (MTL)**

| MTL | Description | Typical examples |
|---|---|---|
| MTL-01 | anti-personnel mine blast type | PMN, PMD-6, Type 72 |
| MTL-02 | anti-personnel mine fragmentation type small-size UXO | POM-Z, OZM-4, OZM-72, PROM-1 Hand grenades, rifle grenades, submunitions |
| MTL-03 | anti-tank blast type | TM46, TM57, TMA-3 |
| MTL-03A | anti-tank blast under wheel | TM46, TM57, TMA-3 |
| MTL-03B | anti-tank blast under hull | TM46, TM57, TMA-3 |
| MTL-04 | medium-size UXO (mortars and artillery rounds) | 60-120 millimetre mortars. Artillery rounds up to 155 millimetres |
| MTL-05 | anti-tank HC | AT-4 |
| MTL-06 | anti-tank SFF | TMRP-6, TMRP-7, TMK-2 |
| MTL-07 | heavy-size UXO | 250-500 kilogram aircraft bombs |

## Effect of mines and UXO on unprotected vehicles, plant equipment and occupants

While the protection of personnel working in mine-affected areas is of paramount importance, the effects of mines and UXO on personnel "in the open" fall outside the scope of this study. This section concentrates on the effects on unprotected vehicles and plant equipment, with particular emphasis on the safety of the occupants and crew inside.

The mass of the vehicle or equipment plays an important role in determining the effects of mines and UXO on them. The heavier a vehicle, the less damage is caused by the mine or UXO. Vehicles and equipment are therefore classified by mass in order to facilitate this discussion, although hull shape and materials used are also of importance.

**Table 2. Classification of vehicles and plant equipment**

| Classification | Mass (metric tonnes) | Examples (unprotected non-military vehicles) |
|---|---|---|
| Light | < 3 | Sedan vehicle, light pick-up, lorry, light back-actor |
| Medium | 3-15 | Medium lorry, bus, D-4 bulldozer, excavator |
| Heavy | 15-30 | Heavy lorry, D-8 bulldozer, heavy excavator |
| Extra heavy | > 30 | Low-bed with freight |

## Anti-personnel blast type (MTL-01)

### Light vehicles

The blast effect associated with the detonation of high explosive manifests itself in the form of a high-speed shock wave with very high overpressure being emitted from the charge. This overpressure decays very rapidly with distance due to expansion into the surrounding air as depicted graphically in Figure 4 below. The graph depicts the decay of reflected overpressure with distance for the detonation of 250 grams of trinitrotoluene (TNT) on the surface. The overpressures were calculated from the Rankine-Hugoniot equation, which enables the overpressure to be calculated at given distances for a TNT charge detonated on the surface. The overpressure can be calculated and presented in two ways, either as reflected pressure or "side-on" pressure. The difference is the way in which the blast wave is viewed.

**Fig. 4. Blast overpressures against distance in metres for 250 grams of TNT charge**
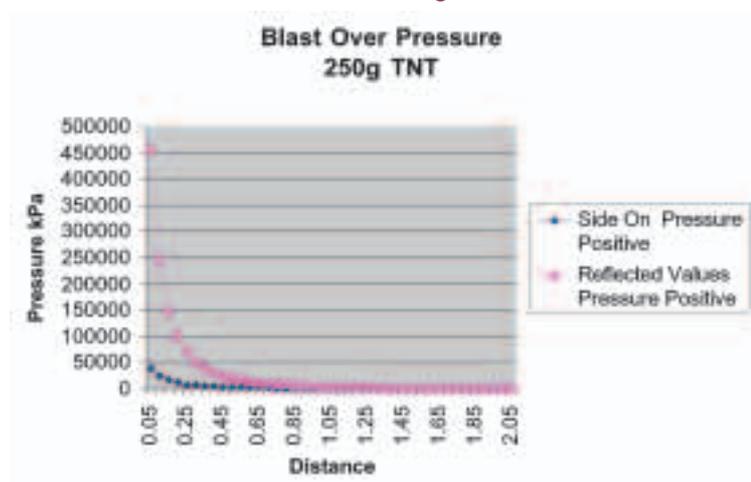


Reflected pressures are obtained when the blast wave is viewed directly from the front, i.e. the measuring probe is positioned directly in front of the approaching wave. The wave hits the surface of the probe directly and reflects back towards the point of its origin. The direction of measurement is in the same direction as that of the blast wave.

"Side-on" pressures are obtained when the blast wave is viewed from the side, thus the direction of measurement is 90° perpendicular to the direction in which the blast

wave is travelling. "Side-on" pressures are much lower than reflected pressures, depending on conditions. Reflected pressures are more useful in engineering applications because they give an approximation of what pressure and associated impulses are exerted on materials and structures when subjected to explosives blast waves. Care should be taken when using quoted or calculated pressures to always establish how the blast wave was viewed when pressures are quoted or calculated.

While the Rankine-Hugoniot equation is useful to estimate the resulting overpressure for a given explosive charge size, it is only valid for ideal conditions for the explosive charge suspended in free air. It further assumes that the shock front and blast wave develop and expand evenly away from the point of detonation. It does not take soil effects into account. When explosive charges are detonated under the surface of the soil, factors such as soil type, moisture content and depth have a profound effect on the development of the blast wave. The wave will develop in the direction of least resistance and will project the soil on top of the charge in these directions, causing zones of pressures much higher than calculated. In spite of this, the Rankine-Hugoniot equation is handy to establish the order of magnitude of overpressures expected at certain distances from a given explosive charge size.

From Figure 4 above it is evident that the blast effect is limited to less than one metre from the detonation point. Thus, the effect of anti-personnel blast type mines on light vehicles is restricted to local damage in the wheel area. The tyre is punctured and the tyre rim and wheel studs may be damaged by the bigger type anti-personnel mines, such as the PMN or PMD-6. Hydraulic brake lines may also be damaged.

The threat to occupants caused by the blast effect is minimal. The biggest threat to occupants is the ensuing accident resulting from the sudden puncture of the tyre, similar to a tyre blow-out in normal vehicle accidents. Occupants are shielded from the blast effect by the vehicle body and are usually more than two metres removed from the detonation point. The resulting blast from the detonation of this class of mines is insufficient to rupture body panels and thus prevents the blast and associated shock wave from entering the vehicle compartment.

### Medium, heavy and extra heavy vehicles

The effects are similar to those on light vehicles, but with less damage to the wheel station. There is no damage to tracked vehicles, especially with heavier vehicles and plant equipment.

## *Anti-personnel fragmentation mine and small UXO (MTL-02)*

### All vehicle classes

The detonation velocity in cast explosives such as TNT is approximately 7,600 metres per second. When a column of explosives is encased in steel, the velocity of the ensuing shock wave (approx. 7,600 metres per second upon detonation) exceeds the velocity of sound in steel (approx. 6,000 metres per second). Energy is pumped into the steel at rates higher than those with which the steel can conduct this energy. This leads to the build-up of very high, localised stresses within the material along the molecular grain boundaries. This results in the fracture of the material along the grain boundaries. These fractured pieces are referred to as fragments and are propelled away from the detonating explosive charge at velocities in the order of 1,000 to 1,800 metres per second. The size and shape of these irregular fragments depend very much on the material properties of the steel.

The fragmentation emitted by this class of mine and small UXO is capable of penetrating the body, windshield and windows of the vehicle at distances of up to 30 metres causing a serious threat to occupants or operators. Shrapnel can also cause severe localised damage to vehicle systems such as brakes, cooling, hydraulic and fuel lines.

Tripwire-operated mines pose a serious threat to plant equipment working in mine-infested areas. The equipment can activate the mine by disturbing the tripwire up to 10 metres in front of the machine, but the mine may be positioned right next to the machine, resulting in a detonation very close to it. Shrapnel velocities in such close proximity average between 800 to 1,000 metres per second that can easily penetrate 10 millimetres of mild steel.

Bounding mines pose an additional danger. They are expelled from the ground with considerable force when activated. The mine itself can easily penetrate the soft belly of an unprotected vehicle. In one instance, a Casspir MPV was hit by an OZM-72 bounding mine which detonated just behind the rear door. The mine hit the side of the three-millimetre-thick "checker plate" step with sufficient force to bend the plate out of the way before detonating.

### Blast of anti-tank mines under a wheel (MTL-03A)

#### General considerations

When anti-tank blast mines are initiated, the blast and shock front is formed exactly in the same manner as that for the initiation of anti-personnel blast mines. The difference is that the ensuing blast wave generates overpressures much higher than that of anti-personnel mines. Anti-tank blast mines are thus capable of causing damage at much further distances from the detonation point. The relation between blast overpressures and distance for a seven kilogram TNT charge is depicted in Figure 5.

**Fig. 5. Blast overpressure *v.* distance in metres for 7 kilograms of TNT**
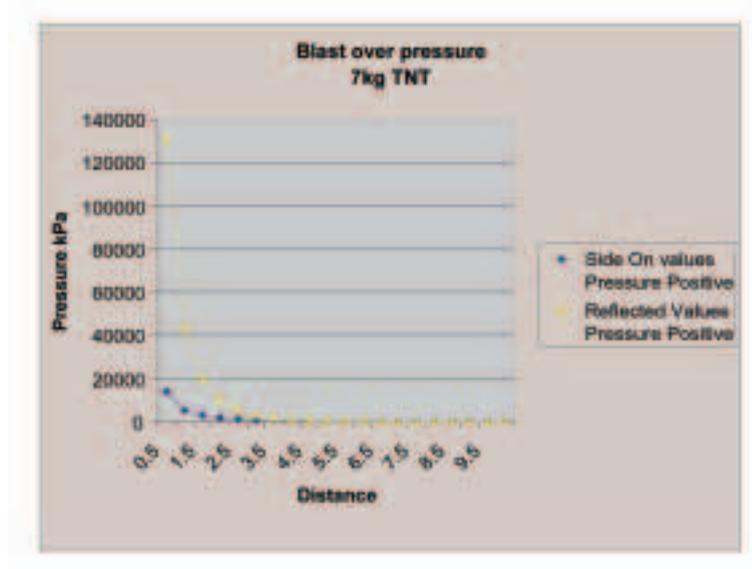


The high-pressure zone associated with the extremely high associated reflected pressure (3,300 kiloPascals) is now extended to three metres.

The initial shape of the blast wave as it emerges from the ground depends on the depth of the charge as well as soil conditions (moisture, soil type and hardness), but is generally cone-shaped with an angle between 45 and 60 degrees. This wave flattens out to an inclusive angle of 100 to 120 degrees in the final development of the blast wave due to the sideways expansion parallel to the soil surface as indicated in Figure 6. This picture was captured on film approximately five milliseconds after initiation.

**Fig. 6. Final development of explosive shock wave approximately 5 milliseconds after initiation of a 7 kilogram TNT test charge buried 100 millimetres under the surface.**



The position of the shock wave edge is clearly visible along the surface by the dust kicked up as the shock wave passes over the ground. The dotted red line depicts the theoretical position of the shock wave at this stage, had the shock wave formed symmetrically upon emerging from the soil. This edge is further away from the detonation point than the following plume that contains smoke (detonation products), sand and dust particles. These particles, and thus the plume, travel at the so-called particle velocity which is less than the shock wave velocity. The black objects emerging above the plume are solid debris (e.g. stones), which were initially projected upwards through the impulse caused by the blast wave.

At this point their velocity is greater than that of the shock wave and they are in front of the shock wave. The velocity decay of the shock wave in air is greater that that of solid objects with a certain level of kinetic energy. This is due to the expansion in air.

While the reflective pressures generated by the horizontal development of the blast wave is of the same magnitude as the vertical development, the reflected pressures associated with the vertical development are of greater importance where the blast effect on vehicles is concerned. This is the area included within the 100° cone above the detonation point (depicted in Figure 6), also referred to as the "cone of destruction". Local overpressures within this cone are normally of such a magnitude that they lead to the complete destruction of vehicle chassis parts, panels and even the engines of unprotected vehicles.

The size of this cone of destruction as well as associated reflected pressures, particle velocity (plume velocity) and time of arrival of the shock wave against the vertical distance from the detonation point are given in Table 3. The values were calculated

from the Rankine-Huguniot equation and can therefore only be regarded as indicative of the order of magnitude. The calculations to establish the cone diameter are contained in Annex 1 to this chapter.

#### Table 3. Shock wave characteristics *v.* distance for a 7kg TNT test charge

| Distance above detonation point (metres) | Cone diameter (metres) | Reflected pressure (kPa) | Shock velocity (m/s) | Particle velocity (m/s) | Arrival time of shock wave (millisecs) |
|---|---|---|---|---|---|
| 0.5 | 1.2 | 131,000 | 3,610 | 3,290 | 0.08 |
| 1.0 | 2.4 | 43,500 | 2,440 | 2,020 | 0.24 |
| 1.5 | 3.6 | 19,800 | 1,840 | 1,430 | 0.49 |
| 2.0 | 4.8 | 10,400 | 1,440 | 1,060 | 0.81 |
| 2.5 | 6.0 | 5,720 | 1,160 | 815 | 1.22 |
| 3.0 | 7.2 | 3,300 | 936 | 637 | 1.72 |
| 3.5 | 8.4 | 1,950 | 812 | 507 | 2.33 |
| 4.0 | 9.6 | 1,250 | 714 | 412 | 3.01 |
| 4.5 | 10.8 | 838 | 642 | 340 | 3.79 |
| 5.0 | 12.0 | 583 | 588 | 284 | 4.65 |

### Blast effect on light unprotected vehicles

Based on an "average" light vehicle five metres long and two metres wide and with a ground clearance of 50 centimetres, the cone of destruction will encompass roughly one quarter of the vehicle when an anti-tank blast mine is detonated under a wheel. Three quarters of the blast effect is dissipated into the surrounding air, but the blast wave generates extremely high reflected pressures on the chassis and hull of the vehicle close to the ground. These high reflected pressures simply destroy and remove everything in its path. The vehicle itself is flung into the air, and pending on its initial velocity, normally lands five to 10 metres away from the detonation point.

The effect of the cone of destruction resulting from a wheel blast underneath a light unprotected vehicle is depicted schematically in Figure 7. The part of the vehicle coloured in red is usually completely destroyed and the likelihood of occupants within this area surviving is slim.

#### Fig. 7. Illustration of the "cone of destruction" in wheel blasts on light unprotected vehicles
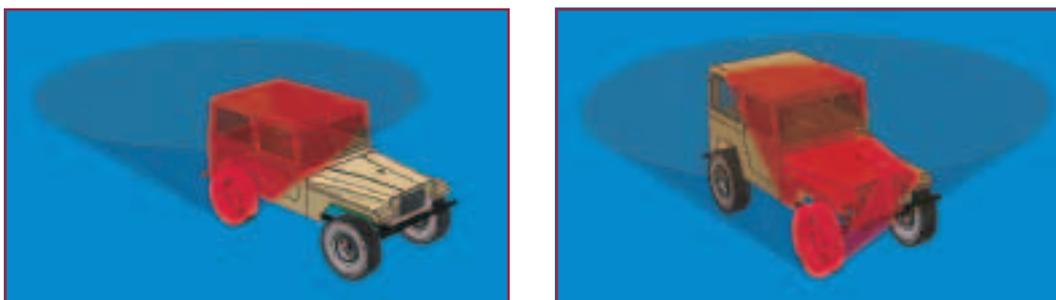
Figure 8 depicts a light unprotected pick-up that detonated a single TM 46 anti-tank blast mine under the left front wheel. The entire cab and engine compartment have been destroyed (the areas within the cone of destruction). Note that no damage occurred to the left rear wheel and wheel-base as well as the rear area outside the cone of destruction.

**Fig. 8. Light unprotected pick-up destroyed by the blast from a single TM 46 anti-tank mine under the left front wheel**



The effect on the occupants depends on their position relative to the detonation point. If an occupant is positioned within the cone of destruction, death is almost certain.

Statistics of the effect on the occupants of the explosion of single anti-tank mines under the wheels of light unprotected vehicles in the former Rhodesia (1972-1978) are summarised in Table 4. They indicate that in recorded incidents 28 per cent of the occupants were killed outright and a further 36 per cent sustained severe injuries. Injuries included severe tissue damage and lacerations (some leading to amputation of limbs) sustained by secondary fragmentation generated by the blast wave. Further injuries included impaired hearing, damage to eyesight and, though to a lesser extent, lung damage.

**Table 4. Mine incidents recorded in Rhodesia (1970-1978)**
**Blast effect on medium and heavy unprotected vehicles**

| Vehicle | Detonations | People involved | Deaths | Injuries |
|---|---|---|---|---|
| Unprotected Land Rovers | 22 | 88 | 81 (20%) | 52 (59%) |
| Unprotected Land Rovers, front wheel only | 7 | 24 | 2 (8%) | 15 (60%) |
| Protected Land Rovers, steel plates next to wheels | 118 | 397 | 25 (6%) | 185 (47%) |
| Protected Land Rovers, front wheel only | 81 | 249 | 3 (1.2%) | 120 (48%) |
| Leopard | 37 | 139 | 0 | 18 (13%) |
| Rhino | 12 | 45 | 1 (2%) | 15 (33%) |
| Hyena (SA) | 99 | 407 | 1 (0.2%) | 82 (20%) |
| Kudu | 14 | 70 | 7 (10%) | 39 (56%) |
| Puma (heavy vehicle) | 82 | 715 | 2 (0.2%) | 106 (15%) |
| Unprotected light vehicles (cars, etc.) | 95 | 498 | 139 (28%) | 181 (36%) |
| Unprotected heavy vehicles | 173 | 1949 | 103 (5%) | 397 (20%) |

The blast effect and associated damage caused by single anti-tank mines exploding underneath medium or heavy unprotected vehicles tend to be more localised. This is due to the bigger size and mass of the vehicle as well as the higher ground clearance. The cone of destruction associated with the blast effect covers a proportionally smaller area of the vehicle than that for light vehicles. In spite of this, local damage is just as severe as in light vehicles and leads to the complete destruction of a segment of the vehicle as depicted in Figure 9. This 10-tonne truck detonated a single anti-tank mine under the right front wheel.

**Fig. 9. Unprotected medium-sized vehicle that detonated a single anti-tank mine under the right front wheel**



The cab was destroyed with little or no damage towards the rear of the vehicle or the lower left hand side in front. The driver of the truck was killed instantly.

Statistics in Table 4 indicate that five per cent of occupants were killed and 20 per cent injured during incidents involving the detonation of single anti-tank blast type mines underneath medium to heavy unprotected vehicles. These figures are much less than those for light unprotected vehicles due to the fact that occupants are further removed from the detonation point in these bigger and heavier vehicles than in the smaller light vehicles.

**Fig. 10. Bulldozer after detonating a single TMA 3 mine in Mozambique**



*After some of the roads were cleared by manual teams in Mozambique this was the fate of road-building equipment following them up. Hand-held metal detectors and prodding sticks were cleaning to a depth of some 100mm. The TMA-2 mine detonated after the blade had removed enough cover. The mine was too deep for other vehicle traffic to detonate it.*

Figure 10 depicts a bulldozer that detonated a single TMA-3 anti-tank blast mine underneath the right hand track. The blast effect shattered the track and damage was limited to the right hand side alone. The blast effect was insufficient to throw the vehicle out of the crater created by the blast. The driver survived and sustained severe lacerations due to the secondary fragmentation effects.

### Blast effect on extra heavy size unprotected vehicles

The blast effect of anti-tank blast type mines detonating under the wheels of extra heavy unprotected vehicles is similar to the effect on heavy vehicles. The difference is that the effect is more localised due to the bigger size and mass of the vehicle. However, the localised effect when detonating an anti-tank blast mine under a front wheel is sufficient to cause extensive damage to the cab of the vehicle and can cause death or serious injuries to the occupants.

## Detonation of anti-tank blast mine underneath hull (MTL-03B)

### General considerations

Double anti-tank blast mines became common during the middle of 1978 in the former South West Africa with the advent of the first generation mine-protected vehicles (MPVs). These mines appeared in both the linked or "goggle" configuration causing blast effect directly under the vehicle hull or, in the stacked configuration (triple mines were not uncommon), detonating underneath the wheel.

The number of mines involved in incidents in South West Africa (now Namibia) during July/August 1978 is reflected in Table 5.

**Table 5. Number of mines detected and involved in incidents
in South West Africa in July-August 1978**

| Type | Mines located | | Detonations | Total |
|------|------|------|------|------|
| | Visual | Detected | | |
| **Single mines** | | | | |
| TMA-3 | 0 | 1 | 0 | 1 |
| **Total** | **0** | **1** | **0** | **1** |
| **Double mines** | | | | |
| Stacked TMA-3 | 0 | 2 | 3 | 5 |
| Linked TMA-3/ TM 46/57 | 0 | 3 | 1 | 4 |
| Linked others | 0 | 2 | 0 | 2 |
| **Total** | **0** | **7** | **4** | **11** |

The blast effect of these multiple mines was much more devastating on unprotected vehicles than when single mines were detonated underneath the wheels: more occupants were killed and injured. This is depicted in Table 6.

Table 6. Number of people killed and injured in vehicle mine incidents
in South West Africa: January-July 1978

| Vehicles | Incidents | People involved | Killed | Injured |
|----------|-----------|-----------------|--------|---------|
| Unprotected | 22 | 117 | 43 (37%) | 61 (52%) |
| Protected | 48 | 356 | 5 (1.4%) | 32 (9%) |
| **Total** | **70** | **473** | **48 (10%)** | **93 (20%)** |

## Blast effect on light and medium unprotected vehicles

The blast effect of multiple mines on unprotected light- and medium-sized vehicles is much more severe than that of single mines. If multiple mines are detonated in the linked configuration, the mine initiates underneath the hull of the vehicle. Blast damage is not localised to the wheel area, as in the case of single mines detonating under the wheel. The full force of the mine causes much more damage to the vehicle as depicted schematically in Figure 11.

Fig. 11. The effect of the cone of destruction on a light, unprotected vehicle from a centre blast underneath the hull
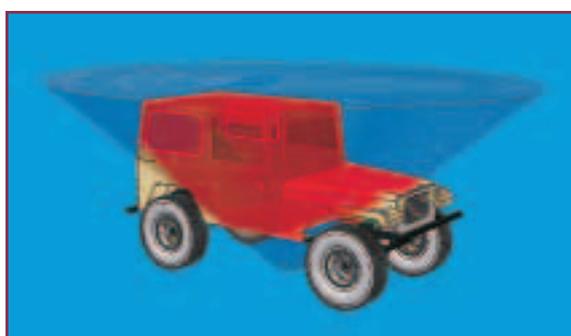


The effect of a centre blast underneath the hull of a light unprotected pick-up is depicted in Figure 12. While the front of the vehicle, engine compartment and cab have been destroyed and removed, the rear area suffered relatively little damage. Note that the one rear hubcap remained fixed to the wheel: this area was obviously outside the cone of destruction.

Fig. 12. The effect of a single TM-46 anti-tank blast mine detonated underneath the centre of an unprotected light vehicle

When multiple mines are stacked (either double or triple), the ensuing blast effect on the vehicle, even for a detonation under a wheel, is much bigger due to the increase of explosive charge. Figure 13 depicts a light unprotected vehicle almost completely destroyed by a double mine. The mine detonated underneath the right front wheel. All five occupants were killed instantly.



**Fig. 13. Damage to a light unprotected vehicle from a double mine detonating under the right front wheel**

### Blast effect on heavy and extra heavy unprotected vehicles.

The blast effect of multiple mines on heavy and extra heavy vehicles is just as severe as that on light and medium vehicles, especially for detonations underneath the hull. Overall damage, though, tends to be less severe due to the bigger size and mass of these vehicles.

### *Medium-size UXO (MTL-04)*

The biggest danger from medium-size UXO is when they are used as booster charges in conjunction with anti-personnel or anti-tank blast mines. The effect is similar to that of multiple anti-tank blast mines, but with an added fragmentation effect.

When used as booby-traps and initiated above the surface with the aid of tripwires, the fragmentation from this class of UXO poses a threat to unprotected vehicles up to 100 metres away. It also poses a threat to plant equipment engaged in excavation or bush clearing activities. Figure 14 shows artillery shells and 122 millimetre rocket warheads (BM-21) used as booster charges in the road. These warheads were connected to anti-personnel blast mines in the road with detonating cord.

**Fig. 14. Rocket warheads shells used as booster charges located in a road in Angola**

### Anti-tank HC Mines (MTL-05)

Although anti-tank HC mines are mostly "scatterable mines", which lie on the surface after being deployed against armoured vehicles from the air, the hollow charge effect can penetrate armoured steel up to 40 millimetres in thickness at five metres. This allows the blast effect to enter into the vehicle and cause extensive damage. These types of mines will cause severe localised damage to all classes of unprotected vehicles and occupants will similarly be exposed to the blast effects, resulting in deaths and injuries. The effect of a Soviet TMK-2 HC mine on a Casspir MPV is depicted in Figure 15.

Fig. 15. The effect of a TMK-2 HC mine on a Casspir MPV



However, when these mines are detonated under the wheel, the hollow charge effect is neutralised if the hull of the vehicle does not extend over the wheel and the effect is similar to that of a single anti-tank blast mine detonating under the vehicle's wheel.

### Anti-tank SFF Mines (MTL-06)

The SFF type of anti-tank mines is designed to incapacitate heavy armoured vehicles so they have a devastating effect when detonated under unprotected vehicles. Such SFF mines will completely destroy light unprotected vehicles and cause severe localised damage to the heavier classes of vehicles. The chances of occupants surviving the blast are slim.

A black powder charge explodes and dispels soil from the top of the mine upon initiation. This is required to allow for the optimal formation of the "platter slug" in air during the detonation of the main charge. This molten slug (approximately 0.74 grams of steel) is projected towards the target with a high velocity. Velocities of up to 2,500 metres per second have been measured and the associated kinetic energy is sufficient for the slug to penetrate up to 80 millimetres of armour plate at distances of four metres.

The most damaging effects are obtained when the mine is detonated under the hull of a vehicle, which is why tilt rods are the preferred way of initiating these mines, allowing for the full width of the vehicle as the attack area. The penetration of the

armour plate allows the blast effect to enter the vehicle and cause further damage.

When these mines are detonated underneath the wheel of a vehicle, the "platter slug" is not formed optimally, however the resultant blast effect on the vehicle is similar to that of a double mine. Figure 16 depicts the effects of a TMRP-6 SFF mine detonated underneath the wheel of a Casspir MPV during a test. The wheel was filled with a liquid rubber compound that solidifies after a short period to minimise the effect of smaller anti-personnel type mines as well as to reduce punctures.

### UXO Heavy (MTL-07)

The use of 250-500 kilogram aircraft bombs as mines or booby-traps is not uncommon in certain regions. These bombs are buried in the road and linked with detonating cord to either anti-tank or anti-personnel mines, which are used to trigger the devices. The resulting blast effect from these devices will destroy all types of vehicle classes (from light to heavy) with virtually no chance of survival for the occupants. Figure 17 depicts a 500 kilogram aircraft bomb connected with detonating cord to several anti-personnel mines.



Fig. 16. Effects of a TMRP-6 SFF mine exploding under the wheel of a Casspir MPV



Fig. 17. A 500kg aircraft bomb rigged as a mine

This type of UXO also poses a serious threat on its own to unprotected plant equipment used for bush clearing or excavation.

## Mine/UXO protection levels

The mine or UXO protection levels for vehicles are generally defined in terms of the likelihood of the occupants surviving the effects of the explosion as well as the possibility of the vehicle being able to be repaired.

## *The likelihood of occupant survival*

It is difficult to categorise the survivability of occupants of vehicles involved in mine blasts. This is because the position of a particular occupant relative to the detonation point as well as the cone of destruction created by the blast effect will be determinant factors.

Nonetheless, statistics recorded during the Rhodesian War (1972-1978) indicate that the size and mass of the unprotected vehicle plays an important role in determining whether the occupants survive a blast or not. The analysis of these statistics, which are related to the detonation of a single blast mine underneath one of the wheels (MTL-03A), is depicted graphically in Figure 18.

**Fig. 18. Percentage of occupants killed and injured against vehicle size**
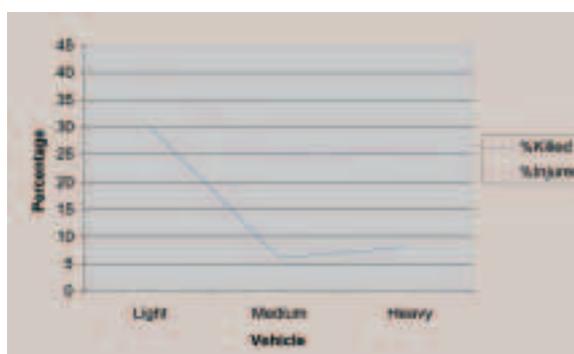


The percentage of occupants killed in light vehicles differed slightly when compared with those injured (30 per cent killed and 38 per cent injured). For medium and heavy vehicles the difference increased considerably (less than 10 per cent killed and 25 per cent injured). Occupant survivability and associated medical care required are defined in Table 7.

**Table 7. Definition of survivability levels for vehicle occupants**

| Survivability level (OSL) | Immediate condition | Medical care required | Estimated time to full recovery |
|---|---|---|---|
| OSL-04 | No incapacitation | Nil | N/A |
| OSL-03 | Temporary loss of hearing<br>Light lacerations<br>Minor fractures of limbs<br>Not life threatening | First aid | Hours |
| OSL-02 | Temporary loss of hearing<br>Severe multiple lacerations<br>Severe multiple fractures<br>Not life threatening | First aid and stabilisation<br>Casualty evacuation to clinic | Days |
| OSL-01 | Partial/complete loss of hearing permanent<br>Temporary/permanent loss of sight<br>Severe multiple lacerations<br>Blast lung<br>Limbs completely torn off<br>Multiple fractures<br>Life threatening | Stabilisation and immediate casualty evacuation<br>Trauma surgery and amputations | Months |
| OSL-00 | Instant death | N/A | N/A |

## Vehicle repairability

Vehicle repairability levels are defined in terms of the skills levels, required capabilities and time required to carry out repairs after a mine or UXO explosion. The vehicle repairability levels are defined in Table 8.

**Table 8. Definition of vehicle repairability levels (VRL)**

| VRL | Immediate condition | Repair capability and action | Duration |
|---|---|---|---|
| VRL-04 | No incapacitation | Nil | NA |
| VRL-03 | Temporary incapacitated | Effect repairs on site | Hours |
| VRL-02 | Temporary incapacitation No structural damage | Recovery to field workshop Requires general components | Days |
| VRL-01 | Semi permanent incapacitation Light to medium structural damage | Recovery to field workshop Requires factory supplied subsystems | Weeks |
| VRL-00 | Destroyed beyond economic repair | Recover to workshop Salvage usable parts and systems | NA |

# Principles for the protection of vehicles and plant equipment against the threat of mines and UXO

## General considerations

Steel plating (usually armour plate) is used to neutralise the blast and fragmentation effect of mines and UXO in order to render protection to vehicles, plant equipment and their occupants. However, any design incorporating the use of steel plating adds considerable mass to the vehicle.

Automotive engineers usually accept a power-to-mass ratio of 27kw per metric tonne to ensure vehicle mobility that also caters for off-route conditions. Another aspect that needs to be considered is axle loadings. In general, it is more difficult to protect the light to medium range of vehicles than the heavier classes, as depicted in Fig. 19.

**Fig. 19. Difficulty of protecting vehicles against mine threat**
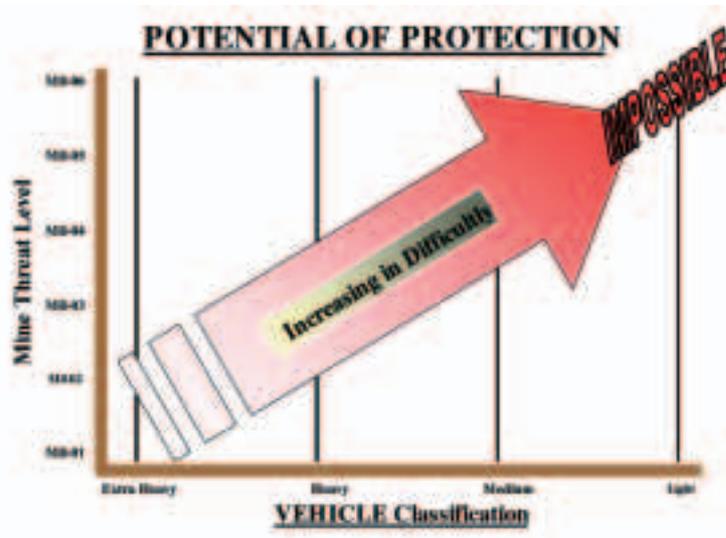
## *Principles for the protection against blast effect*

The following principles can be incorporated into the design of vehicles and equipment to render protection against the blast effect of mines:

> ➢ absorption of energy,
> ➢ deflection of blast effect away from the hull, and
> ➢ distance from detonation point.

### Absorption of energy

A simple and cost-effective manner to incorporate this principle has been found to fill the tyres of wheeled vehicles with water. This concept increases the protection level of light and medium vehicles considerably against the threat of single blast anti-tank type mines detonating underneath a wheel. Figure 20 depicts a three-ton Bedford truck that detonated a single TM46 anti-tank mine under the left front wheel.

**Fig. 20. Bedford truck with water in the wheels that detonated TM 46 anti-tank mine**



It was previously thought that the water absorbed energy by being converted into spray and vapour, but recent studies suggest that the water, being much heavier than the air in the tyre, deflects the shock wave sideways thereby flattening the cone of destruction.

This concept can be enhanced by adding protection plates to shield the vehicle occupants from the blast effect. However, these plates must be able to withstand the blast effect (although considerably less) within the cone of destruction. Otherwise, they could form deadly secondary fragmentation when shattering or shearing off during the blast. The general positions for inserting protection plates on a light vehicle are indicated in green in Figure 21. The windscreen and side windows should be replaced by reinforced, laminated glass to withstand the blast effect of the mine and render protection against fragmentation.

**Fig. 21. Schematic layout for insertion of protection plates in light vehicles**
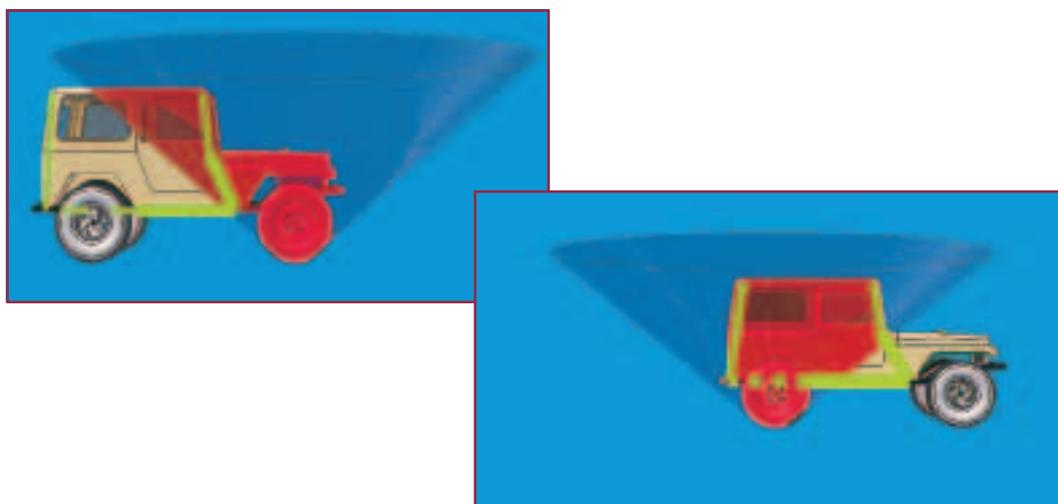
Figure 22 depicts a Unimog vehicle fitted with protection plates in the wheel area and tyres filled with water. This vehicle detonated a TM 57 anti-tank mine under the right wheel. Damage is considerably less than it would otherwise be, and is limited to the wheel area.

However, it should be noted that the use of water in the wheels and the installation of deflection plates will only render protection against *single* anti-tank mines detonating underneath the wheel (MTL-03A).

**Fig. 22. Unimog vehicle fitted with protection plates in wheel area and wheels filled with water**



### Deflection of blast away from the hull

The effect of blast against the hull of a vehicle can be reduced considerably by incorporating steel plates at an angle to the direction of blast. Reflected pressures are generated when the blast direction is at a 90° angle to the plate. Side-on pressures are approached if the blast direction corresponds to a 0° angle to the plate angle. It can thus be expected that the resultant pressure will be reduced to a value between the reflected pressure and the side-on pressure, should the plate be angled between 0 and 90°. In classical gas dynamics this is referred to as an oblique reflected shock wave. This approach has lead to the introduction of V-hulls, which have been successfully used in the mine protection of light- and medium-sized vehicles.

Protection can be rendered to lightweight vehicles against single anti-tank blast mine detonations underneath the hull (MTL-03B) by incorporating the design of a V-shaped capsule onto the chassis of a standard light commercial vehicle. The additional mass of the armour plating involved and the engine power limit the size of the capsule, therefore maximum use must be made of the deflection principle in the design. Design options are further limited by the vehicle configuration itself. Figure 23 depicts one of the successful designs issued to farmers in mine-affected areas in South Africa during the mid-1980s.

**Fig. 23. An example of a V-shaped capsule mounted on the chassis of a light commercial vehicle**

It is also important to prevent the "entrapment" of the blast wave. Lightweight, "blow away" panels should be used in areas within the cone of destruction, such as in the wheel wells.

### Distance from the detonation point

The blast effect diminishes drastically with the distance from the detonation point. Thus, by increasing the ground clearance height and by spacing the wheels further apart, maximum distance can be obtained from the detonation point. Practical considerations such as mobility, turning circle and ease of driving limit the extent to which this principle can be applied.

**Fig. 24. Rear view of South African Casspir MPV**



These principles were incorporated in the design of the South African Casspir MPV as depicted in Figure 24. Note the maximum use of wheel spacing (the wheels run on the outside of the body), the V-shaped hull to incorporate maximum deflection of the blast wave and optimal use of ground clearance.

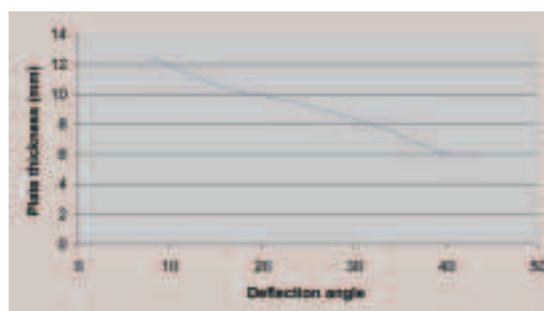## *Principles for the protection against the fragmentation effect of mines and UXO*

Protection against fragmentation is achieved by using steel plating and armoured glass of sufficient thickness. Normal ballistic protection levels as required for military combat and armoured vehicles are used effectively for the protection against the fragmentation effect of mines and smaller UXO (MTL-02). The plate thickness required to render protection against blast usually renders protection against the fragmentation effect of mines and smaller UXO (MTL-02).

A commonly used standard is to protect against the penetration of North Atlantic Treaty Organisation (NATO) 7.62 x 51mm anti-personnel rounds. These protection levels are defined in Military Standards such as STANAG 4569.

Armoured plating is currently being used instead of mild steel to create vehicles with lower weight. A rule of thumb is that an armoured plate of a given thickness renders the same ballistic protection as a mild steel plate of twice the thickness (thus half the mass).

The principle of deflection can also be used in designs to render protection against the fragmentation effect. Figure 25 illustrates the effect of incident angle on the thickness of a

**Fig. 25. Effect of incident angle on plate thickness required to stop 7.62 x 51mm NATO anti-personnel rounds**

typical armour plate required to stop penetration from a NATO 7.62 x 51mm anti-personnel round.

## Principles for the protection against hollow charge (HC) and self-forming fragment (SFF) mines

The amount of steel (armoured plate) required to neutralise the effect of various HC and SFF mines is depicted graphically in Figure 26. From this graph it is evident that the Soviet TMK-2 HC mine poses the biggest threat. Fortunately this mine is rarely encountered in current humanitarian and commercial demining operations.

**Fig. 26. Amount of steel required to neutralise the effect of various HC and SFF mines**
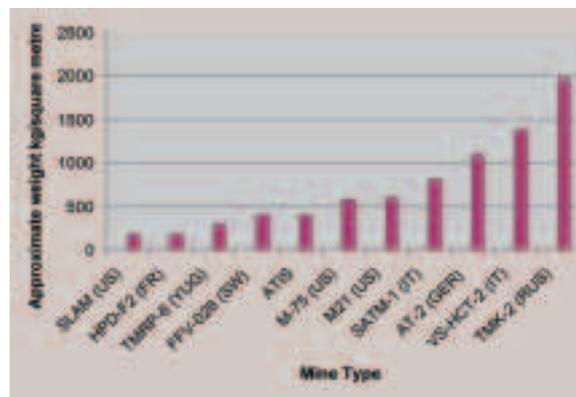


### Protection against HC mines

The Munroe effect associated with HC mines requires a stand-off distance in free air to form the high-speed jet. This stand-off distance is usually determined by the cone diameter and length of the charge. The optimal formation of this high-speed jet can be prevented by positioning a "capture plate" between the vehicle hull and the ground surface. This capture plate can cause the break-up of the jet. This will reduce the penetration capability of the jet against the vehicle hull.

This concept will reduce ground clearance of the vehicle considerably and thus impairs vehicle mobility, especially in wet conditions.

### Protection against SFF mines

The high-speed slug formed in SFF anti-tank mines requires less distance to optimally form. The effect of this mine can be reduced by introducing a thick "capture plate" between the vehicle hull and the soil surface. This plate must be thick enough to stop the slug completely. Current designs incorporate the use of armour plate and composite materials to reduce mass. The vehicle hull above the "capture plate" must be able to withstand the associated blast and shock effect of the mine as well. A typical "capture plate" underneath a V-shaped hull is depicted in Figure 27, as well as the after-effects of the SFF test mine.

The capture plate neutralises the effect of the V-shaped hull when fitted underneath a vehicle. If the vehicle detonates a conventional blast mine, either under the wheel or directly underneath the capture plate, the blast effect is trapped underneath the capture plate. The vehicle is then subjected to higher impulse and momentum transfer than in the case where the V-shape deflects most of the blast effect.

**Fig. 27. Effect of a SFF test mine on a capture plate fitted underneath the hull of a MPV capsule**



## *Application of other principles to render protection against the effect of mines and UXO*

Consideration should be given to the application of the following general principles to further increase the protection level of vehicles:

  ➢ use of safety belts,
  ➢ seating design and footrests, and
  ➢ "good housekeeping" (no loose items).

### Use of safety belts

Although the measures described above can all reduce the blast effect on a vehicle, significant impulse and momentum transfer to the vehicle may still occur. This causes a sudden vertical acceleration of the vehicle, i.e. the vehicle is thrown into the air. The lighter the vehicle, the more pronounced is this effect.

This sudden vertical acceleration, coupled with the original forward movement of the vehicle, can cause serious injuries to the occupants if they are not properly strapped into their seats. Conventional safety belts as used in the automotive industry do not render sufficient protection. Double straps with at least four adhesion points to the hull should therefore be used.

### Seating design and footrests

The shock associated with the blast wave is transmitted through the steel hull of the vehicle when subjected to the blast effect of a detonating mine. If the seats are attached to the floor of the vehicle, the shock wave can be transmitted through the steel directly to the seat and subsequently into the body of the person occupying the seat. This additional shock, in conjunction with the sudden vertical movement of the vehicle, can increase the extent of injuries sustained. As a result, it is far better to suspend seats from the side, or even better from the roof of the vehicle, to reduce shock transmission.

The same effect is encountered when occupants rest their feet directly onto the floor of the vehicle during a detonation incident. The shock wave is transmitted through the floor directly into the feet and lower limbs of the occupants, causing injury to those body parts. This effect can be minimised by producing footrests attached to the side of the vehicle or forming part of the seat arrangement. Footrests should not be attached directly to the floor section.

### "Good housekeeping"

Good housekeeping implies that the interior of the vehicle should be kept clean and free from foreign objects lying on the floor. Nuts, bolts, spare parts, tools and other foreign objects lying around on the floor of the cabin can be accelerated due to the blast effect and associated vertical movement into the air. These objects can cause injury to personnel inside the cabin.
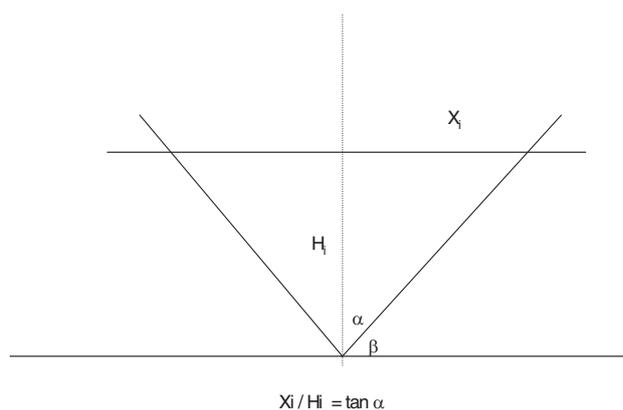
# Trigonometry regarding the cone of destruction



$$X_i / H_i = \tan \alpha$$

**Table 1. Trigonometry relations for the cone of destruction**

| Angle $a$ | Tan $a$ | Height $H_i$ (metres) | Cone radius $X_i$ (metres) $H_i \tan a$ | Cone diameter (metres) $2X_i$ |
|---|---|---|---|---|
| 50 | 1.19 | 0.5 | 0.595 | 1.19 |
| 50 | 1.19 | 1.0 | 1.190 | 2.38 |
| 50 | 1.19 | 1.5 | 1.785 | 3.57 |
| 50 | 1.19 | 2.0 | 2.380 | 4.76 |
| 50 | 1.19 | 2.5 | 2.975 | 5.95 |
| 50 | 1.19 | 3.0 | 3.570 | 7.14 |
| 50 | 1.19 | 3.5 | 4.165 | 8.33 |
| 50 | 1.19 | 4.0 | 4.760 | 9.52 |
| 50 | 1.19 | 4.5 | 5.355 | 10.71 |
| 50 | 1.19 | 5.0 | 5.95 | 11.90 |

$a$

## Annex 2.

# Guidelines to estimate the survivability of vehicles, plant equipment and their occupants in the field

The following guidelines have been established in order to allow technical advisors assigned to a mine action centre or other entity involved with the coordination or regulation of mine action, to make decisions regarding the suitability of vehicles, plant equipment and their occupants faced with specific mine threats.

## *The assessment process*

There are very few defined "yes-no" situations in assessing the survivability of mine protected vehicles (MPVs), plant equipment or their occupants against a mine threat. However, the following process should eliminate a number of uncertainties and thereby reduce risk:

- ➢ establish the mine threat level;
- ➢ establish the required protection level in terms of the survivability of the occupants and the repairability of the vehicle;
- ➢ establish the stated protection level claimed by the designer or manufacturer;
- ➢ verify the protection level achieved in the final product;
    - ➢ design process,
    - ➢ materials used,
    - ➢ construction processes,
    - ➢ design features,
    - ➢ test and evaluation; and
- ➢ ask for assistance.

### Mine threat level (MTL)

Ensure that the assessment is conducted against the primary threat level. This will normally be a combination of MTL-01 (anti-personnel blast) and MTL-02 (anti-tank fragmentation) and MTL-03 A and B (anti-tank blast) in the humanitarian demining scenario. MTL-06 (anti-tank SFF) is currently restricted to the Balkans.

### Protection levels

Establish the protection levels required by donors, the regulating authorities, as well as insurance requirements and operators. This is in fact a statement of acceptable risk and should be determined by taking into account aspects such as availability of medical facilities, casevac SOPs and availability of repairing facilities.

## Stated protection level

Establish the stated protection level of the system or product. This is easily done by extracting data from the manufacturer's product data sheet or brochure. If the manufacturer does not have the data available in this format, simply ask him.

Establish if this stated protection level meets the requirements of the actual mine threat and required protection level. A sound understanding of the actual threat and required protection level is required to achieve this.

For instance, a manufacturer may claim ballistic protection for a particular vegetation-cutting machine or flail, based on a commercial tracked excavator, against the fragmentation of a PROM-1 mine 10 metres away from the cab. This assumption would not represent the real threat. The PROM mine can be activated by tripwire. The machine may activate a tripwire with its working part 10 metres of the machine, but it could initiate a PROM mine within one metre away from the machine. If the design allowed for protection at 10 metres away, the possibility exists that no protection will be rendered at one metre, thus resulting in the death or injury of the operator.

## Verification of the protection levels achieved in the product

### Design process

Request the manufacturer to submit design detail such as drawings and calculations to verify the claimed protection level. Ask questions such as "Why is this plate this thickness, or why did you use this angle of deflection?" If the manufacturer is not capable of answering these basic questions, the design of the product becomes questionable. Establish the total mass of the vehicle or machine.

### Materials

Establish what materials are used and in what position. Ductile steel with sufficient toughness should be used in the lower regions close to the blast and the more brittle armour plates used higher up along the hull. Request material certificates from the suppliers of the steel to verify what material was used in the design.

### Construction methods

Establish what construction methods were used in the design. Bolted sections securing the lower part of the hull immediately identifies a questionable design. Capped welding in the lower areas would be better with bending of the plates as the best solution.

### Design features

Evaluate the product's design features through visual inspection.

Assess the free height of the hull above ground level. This height will determine the intensity of the impulse and area size of the shock wave. Visualise the size of the cone of destruction at this height and look out for the following:

- ➢ any bolted sections within this area?
- ➢ are all welded sections capped in this area?
- ➢ did they use a ductile material in this area?
- ➢ is the design smooth and clean to deflect the blast sufficiently?

➢ Are there any pockets to trap gas underneath the hull?

➢ Will the fuel tank be subjected to direct shock?

➢ Can water be used in the wheels to effect blast reduction?

Assess the ballistic protection of the product. If armour plate thinner than eight millimetres (or, in the event of mild steel, 16 millimetres) has been used, ballistic protection is deemed to be insufficient. Bullet resistant glass with a thickness less than 53 millimetres should not be used for windows. Pay attention to the screening off of hydraulic piping, electrical cables and other systems to reduce secondary damage caused by fragmentation.

Inspect quality of the welding and check for undercuts.

*Test and evaluation*

Ask the manufacturer if the design of the product had been verified through blast testing. If so, request test data and results. If the machine or vehicle had been involved in previous mine incidents, request incident and investigation reports for further analysis and study.