13th Seminar "New Trends in Research of Energetic Materials", Part II, pp. 797-814, ISBN 978-80-7395-249-5,
University of Pardubice, Pardubice, Czech Republic, April 21–23, 2010.

Dispersion of PGU-14 ammunition during air strikes by combat aircrafts A-10 near urban areas

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Abstract:

Nineteen air strikes onto seven target locations in Bosnia and Herzegovina were carried out by aircrafts A-10, using ammunition PGU-14. During these air strikes, 10.086 pieces of PGU-14 were fired, strafing such targets as armoured vehicles, trucks and bunkers. Exact locations of targets and PGU-14 ammunition quantity, which were spent for six attacks, are still unknown. But for one target, which was located near Sarajevo at suburb settlement Hadzici it was possible to collect more information. Two targets, an ammunition depot and the tanks and armoured vehicles maintenance facility, were attacked at the Hadzici location. During the five air strikes, 3.400 DU projectiles of PGU-14 ammunition were fired onto these targets. One of the targets was located within the urban part of the settlement, while another one was at suburb part of the settlement. Research points to very large number of unknown locations and uncompleted data on quantity of ammunition PGU-14 that was fired onto individual targets. There is disproportion between points of impact of DU penetrators into hard surfaces and number of located penetrators (ricochet effect), which in longer time period increases health risks for civilian population. Purpose of this paper is to perform an estimation of the dispersion zone with ground-penetrated projectiles PGU-14 using ballistic trajectory simulation for aircraft gun GAU-8/A and ammunition PGU-14 fired from aircraft A-10 and available input data such as aircraft velocity during the air strikes and ballistic performances of projectile PGU-14. In order to obtain final dimension of the hit dispersion pattern, theoretical results are corrected by using a dispersion figure gained from a real combat action. For this purpose, a detailed analysis of video-records (1995-2008 years) of combat actions carried by aircrafts A-10 on area targets without anti-aircraft protection and under conditions of very intensive anti-aircraft fire. Hit probability is determined on the base of US researches, which were performed during 1978 and 1979, in order to simulate attacks on Russian tanks under low attack angles. Based on the estimated number of hits for armoured or other hard targets, it is possible to approximately determine dispersion of PGU-14 ammunition during air strikes in target zone near urban areas.

Keywords: DU ammunition; PGU-14/B, GAU-8/A, penetrator, dispersion, airstrikes

1 Introduction

In the early 1970s, the Air Force developed the GAU-8/A air to surface gun system for the A-10 close air support aircraft. Weapon GAU-8/A is eight-barrelled 30 mm cannon, and was designed to blast through the top armour of even the heaviest enemy tanks [1]. In military applications, depleted uranium is ideal for use in armour penetrators. Depleted uranium (DU) penetrator is used in ammunition 20 mm MK149, 25 mm PGU-20, 25 mm M919 APFSDS-T, 30 mm PGU-14/B API, 105 mm M774 APFSDS-T, 105 mm M833 APFSDS-T, 105 mm M900 APFSDS-T OFL 105 F2 105 mm APFSDS (for AMX-30B2 tank), 3UBM-13 115 mm APFSDS (for T-62 tank), OFL 120 F2 120 mm APFSDS (for Leclerc tank), 120 mm M827 APFSDS-T, M829/A1/A2/A3 120 mm APFSDS (for Abrams tank), 3BM32 125 mm APFSDS (for T-72 tank), L27A1 CHARM 3 120 mm APFSDS (for Challenger 2 tank), M67 and small amounts of DU are used as an epoxy catalyst for the M86 Pursuit Deterrent Munition (PDM) and the Area Denial Artillery Munition (ADAM). DU is also used as an armour component on the M1 series heavy armour (HA) tanks [2].

During the period spanning from 1976-1977 and 1982-1993, the A-10s fired approximately 90.000 DU munitions PGU-14 at Target 63-10; an average of 7.500 munitions per year [3].

During operation DESERT STORM in the 1991, the Air Force fired 30mm Armour Piercing Incendiary (API) PGU-14/B munitions from the GAU-8 Gatling gun mounted on the A-10 Aircraft. The Air Force fired a total of 783.514 rounds of 30mm API PGU-14/B during Operation Desert Storm. During of one flew sortie about 97 DU rounds fired. Most of targets were outside of urban areas. The Marines sent 86 AV-8B Harrier aircraft to the Gulf, which flew 3.342 sorties and fired 67.436 ammunition 25 mm PGU/20. Each 25mm PGU-20 munitions contains 148 g of DU [4].

There were 980 munitions 30 mm PHU-14/B used by NATO A-10 aircraft in Bosnia and Herzegovina during August-September 1994 (operation “Deny Flight” [5]) for striking two targets at two locations. During operation “Deliberate Force" between August 30 and September 20, 1995, Air Force used 10.086 munitions 30 mm for GAU-8 weapon and 29 targets at seventeen locations were fired upon [6]. On eight locations, 18 targets located on urban and water-supplying zones, were attacked. In wider area of Sarajevo, 7.686 munitions 30mm were fired, and 4.284 munitions were unaccounted for. With direct insight on known firing locations there were some differences in coordinates comparing to NATO data. In area of Han Pijesak 2.400 munitions 30 mm were fired at six targets. Army of Republic of Srpska was performing military recruitment on locations contaminated by ammunition PGU-14/B with depleted uranium in period from 1995-2001 [7]. In Bosnia and Herzegovina, in period from 1994-1995, 11.066 munitions were fired from gun GAU-8/A.

For the Operation “Allied Force” (23.03. - 10.06.1999), in March 2000, NATO confirmed the use of approx. 31.000 PGU-14 ammunition 30 mm in Kosovo. In this battlefield, 112 attacks against 96 targets were flown. Hereby, approx. 31.000 rounds of 30 mm ammunition have been fired. Ammunition 30 mm PGU-14/B was also used in urban areas.

United States Air Forces Central issued Operation “Iraqi Freedom” in 2003. Sixty A-10s were deployed in Iraq. The A-10 in the war fired 311.597 rounds of 30 mm API ammunition PGU-14/B and 16.901 ammunition 20 mm M919 [8].

There are no data on DU ammunition quantity used in Afghanistan in period from 2001-2003. There is also no doubt that ammunition PGU-14/B was used from A-10 aircraft. Number of videos show engagement of A-10 aircraft in urban zones and communication areas. From following data it is possible to conclude approximate number of ammunition used from gun GAU-8/A. During its deployment to Afghanistan in 2007, the 354th Fighter Squadron dropped more tonnage than any other squadron since Vietnam and it fired one million 30 mm rounds. In 90 percent of the sorties, no weapons are dropped. In combat, a pilot may hit 10 different targets during a single sortie [9]. During period from 19.07.2009. to 15.09.2009., 12.000 rounds of 30 mm were fired since the arrival of the A-10 thunderbolt [10]. From July thru December, 2009, 354th Expeditionary Fighter Squadron's employed approximately 36.915 rounds of 30 mm. A-10 unit marks 10.000 flight hours, 2.500 sorties in 6-month tour in Afghanistan, more than 400 sorties a month [11].

1.1 GAU-8/A 30 mm Avenger gun system and ammunition PGU-14/B

The General Electric-built GAU-8/A 30 mm Avenger gun system could hold up to 1.174 ammunition and could fire ammunition with either armor piercing incendiary, high-explosive incendiary, or training practice projectiles [12]. This gun can fire 3,900 rounds per minute and a typical burst of fire occurs for 2 to 3 seconds and involves 120 to 195 rounds. The gun takes about half a second to come up to speed, so 50 rounds are fired during the first second, 65 or 70 ammunition per second thereafter. The numbers of DU rounds used in one target area range from 30 to 2.320.

In its combat role, the A-10 fires a combat mix consisting of 5 Armour Piercing Incendiary-API PGU-14/B DU projectile (weight of about 425 g) and one High-Explosive Incendiary (HEI) projectile PGU-13/B (weight of about 360 g) to sustain the operational combat effectiveness of the A-10 weapon system [13]. DU is the primary munitions for the A/OA-10 in a combat environment.

The accuracy of the GAU-8/A, installed in the A-10, is rated at "5mil, 80 percent", meaning that 80 percent of rounds fired at 1.220 m will hit within a circle of 6,1m radius [14].

PGU-14/B, Armour Piercing Incendiary ammunition with high density penetrator (depleted uranium) provides excellent armour penetration capability and after-armour effects against tanks and armoured personnel carriers. The PGU-14 API has the kinetic energy needed to defeat armour. Its projectile possesses high-density penetrator and demonstrates follow-through fragmentation and pyrophoric effects for maximum effectiveness.

The type of DU ammunition that the A-10 Warthog aircrafts uses has a conical DU penetrator. Its length is 95 mm and the diameter at the base 16 mm. The weight of the penetrators is approximately 300 g. The penetrator is fixed in a "jacket" (also called "casing"). The aluminium casing has a diameter of 30 mm and a length of 60 mm.

The jacket fits the size of the barrel of the A-10's Gatling gun and assists the round in flying straight. When the penetrator hits a hard object, e.g. the side of a vehicle, the penetrator continues through the metal sheet, but the jacket usually does not penetrate.

The USAF chose two companies, Aerojet and Honeywell (now ATK's Ammunition Systems Group), to develop and produce PGU-14 ammunition for the A-10 under its 'second source' philosophy: when items are acquired in large quantities, the USAF buys them from two organizations, and lets them bid competitively for each year's order.

Figure 1: Improved GAU-8/A Ammunition [15] and ammunitions PGU-14B [16-18]

There are significant differences in data on geometric, mass and ballistic characteristics for ammunition PGU-14/B. According to data [19], DU ammunition from gun GAU-8 was used from two different suppliers (Aerojet and Honeywell or now ATK - Alliant Techsystems) with certain differences in design and performances.

Projectile cartridge case was made from aluminium alloy instead of steel or brass. Projectile body was manufactured also from aluminium alloy, penetrator core from alloy of depleted uranium and 0,75% titanium. Front part of projectile (ballistic cap) was constructed from aluminium alloy with thickness 0.8 mm.

There are more variants of ammunition (PGU-14/A, PGU-14/A/B, PGU-14/B, PGU-14/B/A) and these differences are mostly in the design of projectile end part and rotating band.

Table 1. Data on geometric, mass and ballistic characteristics for ammo PGU-14.

	PGU-14/B, ATK's Ammunition Systems Group	PGU-14 Aerojet Ordnance Tennessee Inc.	PGU-14 Honeywell's defense systems division (now ATK)
Ammunition mass, g	727	748	717
Projectile mass, g	425	430	390
Penetrator mass, g	298 or 272 [20]	298	298
Projectile diameter, mm	30	30	30
Ammunition length, mm	290	290	290
Penetrator diameter, mm	16	16	16
Penetrator length, mm	99	99	99
Projectile velocity, m/s	983 or 1036 [21]	980	1030

According to company ATK from 2005, projectile doesn't have tracer inside its rear part and this space is partly occupied by penetrator of greater length [15].

The projectile is gyroscopically and dynamically stable, with predicted maximum yaw limit cycle of 1 degree [22].

Development of penetrator for ammunition PGU-14 was comprehensive, with different dimensions of penetrator material. The tests conducted at Eglin Air Force Base included six types of penetrators, numbered 3 through 8. Types 3 and 5 were made of steel, types 4 and 6 of tungsten carbide (WC), and types 7 (penetrator PGU-14) and 8 of depleted uranium. The six penetrators are shown in three groups of two, since three different materials were used, and two shapes were chosen for each material. The numbers are not sequential in this grouping, however.

Values of the ballistic limit velocity, as functions of the plate thickness (T) and the obliquity Θ are shown on figure 2. Both of these variables produce increases in ballistic limit velocity, but the dependence of ballistic limit velocity on the plate thickness and Θ are not very consistent from one data set to the next. In particular, for a fixed value of Θ, ballistic limit velocity is essentially a linear function of the plate thickness [23].

Later there were experiments conducted in order to increase penetration with ammunition 30 mm PGU-14/B API (fig. 3), with aircraft velocity of 128,61 m/s (250 Knot) and with attack angle of 30° on armour plate with hardness BHN 300. Achieved penetrations were 55 mm on distance from target of 1.220 m, to 76 mm on distance from target of 300 m. For this type of ammunition penetration of 54 mm was demanded on distance of 1.220 m [24].

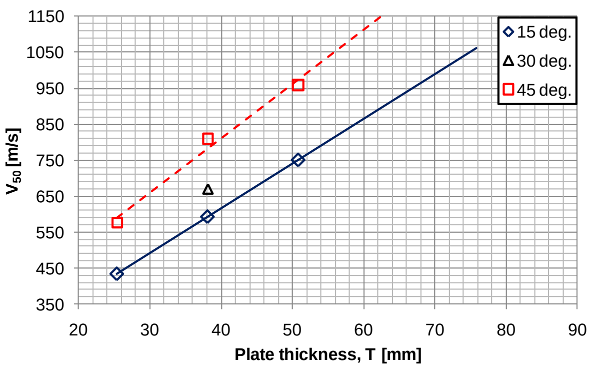

Figure 2: Ballistic limit velocities vs. Plate thickness and the obliquity Θ [23].

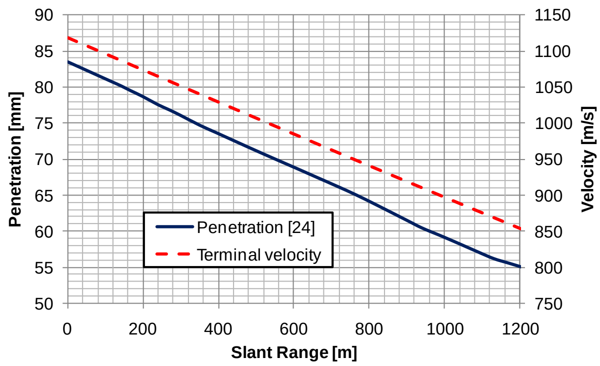

Figure 3: PGU-14 Penetration Results (BHN 300; 30°; 250 Kn Aircraft Launch).

Using simulations of ballistic trajectories for projectile PGU-14 (software MMPM [26]) and for conditions from tests conducted by Brian Tasson and John Burnett, analysis of projectile impact velocity vs. range was performed. In order to achieve penetration capabilities for armour thickness of 54 mm, limit impact velocity should be min. 800 m/s. Impact angle influences the effects of penetration, so situation is additionaly complicated. But, simulation shows that maximal effective range with which certain effect of pentration can be achieved against armour targets is 1.220 m.

The amount of intact DU that is embedded in the sand is impossible to estimate. Some of the ammunition 30 mm PGU-14 and ammunition 25 mm PGU-20 with DU penetrators have been found intact at a depth of 300 mm in soft soil.

2 Dispersion of PGU-14 ammunition during air strikes by combat aircrafts A-10

2.1 Ground attack maneuver scenario

In the close air support (CAS) role, a wide variety of attack maneuvers may be characterized by three general phases (Fig. 4). The first phase, initiated by the pilot perceiving the target, consists of a target acquisition maneuver. This maneuver consists of a rapid rollin toward the target while a normal load factor of 4 - 5g is developed. The roll angle end load factors are maintained until the gun cross or pipper line of sight is near the target. At this point a rollout to wings level, together with a load factor reduction to 1 g, occurs. The second phase of the attack maneuver is the weapon delivery or tracking/firing phase. In this phase, the errors present at the conclusion of the target acquisition phase must be eliminated, and the pipper should be maintained on the target while the gun is fired. The final portion of the attack is characterized by a break phase, which consists of a gross manoeuvre generally, intended to place the aircraft in position for another attack while maximizing aircraft survival. Each of these attack phases will now be examined to obtain the functional requirements [30].

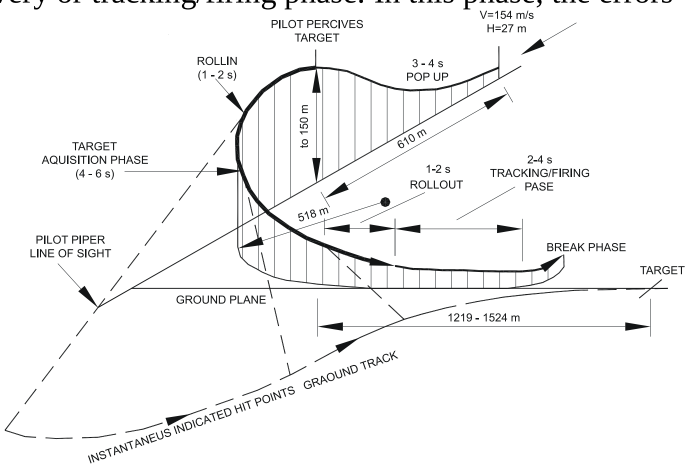

Figure 4: Ground attack maneuver scenario.

Performance of aircraft system depends on system errors and target type, manoeuvre of target, range and especially on air defense system intensity. System errors are error group such as ammo dispersion, gun pointing error, fire control prediction error, aircraft position, orientation, speed and acceleration errors, bore sight errors, target track errors, range errors, state estimate errors including time of flight error, body bending error, etc. With aircraft A-10 mission it is necessary to point out that its efficiency for armour targets with gun GAU-8/A significantly depends on height, distance and attack angle. Higher the distance, height and attack angle, zone of dispersion is increased and system efficacy is reduced.

US research on uses of aircraft A-10 A-10 with gun GAU-8/A against a Soviet tank company simulated by combat loaded M-47 or T-62 tanks are conducted from February 1978 to December 1979. The pilots making the firing passes attacked at low altitude and used correspondingly low dive angles in order to simulate movement through a hostile air defense system [31-37, 42]. In Air Force tests, the A-10 Thunderbolt flew at an altitude about 60 m, an angle of 1.8 to 4.4 degrees, and a slant range of 800 m to 1300 m. The weapon effects on the hard target were 72-90 % miss and 10-28 % percent hit with a 1,7-3,8 % kill. During these tests tanks were attacked with 40-160 ammunition PGU-14 in every aircraft swoop.

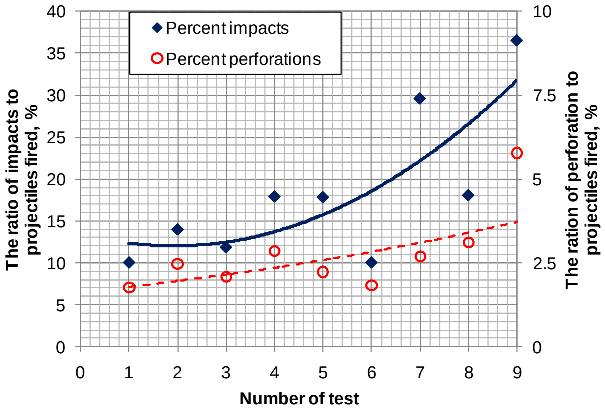

Figure 5: The ratio of impacts/perforation to projectiles fired [31-37,42]

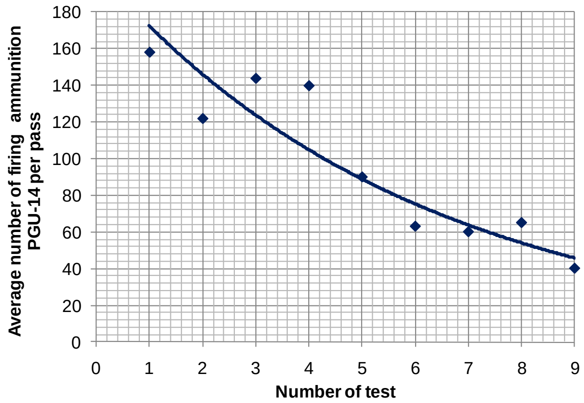

Figure 6: Number of firing ammunition PGU-14 [31-37,42]

2.2 Model for simulation of air-to-ground gun effectiveness

For simulation of projectile trajectory modified point mass model, also known as 4DOF model, was used. Model includes all the major spin effects (equilibrium yaw drift/drag). It provides extremely accurate data for conventional artillery shells. The basic assumption is that the epicyclic pitching and yawing motion of the projectile is small everywhere along the trajectory.

The modified point mass trajectory dynamic equations can be represented with the following two differential equations:

- for vector velocity:

$$m\frac{d\vec{V}_k}{dt} = m\vec{g} + \vec{D} + \vec{L} \qquad \textbf{(1)}$$

- and roll rate of a projectile with no fins:

$$\frac{dp}{dt} = \frac{Sd^2}{4I_x}\rho V C_{lp} p \qquad \textbf{(2)}$$

Drag force is:

$$\vec{D} = -\frac{\rho \cdot \pi \cdot d^2}{8} \cdot C_D \cdot v \ \cdot \vec{v} \qquad \textbf{(3)}$$

where:

$$C_D = C_{D0} + C_{D\sigma^2} \cdot \sigma^2 \qquad \textbf{(4)}$$

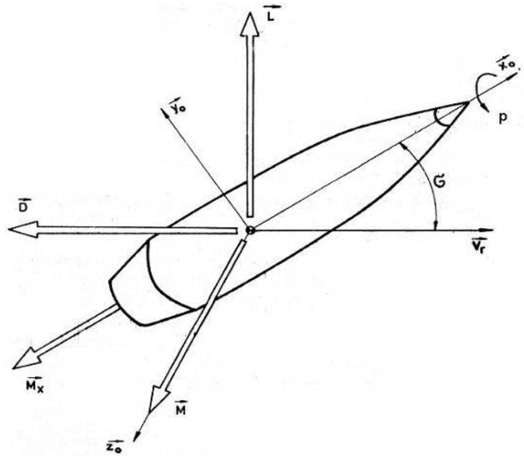

Figure 7: Forces and moments.

C_{D0} - drag coefficient at zero yaw , $C_{D\sigma}{}^2$ - yaw drag coefficient.

Lift force:

$$\vec{L} = \rho \frac{\pi \cdot d^2}{8} \cdot C_{L\sigma} \cdot \left[\vec{V} \times \left(\vec{x}_0 \times \vec{V}\right)\right] \qquad \textbf{(5)}$$

where the magnitude of lift force is:

$$L = \rho \cdot \frac{\pi \cdot d^2}{8} \cdot C_{L\sigma} \cdot V^2 \cdot \sin\sigma \qquad \textbf{(5a)}$$

$C_{L\sigma}$ – lift coefficient

Overturning moment:

$$\vec{M}_a = \rho \cdot \frac{\pi \cdot d^3}{8} \cdot C_{\overline{m}\sigma} \cdot V \cdot \left(\vec{V} \times \vec{x}_0\right) \qquad \textbf{(6)}$$

where the magnitude of overturning moment is:

$$M_a = \rho \cdot \frac{\pi \cdot d^3}{8} \cdot C_{\overline{m}\sigma} \cdot V^2 \cdot \sin\sigma \qquad \textbf{(6a)}$$

$C_{m\sigma}$ – overturning moment coefficient

Roll damping moment:

$$\vec{M}_x = -\frac{\rho \cdot \pi \cdot d^4}{16} \cdot C_{lp} \cdot p \cdot V \cdot \vec{x}_0 \qquad \textbf{(7)}$$

where the magnitude of roll damping moment is:

$$M_x = \frac{\rho \cdot \pi \cdot d^4}{16} \cdot C_{lp} \cdot p \cdot V \qquad \textbf{(7a)}$$

C_{lp} – roll damping moment coefficient for the non-dimensional spin:

$$p^* = \frac{p \cdot d}{2 \cdot V} \qquad \textbf{(8)}$$

Using projection of vectorial equations on axis of local coordinate system, and adding equation for angular velocity, model of modified material point is obtained [26]:

$$\frac{du_k}{dt} = -E\left(C_D \frac{u_k - u_w}{V} + C_{L\sigma}\tilde{\beta}_p \frac{w_k - w_w}{\sqrt{V^2 - v^2}}\right) \qquad \textbf{(9)}$$

$$\frac{dv_k}{dt} = -E\left(C_D \frac{v_k}{V}\right) - g \qquad \textbf{(10)}$$

$$\frac{dw_k}{dt} = -E\left(C_D \frac{w_k - w_w}{V} + C_{L\sigma}\tilde{\beta}_p \frac{u_k - u_w}{\sqrt{V^2 - v^2}}\right) \qquad \textbf{(11)}$$

$$\frac{dp}{dt} = \frac{Sd^2}{4I_x}\rho V C_{lp} p \qquad \textbf{(12)}$$

$$\frac{dx}{dt} = u_k, \quad \frac{dy}{dt} = v_k, \quad \frac{dz}{dt} = w_k \qquad \textbf{(13-15)}$$

where:

$$E = \frac{\rho V^2}{2}\frac{S}{m} \qquad V = \sqrt{(u_k - u_w)^2 + v_k^2 + (w_k - w_w)^2} \qquad \tilde{\beta}_p = -\frac{2I_x}{\rho S d}\frac{g\cos\gamma}{V^3}\frac{p}{C_{\overline{m}\sigma}}$$

I_x - axial moment of inertia of the projectile, p - projectile spin rate (angular velocity), d - projectile diameter, ρ - air density, V - projectile velocity with respect to wind system, $C_{m\sigma}$ - overturning moment (yawing moment) coefficient derivate, depending on projectile geometry, Mach number and Reynolds number.

For solving previous differential equations system, we need to add:

- aerodinamic functions $C_D(M), C_{L\sigma}(M), C_{\overline{m}\sigma}(M)$ and $C_{lp}(M)$
- constants d, m, I_x,
- data for atmosphere $\rho(y)$, $a(y)$ and data for wind $u_w(y)$, $w_w(y)$,
- initial conditions x_0, y_0, z_0, V_{0p}, Θ_0, χ_0 and p_0.

Aerodynamic coefficients of drag and moments, necessary for calculation of trajectory, were obtained from program AERO_SPINER [25, 27] as a function of Mach number, and are shown in following figures.

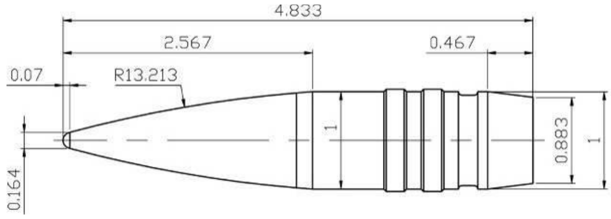

Figure 8: Projectile 30 mm PGU-14/B API (dimensions in calibers)

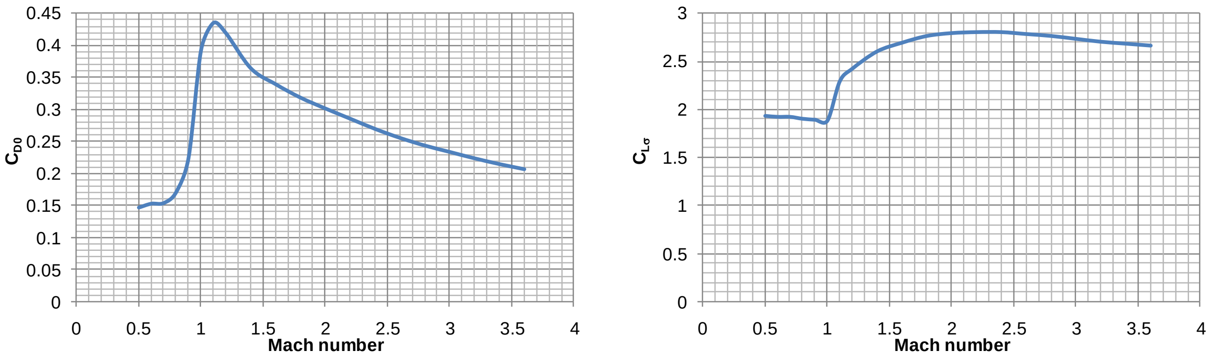

Figure 9: Aerodynamic coefficients: axial force (left) and normal force (right).

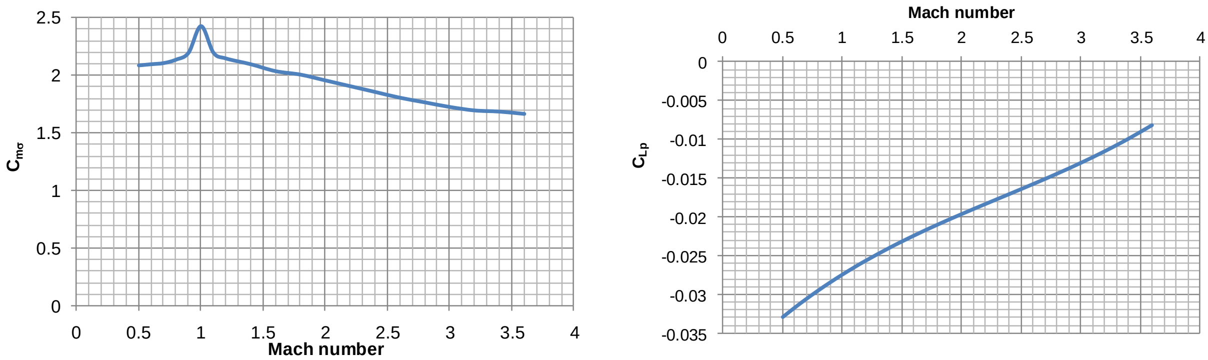

Figure 10: Aerodynamic coefficients: pitching moment and axial (left) damping moment (right).

For verification of modified point mass model in determination of projectile trajectory, results obtained from program MPMM are compared with results given in reference [22]. Simulation is conducted with projectile 30 mm PGU-14/B API with following mass characteristics (fig. 11):

- Projectile mass 426 g,
- Axial moment of inertia, I_x=0.00002999 kg m^2.

Initial conditions used in simulation were:

- Launching height 1300 m,
- Projectile velocity 990 m/s, and aircraft velocity 154.3 m/s (300 knots),
- Launching angle 6°, and
- Standard ICAO atmosphere.

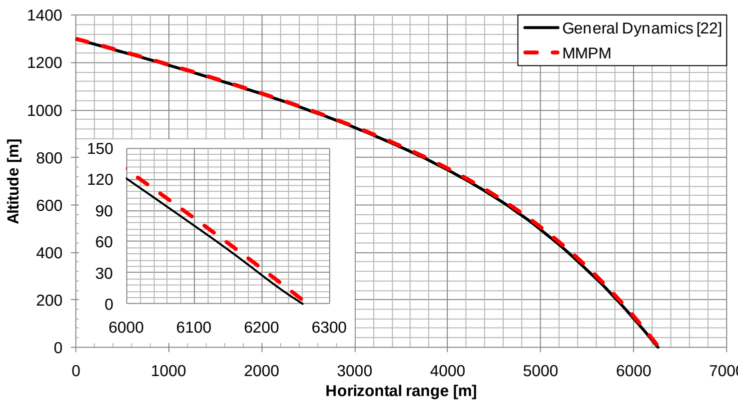

Figure 11: Comparison of trajectory based on simulation with MPMM model and reference [22].

Model which simulates air-to-ground gun effectiveness against a stationary target is shown in figure 12. In the moment of firing from gun GAU-8, aircraft is firing under angle Θ_0 at initial height ($t=0$). At the same time, an initial angle of gun barrel is the same as initial firing angle of aircraft. Aircraft is flying with velocity V_a and firing N projectiles in time t_f with projectile initial velocity V_{0p}. So, projectile initial velocity is now:

$$V_0 = V_{0_P} + V_a \qquad \textbf{(16)}$$

Assuming that, for the time of firing t_f (0.5 to 3 s), aircraft doesn't change its direction, angle and flight speed, change of initial coordinates for every individual projectile is changing according to following equations:

$$x_0(t) = x_0 + t_i \cdot V_a \cdot \cos\Theta_0 \qquad \textbf{(17)}$$

$$y_0(t) = y_0 + t_i \cdot V_a \cdot \sin\Theta_0 \qquad \textbf{(18)}$$

where t_i is change of initial time for N-th projectile. Time t_i depends on firing speed ($V_{N_{projec/s}}$) from gun GAU-8 (65 rounds/sec):

$$t_i = t_{i-1} + \frac{1}{V_{N_{projec/s}}}, \ (t_i\text{=0 to } t_f) \qquad \textbf{(19)}$$

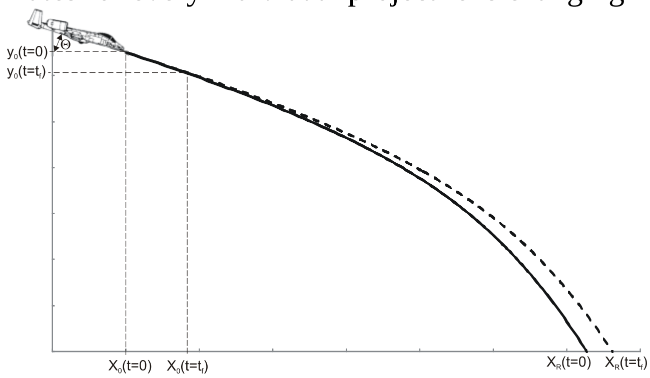

Figure 12: Model of aircraft flight and firing at horizontal static target

In order to assess dispersion on N projectiles during firing in time t_f, it was assumed that there are no changes in elevation angle and drift angle. Model providing the prediction of paths for group of N projectiles, with changes projectile launching angles from -1° to 1° is based on:

- Elevation angle

$$\theta_0 = \theta_0 + \xi \qquad \textbf{(20)}$$

- Azimuth angle

$$\chi_0 = \chi_0 + \xi \qquad \textbf{(21)}$$

where ξ is generated random value of given limitation.

Depending on target distance (from 600 m to 1600 m) and aircraft attack angle, change of aircraft attack height is given in fig. 13.

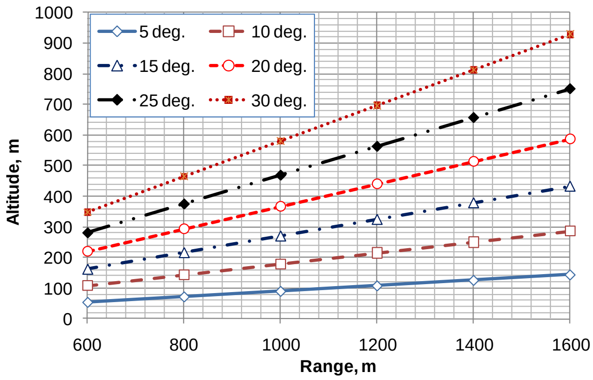

Figure 13: Change of attack height as a function of target distance and aircraft attack angle

For target at distance of 1.000 m and aircraft elevation angle of 5° when firing times were 0.5 s and 3 s, dispersion of hits on horizontal target is shown in following figure.

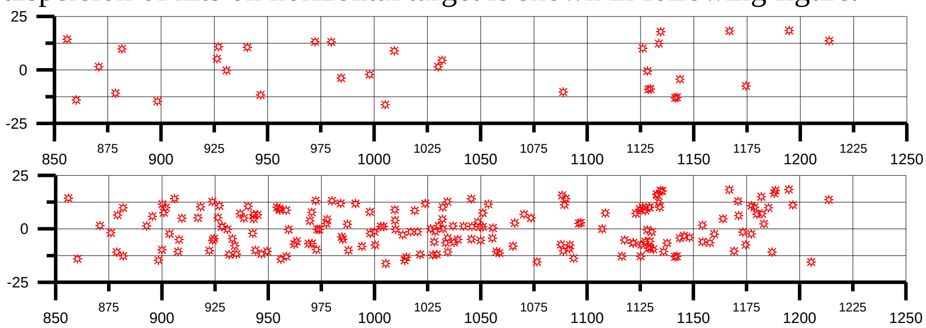

Figure 14: Dispersion of hits on horizontal target for firing times of aircraft $t_f = 0.5$ s (fig. above) and $t_f = 3$ s (fig. below)

Based on hits dispersion, given by previous model, probable error in range, PE_R and probable error in deflection PE_{DF} (figure 15) were determined by:

$$PE = 0.6745 \cdot \sigma \qquad \textbf{(22)}$$

where σ is standard deviation in range (σ_R), or standard deviation in deflection (σ_{DF}).

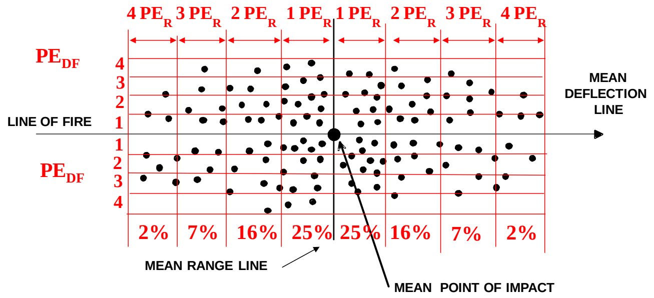

Figure 15: Probable Error in Range and Deflection

Based on hits dispersion for different target distances, aircraft attack angle and firing time, probable error in range and probable error in deflection (fig. 16) are defined.

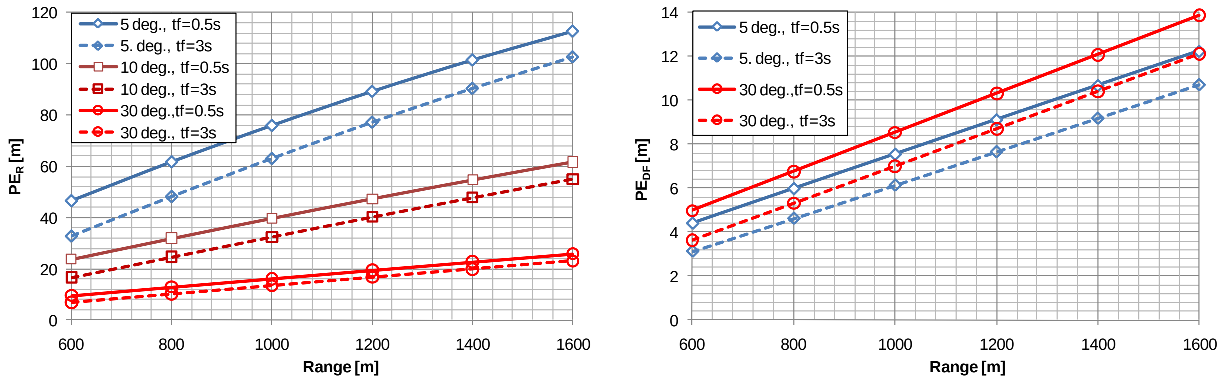

Figure 16: Probable Error for firing times $t_f = 0.5$ s and $t_f = 3$ s, in Range (left) and in Deflection (right)

Analyzing the change of probable error in range, it can be seen that probable error is larger with smaller aircraft attack angles. Compared to attack angle of 5 degrees, probable error in range is decreasing with higher angles, and in the case of 30 degrees the error is reduced by about 4,5 times. Also, it is noticeable that by increasing the firing time, probable error in range is reduced. For firing time of 3 s and target distance of 1.600 m probable error in range is reduced for 12% in regard to probable error in range for the same conditions at firing time of 0,5 s, but for target distance at 600 m probable error in range is reduced for 40%.

Comparing to probable error in deflection, probable error in range is larger with higher angles of attack, but it is less sensitive to changes in attack angles. With increase of firing time the same dispersion trend is maintained and they are in similar relation as with probable error in range.

Probable error in range and probable error in deflection enable us to assess total dispersion zone of projectile (4 PE_R and 4 PE_{DF}).

Simulation shows that dispersion in range and deflection is significantly different from available data. According to these data, dispersion is 5 mill radians diameter in 80 % circle or 80% of ammunition fired at 1.220 m hit within a 6 m radius [38]. Simulation shows that probable error PE_R = 77-90 m and probable error PE_{DF} = 7,5-9 m, depending on firing time (0,5-3,0 s) with firing angle of 5 degrees and range of 1.220m. These differences show that with great concern and reserve we should take into account available data.

Probability of hits is significantly increased when firing time is longer, even though total dispersion zone of ammunition is almost identical. In reality, education and capabilities of pilots should be taken into considerations, as well as his combat experience and especially intensity of anti-aircraft defense, so zone of dispersion can be significantly increased and target efficacy reduced in real combat conditions and harsh resistance of enemy.

3 Aerosolization and oxidation of DU penetrator PGU-14/B at target

During the process of penetration of multiple armour targets, depleted uranium penetrators undergo severe fragmentation. With the type of targets utilized in the study, the only recognizable remaining portion of the original penetrator is normally a small section near the base. Fragments produced are ignited spontaneously by a combination of shock and friction heating at impact. Combustion of fragments in air is exothermic and self-sustaining [39]. Damage to a tank or armoured vehicle target by a DU round can be caused from DU penetrator entries, ricochets, and penetrator splatter fragments.

The five experimental shots were made with DU penetrators PGU-14 of average mass of 271,8 g containing 0,63 to 0,70% titanium. Fragments produced by four DU penetrators fired into armour plate targets are shown a higher concentration of large particles in the exit chamber than in the entrance chamber. They were fired into vertical armour plate targets at 0° obliquity at velocities that varied by only 2% from maximum to minimum. For these tests, typically 1 to 2% of the penetrator mass (~5 g) was aerosolized on the entrance side of the armour plate and an average of about 20% on the exit side (corresponding to the inside of a vehicle). Penetration by DU munitions is a complex mechanism that generates fragments whose armour plate and DU compositions are highly variable. One of the five test shots did not penetrate the armour. For this shot, less than 1% of the penetrator mass was released on the entrance side of the armour [40].

When the penetrator hits a hard object, e.g. an armoured vehicle, the penetrator pierces the metal sheet, generally leaving the jacket behind. The DU dust which may be formed during impact can be dispersed and contaminate the environment. Quantity of aerosol that is formed in the moment of penetrator impact into hard target depends on velocity (critical velocity for given projectile) and penetrator impact angle into the target.

During the research by Hanson and colleagues, with ammunition 30 mm PGU-14, they registered, during the impact of DU penetrator into steel plate, around 0,76 % substances of DU which have dimensions smaller than 53 µm, and around 95 % of fragments had dimensions larger than 500 µm [40].

With penetrators of ammunition PGU-14/B with velocities beneath 800 m/s they achieved perforation of the target by volume deformation and/or plugging. For tank KE projectile velocities above 1.000 m/s the mechanisms of volume deformation and plugging are replaced by hydrodynamic penetration, where the projectiles are eroding during the penetration process.

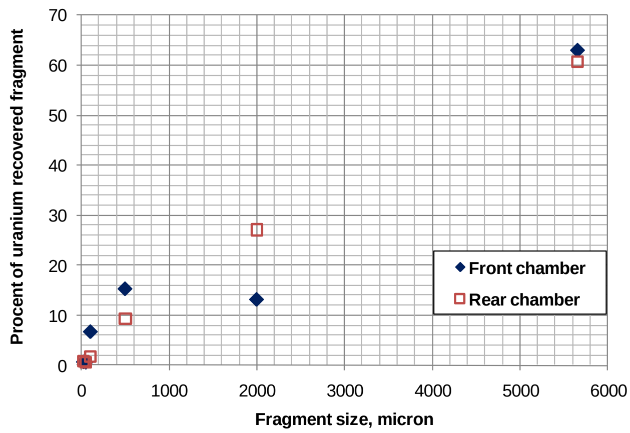

Figure 17: Aerosol vs larger fragment components of Uranium [40]

Penetrators that hit armoured vehicles form an aerosol upon impact or ricochet. Bigger fragments and pieces of DU will remain intact on the ground surface.

Most of the penetrators that impact on soft ground (e.g. sand or clay) will probably penetrate intact more than 500 mm into the ground and remain there for a long time. Penetrators that impact on a hard ground surface such as concrete, rock or stony soil are, after dispelling their kinetic energy into the superficial ground layer, often found lying on or near the soil surface. They are usually found almost intact, or split into large fragments, and have lost only a small part of their mass through the formation of dust or small uranium particles. UNEP established the losses to be 2-5 g in Kosovo after 1,5 years; 11-38 g in Serbia and Montenegro after 2,5 years; and 66-93 g in Bosnia and Herzegovina over 7 years after the conflict (not corrected for loss of weight due to formation of DU dust during the impact). The Han Pijesak Artillery Storage and Barracks was hit with 2.400 pcs. of DU ammunition. There were many hidden DU penetrators at this site. DU was detected in air, soil and lichen samples [29].

By direct evaluation of the area where an Air-strike by A-10 took place in Hadzici, Military Repair Facility, authors identified a number of PGU-14 ammunition impact remains on concrete plateau and facilities. There is relatively small number of identified penetrators comparing to number of identified points of attack. Identified penetrators containing DU or remains of penetrators were mostly in oxidizing state of depleted uranium (green-yellow oxide) on the surface (figure 18).

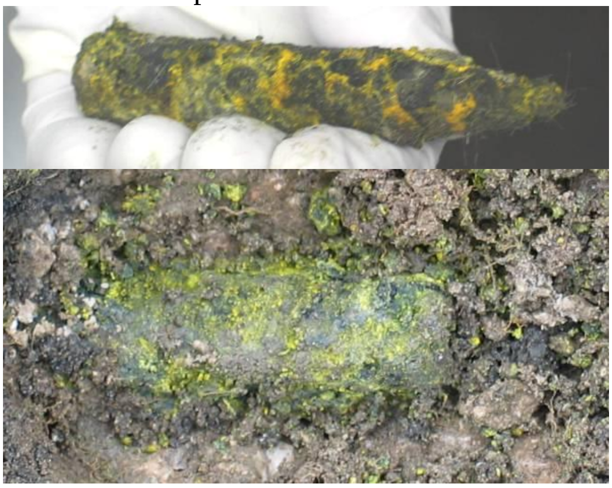

Figure 18: Oxidations of penetrators of ammunition PGU-14/B (Military Repair Facility)

Report of Federal administration of civil protection, Federation of Bosnia and Herzegovina, Bosnia and Herezgovina, number 03-49-1-65/05 from March, 2005, addressed to author Berko Zecevic justifies observation of author on disbalance between retrieved penetrators compared to number of registered points of attack of penetrators. This Report states that there are 643 registered points of contamination with DU but only 40 of them and their parts are identified and two coatings of projectile PGU-14. Within Military Repair Facility there are 92 registered points of contamination and 41 penetrators or their remains (fig. 23).

That clearly indicates that a big number of penetrators after impact on concrete plateau ricochets and failed on larger urban zone of Hadzici. Picture 19, on the right side, shows structural deformation of one of the penetrator which ricocheted and did not penetrate into soil or concrete base. Figure 20, on right side, shows penetrator and coating of projectile together (there was no separation in this case).

Figure 19: Deplete uranium penetrators of ammunition PGU-14/B

Figure 20: Impact penetrator in brick and concrete target

Figure 21 on the left side clearly shows that urban area of town Hadzici is very near Military Repair Facility which was exposed to the air-strike by aircrafts A-10. Due to ricochets of penetrators, a huge number of penetrators are located in urban zones which are used by population and there is a realistic danger from oxides of uranium penetrators in soil that are not found in large amount.

Figure 21: Military Repair Facility in Hadzici and armour vehicle

4 Analysis of an effect of PGU-14 ammunition near urban areas

Mass use of ammunition PGU-14/B in combat actions began some 15 years ago and this ammunition is increasingly used in urban zones. Information on locations and quantity of use of ammunition PGU-14/B are not precise and often contradictory. There is also lack of data on tactics of use of ammunition 30 mm PGU-14/B on different targets from point of view of aerosolisation of DU fragments, oxidation effects of penetrators in different structure of ground etc. A few samples of ammunition 30 mm PGU-14/B that was used will be considered. For this ammunition, there is photo documentation and other data.

Nearby Sarajevo, in town of Hadzici, 3.400 pieces of ammunition PGU-14/B were fired on Military Repair Facility and Ammunition Storage Depot. On Military Repair Facility was fired 1.500 rounds of 30 mm PGU-14/B and registered only 735 points of contamination, 81 penetrator or its parts. In remaining areas of Sarajevo, 5.266 peaces of PGU-14/B were fired but there is no precise data on targeted locations.

Figure 22: Locations of targets in urban parts around Sarajevo (left) and Han Pijesak (right)

Following figures are showing concentration zone of contamination spots in centre of Hadzici (figure 23). Contamination zones within Ammunition Storage Depot have not been identified yet due to luck of financial funds, although 15 years passed after use of ammunition with depleted uranium.

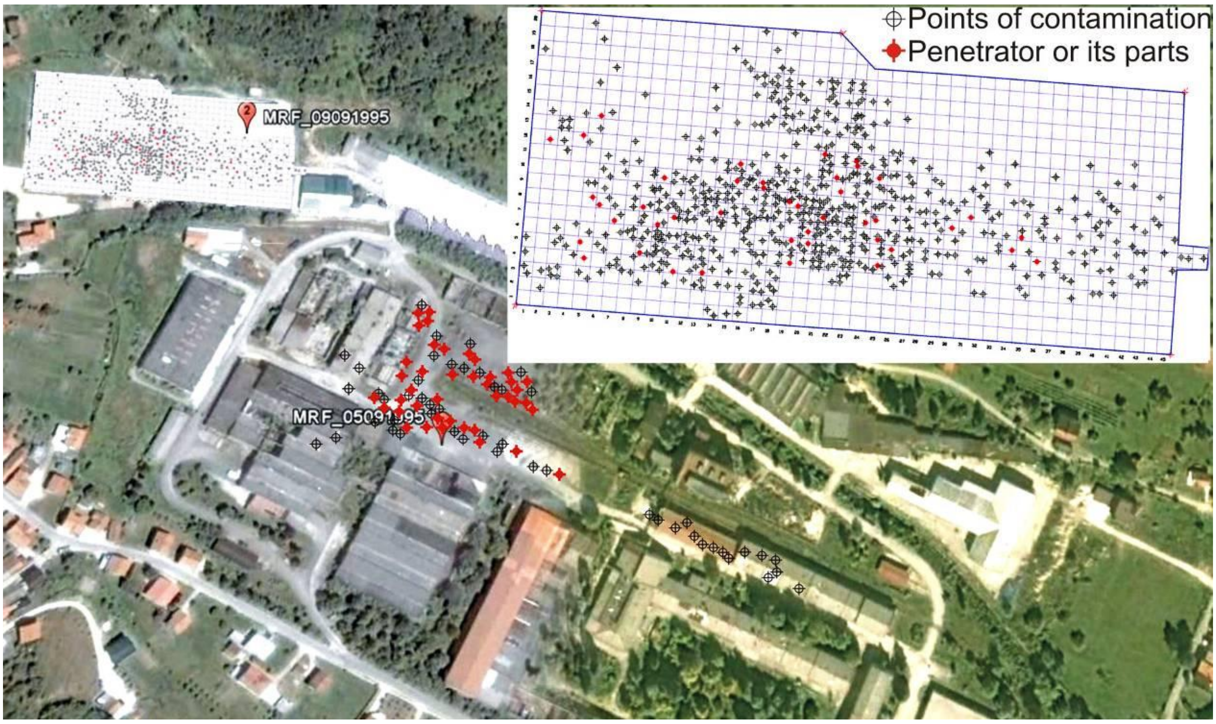

Figure 23: Sarajevo, Hadzici, Military Repair Facility (1995.) [43]

Experience of author during training of local experts conducted in Sarajevo, in September 2003, in terms of identification of contamination spots with DU, scope, quality equipment and procedures demonstrated is not encouraging. There was a lot of improvisation and there was no serious intention to train local experts to enable them to independently detect and decontaminate firing spots with ammunition PGU-14/B. The fact that spots of contamination in Ammunition Storage Depot are not identified yet speaks for itself.

Based on detailed analyses of available video recordings of Agency MS NSB, there were 2 registered attacks on building of Planning and Information Ministries in Baghdad on 8th of April 2003 (Operation Iraq Freedom). Building was hit by minimum 49 ammunition API 30 mm PGU-14/B and with 15 ammunition HE 30mm PGU-13 (figure 24). Expert observers considered that DU ammunitions were used in these attacks. Building is located within the urban part of Baghdad, angle of attack was law and one part of fired ammunition hit the area around building or most probably some of the buildings in vicinity [25].

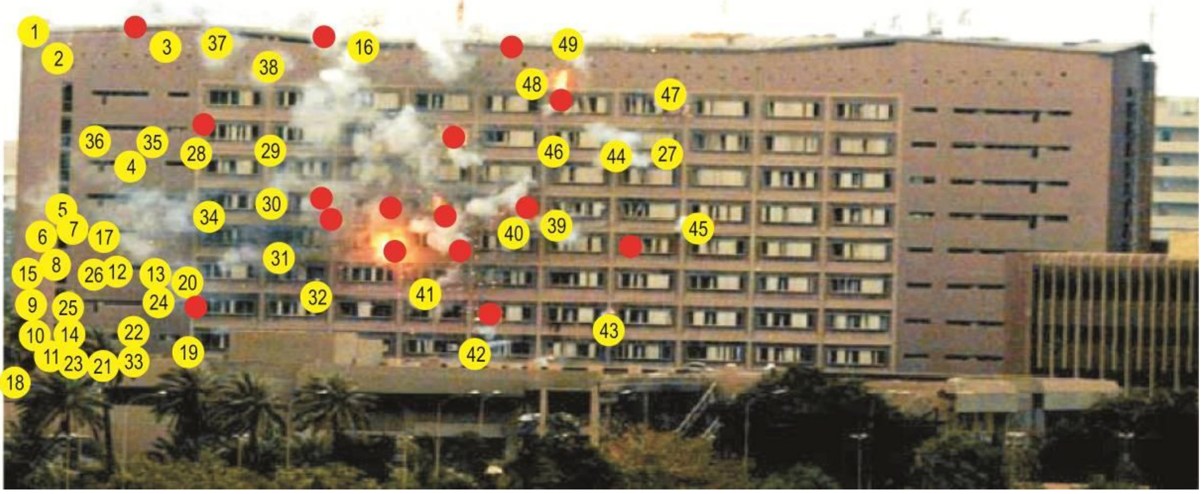

Figure 24: Picture of attack remains on the building of Planning and Information Ministries in Baghdad (HEI-red, DU-yellow)

In Afghanistan, Aircraft A-10 are being used since 2001, for actions against Talibans. As per available video recordings that can be found on internet, those attacks were direct on firing of small facilities in Afghan villages, on road communications, and bunkers on mountains. Data on firing locations is probably not available to Afghan Government and even if they get aware of it, there is no enough of knowledge about it, there is no enough of finances for decontamina-tion of targeted locations with use of DU. On following pictures, there is visible degree of con-tamination with ammunition 30 mm PGU-14/B with penetrator made of depleted uranium (figures 25 and 26).

Figure 25: U.S. Army Paratroopers Call In A-10 Gun Run In Korengal Valley (spots of impact with HEI and API ammunition are visible) [41]

Figure 26: Close air support A-10 Warthog in Afgahanistan

5 Conclusion

Through analyses of use of ammunition with depleted uranium, in war conflicts, in past fifteen years, authors have come to following conclusions:

- There is a huge number of partial or non precise data on real characteristics of 30 mm PGU-14/B ammunition. There are different versions of ammunition PGU-14, with and without tracers, with one or two rotating bands. There is also improved ammunition PGU-14/B with pene-trator.
- Dispersion of ammunition 30 mm PGU-14/B in realistic combat conditions is significantly higher than data for Gattling gun system GAU-8/A produced by General Dynamics Armament. This gun is integrated in the U.S. Air Force's A-10 Thunderbolt II aircraft.
- Projectile PGU-14/B impact on target with velocity less than 850 m/s process penetration is based on mechanism by volume deformation and/or plugging. This mechanism does not have eroding during the penetration process and it does not generate (respiratory sensitive) aerosol particles.

- By impact of DU ammunition PGU-14/B penetrator on armour plate, there were 0,76% DU particles with mass less than 53 µm, or, in other words about 95 % of fragments had dimensions larger than 500µm.
- By impact of penetrators on hard targets, a huge number of penetrators ricochets and contaminates a big zone. That was very often the case in vicinity of Sarajevo. On Military Repair Facility were fired 1.500 pieces of ammunition 30 mm PGU-14/B, only 735 points of contamination were registered while only 81 penetrator or its remains were identified.
- Most of the penetrators had impact on soft ground (e.g. sand or clay) and an intensive oxidation of depleted uranium was registered.
- Ammunition 30 mm PGU-14 is being increasingly used worldwide and very often in urban zones. Local governments do not get required data from NATO to be able to decontaminate those zones. Special issue here is the fact that those are poor countries, with the lack of knowledge, equipment and methods for decontamination.

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