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A NEW APPROACH TO MUZZLE CLIMB REDUCTION IN ASSAULT RIFLES

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Abstract: *The paper addresses a crucial problem in assault rifle design and exploitation, the muzzle climb, proposing a new approach which relies on a combination of high-geometry butt stock and a foldable sighting periscopic, which rise the line of sight to anatomically optimal height. A general frame of the issue is given through critical and comparative analysis of main existing assault rifles from this aspect. Also, a sufficiently thorough qualitative review of recoil process, preceeding the climb, is presented in order to identify points and factors where one can intervene to reduce the effect. For both a broad reference list is provided. The solution is illustrated by a detailed design of optical system comprising an integral prism as the basic part, with the sighting openings, provided through several precise drawings, clearly explaining the idea. A few versions of the solution are given. In the conclusion pros and cons of the proposal are discussed.*

Keywords: *assault rifle, recoil, muzzle climb, butt stock, sight, periscope.*

1. INTRODUCTION

The muzzle climb phenomenon is significant since it influences the directivity of fire, particularly of semi/automatic small arms. It is the result of the complex interaction of two systems, the firearm and the shooter.

The issue of muzzle climb reduction was recognised very early, but only since the WWI it got significance, with an idea to put a scaled down machine gun performance in hands of individual frontline soldier.

There are several aspects of muzzle climb, not separated but rather combined: the cartridge (energy, impulse), firearm system of operation, weapon geometry (in regard to recoil), muzzle attachments, shooter's training level etc.

To acomodate functional anatomy of the (military) rifle shooter, sighting line and its paralel at the top of the butt-stock foot, should be 40-50 mm apart. In conventional rifle configuration, the barrel axis is well above the said butt stock line, which produces a significant recoil torque, hence the muzzle climb.

This paper proposes a new approach to the reduction of muzzle climb by reshaping the butt stock and adding a foldable sighting periscopic, intended to accommodate convenient sighting.

1.1. Aspects of muzzle climb

The muzzle climb, as interaction of two complex systems (firearm and shooter), is triggered by recoil, where the free recoil [#/Free recoil][1] is to be distinguished from the engaged recoil (the firearm firmly supported by the shoulder).

1.2. Firearm – the climb source

The recoil involves (bulet+gases) momentum and the system of transferring this impulse onto the shooter's body. The first means the total energy delivered to the system, while the other the rate of this delivery (impulse diagram) [1-4].

Two categories of firearms can be distinguished: (a) with fixed bottom, and (b) with movable bottom of the cartridge chamber, which means sharp and smother transfer of recoil impulse.

The effect of recoil is best viewed in slow motion, for both of said basic categories of firearms [5-10], with an accent on the gas operation [9-11]. There are also subcategories of the movable bottom principle (blowback - simple, delayed, gas retarded (HK P7, Steyr GB), gas operated (usual for assault rifles), floating automatics (HK G11, AN94), balanced automatics (AEK-971, AK-107 [12]), balanced impacts in automatics (Russian smg Baksan RG-063, AN-94, Russian machine pistol Stechkin's Pernach), long recoil (GM6 Lynx) [13-15], which is of special interest to this research, etc.).

[1] Since the Wikipedia is controversial reference, but often provides valuable information, it will be not quoted in References but only troughout the paper, according to the referencing scheme: https://en.wikipedia.org/wiki/Free_recoil = #/Free recoil

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1.3. The shooter – response to recoil

In the said interaction, the shooter is more complex than the firearm, being a deformable and movable dynamic chain of mutually connected body parts from the hand down to the feet on the ground [16]. As before, participation of the shooter body can be seen in slow motion, in previous videos. It brings difficult to define factors, such as body size, strength of limb conections, level of training, pchychological mood etc.). It is in contrast with fixed or movable (rails and carriage) laboratory firearm support.

The general factors of muzzle climb can be further detailed into: caliber/cartridge, firearm system of operation, firearm configuration (geometry and mass distribution in respect to recoil torque), muzzle breaks, compensators and silencers, contact surfaces between the firearm and the shooter, buffers in the firearm, butt stock geometry (with buffering supports and devices [17], [#/Bump_stock], [18]), burst limiters and cadence reducers, etc.

2. Muzzle climb: Excerpts from comparative chronology

Nearly the three centuries of military rifle evolution was crowned by bolt action rifles, with a typical example of Mauser model 98 (1898) [19]. The form of the butt stock in these rifles, with the butt foot and the neck as the grip, can be considered as optimal to shooter anatomy. The sights mounted just on the barrel are giving the rifle a slim and smooth outlook [19], [20]. The descendants of the Mauser two-lug-lock bolt are locking systems in AK47, and, as 7-lug lock, in M16 [21].

The center-fire cartridge (1866-70), with closely repeatable parameteres in production, Maxim's patent of semiautomatic operation (1881/83), Lebel rifle (1886), first to use smokeless powder (with adjustable pressure diagram) set the stage for a wave of semiautomatic rifle designs (1885-1940), all that to finish with only two widely used models (SVT-38 Tokarev (7.62x54Rmm) and M1 Garand .30 (7.62x63mm)). In respect to butt stock configurations they followed manually operated counterparts.

Among all of them the Avtomat Fedorov (Fyodorov) is worth mentioning, developed in 1913 around Japanese 6.5×50mmSR Arisaka (6.5x51R by C.I.P.), official military cartridge (from 1897), because of lower energy than Russian 7.62x54R (3,140J vs. 3,550J of muzzle energy). Just to compare, the .30-06 (7.62x53mm) delivers 3820J for 151gr (10g), while 7.92x57mm 3934J with 181 gr (11.7g). Arisaka's 6.5mm is obviously related to small-stature Asian troops. Following this logic, the 7.62x54Rmm have similar considerations [#/6.5%C3%9750mmSR_Arisaka], [#/Fedorov_Avtomat], [22].

The real corner stone was the StG44 ('StG' stands for 'sturm gewehr', eng. the 'assault rifle' - AR), gave the name to the whole class of weapons, and opened a new era in design [#/List_of_battle_rifles], [#/List_of_assault_rifles]. It is renamed from the German MP44 (MP - Maschinen Pistole, eng. Submachine Gun - SMG), designed around a new cartridge 7.92x33mm, a scaled-down 7.92x57mm in size and energy. It was a new weapon system, introduced nearly the in-line configuration of the firearm, and iron sight raised above the weapon contours.
The Soviet 'answer' or, better to say, 'parallel work' was 7.62x39mm, M1943. Besides, the 7.62x39mm was not a simple follower of 7.92x33 but also stem from Soviet very good experience with PPSh41 and PPS43, both in 7.62x25mm. Not to overlook the Japanese Type 95 cartridge 6.5×30 mm [22], as a shortened version of 6.5×50mmSR, proposed for the Experimental 1934 Model 2A submachine gun, 10 years before the StG44.

Prior to the StG44, Germans issued the FG42 (Fallschirm Jaeger Gewehr - paratroop machine rifle), a remarkable machine small arm, chambered by 7.92x57mm, which featured full in-line configuration, with coincidence of stock and barrel axes, huge and ergonomic foot of the butt stock, and, hence, both sticking-out foldable iron sights. It fires semiautomatic from the closed bolt and automatic from the open bolt. All these basic features, in combination with a very effective muzzle brake and compensator, reduction of recoil by the spring buffer in shoulder stock, yield a a remarkable stability of semi- and automatic fire for a very powerful cartridge [23-26].

As for the pre war developments of semiautomatic military rifles, the post war period faced the flourishing developments of ARs [#/List_of_assault_rifles]. It seems that the AR design and the problem of muzzle climb are synonyms.

Accordingly, in this paper several designs are considered, conditionally divided into four categories, in respect to rifle configuration and butt stock geometry, recoil torque and sights, as explained above:

- conventional configurations (e.g. AK47 and its descendants),
- near-in-line configurations (e.g. StG44, FN FAL),
- in-line configurations (e.g. M16),
- true in-line configurations (e.g. FG42, SIG SG 510),

with the categorization parameter P, defined as the ratio (Figure 1) $\Delta h/H$, where the Δh is the distance between the stock spine (upper edge) line and the barrel axis, and the H is the stock foot height.

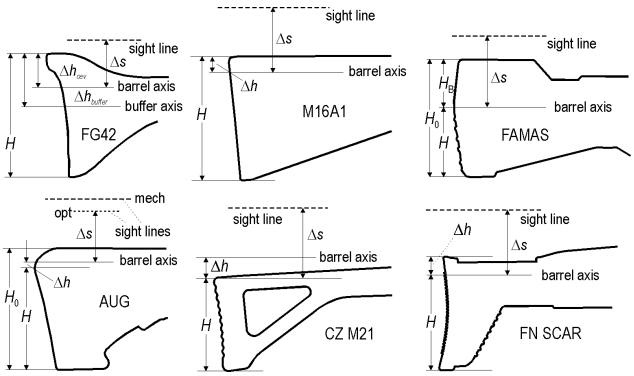

Figure 1. The geometry of butt stock in some ARs explains the idea of the categorization parameter P. Its meaning is umbigous for FAMAS and AUG, and negative for CZ M21. Label Δs designates the distance between

barrel axis and sighting line. (The drawings are not in one scale; zoom in for details)

The magnitudes of the *P* for some ARs are: StG44 (1/10); FN FAL (0) (1/4 in prototype); HK G3 (0); SIG Type SG510-1 (1/3); SIG AM55 (1/3); SIG530-1 (0); AK47 (minus 1/4); AKM (0); M16A1 (1/11); IMI Galil (0); Valmet M76P (1/10); XL70E3/L85A1 (1/3) (XL64 prototype (6.5/28)); Madsen LAR (3/11); Japan Type 64 (3/23) (prototype 5/20); FN SCAR (10/45). Attention should be paid to SIG SG 510 and Stgw 57, in7.5×55mm Swiss, and 7.62×51mm NATO [#/wiki/SIG_SG_510].

Certain AR models are umbiguous, because the butt foot does not cover the whole butt height (H_0 on Fig.1 for FAMAS and AUG). In the FAMAS, which stock appears to provide an excellent P=1/3, there seems to be an active part of foot, while the rest of H_0, labelled by H_B, is on other angle. In the standing firing posture, only the down part of the stock foot engages the shooter shoulder, giving P=0 and convenient anatomy for aiming. Conversly, in the laying firing posture, the upper part of the stock foot is engaged against the shooter shoulder, providing P=1/3 and still convenient anatomical position for aiming. This part of the stock, compising the counter buffer with the hook, serves also as the suitable cheek support, and is instinctive in engagement. So, the FAMAS butt stock is designed with two values of the *P*. In the AUG, with a rounded corner on the stock, decreasing the foot height and lowering its up end, similar effect is not so slear, giving almost P=0.
The recoil and climb of certain ARs can be seen in [27]

Note how the bullpup configuration consequentlyz rises the sight line [#/List_of_bullpup_firearms].

The light machine gun (LMG), being automatic firearm based on powerfull cartridge, features a carefully designed butt stock. The magnitudes of parameter *P* for some models of LMG are: Steyr-Solothurn S2-200/MG 30 (10/23) [28]; FG42 (1/3); Madsen/Saetker (4,5/18); MG34 (6/19); MG42 (8/23); M60 (8/26 for barrel axis) (12/28 for buffer axis). The AR can be considered as smaller version of LMG, adapted to individual soldier. There is a tactical difference between AR and LMG, such that the AR should be portable and easy to carry, while the LMG is more stationary, and often with the assistant to machine gunner. But it does not mean that the LMG stock measures cannot be applied to the ARs. As a good and instructive example is the FG42 (not to be confused with MG42) [#/FG_42].

The risen geometry of butt stock, as significant factor for muzzle climb reduction, calls for consecutive rise of sighting line, i.e. placement the sights (iron or optical) on some platform or support, in firm (e.g. M16, FAMAS, HK G11 or G36, AUG, L85) or foldable manner (e.g. FG42, FN SCAR, QBZ-191, and in almost all LMG). It causes increase of firearm hight, sometimes with design compensation, such as unusual but comfortable and ergonomic forms of hand grips (in FN P90 and FN FS2000, firstly in FG42). These are low-profile pistol- and hand grips, because the usual ones would make the firearm cumbersome in height. It is not applied in FAMAS, because a sufficient length of AR better compensates increased hight than in the case of short FN P90 submachine gun.

It occassionally results in clumsy (as sighting bridge in L85 and in [29]) and bulky (as in FN FS2000) shapes, whatever it may look futuristic in appearance. Introduction and widespread use of Picatinny rail, combined with red dot reflex sights, enabled use of very flexible pallette of mountable and foldable moduli of iron sights (B&T APC223/556, FN SCAR, APC9K, M4 carbine, HK MP7 etc.) red dots, holographic sights etc.

Here, iron sights and 1:1 optical sights (AUG A1 [30] [31], FN P90, HK G11 [32]) are considered as minimal sights, durable, with low maintanance, while all red dots and holographic ones, appart from being excellent, efective, fast acquisition, are sensitive to dust (particularly in urban combat areas) and moisture conditions.

On the other hand, in AN94, with high precision two-shot burst capability, there are fixed iron sights, with conventional stock configuration (P=minus 2/30-3/33) [#/wiki/AN-94], [33-38].

The case of AN94 clearly confirms the methodology of considering the whole set of factors influencing the final climb effect. In order to study one of them the rest should be kept unchangeble. Namely this approach is applied in this paper.

3. Proposed solution for muzzle-climb reduction

Among all methods for reducing the flip effect, this paper considers rising the AR butt-stock axis (the line passing through the middle of the butt-stock foot) close to the barrel axis. This implays the rising of the sightline. As it was said above, it has been usually attained by foldable sighting posts or by placing the sights on a bridge. In the first case, the sights are exposed to impacts and damage, while in the second it increases verrical dimensions of the AR. Solution with foldable iron sights is only partialy effective (e.g. HK MP7, with P=1/3, and B&T APC9 K Pro), where both sights pretty stick out of the weapon contours.

This paper proposes a high geometry stock, fixed or folding, on a new or existing firearm, primarily AR, with the parameter *P* magnitude between 0.3 and 0.5. Then, a foldable sighting periscopic module is installed on the firearm, which, in open position, allows the shooter to comfortably look along/through the iron sights, positioned low on the barrel or on the receiver (Figure 2). In the folded position, while in passive, marching or storaging modes of the weapon use, the sighting periscope is completely into the firearm contour, and can be immediately streched out prior to the action or at the alert mode.

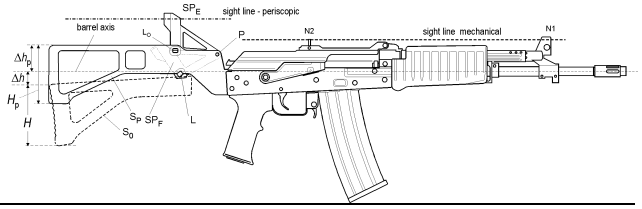

Figure 2. The concept of foldable sighting periscope (SP), installed in the neck of butt stock (here taken as fixed) with risen geometry, showing folded (SP_F) and opened (SP_E) positions, fixed by simple lock (L). (zoom in for details)

There are several variants of the proposal, clearly explained on Figures 2-6. In the basic one, the SP is installed in the cavity of the stock neck (Figure 2 and 3). The slanted wings (39) of the periscope module (SP) protect it from impacts in its open position. The simple lock (L) keeps the periscope firmly in both positions. The cavity shape follows the SP contours, preventing the penetration of dirt in folded position, but enables easy cleaning (in position A of fully opened SP). The periscope's eyepiece window (34) is shielded (33) against direct sunlight, while the objective window (35) by the periscope wings (32, 39).

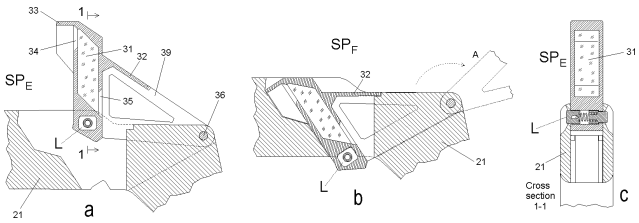

Figure 3. Details of SP simple design, shown in both positions, opened (a) and folded (b). The cross section (c) reveals the lock (L) function.

The compact version (V2 in Figure 4) keeps the basic idea but the placement of the SP is moved forward, providing to the shooter more room for comfortable aiming.

The SP can be also mounted on the receiver (dust cover if CZ M21 (AK) is considered, version V3 on Figure 4), either directly or on Picatinny rail. Positioning of rear sight on the AK47-type dust cover is applied in e.g. Galil, Valmet RK 62, M76F/P/T/W, RK 95TP) [#/RK_62], [#/RK_95_TP]. Folded SP does not obstruct iron sights.

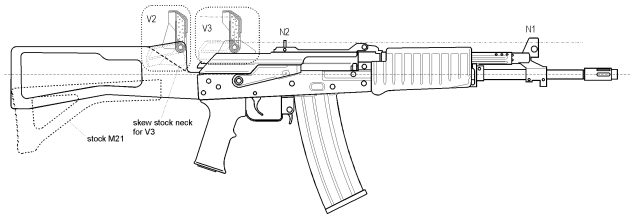

Figure 4. Dotline frames show folding SP in both variants (V2 and V3). Dash line show sighting line over iron sights N1 and N2, through the SP

In another version, the SP is combined with low magnifying optical sight, situated low on the dust cover (receiver) (Figure 5), and not on a high bridge, as in AUG, HK G11, HK G36 etc.

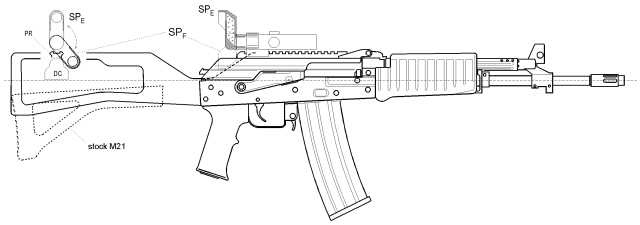

Figure 5. SP as an extension of optical sight mounted on Picatinny rail, shown in extended (E) ad folded (F) positions. Insert on the stock frame shows axial projection of SP, profile of dust cover (DC). The dashed line arc shows lateral rotation between two positions. (zoom-in for details)

Mechanical (iron) sights are the most resistant to dirt, dust and dewing. By inserting any glass surface in the sighting line adds a place for dust and/or dew catching. The proposed solution brings in this shortcoming not more than any other case. The designers admitted that fact by adding auxiliary crude iron sights besides the main optical one (as in AUG A1 and FN P90). In general, the designers admitted inadequacy of foldable iron sights by making them foldable.

This solution makes the rifle slimmer, which has positive effects on its design, production and mass. It also greatly improves overall manipulability (carrying, operation), suitability to place, store and transport. It is a well known rule in industrial design: effective design is elegant [39,40].

Apart from being prone to dust and moisture, each optical element in sighting line inserts attenuation of light. Even for iron sights the notion of sight transparency is valid, especially for aperture sights. Also, protective shields on front sight are not out of consideration, e.g. TV-like protective frame on AN-94, or the difference in size of protective cylindical shield on AR Galil, versions for Israel and for South Africa. This solution provides a reserve for lateral broadening of sighting aperture in order to increase illuminance.

Optical sight, with the reticle (e.g. AUG A1, FN P90) provides one-point alignment with the target, which means far qucker acquisition than by alining two iron sights with the target, parallax involved.

As for the butt stock, two versions are possible, fixed or foldable, with the latter in two variants: on the left, as in AK familly, or on the right, as in this proposal. It is a loop-form stock, with long opening for easy reach of cocking handle, safety lever, not obstructive to cases ejection (Figure 4).

Some originally 'optical' firearms (Steyr AUG A1, FN P90) were converted into Picatinni-open platforms. The same is for AK74 successors, CZ M-21 included, used here as a platform for proposal illustration (Figure 5). But the foldable mechanical sights remaind in, now just taking modular, accessory form (FN SCAR, HK MP7, B&T APC9 etc). Broad application of red dot reflex sights essentially changed this issue. Having necessary hight, they alow the risen stocks, but such sights still are sticking out of the AR contour.

When applying (transferring) distinct linear configuration of LMGs to ARs, one should keep in mind that the LMG recoils mostly the lying-down gunner, with some percentage of exceptions of standing or kneeling posture (usually in the shelter). It seems that the LMG counteracts the shooter's whole mass, but it is rather a dynamic process, beginning with the jerk in the shoulder, starting a deformation shockwave which propagates alog the gunner

lying body. On the other hand, the slow motion of the continuos fire from a LMG, whith the gunner in standing posture, and not from the hip but from the shoulder, shows pretty narrow burst cone, giving the confirmation for the said transfer LMG – AR. This is why the consideration of LMGs is included in this research.

Speaking of the muzzle climb, it would be better to call it 'flip' than the 'climb', since there is a combination of vertical hop of the firearm and also a lateral one, as a consequence of recoil torque around the torso axis (spine) [23].

The LMG class of firearms is an obvious example what effect provides the butt stock with high geometry. Already mentiond German FG42 is possibly one of the most striking cases how to put heavy recoil under control. Here, one should not overlook contribution of very efficient muzzle break, and a spring buffer in the line of recoil, which, again, confirms combined and inseparable influence of all factors in climb reduction. Anyway, it is evidently that the butt stock high geometry is one of main factors. Similar effect can be noticed in SMG Walther MPL/K [7].

In general, the sliding mechanism (so-called long recoil), as with the cannon on its carriage, or in some small arms (e.g. HK G11 [42], AN94, GM6 Lynx, Hungarian heavy sniper rifle [13-15]) is able to transfer the recoil almost without disturbing the receiver (which mass includes (a part of) the shooter mass). What it demands is the length, a very precious resource in a firarm design. But it is a very obvious demonstration of recoil. In this context, it will be interesting to compare the 2-burst and 3-burst long recoils in AN94 and in HK G11, respectively, taking into account the energy of 5.45x39mm and of 4.73x33mm cartridges, through an multiaspect study (recoil length, complexity of mechanism, rifle verical bulk etc.) [#/Heckler_%26_Koch_G11], [32], [41-45].

Here a lot of attention has been paid to HK G11 and Russian AN94, though they both did not find their way to service ARs, but the are conceptualised right to muzzle climb reduction and are a instructable cases which reveal basic ingredients of the phenomenon.

4. CONCLUSION

The muzzle climb is the result of interaction firearm-shooter, comprising many factors. The reduction of this effect involves many aspects, which act in sinergy. If certain is individualy considered then the rest are assumed constant. Because of the said sinergy, it is not easy to establish a hierachy in the list of factors, but also it is not impossible.

This research has been focused on high geometry of butt stock as a means for the muzzle climb reduction. This imposes high sight line either through foldable sights or firmly rised sights (bridge, post).

The proposed solution is illustrated through several variants, thereby confirming the potential. It is actually not a part of the sight but rather an optical extension of existing low sightline. There is no need of zeroing of the SP at each (un)folding.It is not a periscopic sight but the sighting periscope (SP).

It is easilly applicable even on existing models, providing advantageous effects.

However, such solution brings glass surfaces into the sighting line, as spots susceptible to dust, dirt and dew, but nothing more than in other sights with optical elements (e.g. red dot, holographic, optical sights).

Speaking of e.g. red dots, they are fast-acquisition and easy-to-use, with one-point alignment. The SP, relying on existing iron sights, demands two-point alignment. The red dot is usually with wide window, either in 'tube' or 'open' designs, delivering a high sight transparency to the shooter's eye. The periscope windows (apertures), although having modest openings, provide high transparency because its aperture is close to shooter eye. As for the maintanance of red dots (cleaning, battery replacement), the cleaning is more critical (two glass surfaces), but one battery enables run for hundreds and even tens of thousands of hours.

The iron sights are of minimalistic design, low profiled (do not stick off the firearm contour, not prone to impacts and damage), quite resistant to dust, dirt and moisture, reliable, no power consumption, low maintainance. In brief, the author's intention has been to preserve such minimalistic and reliable design but to incorporate it in the high-profile butt stock. Therefore, the proposed solution keeps the firearm vertical compactness. The sighting periscope is only an optical extension of available iron sights.

One more point: the high-positioned butt stock goes off its line of joint to the AR receiver, which causes recoil torque at the joint. Anyway, such load is considered as modest, and easy to handle with proper design.

As the final line, the proposed solution can be cosiderd as promising, giving the room and perspective for further research and application.

A part of it is implemented through a prototype, with a periscope having two little mirrors (instead of a prism). The periscope module (version for on-top receiver) has been mounted on several models of firearms (AUG A2, HK MP5, FN P90 (with Picatinny rail)) just to examine throuhg-visibility of target, speed of instinctive target acqusition, parallax and double image effect in aiming with both eyes.

Because of obvious reasons the high profiled butt stock was not prototyped to examine the main issuu of thiss research – muzzle climb reduction. These virtues of the proposal were left for further examination and verification by practical implementation.

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