# Maintaining Overmatch and Standardization for Future NATO Small Arms

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# In Memory of Jim R. Schatz (1959-2017)

**2015 Chinn Award Winner, US Army Veteran, Small Arms Expert and Mentor**

# Basic Terminal Performance Information

- Instantaneous incapacitation can only occur if the CNS is disrupted.
- Absent of CNS disruption, physiological incapacitation is generally due to inflicting enough damage to the major organs and blood vessels in the trunk to induce circulatory system collapse.
- A bullet has to penetrate at least 12 inches of tissue to damage the vital organs and major blood vessels within the trunk from unideal angles and through intermediate body parts.
- The two wounding mechanisms of small arms bullets are: TISSUE CRUSH (PERMANENT CAVITY) and TISSUE STRETCH (TEMPORARY CAVITY).
- SHOT PLACEMENT is always the most important variable for physiological incapacitation. However, the AMOUNT OF TISSUE DAMAGE and the DAMAGE LOCATION are also significant factors.

# Basic SS109 Information

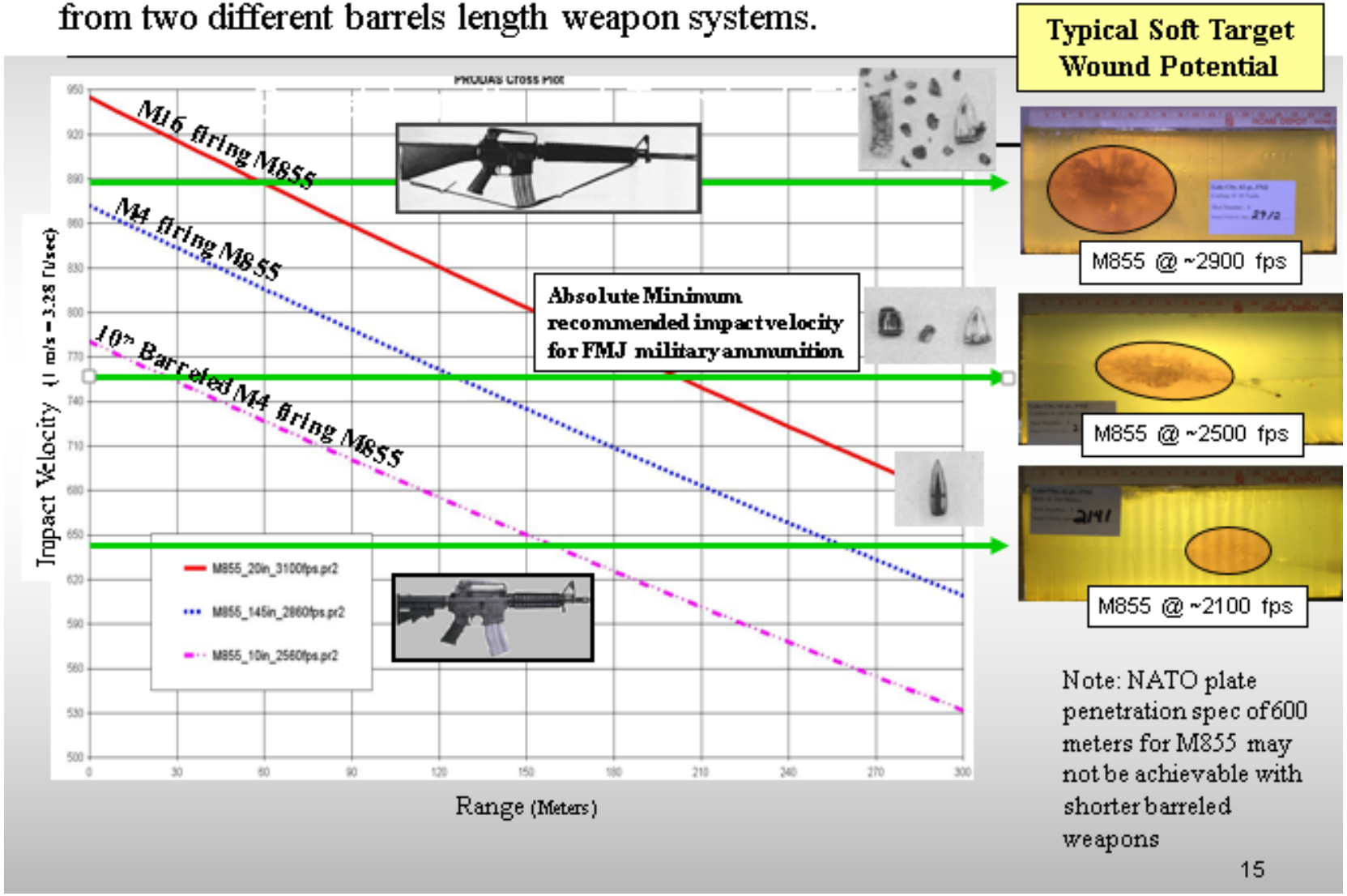
- SS109 style cartridges are the current NATO standard ammunition for 5.56mm rifles and LMGs.
- All 5.56mm SS109 FMJ rounds weigh 62 grains and have a steel penetrator but their jacket thickness and steel penetrator sizes, “the type and position of the cannelure and overall bullet length” can be different depending on the country of manufacture.[1]
- Although the performance of 5.56mm SS109 projectiles are still acceptable for LMG use, the GWOT has shown that SS109 style rounds are not ideal for rifle use.

[1] Lucien C. Haag, “5.56x45mm SS109/M855 Bullets: Design, Exterior and Terminal Ballistic Performance,” *AFTE Journal* 33 (2001): 21.

# Terminal Performance of US and BEL SS109 Rounds

- US M855 may yaw and fragment in soft tissue if the impact velocity is at least 2700 fps.
- Bullet fragmentation acting in synergy with a large temporary cavity can result in an enlarged permanent cavity. If a rifle projectile fragments in tissue and the individual bullet fragments travel laterally away from the main wound track, then the tissue that was perforated by bullet fragments can no longer withstand the subsequent temporary cavity stretch and pieces of tissue become detached.
- The M855's terminal performance is reduced when its impact velocity is under 2700 fps because it will no longer fragment but may break into two pieces until the impact velocity is under 2500 fps.
- The soft tissue terminal performance of Belgian manufactured SS109 is very similar to that of M855.

Below: Cross-Plot showing two different ammunition types, from two different barrels length weapon systems.




Source: Mark D. Minisi, "Soft Target Terminal Ballistic Testing Standardization for the U.S. Military" (presented at the National Defense Industrial Association Conference, Las Vegas, Nevada, May 10-13, 2004, http://www.dtic.mil/ndia/2004arms/session9/minisi.ppt), 15.

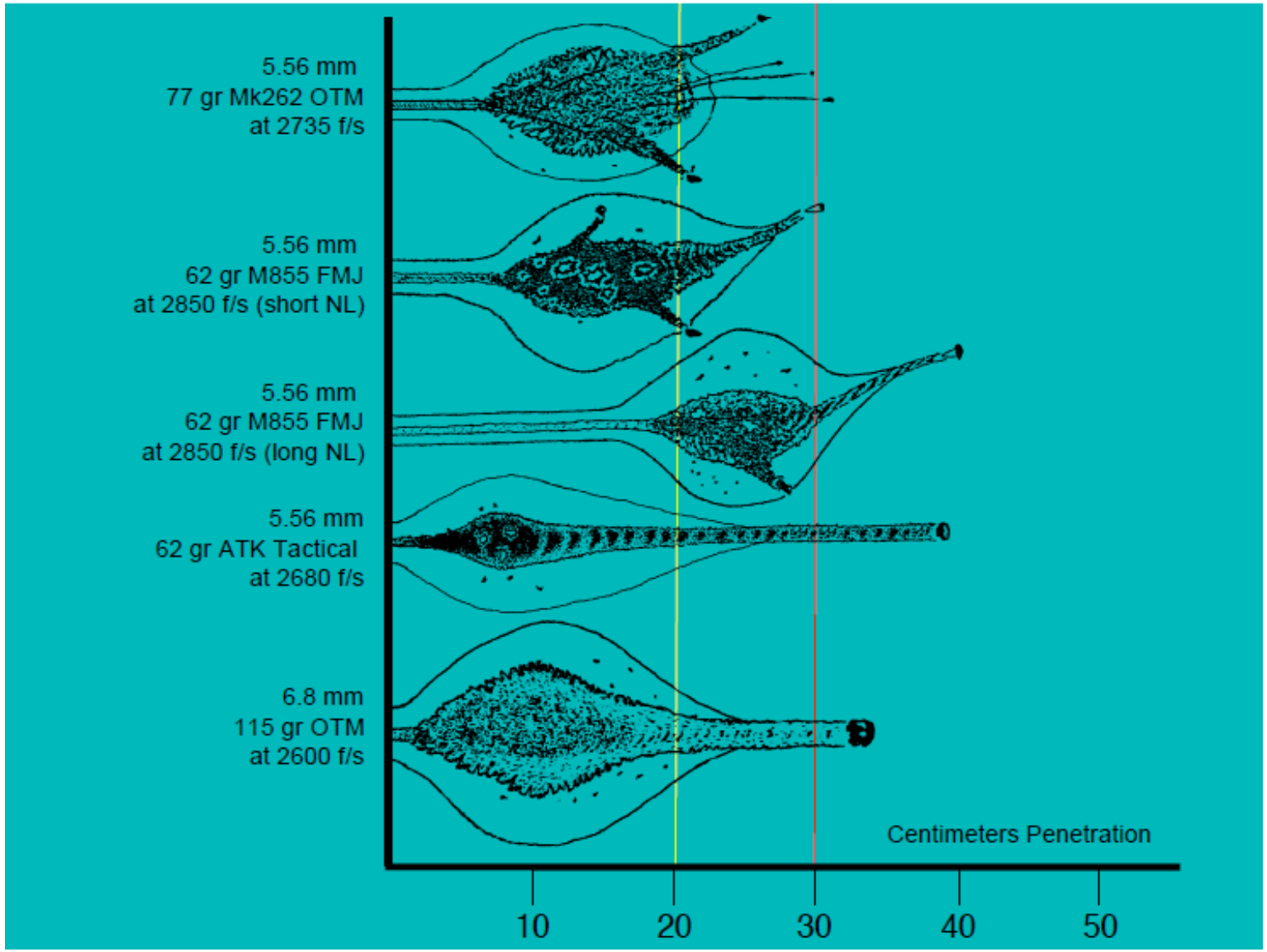
# Impact Yaw Induced SS109 Terminal Performance Variations

- Dr. Gary K. Roberts, a member of the JSWB-IPT, explained that:

  > JSWB-IPT testing demonstrated that 5.56 mm [military] projectiles are highly susceptible to AOA variations, particularly when using FMJ loads such as M193 and M855. For example, 5.56mm FMJ bullets at higher AOA's, like two to three degrees, had a shorter Neck Length and upset rapidly, thus providing adequate terminal effects; at low AOA, like zero to one degree, 5.56mm FMJ rounds penetrated deeper than ideal prior to initial upset (ie. long Neck Length) with significantly reduced terminal effects. Open Tip Match (OTM) were less susceptible to AOA variations than FMJ. Fleet Yaw is the other significant yaw issue discovered by the JSWB-IPT. Fleet Yaw is the terminal performance variation caused by inherent variability in each rifle and occurs in all calibers. 5.56 mm FMJ appears to suffer more Fleet Yaw induced variability than other projectile calibers and types.[2]

- A bullet's penetration depth before upset (yaw, deform or fragment) is known as the Neck Length.

[2] Gary K. Roberts, "Review of Infantry Magazine 2006 Lethality Article" (Unpublished material).




Source: Gary K. Roberts, "Time for a Change: U.S. Military Small Arms Ammunition Failures and Solutions" (presented at the National Defense Association Conference, Dallas, Texas, May 19-22, 2008, http://www.dtic.mil/ndia/2008Intl/Roberts.pdf) , 16.

# Post-Barrier Terminal Performance of SS109 style projectiles

- 5.56mm SS109 style ammunition usually exhibits poor terminal performance against adversaries who are protected by intermediate barriers such as automobiles, glass and walls and these threats are often encountered during the GWOT.

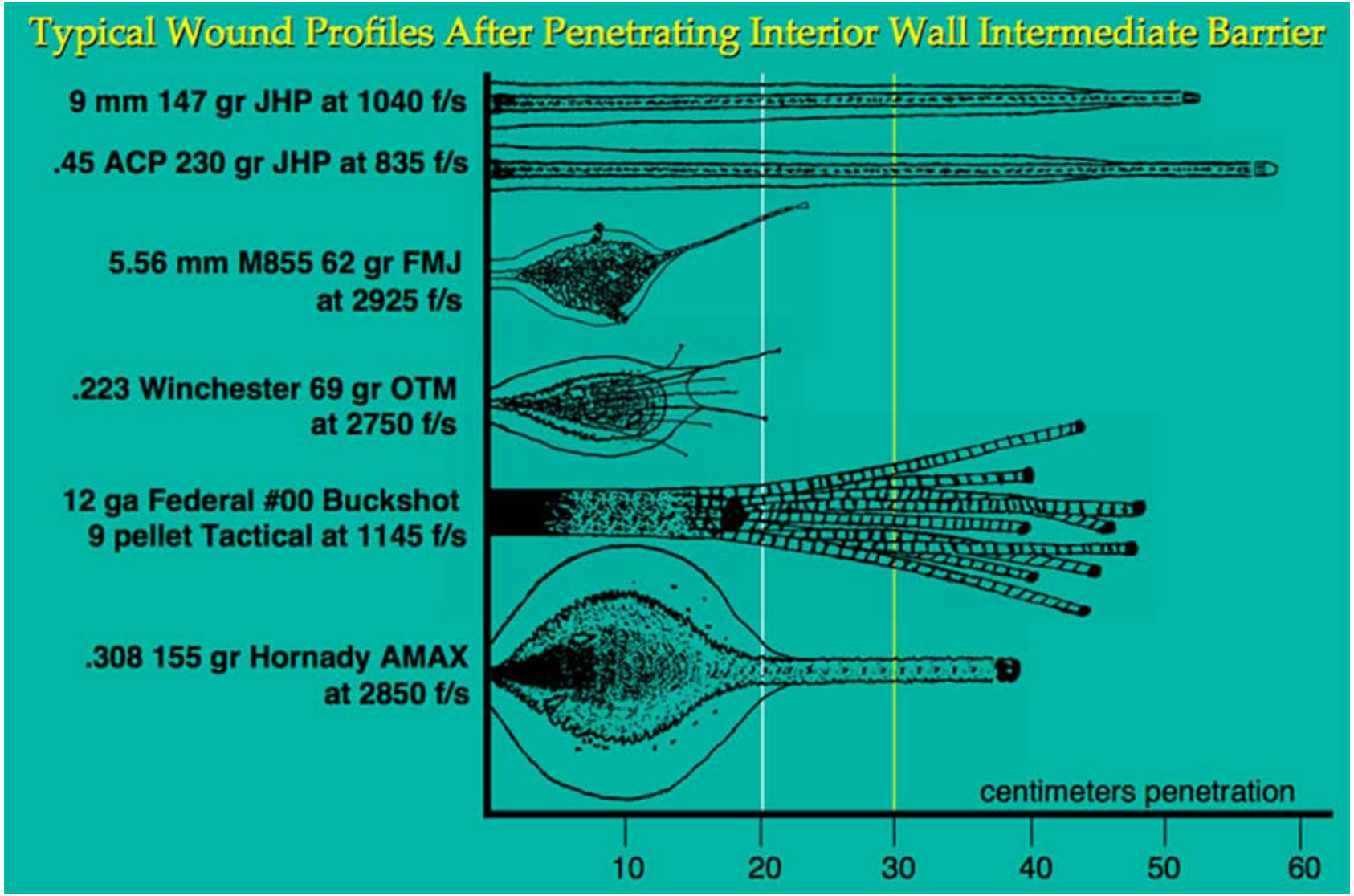
M855 fired from a M4A1 carbine through automobile glass set at 45 degrees into calibrated 10% gelatin at 5m, 100m and 300m (left to right) .

Source of Images: Shawn P. Spickert-Fulton and Jeffrey Schutz, “Blended Metal Technologies Projectiles Review and Analysis” (Technical Report, Armament Research, Development and Engineering Center, 2007), 119-121.

## Table 1: M855 fired from the M16A4 rifle and M4A1 carbine through automobile glass set at 45 degrees into calibrated 10% gelatin

| Ammunition/Weapon Combination | Range | Average Values for Maximum Penetration Depth |
|---|---|---|
| M855/M16A4 | 5m | 8.86 inches |
| M855/M4A1 | 5m | 8.52 inches |
| M855/M16A4 | 100m | 8.32 inches |
| M855/M4A1 | 100m | 7.34 inches |
| M855/M16A4 | 300m | 7.50 inches |
| M855/M4A1 | 300m | 7.02 inches |

Source : Shawn P. Spickert-Fulton and Jeffrey Schutz, “Blended Metal Technologies Projectiles Review and Analysis” (Technical Report, Armament Research, Development and Engineering Center, 2007), 119-122.




Source: http://i459.photobucket.com/albums/qq319/DocGKR/Interior_wall_shots_zps66defaff.jpg

# Table 2: Key Performance Parameters

**Key Performance Parameters Chart (KPP)**

| KPP# | Minimum Performance Requirement of individual characteristics seen in the gelatin block test | To maximize effectiveness of the projectile… |
|---|---|---|
| 1 | Initial Yaw, or "onset of first significant yaw", should be less than 3 inches from impact point. | •The closer IY is to the impact point the better. |
| 2 | Distance from impact point, to Temporary Cavity Maximum Diameter should be between 4 and 6 inches. | •The larger the TCD is (in the 4 to 6 inch range) the better. |
| 3 | Minimum penetration depth should be no less than 12 inches. | Deeper is better. (Note rule 2) |
| 4 | Fragmentation/Expansion is desirable.<br>•Make note of the general pattern, mass-distribution, projectile mass recovered and fragment sizes. Fragments under 1/8" ignored.<br>•NOTE: International Law must be observed as required | •The deeper the distributed pattern, the better.<br>•Greater mass-percent recovery is better.<br>•Larger wound channels are better |
| 5 | Consistency is desirable from shot-to-shot.<br>•The Average standard deviation of any of the individual measured characteristics should be no more than 20%. | •The smaller the deviations, the better. |

Source: Mark D. Minisi, "Soft Target Terminal Ballistic Testing Standardization for the U.S. Military" (presented at the National Defense Industrial Association Conference, Las Vegas, Nevada, May 10-13, 2004, http://www.dtic.mil/ndia/2004arms/session9/minisi.ppt), 11.

# “Eight Points of Light”

- Buford Boone of the FBI BRF recommended his “Eight Points of Light” to dictate general purpose rifle ammunition performance. Granted that the “Eight Points of Light” are ratified as a whole, they would conform to legitimate military needs and not contravene accepted international laws. Projectiles need to:
  - Be blind to impact yaw
  - Limit penetration to 12-18 inches
  - Resist yaw in tissue, with no yaw earlier than 12 inches
  - Continue on shot line after penetrating tissue
  - Be blind to barriers
  - Limit fragmentation
  - Perform consistently from 0 – 300 meters
  - Be accurate enough to engage human targets to 600 meters[3]

[3] Gary K. Roberts, “Wounding Effects of Military Small Arms during the Past Century” (Unpublished material), 13.

# Larger Intermediate Rifle Calibers for Military Use

- Newer, improved US 5.56mm military bullet designs have maximized the performance of the 5.56mm caliber for military use. But the US military desires further improvements in ammunition capabilities for future small arms.[4]
- A caliber study conducted by US Army RDECOM tested identical modern bullet configurations in .224”, .243”, .257”, .277” and .30” caliber and showed that the .277” (6.8mm) caliber was ideal in terms of physiological damage potential. This caliber study was presented by Mark Minisi in March 2010.

5.56mm Section View & Upsets

Source of Image: ATK, “5.56mm & 7.62mm Special Carbine, Barrier,” accessed October 20, 2015, http://lem.nioa.com.au/products/download/192/presentation-556-762-special-carbine-barrier-international.pdf.

The 5.56mm Mk318 Mod 0 SOST round is blind to impact yaw and blind to barriers, thereby addressing the SS109’s terminal performance issues.

[4] Email communication from MAJ James Williamson (USMC) to author, October 30, 2014.

# Some of the major findings from the RDECOM caliber study's Summary of Analysis are the following:

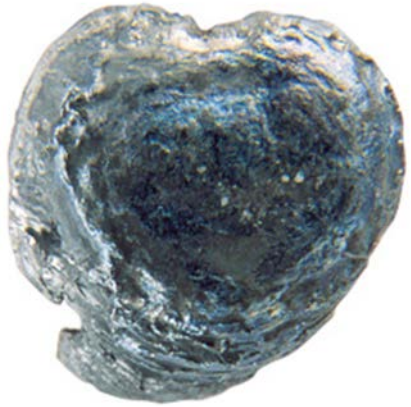
- Larger caliber bullets do more damage to the target, mostly proportional to MV^3/2--increase in damage capacity is larger than increase in system weight.
- Barriers: Larger caliber bullets required to penetrate certain barriers (range)
  - On barriers where smaller calibers also penetrated, larger calibers had measurably high post-barrier target damage.--.277 split top performer by weight, with .30 in these tests.
- Damage based methods and methods that focus on "good hits" will favour larger calibers--.277 caliber the best performer, by weight in this test.
- Stowed kills:
  - Will always favor lighter systems
  - Disproportionately biases weight against performance
  - Mathematically, we should choose BB guns
  - Should be coupled with other gages (requirements) to be meaningful to the soldier
  - .224 caliber was the best performer by weight when using this method [5]

[5] Jim Schatz, "Where to Now?" (presented at XXVIIth European Small Arms and Cannon Symposium, Shrivenham, UK, August 21 2013), 19.
Note: For the complete Summary of Analysis, please refer to Jim Schatz's presentation cited above.

# Potential Intermediate Caliber Options

- A 6.5-7mm caliber intermediate cartridge with a case capacity around 40 grains H2O can offer improved terminal performance over 5.56mm along with good external ballistics.
- Current examples of such intermediate cartridges developments include Cris Murray's 7x46mm and 6.8x46mm UIAC and the AMU's .264 and .277 USA.
- A general purpose rifle projectile for 6.5-7mm caliber should produce a Neck Length of 2 inches or less along with the most tissue damage in the initial 10 to 12 inches of penetration and be compliant with Buford Boone's "Eight Points of Light."
- A SOST-style design manufactured with a bonded core may likely be the military projectile configuration that best meets the "Eight Points of Light."

- A bullet design with a bonded core is less likely to experience jacket and core separation after striking an intermediate barrier, which generally results in better weight retention.[6]
- “This mass retention aids in conservation of momentum, which helps lead to ideal penetration depths and provides for a very controllable, repeatable and ‘programmable’ upset. When the bullet geometry is known and inconsistent or unexpected fragmentation does not occur, it is typically much easier to design a bullet to perform consistently throughout all different mediums.”[7]



Source of Image: http://www.le.vistaoutdoor.com/wound_ballistics/load_comparison/images/LE223T3_Bare_Gel_EB.jpg

.223 caliber Federal Tactical Bonded JSP is an example of a successful barrier blind loading that is used by US LE.

[6] Email communication from Justin Pierce, Gov. and Intl. Programs Engineering Manager for Vista Outdoor, to author, June 30, 2016.

[7] Email communication from Justin Pierce, Gov. and Intl. Programs Engineering Manager for Vista Outdoor, to author, July 21, 2016.

- Armour piercing rounds utilizing a tungsten carbide penetrator should be developed for a 6.5-7mm caliber intermediate cartridge for use against peer adversaries wearing hard body armour.
- In order to reduce weight, a 6.5-7mm intermediate caliber could be developed as polymer cased telescoped ammunition or with a polymer and brass hybrid conventional case.

Source of M993 Image: https://fas.org/man/dod-101/sys/land/m993.htm

Source of Mk323 Mod 0 Image: http://portairspace.com/news/article/mac-llc-develops-lightweight-ammo

# Basic Information about NATO Qualification for Ammunition

- Small caliber ammunition designs that have passed the tests defined in the M-C MOPI and their respective STANAGs are considered to be NATO Qualified.
- The Qualification Approval Test is intended to confirm whether a candidate ammunition design complied with its respective STANAG and the M-C MOPI.
- One of the tests conducted for the Qualification Approval is the Function and Casualty Test using NATO Nominated Weapons (NNW).
- Currently, the following assault rifles are 5.56mm NNWs: M16A2/A4, G36, FNC, SA80A2 and AR70/90.
- For the Function and Casualty Test, each 5.56mm NNW assault rifle model is required to fire 500 rounds (160 rounds at +52 °C, 180 rounds at 21 °C and 160 rounds at -54 °C) of the contending ammunition design (apart from the retest ammunition quantity).

- The acceptance/reject criteria for the portion of the Function and Casualty Test conducted with 5.56mm NNW assault rifle models are the following (See Table 3):

**Table 3: Function and Casualty Test Information for 5.56mm Assault Rifles**

| | Sample | Sample Size | Cumulative Sample Size | Acceptance | Reject |
|---|---|---|---|---|---|
| Category 1 Defects | 1st<br>2nd | 500<br>Not Permitted | 500<br>Not Permitted | 0 | 1 |
| Category 2 Defects | 1st<br>2nd | 500<br>500 | 500<br>1000 | 0<br>3 | 3<br>4 |
| Category 3 Defects | 1st<br>2nd | 500<br>500 | 500<br>1000 | 2<br>6 | 5<br>7 |
| Category 4 Defects | 1st<br>2nd | 500<br>500 | 500<br>1000 | 7<br>18 | 11<br>19 |

Source: *Multi Calibre Manual Of Proof And Inspection* (NATO Standardization Agency, 2013), 14-13

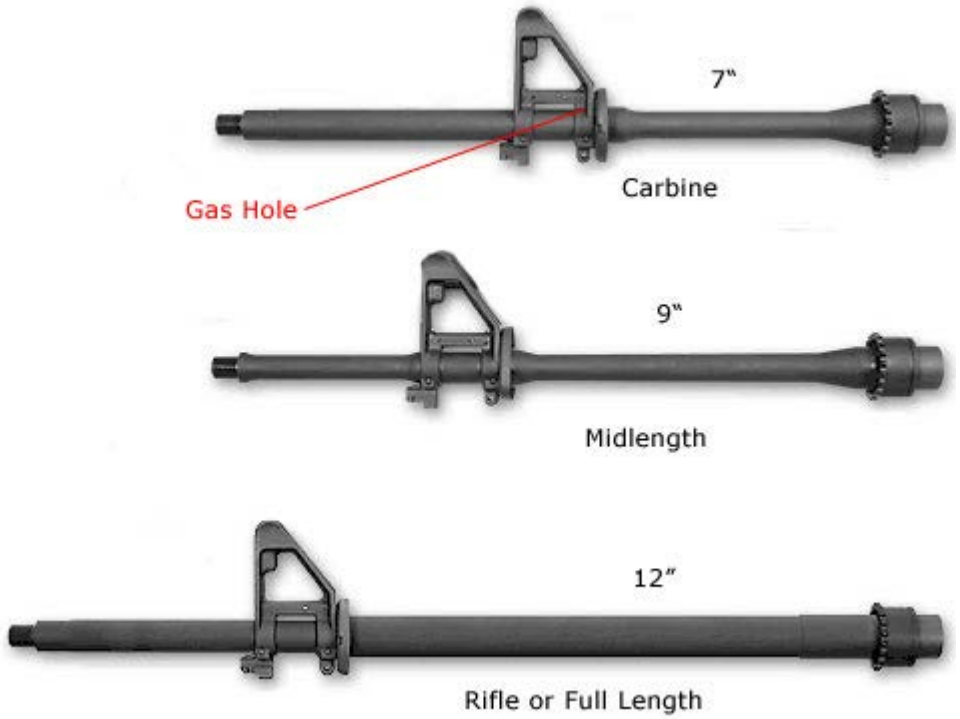
# UK 5.56mm L2A2 Issues in the M16A4 and M4

- The UK's first NATO Qualified 5.56mm round is the L2A2 and met the requirements of STANAG 4172, including its port pressure specification.
- For average port pressure, STANAG 4172 only requires 5.56mm ammunition designs to meet or exceed a minimum level of pressure but there is no maximum port pressure limit.
- The M16A4 rifle and M4 carbine are reliable weapons when firing US military standard ammunition such as NATO Qualified M855 cartridges but had issues when using L2A2 ammunition.[8]
- Sal Fanelli explained that: "the British SA80 rifles had a higher spring rate and internal parts friction than the M4 and M16 and a different port pressure [than that produced by M855 ammunition] was required to operate the SA80 reliably. The L2A2's higher port pressures overdrove the direct gas impingement system components of the M16A4 and M4, which caused earlier than expected component damage and the USMC restricted the use of the British ammunition."[9]

[8] Email communication from Salvatore A. Fanelli, APdM-Engineering USMC, to author, January 8, 2015.

[9] Ibid.

- 5.56mm L2A2 ammunition produced higher port pressures in the M4 than in the M16A4 because the carbine's gas port is located closer to the chamber than that of the rifle.[10]
- In addition to "overdriving the M4's operating components," the L2A2 round caused failure to cycle malfunctions in the M4 because the carbine's "operating components were moving too fast for the ejector to have enough time to eject the spent cartridge."[11]
- Although NATO's 5.56mm ammunition standardization efforts have generally been adequate for interchanging ammunition during logistical emergencies, the M16A4's issues with L2A2 shows that certain NATO Qualified ammunition designs were not reliable enough for full unrestricted/combat use in certain NNWs.




Source of Image: http://tactical-rifle-blog.com/wp-content/uploads/2011/10/gas-systems.jpg

[10] Email communication from Salvatore A. Fanelli, APdM-Engineering USMC, to author, January 8, 2015.

[11] Ibid.

# 2-325 AIR's Issues with 5.56mm L2A2 in the M4 Carbine

- 2nd Battalion, 325th Airborne Infantry Regiment, 82nd Airborne Division experienced significant reliability issues when using 5.56mm L2A2 ammunition in M4 carbines during training in 2006:
  - Numerous failures to extract (FTX) the L2A2 cartridge case.
  - Company level armourers attempted to retain functionality of the M4 by changing extractors and springs when experiencing FTXs along with increased component wear.[12]
  - "M4 bolts began to break at an excessively high rate, most typically at the locking lugs" adjacent to the extractor and two companies from "2-325 AIR alone had experienced no less than six broken bolts in one afternoon of reflexive firing training."[13]
- These reliability issues caused by the L2A2 in the M4 carbine significantly hindered training tasks.[14]

[12] Jason R. Gillis, "Failure Report in Relation to U.K. 5.56mm Ammunition" (Report to NATO, SG-1, 2010).

[13] Ibid.

[14] Ibid.

- Since the gas port of the carbine length gas system is closer to the chamber than that of the M16 rifle, there is still considerable residual pressure when the M4 begins to extract the cartridge case.[15]
  - Compared to the M16, extraction is less efficient in the M4 and the M4's extractor is more stressed than that of the M16.
  - The M4 extracts properly provided that residual pressure keeps the cartridge case pressed against the bolt face "while the extractor lifts and returns to position."[16]
  - But a FTX may occur in the M4 if there is increased drag on the cartridge case and the extractor lifts.
  - Extractor assembly improvements (stronger extractor spring, improved extractor buffer and Crane O-ring ) address the extractor lift issue and increase extractor tension. Thus, the M4 is still a reliable weapon when using US military standard ammunition.
- The Canadian C8A3 carbine has an enlarged chamber, which allows for "less resistance in extraction" and its improved extractor spring and extractor buffer are sufficient to prevent extractor lift in the CF's experience.[17]

[15] Email communication from Charles Marsh, NSWC Crane, to author, February 7, 2017.

[16] Frank Dindl et al, "Understanding Extractor Lift in the M16 Family of Weapons" (TACOM, 2003), 17.
Email communication from Cris E. Murray, independent military professional and former R&D Gunsmith at USAMU, January 11, 2016.

[17] Author Telephone Interview with CWO John T. Yoshida, DSSPM Senior Technical Authority Small Arms, March 17, 2017.

# Potential Causes of the M4's FTX Malfunctions with L2A2

- The symptoms of the M4 issues with 5.56mm L2A2 rounds suggests that the M4 firing the British 5.56mm NATO ammunition was unlocking under greater pressure compared to a M4 firing M855 cartridges.
- A possible cause of the FTX malfunctions that 2-325 AIR experienced with the M4 was the L2A2's higher port pressure causing the bolt to unlock earlier and faster and beginning extraction while the cartridge case has not had time to shrink away from the chamber walls.[18]

[18] Email communication from Jim Schatz, independent small arms consultant and former VP Military Programs at HK USA, to author, February 25, 2015.

# Suggestions for a New 6.5-7mm Intermediate Caliber STANAG

- If a 6.5-7mm caliber intermediate cartridge is adopted by the US in the 2020s period and NATO decides to standardize it in the future, then a new ammunition STANAG would need to be drafted and ratified.
- STANAG 4172 for 5.56mm SS109 ammunition has specifications for technical requirements such as precision, trajectory, muzzle energy, velocity, chamber pressure, minimum level of pressure for average port pressure, action time, primer sensitivity, tracer performance, barrel erosion, function and casualty test, smoke and flash, fouling, environmental requirements, corrosion resistance, residual stress, bullet pull and waterproofing.

- In order to allow for a greater degree of interchangeability than STANAG 4172, a new STANAG for a 6.5-7mm caliber cartridge should have the following additional technical performance specifications:
  - A standard for case capacity.[19]
  - Standards for case hardness and annealing.[20]
  - A maximum gas port pressure standard.
  - Gas port pressure requirements should be designed for and tested at two different gas port locations.
- Standards for the .50 BMG Mk323 Mod 0 round with a polymer and brass hybrid case are currently being determined. Technical specifications for conventional polymer and brass hybrid cased ammunition should be written for a new 6.5-7mm caliber intermediate cartridge.[21]

[19] Email communication from COL Miroslaw Zahor, Military University of Technology in Warsaw, to author, February 12, 2017.

[20] Author Telephone Interview with CWO John T. Yoshida, DSSPM Senior Technical Authority Small Arms, February 17, 2017.

[21] Email communication from Jim Schatz , independent small arms consultant and former VP Military Programs at HK USA, to author, February 20, 2017.

# Thank you very much for your time!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# Back-up Slides

# Additional Information on Temporary Cavitation

- Subsequent to the bullet's passage through tissue, the momentary displacement of tissue radially away from the permanent cavity results in the formation of the temporary cavity.
- Temporary cavity stretch is similar to blunt trauma and can cause tissue damage if the tissue was stretched beyond its elastic limit.
- In *Bullet Penetration,* Duncan MacPherson explained that "the size of the tissue stress relative to the elastic limit depends on: the magnitude of the energy being stored (a function of drag force), the tissue type and condition (sensitivity to strain), the size of the tissue structure and the anatomical constraints on tissue movement."[22]
- A substantial temporary cavity, 4 to 10 inches in diameter, can significantly injure less elastic tissues and fluid filled organs while elastic tissues are usually able to better tolerate temporary cavity stretch.
- A rifle bullet produces a large temporary cavity if it strikes tissue at a sufficient velocity and deforms, fragments or yaws considerably afterwards.

[22] Duncan MacPherson, *Bullet Penetration: Modeling the Dynamics and the Incapacitation Resulting From Wound Trauma* (El Sengudo: Ballistics Publications, 1994)

# Potential Advantage Regarding Tappet Systems and Ammunition Compatibility

- If a new assault rifle model that is developed has a well designed, self-regulating gas tappet system and is thoroughly tested with most existing ammunition designs, then such a rifle might be able to operate reliably with a wider range of ammunition.
  - For example, HK tested the G36 rifle and its self regulating, pusher rod gas system with 200 different 5.56mm ammunition types and the G36 rifle functions well with most 5.56mm ammunition types found internationally. But a notable exception is lightweight frangible ammunition.[23]
- A well designed, "gas operated system with piston is not very sensitive to the shape of p(t) curve."[24]
- The existing evidence suggests that it might be easier to design certain gas tappet systems to operate reliably with a larger variety of ammunition designs than the direct impingement gas system. Further studies and independent military testing should be done in this area.

[23] Email communication from Jim Schatz , independent small arms consultant and former VP Military Programs at HK USA, to author, February 25, 2015.

[24] Email communication from COL Miroslaw Zahor, Military University of Technology in Warsaw, to author, February 12, 2017.

Source of Image: http://s1224.photobucket.com/user/Marine0303/media/null_zps5b4e61e5.jpg.html.

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