Stars of Empire Experimental Combat Rules

1. Experimental Rules Goals

This document details an alternate / experimental set of combat rules in development for Terry Sofian's Stars of Empire (SoE) Role Playing Game [1]. The goals of this rule set are:

- Incorporate results of variety of weapons and ballistics studies (See Section 5)
- Preserve detail (e.g. placed injuries) where needed, but allow quicker combat resolution by reducing the "state" that needs to be tracked.
- Make combat outcomes more varied and "interesting" (See Section 4). The mainline rules include some high modifiers which could make some rolls too deterministic.
- Expand rules for vacuum, low gravity, armor, and low-light conditions
- Condense and simplify rules by minimizing lookups. Ideally, all key details could be compressed to three or four pages.
- Improve combat with non-humans. The mainline rules primarily focus on human vs. human combat and include some 'corner cases' that made combat with animals unrealistic.

This document summarizes the experimental rule set (Section 2), provides example weapons and armor (Section 3), and provides explanation for how the rules were developed (Sections 4-13). Note: other aspects of combat such as initiative (who goes first), movement, morale, etc. are covered in the core rulebooks. This document focuses on the main combat task of shooting and damaging opponents. Currently, it only covers ballistic attacks, with a focus on guns.

2. Experimental Rules Summary

2.1. SoE Gameplay Basics

2.1.1. Character skills

Both player and non-player characters in the game have skills and attributes which often act as task modifiers. Skill are specific acquired talents, such as marksmanship, lockpicking, or animal handling. Attributes are 'general' abilities such as strength, agility, intelligence, or willpower. A character's "Effective Skill" for a task is a weighted combination of specific skills and a 'default' attribute. For example, an "effective skill" for persuading someone would be calculated by $Persuasion + \frac{Personality+Comeliness}{10}$. An Effective Skill of less than 7 would indicate an ungifted amateur or dilettante. Effective skills of 10-15 indicate a "well skilled journeyman." An effective skill of 30 indicates a master of the craft. With specialization ("Fortes"), it is possible for effective skills to reach 60 or 70 for human characters.

For this document, we often focus on three effective skill levels – 12, 30, and 60 – as they represent important categories that are most relevant to gameplay.

2.1.2. Opposed Roll + RANT

The outcome of almost all tasks in SoE is determined by the "Opposed Roll + RANT" system. In this system, each side (e.g. attacker and defender, player and environment, etc…) rolls one 20-sided die. Rolling a "20" causes another 20-sided die to be rolled and added to that side's total. Situation specific modifiers are added and the higher total succeeds. The greater the difference (the "over-roll"), the greater the level of success or failure.

Example: Two characters are haggling over price. The task is modified by each character's 'haggle' effective skill. The Buyer has a skill of 10 and rolls a 10 for a total of 20. The Seller has a skill of 5 and rolls a 1, for a total of 6. 20-6=14, so the Buyer manages to reduce the price by 14%. (See [1] p65).

Buyer: +10(skill) +10(roll) = 20	Seller: +5(skill) +1(roll) = 6
Buyer Succeeds+14	

Example: A character is listening to hear a light vehicle approach. This task is modified by the character's skill and opposed by +5 (See [1] p57). The character has a skill of 12 and rolls a 3, totaling 15. The opposing roll has a modifier of +5 and rolls a 20, so it rolls again, resulting in a 19, for a total of 44. The character fails to detect the noise.

Character: +12(skill) +3(roll) = 15	Environment: +5(sound) +20(roll) +19(roll) =44
Character Fails -29	

2.2. Experimental Combat Rules

The Experimental rules are similar in form to the mainline combat rules. For each attack, there is an opposed roll to determine if the attacker hits (To-Hit roll, Section 2.3). If they succeed in hitting, another opposed roll determines damage (To-Damage roll, Section 2.4).

2.3. The Rules: To-Hit Roll

The To-Hit roll is a regular opposed roll with the modifiers in Table 1. In many cases, only the "Mode" and "Effective Skill" modifiers will be necessary.

Table 1 To-Hit Modifiers (Applied to shooter)

Modifier	Value	Notes
Mode "Quickfire" "Aimed"	 $+2-4\ per\ 10m$ $+4-3\ per\ 25m$	Character choice. Round range down. +X to initiative

Modifier	Value	Notes
"Sniper"	$+4 - 3\ per\ 100m$	Requires 3 turns, prone, scoped rifle
<u>Effective Skill</u>	$\left\lfloor \frac{Skill}{2} + \frac{Str + Agl}{20} \right\rfloor$	A combination of any skills and fortes and the "Physical Native Ability" for a player. This should be precomputed when the character is created. Round down.
<u>Wind</u>		<u>For ranges > 200m only</u>
Vacuum	+8	
No Wind	+0	
Moderate	-10	Moderate wind: 3-10km/hr
High	-16	High wind: 50 km/hr
<u>Weapon Quality</u>		Weapon or ammunition quality
Very Poor	-8	Poorly made and poorly maintained
Poor	-2	Cheap, low cost, antique or low quality
Standard	0	Normal, mass produced
High	+2	Custom made or accurized
Other	Special	Specific to weapon
<u>Weapon Type</u>		
Rifle	+0	
Pistol	-8	
Other	Special	Specific to weapon
<u>Perfect Ranging</u>	+2	<u>For ranges > 200m only.</u> E.g. predetermined range, zero gravity
<u>Position</u>		
Standing	+0	
Kneeling	+2	Kneeling or sitting
Prone	+4	Prone, "trenched", supported
<u>Movement</u>		
<4 km/hr	-6	Target movement (directional movement, not evasive)
4-18 km/hr	-12	
>18 km/hr	-16	
<u>Target Size</u>		Equivalent circular width
2 cm	-22	Human Eye
10 cm	-14	Slice of bread
30 cm	-8	8.5x11 paper, tennis racket
40 cm	-6	Hubcap
50 cm	-4	Prone / F-type Silhouette / 66% cover
70 cm	+0	Crouching / E-type Silhouette / 25% cover
90 cm	+2	Standing man
1.5 m	+6	Frontal area of large horse
3 m	+14	Side of pickup truck
9 m	+18	Side of a boxcar
18 m	+20	Tennis court
<u>Visibility</u>		
Daylight	+0	~1000-10000 lux. Daytime outdoors.
Indoors	-2	100-1000 lux. Normal indoor lighting.
Twilight	-6	~10 lux.
Full Moon	-10	0.01-0.1 lux.
Starlight	-12	.001 lux.
Overcast Night	-16	.0001 lux.

Modifier	Value	Notes
Target Dodging	$-\left\lceil\frac{Target\ Agility}{6}\right\rceil$	Evasive, random movement. Round up.
Scope	+6	For ranges > 200m only. +6 or specific to weapon, Aimed fire only.
# Projectiles 1 2 3-6 7-10 11-25 25-36 39-75 >75	 +0 +4 +8 +12 +14 +16 +12 +14	The effect of firing multiple projectiles in one action, either through automatic fire, shotgun, or duplex/triplex/n-plex cartridges

When firing, the character must choose a "Mode." This determines how carefully the attacker places their shot and allows a tradeoff between quick reaction and accuracy, especially over range. Also note, the maximum range of a weapon is still a limitation. The Modes are:

- **Quickfire**: Very fast "firing from the hip." This greatly reduces accuracy, but is swift. When firing in this mode, the shooter gets a +2 bonus, but a -4 for every 10 meters (hexes) of range to the target. For example, a character shooting at a target 15m away would have a modifier of –2 ($+2 - 4\left\lceil\frac{15}{10}\right\rceil$). This mode cannot use a scope modifier.
- **Aimed**: A "standard" aimed shot using the weapon sights and balancing accuracy with quick response.
- **Sniper**: A precise, but slow shot. Requires 3 turns (about 18 seconds) and that the shooter be in a prone or supported position. If the range is more than 200m they must be using a rile with a scope.

Other Notes:

- **Perfect Ranging**: This modifier is used if bullet drop can be completely negated or compensated for. For example, in zero-gravity or micro-gravity combat there would be no bullet drop, so perfect ranging would apply. If the character has already measured the distance to a landmark and their target is adjacent to that landmark, the range can be exactly compensated. Also, if the shooter has a technological means (e.g. Martian laser rangefinder) which can determine the range precisely they can compensate accordingly.

2.4. The Rules: To-Damage Roll

The To-Damage roll is a regular opposed roll with the modifiers in Table 2. The outcome (over-roll) of this roll is used to determine damage effects using Table 3.

Table 2 To-Damage Modifiers (Applied to Shooter)

Modifier	Value	Notes
Weapon	Special	Specific to weapon
Toughness	$-\left\lceil\frac{strength}{4}\right\rceil - 3$	Round up. Non-human toughness is target specific.
Armor	Special	Specific to armor

Table 3 Injury Effects

Over-roll	Injury	Delayed Injury (Optional)	Pretrauma (Optional)
-10		N/A	0

Over-roll	Injury	Delayed Injury (Optional)	Pretrauma (Optional)
-9		N/A	-1
-8		N/A	-2
-7		N/A	-3
-6		N/A	-4
-5		N/A	-5
-4		N/A	-6
-3		N/A	-7
-2		Possible / Severe	-8
-1		Possible / Severe	-9
0		Possible / Severe	-10
1	Trivial / -1 HP	Possible / Critical	-10
2	Trivial / -2 HP	Possible / Critical	-10
3	Minor / -3 HP	Possible / Critical	-10
4	Minor / -4 HP	Possible / Untreatable	-10
5	Moderate / -5 HP	Possible / Untreatable	-10
6	Severe / -6 HP	Possible / Untreatable	-10
7	Critical / -7 HP	Possible / Fatal	-10
8	Untreatable / -8 HP	Possible / Fatal	-10
9	Fatal / -9 HP		
10	Fatal / -10 HP		

Table 3 details three effects, based on the over-roll of the To-Damage roll:

- **Injury**: The most common effect is injury. At the Referee's discretion, this can take either of two forms:
  - **General Trauma Table:** The target suffers an effect from the relevant General Trauma Table ([1] p263-267). Each class of trauma has five possible effects, so 1D20/4, rounded up, is used to pick the effect. For example, a roll of 15 on the "Trivial" table would cause the 4th effect – "Torso Injury-Character loses one Action on next Initiative."
  - **Hit Point Reduction:** The target reduces their Hit Points by a number equal to the over-roll. If they reach zero Hit Points, the target will die in the next turn. If they reach negative Hit Points they die immediately. A normal human character will have 8 Hit Points, non-humans may have more.

  The choice of Table or Hit Points gives the Referee flexibility. General Trauma is more useful for Player Characters or important Non-Player Characters as it provides more detail and allow the Referee more leeway in preventing inconvenient death of a character. The Hit Point-based system is faster and simpler – if fighting a large number of nameless minions, it frees the Referee from tracking each injured limb of the opposing party and eliminates a number of table lookups. It is also more appropriate for animal encounters.
- **(Optional Rule) Delayed Injury**: Under this optional rule, it is possible for an injury to have a delayed effect in addition to the regular effect (column 2). After combat, the character rolls an opposed roll modified by strength. If they fail, the character will require medical treatment within 12 hours or they will suffer an injury from the listed General Trauma Table.

- **(Optional Rule) Pre-trauma**: Under this optional rule, a character's effectiveness can be diminished by injury or even if they are not injured. When a character is fired on, if the over-roll is greater than -10, they must make an opposed roll modified by their Will. If they fail, they suffer "Pre-Trauma" as indicated in column 4. While suffering from Pre-Trauma, they will incur a negative modifier to all tasks. For example, a character is hit by the diminutive 5mm Bergmann Pocket Pistol (Damage -5). Their Strength of 17 gives them a +2 and they are wearing armor giving them an additional +4:

Shooter: -5(pistol) -2(toughness) -4(armor) +11(roll) = 0	Character: +3(roll) = 3
Shooter fails. Over-roll = -3	

Though the target is not physically injured, the psychological impact of the graze may leave them shaken. They must make a Will check:

Character: +10 (Will) + 3 (roll) = 13	15 (roll) = 15
Character Fails –2; Pre-Trauma -8 (from Table 3)	

They fail this check and are afflicted with Pre-Trauma of -8 until combat ends or they make a successful Will roll.

If a character succeeds in hitting while firing multiple projectiles, their attack may do more damage. Using the over-roll of the successful To-Hit roll and the number of projectiles fired, Table 4 gives the damage multiplier. For example, A Shooter fires 20 projectiles from their Cei-Rigotti automatic rifle, firing 6.5×52mm Carcano cartridges (Damage +12). Their To-Hit roll succeeds with an over-roll of 14. Their target, a Venusian Lesser Rhino, has a Toughness of 8. The Shooter rolls a 13, the Rhino rolls a 7, so their Base Damage is 10. Consulting Table 4, the intersection of a To-Hit Over-Roll of 14 and 20 projectiles gives a multiplier of 6. So, the total damage is 60HP – enough to seriously wound, but not kill the beast.

Shooter: +12(Rifle) -8(Toughness) +13(roll) = 17	Rhino: +7(roll) = 7
Shooter Succeeds. Base Damage: 17-7=10	
Damage Multiplier: x6(Table 4). Total Damage: 10*6=60HP	

Table 4 Multiple Projectile Damage Multiplier

To-Hit Over-roll	Projectiles Fired									
	2-3	4-5	6-9	10-15	16-24	25-37	38-49	50-74	75-99	>99
+0 to +4	x1	x1	x1	x1	x2	x4	x7	x11	x17	x24
+5 to +8	x1	x1	x1	x2	x4	x6	x10	x14	x21	x29
+9 to +12	x1	x1	x2	x3	x5	x8	x12	x16	x24	x32
+13 to +16	x1	x2	x2	x4	x6	x9	x13	x17	x26	x34
+17 to +20	x1	x2	x3	x5	x7	x10	x15	x20	x29	x37
+21 to +24	x2	x3	x4	x6	x8	x12	x17	x21	x31	x40
+25 to +28	x2	x3	x4	x6	x9	x12	x18	x22	x31	x41
+29 to +32	x2	x3	x4	x6	x9	x13	x18	x23	x33	x42
+33 to +36	x2	x4	x5	x7	x10	x14	x19	x24	x34	x43
+37 to +40	x2	x4	x5	x7	x10	x14	x20	x25	x35	x44
+41 to +44	x2	x4	x5	x8	x11	x15	x20	x25	x35	x45
+45 to +48	x2	x4	x5	x8	x11	x15	x21	x26	x36	x46

+49 to +52	x2	x4	x6	x8	x11	x16	x21	x26	x37	x47
+53 to +56	x2	x4	x6	x8	x12	x16	x22	x27	x38	x48
> +56	x2	x4	x6	x9	x12	x17	x23	x28	x39	x49

2.5. Examples

2.5.1. Validation Examples

To validate the experimental rules, we compared against probabilities derived from several "real world" sources (notably [2], [3], [4], [5], and [6]) and the mainline rules. To combine from multiple sources, we multiple individual probabilities together. For example, [3] gives a skilled sniper a 55% chance of hitting a target at 700m, and [2] gives a 20% relatively probability of hitting a target at night. Combined, they would result in an 11% hit probability. This method of combining is not rigorously tested, but reasonable for our means.

2.5.1.1. To-Hit

We compared four scenarios to compare to-hit results (Figure 1):

- **Aimed Fire**: A "standard" aimed shot. The shooter has Effective Skill of 12 ("journeyman"), range is 100m. Shooter is firing from a prone position.
- **Moving Target**: As 'Aimed Fire', but the shooter is kneeling and the target is moving.
- **Sniper+Wind+Night**: A very difficult shot. A skilled sniper (Eff. Skill 30) firing at 700m, in windy conditions, on a moonlit night. As the mainline rules do not have an adjustment for wind, we include hit probabilities without and using the adjustment for rain as a reasonable extrapolation.
- **Dodging**: A skill 20 shooter quick firing at 20m against a dodging target.

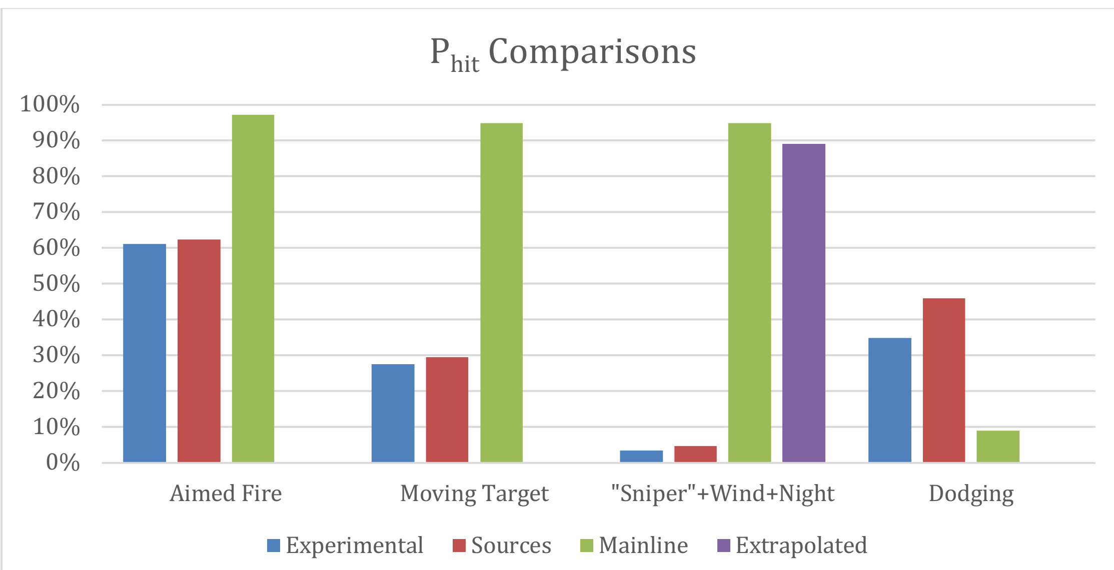


Figure 1 To-Hit Validation Cases: Hit Probabilities

As expected, the experimental rules conform reasonably closely to the sources. The "Aimed," "Moving," and "Sniper" hit probabilities are within 2% absolute error. The "Dodging" case is less precise, but still about 11% absolute error. Average relative error is 14.8%.
In comparison, the mainline rules show a high degree of overestimation for 3 of the 4 cases, and under estimation for the final case. Average absolute error is greater than 55%.

2.5.1.2. *To-Damage*

To validate the To-Damage roll, we compare the experimental rules, sources (mainly [6]) and the mainline rules with two ammunition types: a 9x19mm Parabellum round [7] and a .25-06 Remington round [8] against unarmored targets. For the mainline rules, we assume a to-hit over-roll of 14, the average over-roll from the examples in Section 2.5.1.1. For comparison, we convert the "percentage incapacitation" level from [6] and [9] to the trauma levels of the mainline rules. The experimental rules closely mirror the source material (Figure 2). Since the experimental rules are essentially a quantized version of the methodology presented in the sources, this is to be expected. The mainline rules show a consistent underestimation of lethality. For example, the probability of actually inflicting a fatal injury with the 9mm bullet is about 1 in 180. The chance of doing more than psychological damage (pre-trauma) is only 43%. Even the .25-06 has only a 1 in 13 chance of fatal injury. This is at least in part due to the mainline rule's strong dependence on the to-hit over-roll.

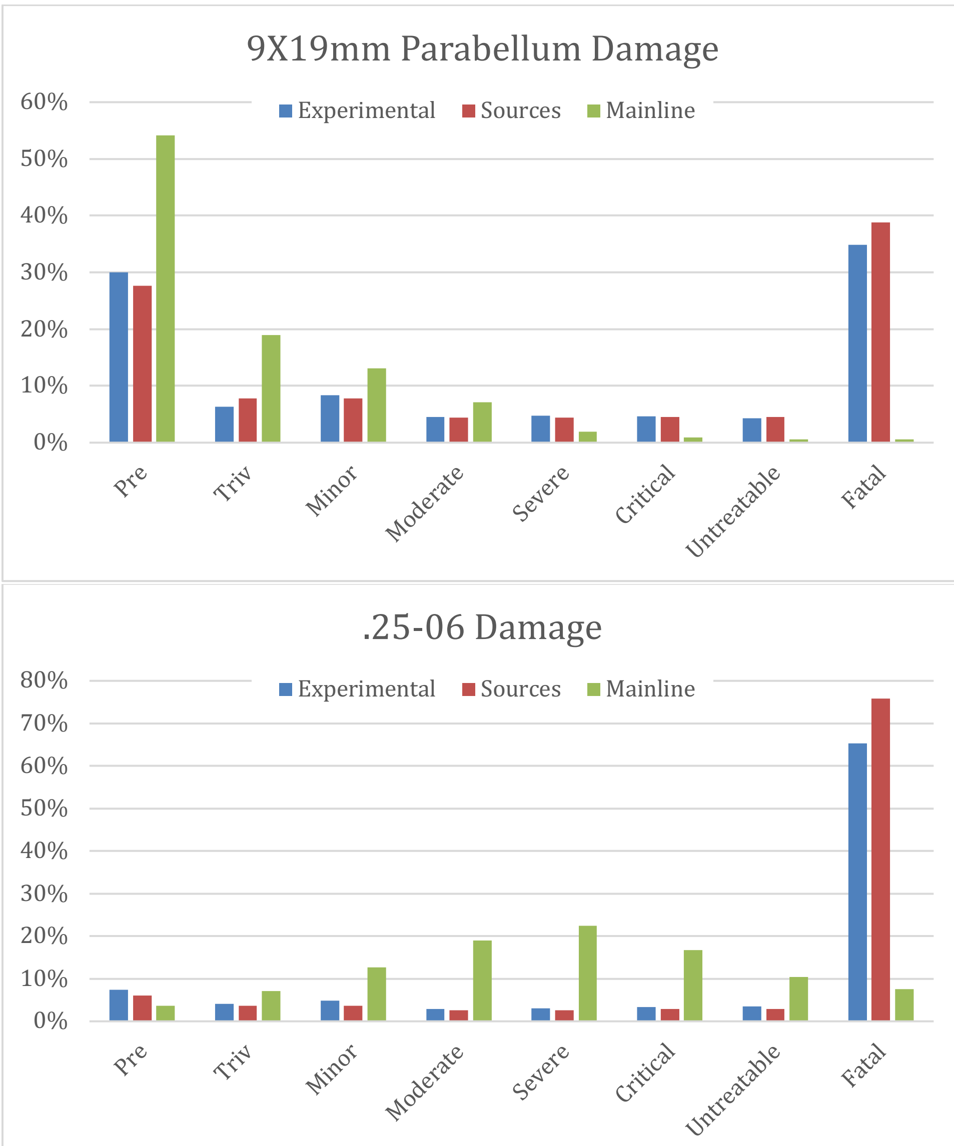


Figure 2 To-Damage Comparisons

2.5.2. Additional Examples

<To be added>

3. Experimental Rules Armory

3.1. Weapons

Table 5 provides damage and To-Hit characteristics for a variety of weapons and ammunition types. Some of these would not be period appropriate, but are provided for comparison.

Table 5 Experimental Rules Weapons (INCOMPLETE)

Weapon	Damage	To-Hit
.50 Bullet	21	
Martini-Henry	14	
.25-06 Remington	13	
Cei-Rigotti, 6.5×52mm Carcano	12	-2
.223 WSSM JSP	11	
5.56mm @ 300	10	
.30 bullet @ 300	10	
Kentucky Rifle	9	-2
.45 ACP / De Lisle Carbine	8	
9mm bullet @ 50m	7	
7.62x25 Tokarev	6	
9x19mm parabellum Federal FMJ	6	
.38 Special	5	
Girardoni air rifle 13mm	5	
HK 4.6x30mm	4	
.22 LR	1	
5mm bergmann	-5	-8
4.15mm Liliput	-7	-8
2mm Kolibri	-15	-8

3.2. Armor

Table 6 lists different body armors. Their defensive value against rifles and pistols is applied to the To-Damage Roll.

Table 6 Armor Characteristics (Incomplete)

Name	Mass (kg)	Vs. Rifle	Vs. Pistol	Coverage	Thickness (mm)
Steel Chestplate	4.1	-2	-3	10%	3.0
Aluminum Cuirass (Front & Back) & Faulds	7.2	0	-8	38%	4.0
"Ned Kelly"–Style Armor	43.7	-1	-10	50%	6.4
Aluminum "Full Plate"	24.9	-1	-13	95%	5.5
Titanium Chestplate	4.0	-2	-3	9%	5.8
Ceramic/Al Rondel	3.3	-2	-1	4%	14.0

Ceramic/Al chest plates	7.5	-3	-3	10%	12.8
Silk Vest (hidden, high quality 18-layer Yun IV-E silk)	1.2	-2	-2	10%	1.8
Silk Vest (torso, upper arms, buttocks, high quality 30-layer Venusian Spider Silk)	2.7	-4	-5	43%	3.0
CNT Plastron	1.3	-5	-4	20%	2.6
Basalt Vest (torso, upper arms, Basalt Fiber)	8.5	-1	-4	40%	4.5
Steel Helmet	1.3	-1	-1	5%	3.0

3.3. Beastiary

<To be expanded>

Table 7 Typical Animal Stats (Incomplete)

Name	Typical Mass (kg)	Typical Toughness	Typical HP
Average Human	62	+0	8
Lesser Venusian Rhino	1100	+8	65
Asian Elephant	3400	+16	149
Cavalry Horse	500	+5	37
Wolf	45	-1	6

4. Statistical Foundation

The standard die roll format in Stars of Empire (SoE) is called "Opposed Roll + RANT." For each action, each side rolls a 20-sided die (d20). The die value of the side opposing the action is subtracted from the side performing the action. All natural "20"s are rerolled and added to that side's total. If the reroll is a 20, it is rerolled again and that is added. Modifiers are applied and the highest roll 'succeeds.' Ties go in the Player's favor. The 'over-roll' is the difference between two sides and may be used as a modifier for future rolls or to indicate how (un)successful the action was.

Example: A character with 'Pick Locks' skill 13 and Physical Native Ability of 2 is trying to pick a Difficult lock (+10). They roll a 7, the Referee rolls an 11. The Player's 7+13+2=(22) is greater than 11+10=(21), so they succeed with an over-roll of 1.

Player: +7 (roll) +13 (Skill) +2 (Native Ability) = 22	Referee: +11(roll) +10(Difficult Lock)= 21
Player Succeeds. Over-roll: +1	

Example: A character with 'Climbing' skill of 16 and Physical Native Ability of 2 is trying to climb a Demanding (+20) obstacle. They roll a 15, the referee rolls a 20, so the referee rolls again, rolling a 5. 15+16+2=33 is less than 20+20+5=45, so they fail with an over-roll of -12. As a result, they fail to make progress and take double fatigue. ([1] p36)

Player: +15 (roll) +16 (Skill) +2 (Native Ability) = 33	Referee: +20(roll) +5(RANT Roll) +20(Demanding Climb)= 45
Player Fails. Over-roll: -12	

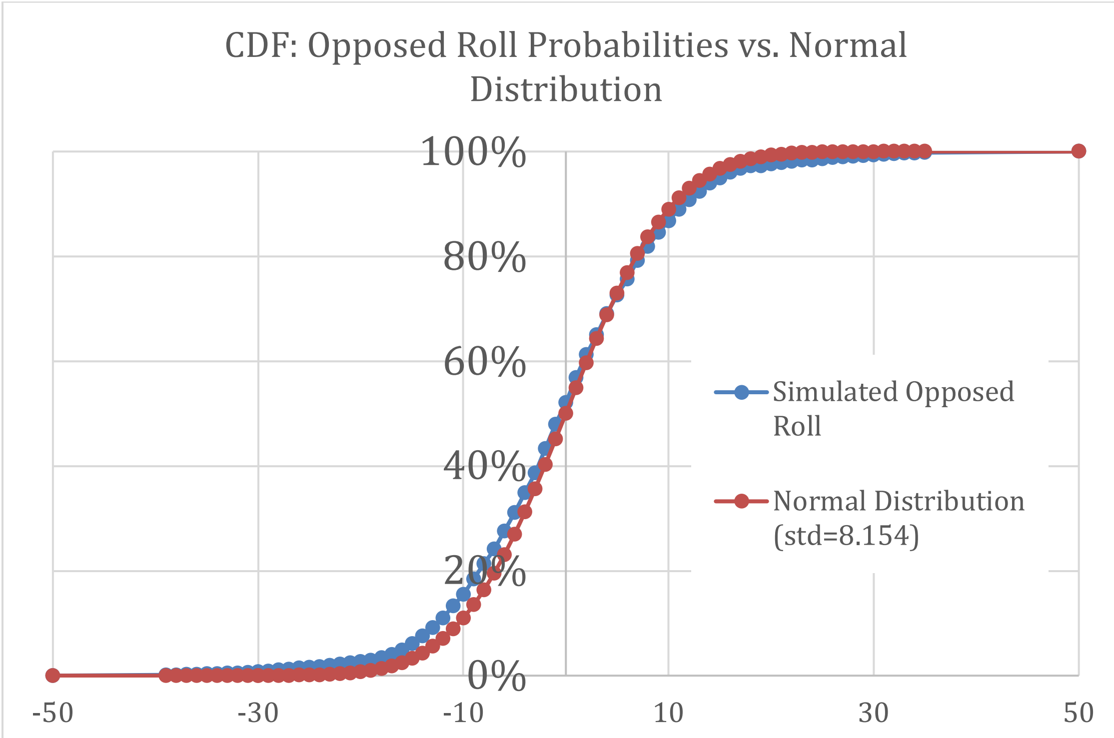


Figure 3 Opposed Roll and Normal Distribution

From a statistical standpoint, Opposed Roll+RANT creates a probability distribution very similar to a normal distribution with mean of 0 and a standard deviation of 8.15. Figure 3 shows the results of 50,000 simulated opposed rolls compared to the cumulative distribution function of a normal distribution.

One interesting aspect of this distribution is that it is roughly linear for part of the domain, and strongly non-linear outside of this region. This region (from about -12 to +12, Figure 4) is also where the results are "interesting" – i.e. there is a substantial probability of both success or failure. Outside of this range, the results are more deterministic and the change in probability more non-linear.

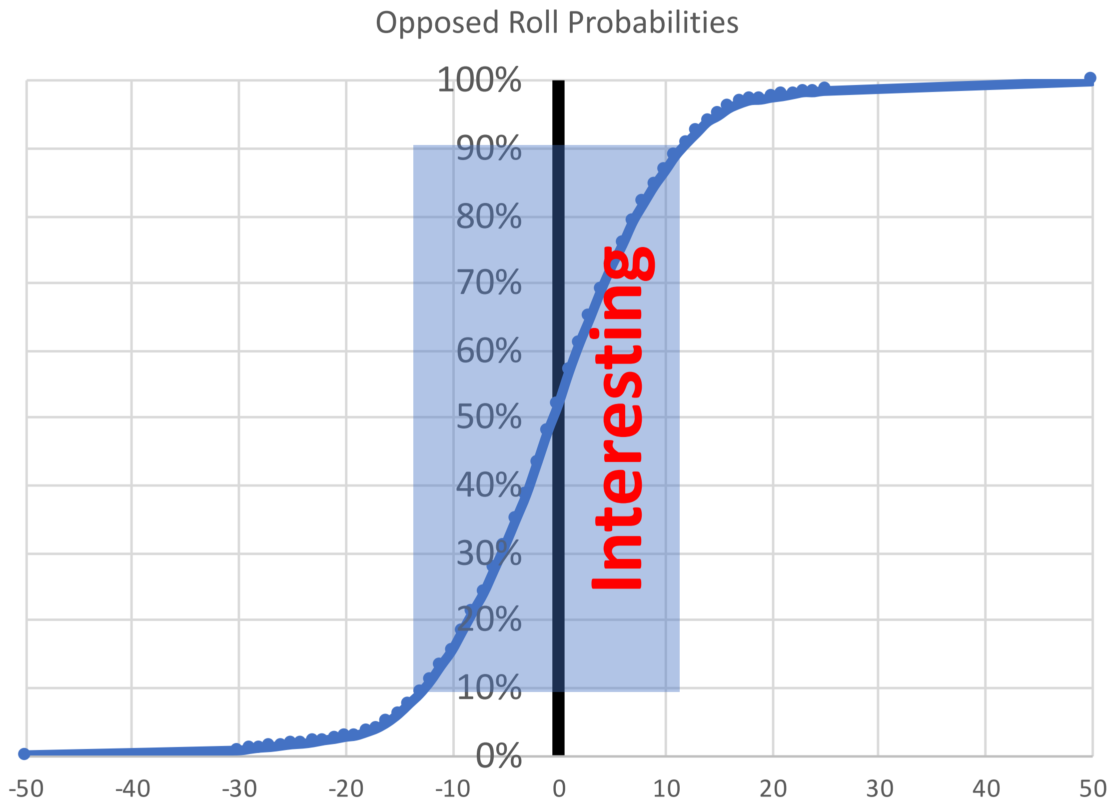


Figure 4 The "Interesting Zone" of the Opposed Roll + RANT probability

From a design perspective, this has two implications. First, if Referee's want to the result of a roll to be in doubt, the should design scenarios where the sum of modifiers lies in the "interesting zone" (Figure 4). Secondly, it can be used to simplify design decisions. If a roll is outsize the "zone," additional small modifiers will probably not have a large impact (e.g. moving from -30 to -33 only changes the probability by 0.2%). If it is "inside" the zone, the probability slope is fairly linear (a slope of about 3.5% per unit). So, for "interesting" probabilities we default to assuming every 3.5% of probability is a modifier of +/-1.

5. Key Sources

Several sources were used to calibrate probabilities for these rules. Some key sources include:

- SALVO I & II: These two studies, SALVO I [2] and SALVO II [10], were perhaps the most influential in developing the 'to-hit' modifiers for these rules. They examine hit rates and estimate damage for a wide array of weapons, ranges, shooter skill, lighting conditions, body posture, and other variables. These studies were influential in late 50s/early 60s weapons development as concepts like "duplex cartridges" were being developed and the move from the M14 battle rifle to the M16 assault rifle was being considered. Key concepts include the "fatalities per mass" metric and examination of duplex cartridges.
- "Criteria for Incapacitating Soldiers with Fragments and Flechettes:" [6]: This study by Kokinakis and Sperrazza was the most influential in developing the 'to-damage' rules. It introduces a formula for estimating the probability of incapacitation if hit by a given projectile (P_{hk}).

- *Armour: Materials, Theory, and Design* [11]: Was the primary source for much of the armor design. It includes summaries of penetration mechanics for ferrous and non-ferrous metals, ceramics, and fibers. [12] is also a valuable resource.
- "Operational Requirements for an Infantry Hand Weapon" [13]: Another influential study, which help lay the groundwork for the move to smaller-caliber high-velocity weapons. Key observations include the effect of terrain, visibility, salvo fire, wound ballistics, and combat accuracy on total effectiveness. It reinforced the notions that "…the infantry basic weapon is actually used, on the average, at shorter ranges than commonly believed," and, due to wound ballistics, "a .21 cal missile of high velocity (about 3500 feet per second muzzle velocity) creates equal or greater damage than the standard .30 cal missiles at ranges up to 800 yd." These insights promoted the movement to assault rifles, changed training practices, and influenced future weapon design. The report also covers some analysis of toxic nerve agent-filled bullets which, thankfully, were not pursued.
- "Sniper Weapon Fire Control Error Budget Analysis" [3]. A 1999 study covering several sources of error (wind, weapon, ranging bias, etc…) for skilled shooters ($\sigma < 0.3$ mil).
- *The White Sniper* [14]: Biography of renowned sniper Simo Häyhä and discussion of sniper training and the effects of cold on ammunition performance.
- "Effect of the Firing Position on Aiming Error and Probability of Hit" [4] covers effect of aiming posture and makes some attempt to quantify effect of stress on the shooter.

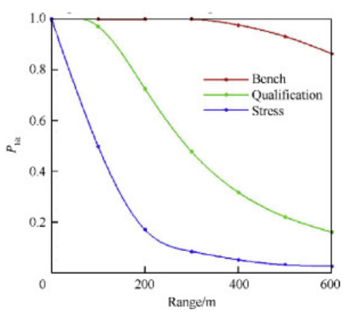


Figure 5 From [4], shows the effect of stress on shooting

- AMSAA TR.461 [15]: Error budget analysis for a number of weapons and skill levels, including a mention of a "Mr. Chronister" who scored an error of 0.03 mils at 1000 yards during a bench rest shooting competition.

6. To-Hit: Range

The To-Hit roll uses three "Modes" of firing – "Aimed", "QuickFire," and "Sniping." These divisions are influenced by [16] and [14]. Rough definitions can be found in Section 2.3.
For each Mode, we used the following process to devise the rules:

1. A literature survey was made to gather data on observed hit rates.
2. This data was normalized, if necessary, for "some stress" – i.e. not bench rest or qualification – by increasing the aiming error by a factor of 1.95 (suggested by [4]) over "no stress" conditions. It was normalized for for prone firing position. In some cases, accuracy was given in terms of mils of standard deviation. To convert to "probability of hit" accuracy, we used equation M3 from [2]:

$$P = 1 - e^{-(\frac{T}{\sigma})^2}$$

Where T is the angular size of the target (i.e. T=target width / distance to target) and σ is the standard deviation of error for the shooter. We normalize targets to a width of 0.37m ("E-Type Silhouette"). This equation was used several times through this document and is referred to as the "M3 Equation."

3. The normalized data was plotted to find accuracy (probability of a hit or P_h) vs. range.
4. An equation to compute opposed roll modifiers was developed to match the plot. The general form of this equation is:

$$max\left(M, B - m\left\lfloor\frac{d}{D}\right\rfloor\right)$$

Where M, B, m, and D are constants and d is the distance to target. In this equation, B indicates a base modifier for the mode of fire. $m\left\lfloor\frac{d}{D}\right\rfloor$ determines how quickly accuracy degrades with range (d). M provides a lower limit for the accuracy at high ranges.

Sections 6.1-6.3 show this methodology being used for each mode.

Other Sources:

- [17] gives an overview of QuickFire (aka Point Shooting, instinctive aiming, Quick Kill, quick-fire)
- [18] is a RAND study on police shootings. It records a surprisingly high miss rates for even short-distance shooting
- [16] examines accuracy under a range of conditions, positions, and aiming sights. It also breaks its analysis into "Quick Fire", "Coarse Aim", and "Precision Aim" with similar characteristics to our modes.

6.1. Aimed Shooting

Data was gathered from several sources: SALVO I ([2]); Swoboda ([19]); GPR([15] "Trainee", "Marksman", and "Less then 2 years" data); Burcham ([20]); and Corriveau ([4]). Averaged normalized accuracy vs range is found in Figure 6.

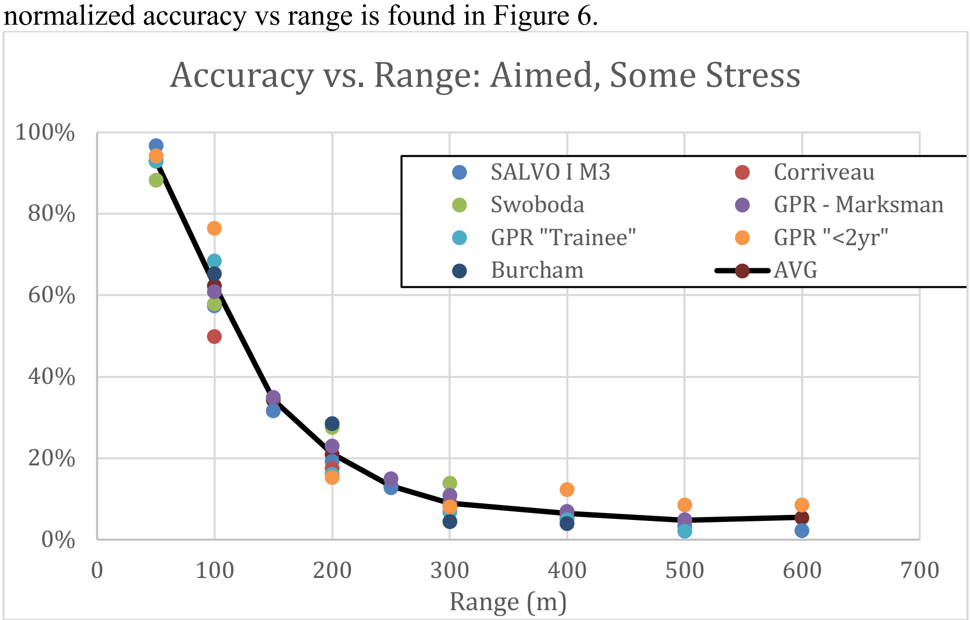


Figure 6 "Aimed" fire, Accuracy vs Range

Opposed roll equations were developed to fit the average curve using D=100 and D=25 (Figure 7).

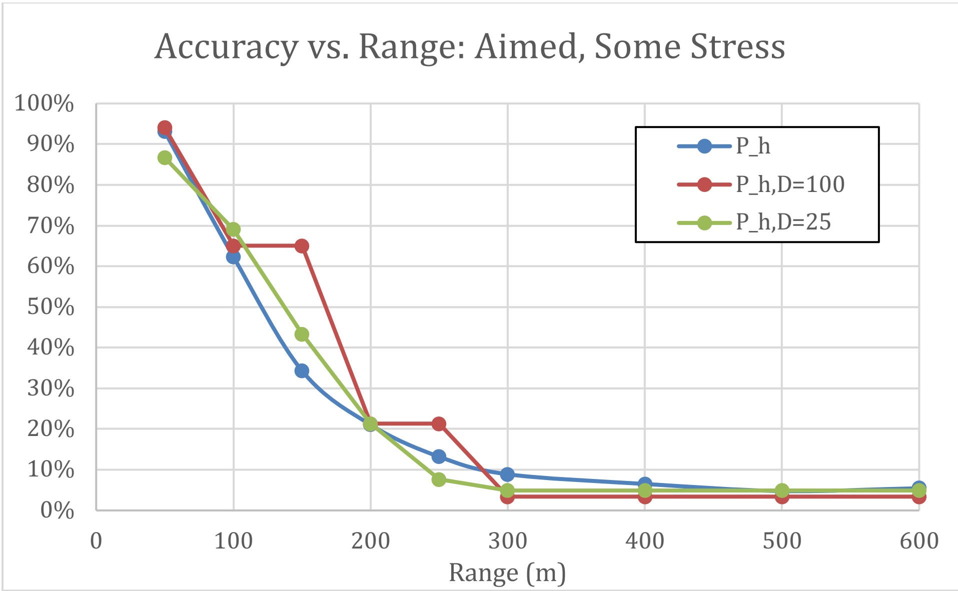


Figure 7 Opposed Roll Rules for Aimed Fire compared to observed data (P_h)

The D=25, M=-16, B=16, m=3 provided a close fit (within 3.8% of the observed P_h).

6.2. Sniping

Sources for "sniping" include [2] (three different accuracy assumptions), Russian sniper data [21], tests from Ft. Benning with different scopes [15], and from Navy SEAL trials [15]. Some additional data from a Williamsport benchrest competition is also include in Figure 8, but is not factored into the average.

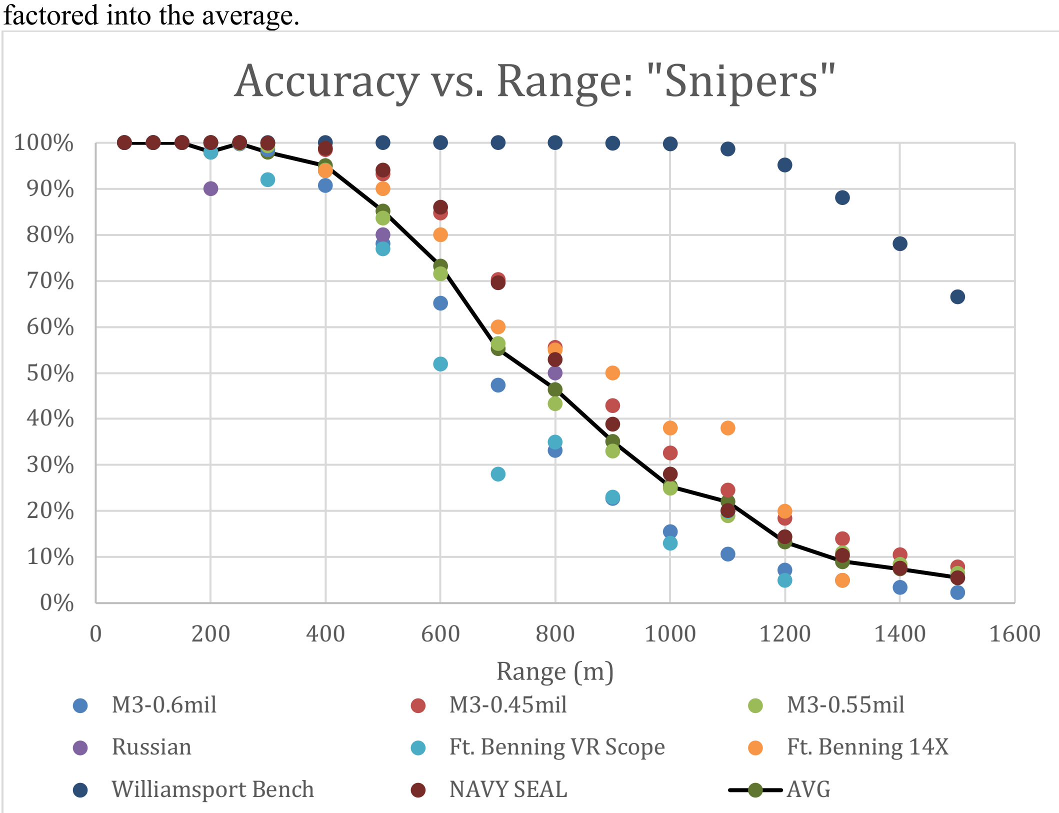


Figure 8 Observed accuracy vs. range for snipers

A modifier equation with D=100, M=-50, B=25, m=-3 was found to give a 4.1% average absolute error from 200 to 1500m (Figure 9).

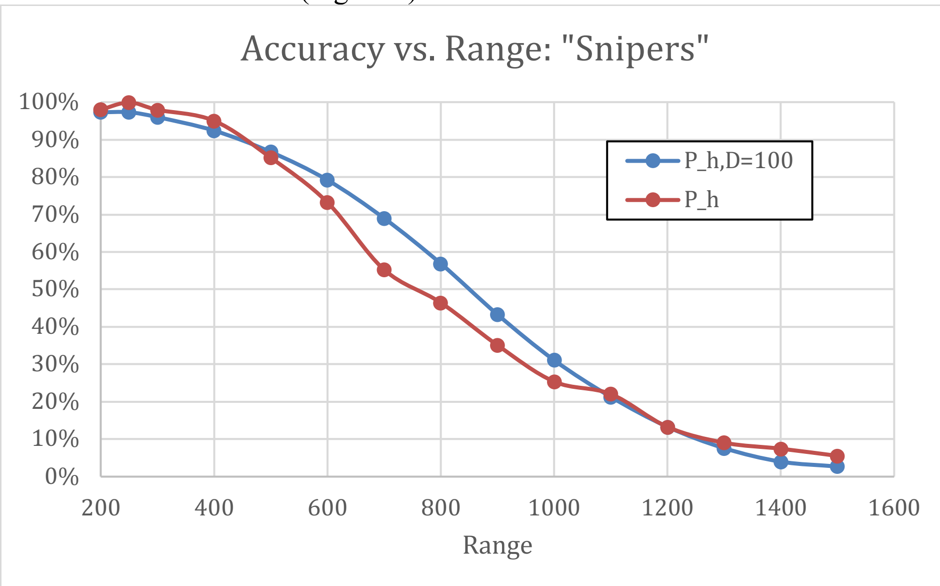


Figure 9 Opposed Roll Rules for Sniping Fire compared to observed data (P_h)

6.3. QuickFire

Sources for QuickFire data include: Swoboda ([19]); MARKSMAN I ([16] two data sets); Sterne & Yuowitch (cited in [22]); HEL: (US Army Human Engineering Laboratory [23]); and RAND Police ([18]).

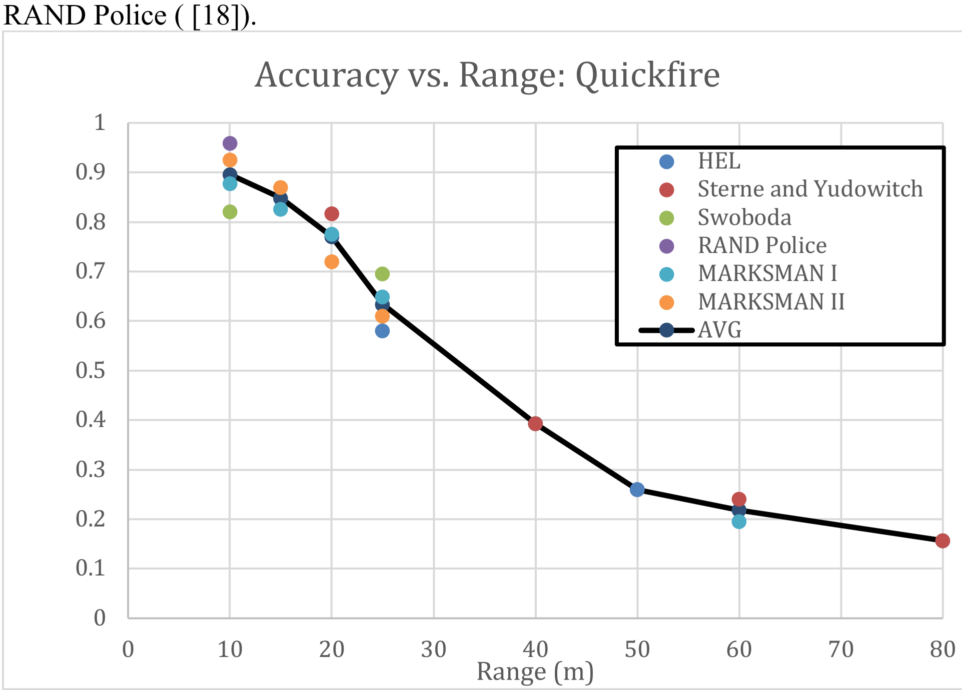


Figure 10 "Quickfire" Accuracy vs. Range

Two modifier equations were tested, and one with D=10, M=-50, B=14, and m=-4 gave a close match to the observed values, with an average error of 5.3%.

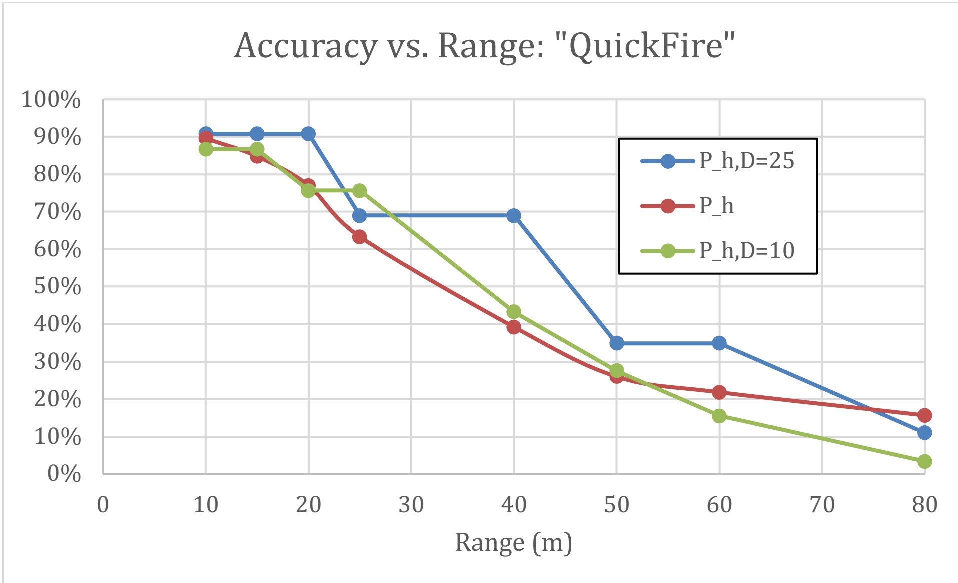


Figure 11 Opposed Roll Rules for QuickFire compared to observed data (P_h)

6.4. Summary

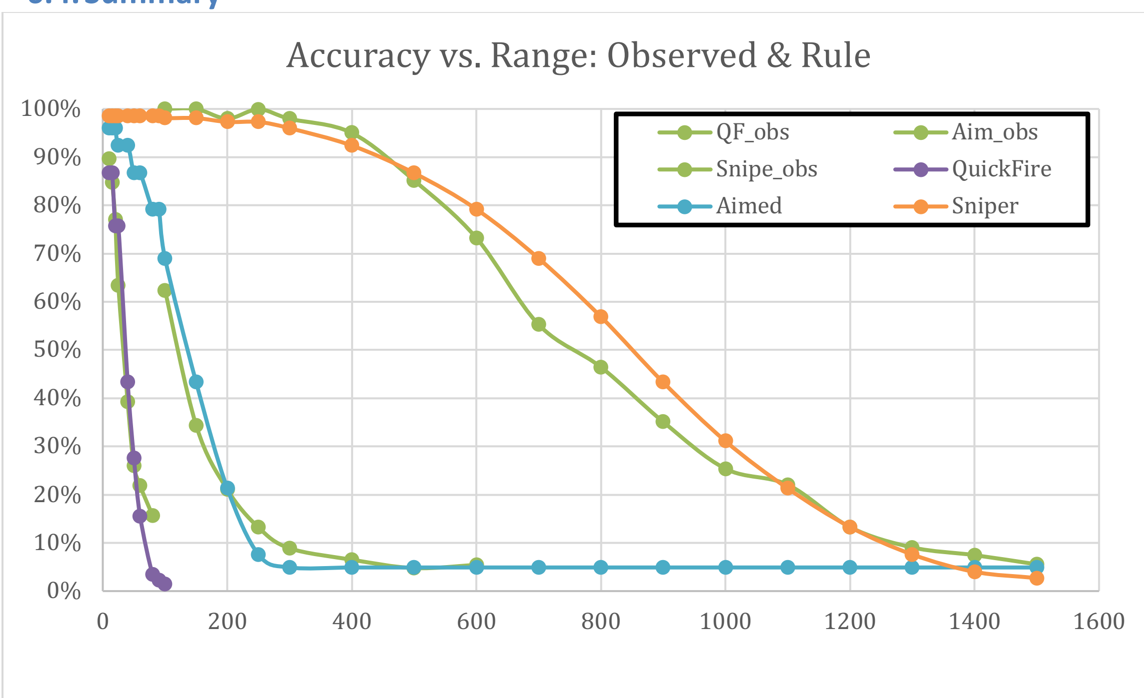


Figure 12 Accuracy vs. Range for Observed and Modifier Rules

Figure 12 summarizes the different modifier equations for each Mode and compares them to the observed data (green lines) across a number of ranges. Though not perfect, the match between the rules and the data observed in the sources is reasonably close.

7. To-Hit: Skill

The process used to determine skill-based to-hit modifiers was:

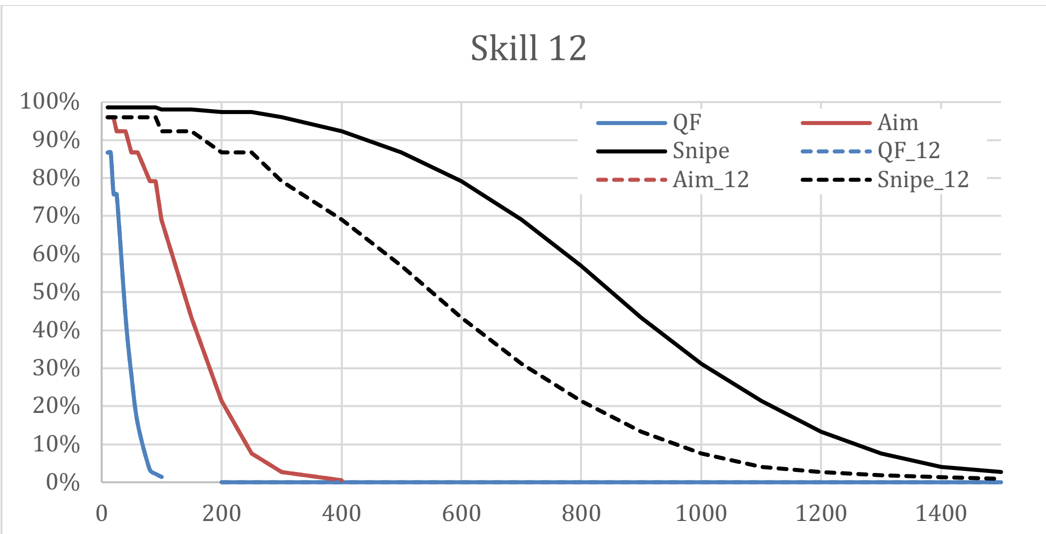
1. Examined several sources to determine the effect of skill on performance. ISSF Olympic match results [22] include computerized targets from competition, allowing estimates of standard deviation. The IPSC classification system [24] and match results from the USPSA [25] PCR division were used to estimate hit rates, and sample course measurements were used to convert these to estimates of standard deviations. Data from [15], [3], and [2] provided additional standard deviations for different levels of skill. These are recorded in Table 8 Column 1. Note: there is probably considerable error in the estimates for IPSC/USPSA results, as practical shooting has different constraints and goals compared to the other data sets, but the results proved useful.
2. From these, we created an ordering of greatest skill to least: Olympic medal winners, Olympic "Top 8" scores, US Marksmanship unit, US snipers, IPSC, US Marksmanship ratings.
3. We then used the M3 equation from [2] and the standard deviations to compute hit probabilities for 200, 400, and 800m. This yields Table 8, Column 3.
4. We assume that the highest level (Olympic medal) is equal to a skill of 70, and a qualified marksman is equal to a skill of 12 (SoE "Journeyman"). We then linearly fit the average hit probability between these two endpoints (skill 70 & 12) and apply this too each of the intermediary points, yielding Table 8, column 4.
5. Noting the CDF of our opposed roll mechanic is similar to a normal distribution (See Section 4), we use the inverse normal distribution to estimate what the roll modifier should be to get the hit probability (P_h) for each level (in MS Excel terms, `NORM.INV(x,0,8.15)`), yielding Table 8, column 5.
6. We estimate a linear relationship between the normal distribution modifiers and the skill (in Excel, `LINEST()`). The Excel function yields a slope of 0.437 and an intercept of -14.87, which, for ease of use we convert to: $Mod = \left\lfloor \frac{skill}{2} - 15 \right\rfloor$. Applying this to the modifier (column 4) yields the modifiers in Table 8, column 6.

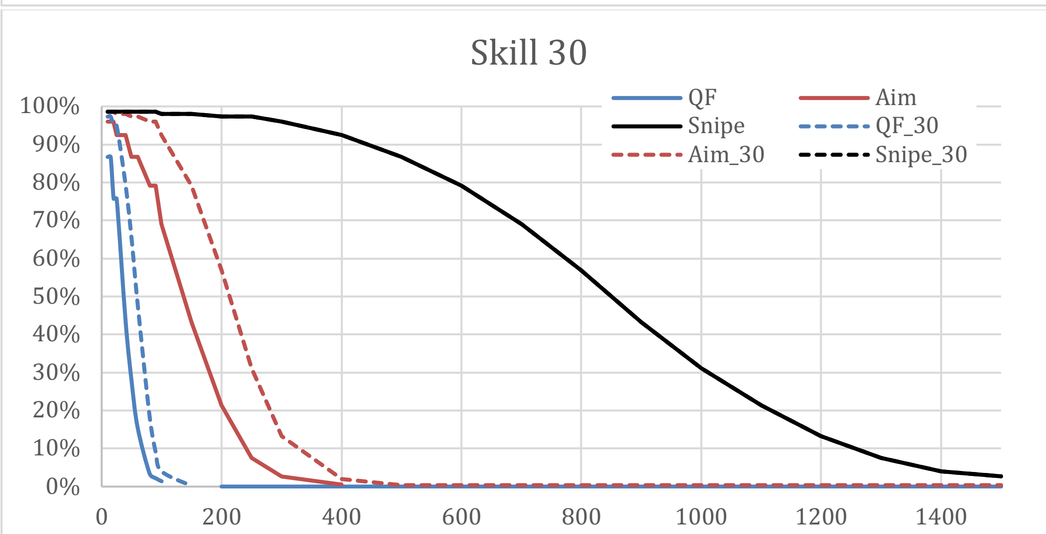
Table 8 Data used to generate skill to modifier rule

Data Source	σ (mil)	Average P_h	Effective Skill	Normal Distribution Modifier	Skill to Modifier Rule
Olympic Medal Shooters	0.23	100%	70	22.1	20
Olympic "top 8" Shooters	0.47	93%	65.6	12.1	17
US Marksmanship unit	0.50	85%	59.9	8.4	14
US Sniper	0.70	73%	51.8	4.9	10
IPSC Grandmaster	1.33	45%	33.1	-1.0	1
IPSC Master	1.42	42%	31.2	-1.6	0
IPSC A	1.49	40%	29.8	-2.1	-1
IPSC B	1.55	38%	28.5	-2.5	-1
IPSC C / SoE "World Renowned"	1.72	34%	25.5	-3.5	-3
Expert Qual	2.50	19%	16.0	-7.0	-8
Sharpshooter Qual	2.70	17%	14.4	-7.7	-8

Marksman Qual / SoE "Journeyman"	3.10	14%	12	-9.0	-9
Amateur			2		-14

We then "tested" this modifier rule in conjunction with the previously developed rules for range (Section 6). We used three different effective skill levels – 12 ("A well skilled journeyman." [1] / Marksman qualified), 30 ("A regionally respected master of the craft" / IPSC Master), and 60 (extremely talented / well ranked sniper). Because most of the QuickFire and "Aimed" range data was either from or adjusted to US soldiers with average shooting qualifications, the range equation bases (constant B) were adjusted so the Skill=12 case aligned with the accuracy curves. The max (constant M) was also adjusted to leave a residual success chance at higher ranges.





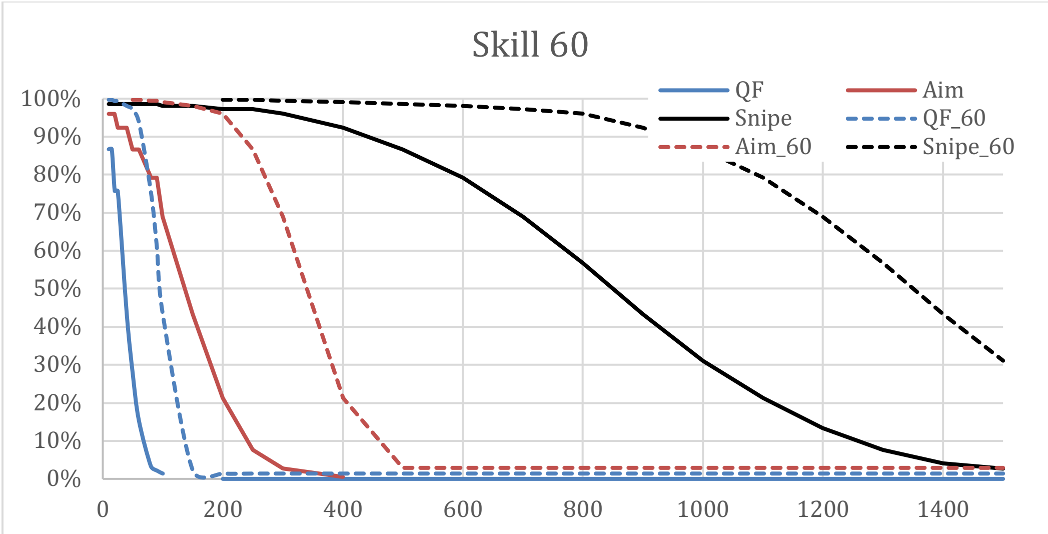


Figure 13 3 Cases: Effect of Skill on Accuracy

The results (Figure 13) matched our goals. In this figure the solid lines are the hit probabilities based on range (Section 6), the dashed lines show the probabilities based on the skill-based modifiers. Skill Level 12 matches the QF and Aimed fire curves. Skill 30 matches the "sniper" curve, and shows improvement. The super-skilled 60 has an even chance of hitting a target at 1350m. These numbers show good correspondence with measured results (e.g. Figure 14)

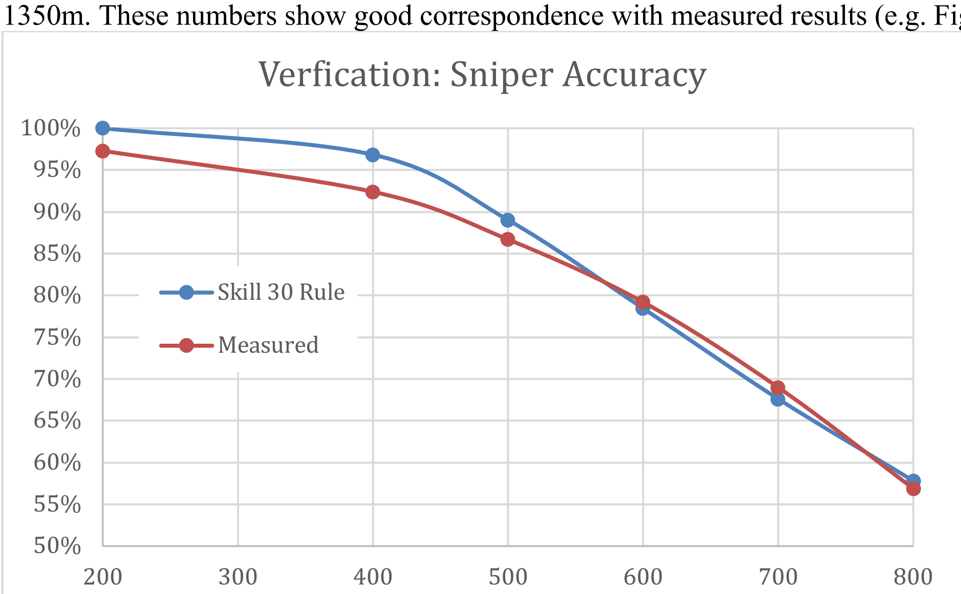


Figure 14 Sniper accuracy verification, measured values from [3]

8. To-Hit: Other

8.1. Wind/Vacuum

Wind effects are estimated from [3] (See Figure 11 in source), in which error budgets for 0 to 10mph were given. A linear least-squares model was developed to estimate error vs. wind speed for an E-type silhouette at 700m. These estimates, expanded from -4 (to account for vacuum cases) to 50 mph, were used to compute hit probabilities using [2] equation M3. These

probabilities were compared with the Skill-30 case at 700m (Figure 13, 69% probability). As a useful validation point, the Skill-30 case at 700m gives a similar hit probability (69%) as the no-wind linear fit case (70%).
The difference between the Skill-30 hit probability (69%) and the linear estimate / M3 equation hit probability was computed for the vacuum (-2 and -4 mph), no wind, "moderate wind" (2 to 6 mph), and "high wind" (34 mph) cases. These differences were divided by our "standard slop" of 3.5% to give a rough modifier. Initial modifiers were in the range of 8.8 to -19.4. This range was compressed slightly (15%) for playability. Modifiers for each case were rounded to the nearest even number.

8.2. Weapon Quality & Type

Sources were used to determine the accuracy of different historical ([26]) and modern ([15]) in mils of standard deviation. These accuracies were used to calculate hit probabilities, using the M3 equation, for 200 to 800m. The average probability of this range was computed and compared against the baseline "high quality" system, an M24 Sniper Weapon System (SWS) firing 300 Winchester Magnum Ammunition. The M24 is based on the Remington Model 700 with a custom free-floating barrel and other improvements.
The average probabilities for different weapons were compared with the baseline M24, the difference was divided by "standard slop" of 3.5% to get a rough modifier. The range of these modifiers were compressed slightly and rounded to the nearest even integer and the weapons were placed into four categories. Accuracy was averaged between each weapon in the category for the final modifier (Table 9).
Clearly, there is abundant room for elaboration on a per-weapon basis.

Table 9 Weapon Quality

<table>
<tr><th>Category</th><th>Weapons</th><th>σ (mil)</th><th>modifier</th></tr>
<tr><td rowspan="2">Low Quality / Poorly Maintained / antique"</td><td>1853 Enfield</td><td>1.75</td><td rowspan="2">-10</td></tr>
<tr><td>AK-47</td><td>0.48</td></tr>
<tr><td rowspan="2">Lower Quality</td><td>AK-47</td><td>0.38</td><td rowspan="2">-4</td></tr>
<tr><td>AK-74</td><td>0.32</td></tr>
<tr><td rowspan="2">Standard</td><td>M16</td><td>0.21</td><td rowspan="2">-2</td></tr>
<tr><td>M1903 Springfield</td><td>0.23</td></tr>
<tr><td rowspan="2">High Quality, Accurized</td><td>MK211, .50cal</td><td>0.13</td><td rowspan="2">+0</td></tr>
<tr><td>M24 300WM</td><td>0.1</td></tr>
</table>

Modifiers for pistols were calculated from data in [20]. Values were averaged over 10 and 300m (where available).
Note: for the final rules, we make adjustment to the mode base (B, see 6) to make "standard" quality have a modifier of +0.

8.3. Ranging / Zero G

The effect of ranging error was estimated in [15]. The impact of "perfect" range estimation or zero gravity was found by removing the ranging error for a skilled sniper, and following a procedure similar to Section 8.2.

8.4. Firing Position

The effects of firing position are derived from [4], which covers firing position and attempts to evaluate stress and in [16]. These sources generally cover fire from a standing position, a sitting/kneeling position, and a prone position. [4] also has limited data on “trenched” firing (upright, but with body and rifle supported as if firing from a trench), which seem to give similar performance as prone firing. The effect on hit probability from 50-300m was estimated using data from both sources and compared to the aimed fire (skill 12) hit probabilities. Differences were averaged, and the “standard slope” was used to compute modifiers.

8.5. Movement

Movement modifiers are based on [5], [22], and [27] which examine aiming brackets, QuickFire, and techniques for shooting at moving targets. An exponential curve fit for the hit probability data in the sources was derived. The impact on hit probability was extrapolated to different target speeds. The “standard slope” was used to convert this to modifiers.

8.6. Cover/Size

Representative target sizes from 2.4cm to 18.2m were selected. Using a “test shooter” with 3.9mil σ accuracy (similar to Skill 12) and the M3 equation, hit probabilities for each size and several ranges between 50 and 1000m were estimated. we use the inverse normal distribution to estimate the modifier for each size/range probability. The standard (0.37m) target size hit probability is subtracted from each. The results are averaged over all ranges for each size, and rounded to the nearest even integer.

For example, a shooter with σ=3.9 mil, aiming at a 30cm target (similar to an 8.5x11” piece of paper) has a 39% chance of hitting at 50m, a 2% chance at 250m, and a 0.1% chance at 1000m. Using the inverse normal distribution translates into modifiers of -2.2, -16.8, and -24.7. Subtracting the 0.37m case’s modifiers yields differential modifiers of -12.6, -7.7, and -5.3. Averaging these with the other ranges yields -8.036, which rounds to -8.

8.7. Illumination

The primary source for determining illumination modifiers is [10], which included night firing tests which showed an 80% reduction in hit probability. The tests were “…conducted with limited floodlighting. …approximated bright moonlight,” which we interpreted as 0.108 lux [28]. [16] (experiment 9 & 10) also covers firing at night, under “half-moon” conditions. [29] has the key insight that visual acuity corelates with the logarithm (base 10) of the illumination. In imitation of the mainline rules, we want to maintain some possibility of hitting, even at lowest light levels. We defined a series of lighting conditions from full daylight (10752 lux) to “Overcast Night” (0.001 lux). Based on [10], we estimated a linear relationship between the log of the illumination of daylight resulting in 100% accuracy and the log of “full moon” lighting resulting in 20% accuracy. Hit probabilities for intermediate conditions could then be calculated (Table 10, column 4). From this was subtracted 92% (chosen to make sure the “daylight” and “overcast” conditions balance out to a modifier of zero) giving us column 5. This was divided by our standard slope of 3.5% to provide raw modifiers between 2.3 and -34.4. For reasons of playability, this was compressed into a smaller range and rounded to the nearest even integer (column 7).

Table 10 Illumination Effects

Condition	illuminance (lux)	log(lux)	P_h	Difference	Raw Mod	Compressed even integer
"daylight"	10752	4.03	100%	8%	2.3	2

"overcast"	1075	3.03	84%	-8%	-2.3	-2
Indoor: office	500	2.70	79%	-13%	-3.8	-2
Artificial Light	200	2.30	72%	-20%	-5.6	-2
Indoor: corridor	100	2.00	67%	-25%	-7.0	-4
"twilight"	10.8	1.03	52%	-40%	-11.4	-6
"full moon"	0.108	-0.97	20%	-72%	-20.6	-10
"1/4 moon"	0.0108	-1.97	4%	-88%	-25.1	-12
"Starlight"	0.0011	-2.96	-12%	-104%	-29.7	-14
"Overcast night"	0.0001	-4.00	-29%	-121%	-34.4	-16

A subset of the different lighting conditions were selected as significant to reduce the length of the table.

Note, this methodology probably overstates the effect of moderate lighting (e.g. indoors), and assumes that visual acuity is the limiting factor for many engagements. This is probably an overstatement, but yields reasonable results for our purposes.

8.8. Scope

Effects of magnifying and illuminating sights of different types are covered in [20] (iron sights, M68, M150, Vortex Razor), and [16] (Experiments 11 and 20, examining trilux and promethium sights).

[20] gives hit probabilities for 100, 200, 300, and 400m for each sight type. From these are subtracted the hit probability for a plain iron sight. This difference was divided by the "standard slope" and the results were averaged and rounded to the nearest even. For the sights for which we have data in [20], this yields a modifier of +6.

Clearly, there is substantial room for elaboration.

8.9. Dodging

To estimate the effects of a dodging target (i.e. one which is moving to evade or erratically, rather than simply moving, which is covered in Section 8.5), we use a simple acceleration model. Essentially, we try to compute how far a target might accelerate away from the aiming point between the time the shooter tries to fire and the bullet reaches the target.

We assume a very fast individual can accelerate at about 7 m/s^2 [30], and an 'average' individual at one third that rate. We examine several ranges (25, 50, 100, 200, 300m). For each range we compute the time of flight (based on starting and terminal velocities found in [31]) and add 0.17 second reaction time. We then compute the maximum distance travelled:

$$d = \frac{1}{2}at^2 * \cos(30^\circ)$$

Adding in an angle term to account for dodges not always being perpendicular to the line of fire. This distance was converted to mils of error and added to the error for an 'average' shooter. We then use the M3 equation to compute the hit probability for both the 'dodging' case and the 'no dodging' case and take the difference of the two (Figure 15). We average these results across all the ranges for both the "fast" and "average" case and use the "standard slope" to compute modifiers. We assume the "fast" target has a relevant skill of 30 and the "average" of 10. A linear fit between these points yields a slope of 0.1605 and an intercept of 0.27. A close approximation is to divide skill by 6 and round up.

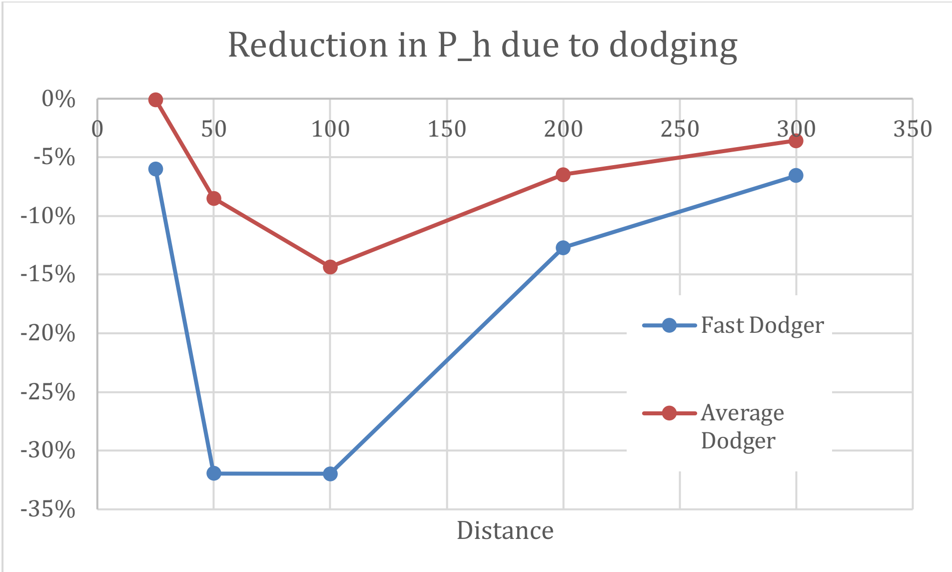


Figure 15 Dodging Results

8.10.Stress

Several sources indicate that in combat tens, hundreds, or even several thousand rounds are expended per hit or casualty. The reasons for this vary (use of suppressive fire, overuse of automatic weapons, etc…). Several sources suggest [32] relatively few combatants fire to hit out of an aversion to killing.

Whatever the cause, these effects are generally neglected for rule design as the added "realism" would mean a dramatic increase in the number or rolls required and would bring gameplay to a virtual standstill. Most of the accuracy studies used for this work have been calibrated to a "lightly stressed" case – more stress than bench or qualification firing, but less than actual combat. In generally, the effect of stress is covered by the "pre-trauma" damage effects.

Other Sources:

- "Men Against Fire" [32] by S L Marshall was a controversial study of US combat performance in WWII. Marshall wrote that only 15-25% of infantry troops actually fired their guns in an attempt to kill enemy combatants (for standard rifles, machine gunners reported higher rates of fire). Though controversial and contested, similar results were found in [33] (summarizing David Rowland's work) which estimated a degradation factor of ~10 between peacetime and combat weapons effectiveness for small arms. It also estimated anti-tank guns had a degradation of about 5, but skilled "hero" gunners would substantially improve this.
- [19] covers the effects of stress and injury on marksmanship
- [23] cover physiological studies of competitive shooting
- [34] examines cognitive load as a proxy for combat stress and target exposure time
- [35] examines the effect of suppressive fire on troops. It found a correlation between the kinetic energy of a round and its effectiveness in suppressing.

9. Multiple Projectiles

Firing multiple projectiles ("automatic fire") has two effects – (1) it increases the chance that at least one will hit the target and (2) it increases the probability that multiple projectiles will hit the target and do more damage.

Additional Sources:
[36, 16] both examine the effects of automatic fire on accuracy.

9.1. Hit Probability

Firing multiple projectiles increases the chance that at least one projectile will hit. In the simplest case, we can assume each trial (projectile fired) is independent (e.g. a Bernoulli process), and the probability of at least one hit is:

$$P(hits > 0, p, n) = 1 - (1 - p)^n$$

Where p is the probability of a single projectile hitting and n is the number of projectiles. However, our case is complicated by an additional factor – as [2] points out, automatic fire impairs individual shot accuracy. So, we decrease the probability by a factor related to the number of projectiles fired:

$$P(hits > 0, p, n) = 1 - (1 - (p * f(n)))^n$$

We compute $P(hits > 0, p, n)$ from $p = 1.4\%\ to\ 98.8\%$ (equivalent to a modifier of -26 to +26) and $n = \{2,4,6,10,16,,25,38,50,75,100\}$. This yields Figure 16.

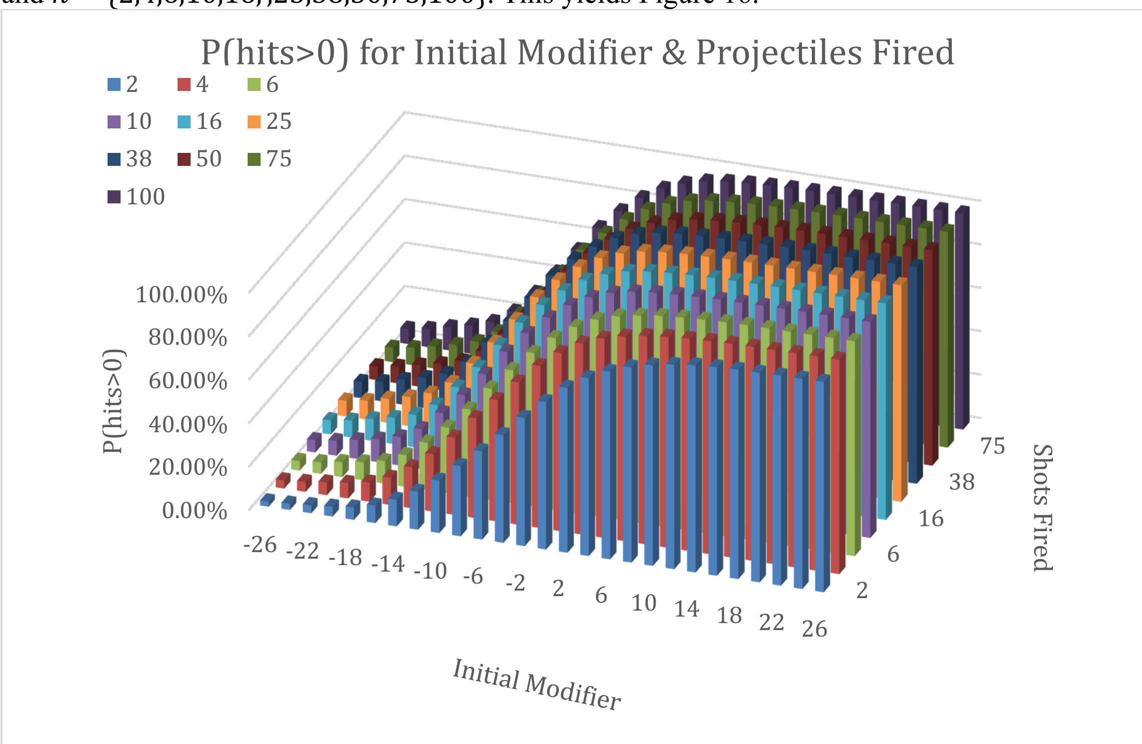


Figure 16 Effect of multiple shots on hit probability

Next, we compute the modifier for the number of shots fired. To do this, we first compute the opposed roll modifier required to model the probability for each $P(hits > 0, p, n)$ value. E.g. $P(hits > 0{,}15.5\%, 6) = 40.19\%$, so the chance of hitting with a -10 initial modifier and 6 projectiles is 40.19%. This is roughly a modifier of -2. If we subtract the initial modifier (-10) from the new modifier (-2) we get +8. We repeat this procedure for each value of p and n, generating Figure 17.

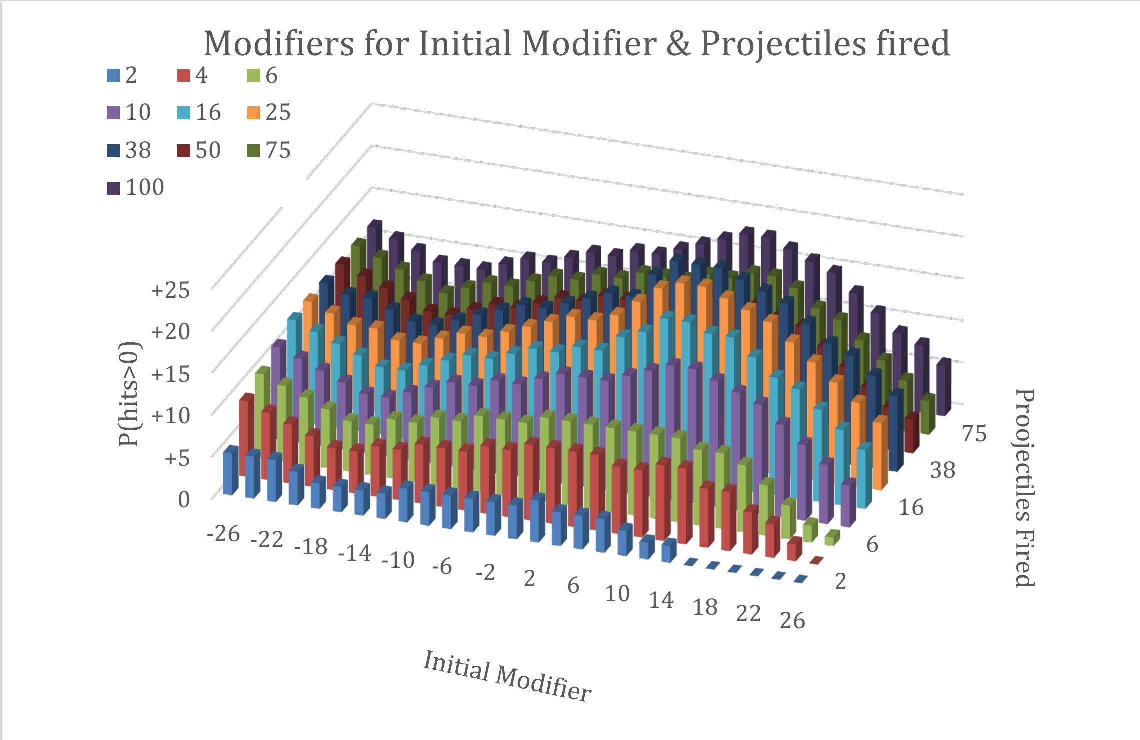


Figure 17 To-hit modifier rolls for Multiple shots

By taking the average values of the modifiers across this range and rounding to the nearest even we can reduce these modifiers to a simple 1D table, while maintaining an average accuracy of within 3 percentage points over the -12 to +12 range:

Projectiles Fired	2	3-6	7-10	11-25	26-38	39-75	76-100
To-Hit mod	+4	+8	+12	+14	+16	+12	+14

9.2. Damage Effects

Hitting with multiple projectiles creates a damage multiplier effect. The scale of this multiplier is based on the over-roll from the "to-hit" roll and the inverse binomial distribution of the number projectiles and probability of hitting.

We start by assuming an 'average' case of 150m with a standard deviation of aiming of 4 mils. Using the M3 formula, this gives us a 32.6% chance per projectile. We generate the cumulative distribution function by using a perl script [37] to generate 10 million opposed roll outcomes, ignoring all 'failed' rolls. The CPF for a given over-roll is used in the inverse binomial distribution as the test probability. To provide a more 'interesting' distribution, we reduce the CPF for over-rolls less than 20.

10. Damage

The primary methodology for damage is derived from [6], by Kokinakis and Sperrazza. This work focuses on determining injury probabilities, or, more specifically, incapacitation probabilities. Probabilities were gathered from a number of animal experiments, ballistic penetration studies, and medical examinations. "Incapacitation" for different activities (e.g. defense, offence, supply, etc…) and different time periods (30s, 5m, 5d, etc…) were estimated and weighted by body area. Curve fits were performed to determine P_{hk}, the probability of a type of incapacitation if hit by a given projectile while wearing a given level of protection. The general form of the equation is:

$$P_{hk} = 1 - e^{-a(mv^{1.5}-b)^n}$$

Where a, b, and n are curve fitting constants, m is the mass of the projectile (in grains), and v is its velocity (in feet/sec). The unit $mv^{1.5}$ is a useful estimate of projectile lethality and is sometimes referred to as SK units or "Sperrazza Energy". This approach was validated [38] and found to be a good predictor for rifle injuries in combat.

For example, for the case of incapacitating a soldier on offense with winter clothing and a helmet, a=7.64e-4, n=0.4957, and b=31000. If the projectile is a 63 grain bullet impacting at 2362 fps, P_{hk}=85.3%. In the case of the soldier being nude and incapacitation in 5 minutes, a=2.73e-3, n=.44545, b=25800, so the P_{hk}=95.7%.

[6] and [39] provide estimates for "% Incapacitation" for different scenarios as well. These incapacitation probabilities appear to follow a normal distribution, so, combined with the formula to calculate P_{hk}, we can use this information to curve fit to the outcomes of an opposed roll. Examination of outputs shows a good fit if 100% incapacitation is equivalent to an over-roll of 8 (i.e. over-roll of 4 is 50% incapacitated).

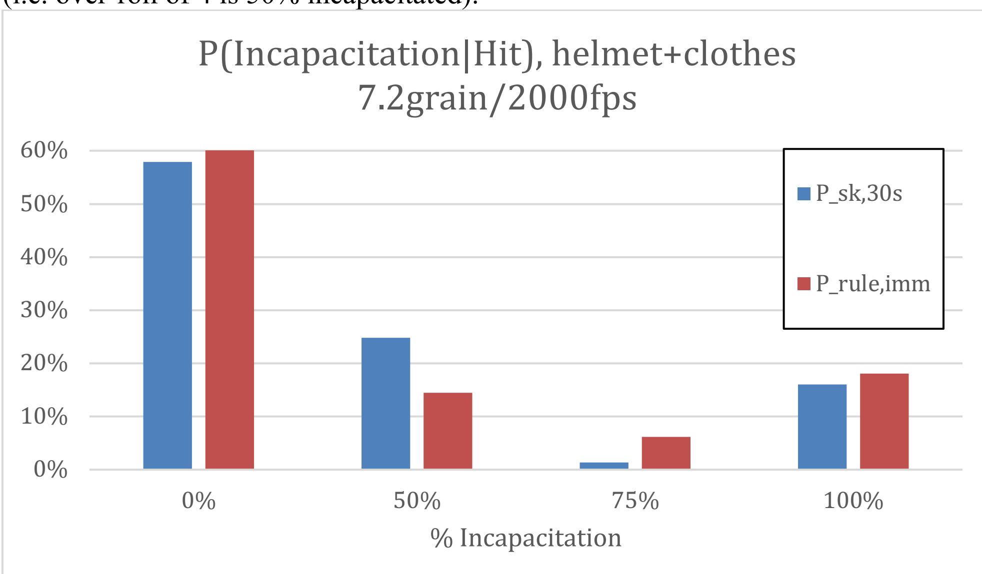


Figure 18 Incapacitation Curve Fit Example. P_sk are probabilities from [6], P_rule is the curve fit for the experimental rules.

For example, in Figure 18, **P_sk,30s** is the reported probability from [6] for different levels of incapacitation from a 7.2 grain projectile at 2000fps. An opposed roll with a +2 provides the probabilities shows by **P_rule,imm** – a reasonably close match. We interpret over-rolls greater than 8 as death.

Similar curves can be generated for other weapons based on their SK units.

A limitation to the version of the methodology used here is that it does not account for all terminal ballistic effects. In particular, tumbling and fragmentation are beyond our scope.

Other souorces:

- [40] Extends K&S work for different projectile types.
- [9] Provides a more comprehensive coverage of wound ballistics
- [41] An ARPA report on different potential sidearms and their damage probabilities. Uses a similar methodology as [6]. Includes analysis of some interesting weapons such as gyrojets and rocket pistols.

10.1.Damage Modifiers

The mainline rules use a standard modifier of (Strength + Size) against all attacks. This gives a very large variation in damage effects, so alternate metrics were examined.

Initially, we examined Cardiorespiratory fitness (CRF) as a proxy for 'toughness,' as it is a good predictor of all-causes mortality [42] and surgical mortality [43]. However, the all-causes mortality variation is fairly small, except for very low CRF [44]. Consultation with medical experts [45] indicated that for trauma, it may not have a large impact on survival, but would have a greater impact on recovery time.

To find a simple mechanism, we instead examine tests of mortality prediction "scores" such as ISS [46] or IMP-ICDX [47]. These scoring systems give criteria to predict the chance of survival for a given severity of traumatic wound.

The prediction error of these methods can be interpreted as evidence of variance between individual's fundamental 'toughness'. Examination of the sources shows an average 29% error. We assume half of that is due to individual toughness, or about 15%. Using the standard slope gives a span of just over 4. We assume a minimal human has a toughness of 10 (size 5 + strength 5) and a very tough individual is 27 (size 5 + strength 22), a linear fit can be approximated by:

$$modifier = \frac{toughness}{4} - 4$$

Optimizing for the case of humans (size of 5), gives a simpler modifier:

$$modifier = \left\lceil \frac{strength}{4} \right\rceil - 3$$

Rounding up ensures than an average human (strength 10) has a modifier of +0.

10.2.Delayed Damage

The methodology developed above focuses on the short term (30 second) incapacitation estimates from Kokinakis and Sperrazza. An optional rule was developed to model the effect of delayed injury by using the Kokinakis and Sperrazza formulas for incapacitation after 12 hours.

Figure 19 shows a comparison of 30 second "offensice" and 12h "supply" incapacitation probabilities. Applying the same curve fitting methodology as above, but matching the 12 hour incapacitation rate gives modifiers which are +3 to +4 higher than the 30s case. We interpret this as a possibility of delayed injury if the over-roll of the To-Damage roll is -2, -1, or 0.

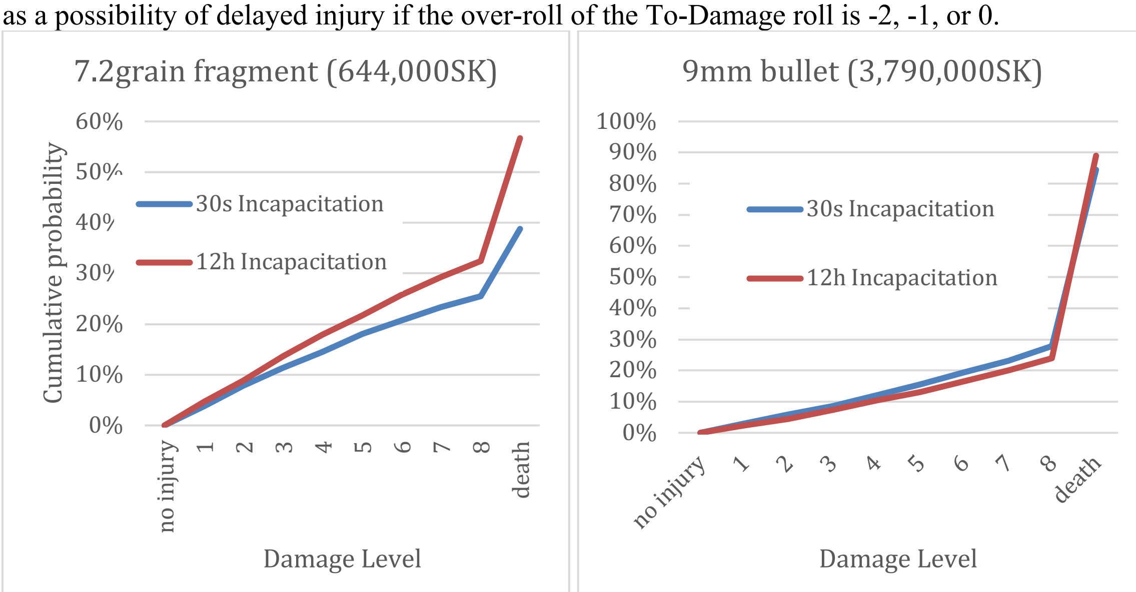


Figure 19 Comparison of 30s and 12h incapacitation probabilities

10.3. Weapon Damage

Based on the process noted above, modifiers for incapacitation for several weapons were found. A close approximation for a weapon's damage modifier, based on SK units is:

$$Damage\ Mod = -ROUND(64.79 + -10.94 * LOG_{10}(SKU))$$

10.4. Called Shot

"Called Shot" (i.e. "shoot the target's head") hit probabilities can be calculated using the size modifiers (Section 8.6). Damage effects cab use the existing "Called Shot Table" ([1] p268) or the Referee's discretion.

10.5. Animal Damage

The mainline rules specify the 'toughness' factor based on strength and size. This could lead to problems as the 'toughness' assigned to animals was quite high. For example, an elephant, with a toughness of 220 could reliably resist a hit with a 12pdr QF gun.

Damage models for animals are less well developed. However, one source, [48], provides some guidance for how terrestrial mammals might be adapted:

- Toughness could be based on $constant * mass^{0.47}$ ([48] eqn .6). This is roughly related to width.
- Hit Points for an animal could be $constant * mass^{0.73}$ which is their formulation for the time required to bleed out from a wound ([48] eqn 9).
- Clearly, there is room for much elaboration.

Setting the "average' human as toughness=0 and Hit Points=8, we can derive constants for the above relationships (mass in kg):

- Toughness: $0.43 * mass^{0.47} - 3$
- Hit Points: $0.393 * mass^{0.47}$

These are used estimate characteristics for several animals in Table 7.

11. Armor

There is a large literature on the subject of body armor. A few sources:

- [49] – Examination of penetration models for soft armor, and tests on goats
- [50] – Some coverage of penetration and behind armor effects for soft armor
- [51] – Discussion of BABT (Behind Armor Blunt Trauma)
- [52] – NIJ body armor definitions
- [53] – Examination of Beryllium-Boride–based ceramic armor
- [54] – Overview of ceramic production methods
- [55] – Overview of exterior and terminal ballistics related to armor, with a focus on fragment geometries and velocity distributions, and penetration into human tissue.
- [56] – History of early armor for mine-clearing

11.1. Helmet

Because helmets are the most common form of body armor, we have a special case for them. Based on [6], we can calculate the probability of incapacitation with and without a helmet for a range of SK units (Figure 20). Using a weighted average of the more likely projectiles (4.5e5 to 1e7 SK units, roughly a light pistol to a .25-06 Remington cartridge), we find the average difference is about 3%. Since the "average slope" of the opposed roll curve is 3.5%, we assign helmets a modifier of 1.

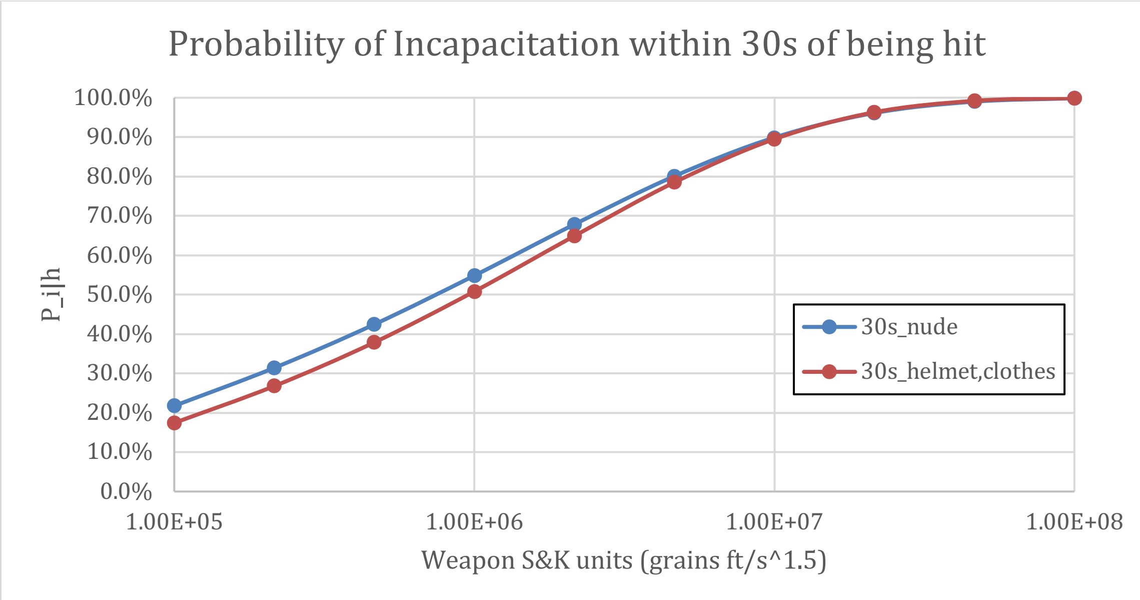


Figure 20 Probability of incapacitation with and without helmet

11.2.Body Armor

Body armor is probably not ubiquitous, but is also not uncommon in SoE. The SoE setting has access to some relatively advanced materials (ceramics, non-ferrous alloys, exotic silks, and basalt fiber from Venus, Martian artifact carbon nanotubes, etc…) and the greater risk of animal attack during the Hive Wars or on Venus may make armor a popular choice.

To evaluate armor, we use the following methodology:

1. Define the projectile's base impact velocity and mass, armor type and thickness, angle of impact, and armor coverage.
2. Calculate the amount of energy absorbed by the armor, based on the material type and thickness (see Sections 11.2.2-11.2.4). Any energy not absorbed is the residual energy (E_r).
3. Calculate the mass which impacts the body (m_i). This is generally the mass of the bullet plus the mass of an armor 'plug' which the bullet displaces. However, for some materials we estimate the erosion of the bullet or (for ceramics) calculate the "cone" of displaced ceramic materials.
4. Calculate the residual velocity (v_r):
$$v_r = \sqrt{\frac{E_r}{2 * m_i}}$$
5. Calculate the SK units (see Section 10) for the impacting mass and velocity:
$$SKU = m_i v_r^{1.5}$$
6. Calculate the probability of incapacitation ($P_{armor}(I|H)$) for the given SK units (see Section 10). This is weighted based on the armor coverage factor (See 11.2.1)
7. Calculate the opposed roll modifier needed to match the probability of incapacitation for the armor, and compare it to the probability of incapacitation for an unarmored target. This gives us the armor modifier for that projectile type, velocity, and impact angle.
8. Repeat steps 1-**Error! Reference source not found.** for different projectile types, velocities, and impact angles (Poor man's uncertainty quantification).
9. Average the modifiers for rifle-type projectiles and pistol-type projectiles for each velocity and impact angle.

This methodology gives us modifiers for each type of armor based against rile- and pistol-type projectiles. We iterate over the following types:

- 4 projectile types (impact velocity, v_i, is 75-80% of the muzzle velocity to account for velocity lost before impact)
  - .577/450 Martini–Henry: v_i: 308m/s, mass: 31.1g
  - .30-40 Krag 100 gr (6 g) SP: v_i: 662m/s, mass: 6.4g
  - 9x19mm parabellum Federal FMJ: 298m/s, mass: 8g
  - .22lr 32 gr. Copper-plated HP: 327m/s, mass: 2.1g
- 3 velocities: $v_i, 0.9 * v_i, 1.47 * v_i$
- 3 impact angles: perpendicular, +22.5 degrees, -22.5 degrees

11.2.1. Armor Area Effectiveness

Different parts of the body are more vulnerable than others. It is assumed that armor which does not cover the whole body would concentrate on the most vulnerable areas. For example, a helmet covers a small portion of the body (4% or so), but provides protection to critical organs. For this work, we assume the effectiveness of armor scales with the square of the area covered. i.e.:

$$Effectiveness = 1 - (1 - coverage)^2$$

So, armor covering 10% of the body would be 19% as effective as full body armor.

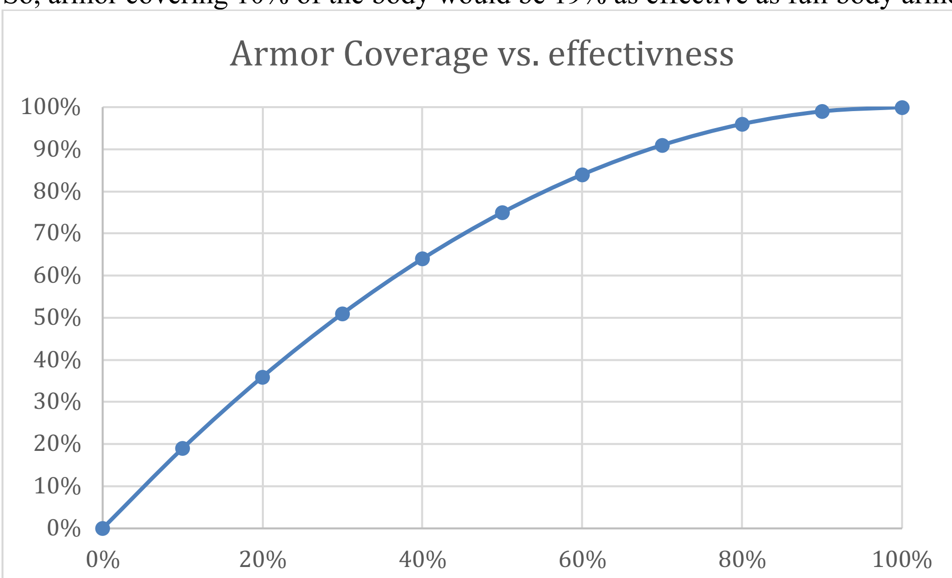


Figure 21 Armor Coverage vs. Effectiveness

11.2.2. Metal

Metal penetration and energy absorption estimates from Project Thor [57]. This study (also summarized in [11]), part of a larger Air Force effort to quantify vulnerability, presents empirically derived formulas for penetration, ballistic limits, residual mass, and residual velocity for a number of materials ([58] covers non-metallic materials).

11.2.3. Metal-backed Ceramic Plates

[59] by Florence presents an analytical model for ceramic plates backed by a metallic material. The model is only compared to experiments of aluminum oxide backed by metals, so we confine our designs to similar materials. Section 7.10.3 of [11] (p231) provides a useful summary of [59]. We also use estimates from [60] for the size of cone formation, used to calculate m_i.

11.2.4. Textile (Soft) Armor

For “soft” textile-based armors, we use the method described by Cunniff [61]. Cunniff defines a key parameter, U^*, defined as:

$$U^* = \frac{1}{2}\frac{\sigma\varepsilon}{\rho}\sqrt{\frac{E}{\rho}}$$

Where σ is the tensile stress at rupture, ε is the tensile strain at rupture, E is the modulus, and ρ is the material density. With this parameter, it is possible to find the v_{50} limit by a relationship:

$$v_{50} = (U^*)^{\frac{1}{3}} f\left(\frac{A_d}{A_p}\right)$$

Where A_d is the mass per unit area of the armor, A_p is the mass per unit area of the projectile, and $f()$ is a function we derived from examination of charts in [61].

To account for armor being “overwhelmed”, if (impact velocity > v_{50}), we reduce the absorbed energy by 40% (suggested by Figure 23(b)).

Additionally, to account for BABT (Behind Armor Blunt Trauma) we use a relationship between the v_{50} of a fabric and the BABT derived from [62] (Figure 22).

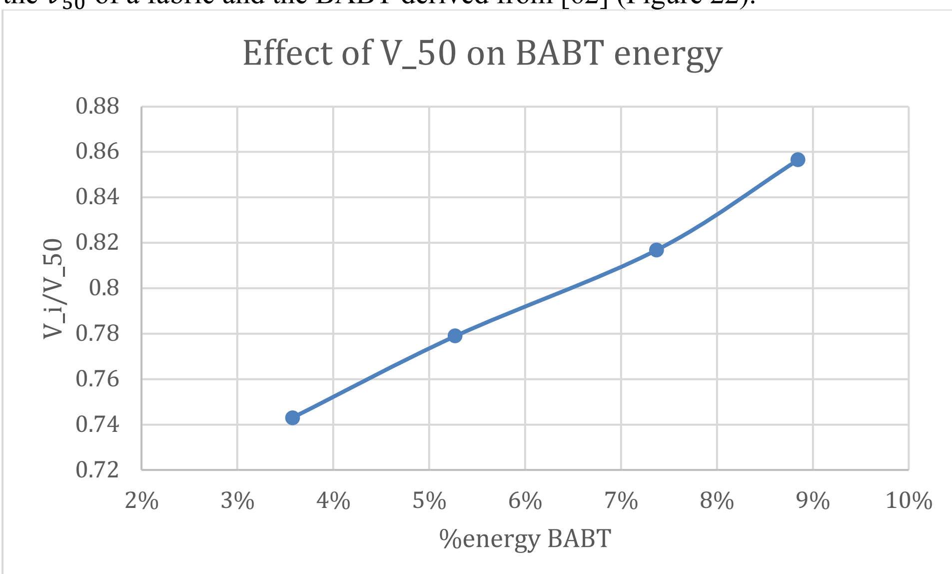


Figure 22 Relationship between v_{50} and BABT

Other sources:

- [63] – Performance of textiles under oblique impact. There are interesting non-linearities and non-monotonic features at different angles.
- [64] – Overview of soft armor materials, manufacturing, testing, and dynamics. Interesting coverage of the contrary requirements of anti-ballistic and anti-stab textiles (Figure 23(a)), and the effect of “overwhelming” on energy absorption (Figure 23(b)).

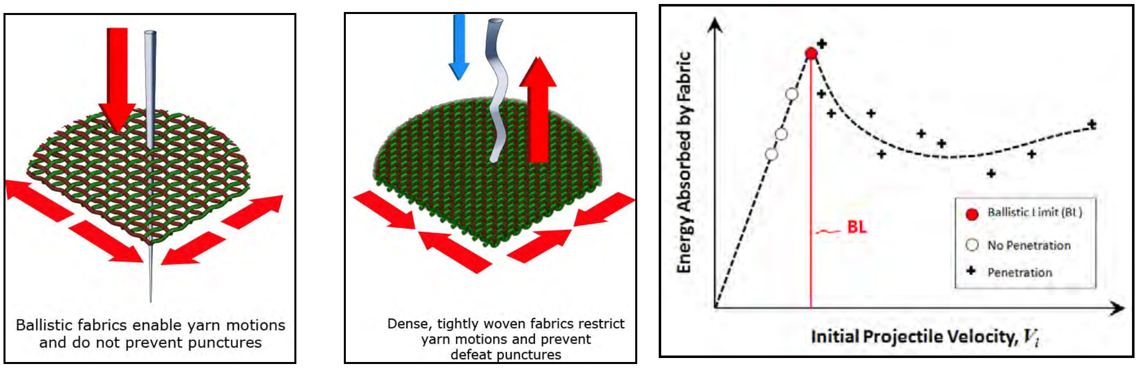


Figure 23 Anti-ballistic vs anti-stab artmor (a) and effect of fabric "overwhelm" on energy absorption (b), from [64]

- [65] – Examination of silk as a material for body armor
- [66] – Mechanical information on silk, the supplementary material [67] is particularly useful. Example armor uses Yun IV-E silk, “Venusian spider silk” has 33% greater $(U^*)^{\frac{1}{3}}$.
- [68] – Analysis of different weaves and types of basalt fibers for military applications
- [69] [70] – Information on Basalt fiber properties
- [71] – Additional information on BABT measurement and estimation

11.3.Side Effects of Body Armor

[72] indicates minimal effect on precision or accuracy when firing while wearing body armor. However, there is some effect on movement speed. The transition between targets or task completion was 10-15% slower, however this effect is negligible if the armor is proper fit, at some cost of decreased coverage. This should impact initiative.

12. Areas for Future Examination

Should shotguns be handled differently?
How should scopes be handled?
Should damage multipliers for multiple projectiles be reduced because of diminishing returns (e.g. if we assume the first bullet is the ‘best’ hit and the others are less damaging)?
Should Player Characters have more than the standard 8 damage points?
How should modifiers be applied? Should, e.g. to-hit modifiers all be applied to the shooter, or should some (e.g. dodge) be applied to the target?
Blast Damage
Fragment Damage
Melee weapon damage
[56] – interesting armor concepts
[13] – toxic bullets
[10]–duplex/triplex bullets
[41]–weapon concepts
https://en.wikipedia.org/wiki/De_Lisle_carbine
https://en.wikipedia.org/wiki/Girardoni_air_rifle
[73] – analysis of coatings to reduce the effects of lasers and nuclear radiation
New fortes: quickfire, aimed, sniping + body position
https://en.wikipedia.org/wiki/APS_underwater_rifle
https://en.wikipedia.org/wiki/Dardick_tround

https://en.wikipedia.org/wiki/Frangible_bullet
https://en.wikipedia.org/wiki/LeMat_Revolver
https://en.wikipedia.org/wiki/Rossignol_ENT
Standschütze Hellriegel 1915
https://en.wikipedia.org/wiki/Sharps_rifle ('coffee')
Borchardt C-93
https://en.wikipedia.org/wiki/Hand_cannon
https://en.wikipedia.org/wiki/.577_Tyrannosaur
https://en.wikipedia.org/wiki/Ljutic_Space_Gun
https://www.guns.com/news/2015/09/17/ljutic-space-gun/
https://en.wikipedia.org/wiki/M6_Aircrew_Survival_Weapon
https://en.wikipedia.org/wiki/Taylor_knock-out_factor#TKOF_comparison
https://en.wikipedia.org/wiki/Shotgun#Pattern_and_choke
https://en.wikipedia.org/wiki/Shot_(pellet)
https://en.wikipedia.org/wiki/.410_bore
https://en.wikipedia.org/wiki/Shotgun_shell
https://en.wikipedia.org/wiki/.410_bore#Handguns_and_shot_pistols
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