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Analysis of the Fire Effectiveness of Medium Calibre Indirect Fire Naval Weapon System

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Abstract: 'Oto Melara' 76/62mm Compact Single Mounting Weapon system is the largest caliber one and only fire control radar coupled weapon system Sri Lanka Navy possessed with by 2019. Yet, this could not effectively used during war time due to prolong defects and its effectiveness also not analyzed by any means we don't follow such a system too. Analysis or the prediction of the effectiveness of a particular weapon system before acquiring and operational use, is an important aspect. This process is mainly based on analysis of all possible static, dynamic error sources and certain environmental parameters related to firing ground, integrated through a calculation model. Single Shot Hit Probability (SSHP) is used in this study for analyzing the fire effectiveness of the said weapon system through a Matlab based calculation model. The model is based on what practiced by PLA Navy (Naval University of Engineering) and considers errors in the Observation equipment, Fire Control, Servo systems, Ballistic Meteorological errors and Dispersion errors for predicting the distribution of shots. SSHP of the system against various targets of large and smaller size kept at various ranges, bearings from the firing ship is considered for the analysis and hitting the target is considered as a kill, due to the effect of the 76mm High Explosive ammunition. Military personnel in the Gunnery field and decision makers would be benefitted with this study by enhancing the knowledge on sources of firing errors and how to predict the effectiveness of a weapon system without choosing the costly method of analyzing actual firing records.

Key Words: Weapon System, Errors, fire Effectiveness

Introduction

Aim of every firing mission is to directly hit the target or to fall the rounds within a specified area that it can Kill or Incapacitate the Target. Even though, first round hitting the target is the most desired condition, it is highly unlikely in actual firing missions even provided with sophisticated systems and executed under controlled conditions.

Projectile leaving from Gun Barrel follows a curved path (Trajectory) due to Earth's Gravitational Pull. Trajectories in the Vacuum and Air; differs due to the presence of Air Resistance in the atmosphere.

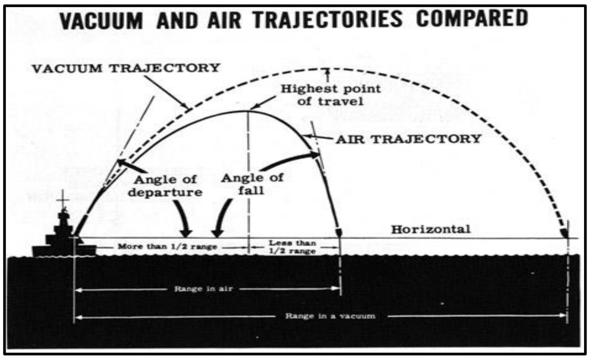

Figure 1: Trajectory of a Gun Projectile in the Vacuum and Air
Source: (United States Naval Academy, 2018)

A. *Naval Firing Process*

Firing process of a shipborne gun weapon system involves many steps followed assuring the desired accuracy under varying conditions. Accordingly, a general procedure for a medium caliber indirect fire gun weapon system is as follows.

i. Initial detection of Targets done by Ship's Search/Surveillance Radars (for Position, Speed)
ii. Target Identification (from available records, EW and target behavior)
iii. Target Acquisition by the Fire Control Radars and/or Optronic Devices (present position)
iv. Target Tracking (obtain Bearing, Range and Speed continuously)
v. Predicting the Target's Future Position
vi. Enter Ballistic Corrections (For changes from Standard Conditions)
vii. Stability corrections for pitching and rolling movements of the ship (using gyro, stable vertical equipment and Fire Control Computer)
viii. Continuous Providing of 'Lead' by the Fire Control System (FCS) with
ix. Provide Gun Laying orders to the mounting (Train and Elevation angles) through Servo System.
x. Firing commenced when target reach the max effective range.
xi. Repeat the process with splash corrections (observing fall of shots)

B. *Standard Shooting Conditions*

Every weapon system is designed and proven best for certain set of conditions called 'Standard Shooting Conditions'. Following are some of the general conditions and firing missions conducted under varying conditions demands corrections refereeing to the Firing Tables made for the particular weapon system.

<u>Weather</u>	<u>Location</u>
Air Temperature	Gun and Target at the same Altitude
Air Density	Accurate Range Obtained
No wind and Rain	Flat Earth Surface and No Rotation

<u>Material</u>

Standard Projectile (weight, shape) and Fuse Status

Standard Propellant Temperature

Leveled Trunnions and Precision Settings (Gun Base)

Standard Muzzle Velocity (as per Firing Table)

C. *Firing Accuracy and Errors*

The standard shooting conditions given for a particular gun weapon system are never met in actual firing environments. These varying conditions; paved the way for firing errors ultimately effecting the desired accuracy. Several Rounds fired from a single gun within a short time under same conditions would follow different Trajectories forming a conical beam. The impacts found to be dispersed on the ground or sea, around a central point; called the Mean Point of Impact (MPI).

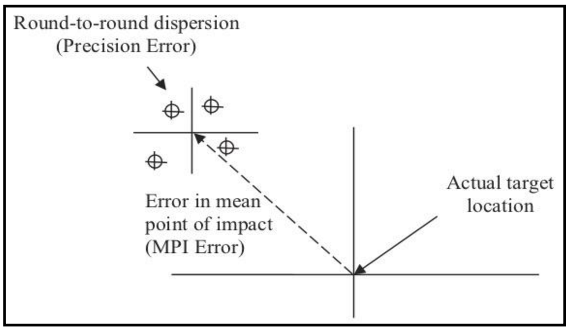

Figure 2. MPI and Precision Errors
Source: (Driels, 2013)

There are various error sources responsible for the fired projectile not hitting the Desired Point of Impact (DPI). All the errors accounted for can be categorized under two errors. They are Precision (Dispersion) and Mean Point of Impact (MPI) errors.

i. *Precision Error*: The precision error is a measure of the dispersion of a group of rounds fired by a single gun about the mean point of impact on a single occasion. The variant qualities of ammunition are mainly responsible for this error.
ii. *Mean-Point-of-Impact (MPI) Error*: The Mean-Point-Of-Impact (MPI) error or the so-called aiming error is a measure of the variability of the mean point of

impact of a single gun, fired at the same target coordinates, over multiple occasions. In a typical weapon system; Observation equipment, Servo System, Fire Control System and Ballistic Meteorological Errors accounts for MPI error.

Firing Errors can be mainly classified as Systematic and Random. Systematic errors are either constant with the time or changes according to a pattern which can calculate and compensated for better results. This further divide as follows.

i. Fixed Biased - Constant errors, Value Not change with the time
ii. Variable Biased - Accumulation errors, Value changes occasion to occasion but follows certain rule (MPI / Aiming errors)

In contrast, Random Error means the values and sign of error changes randomly. (Round to Round Dispersion/Precision errors) where we cannot exactly calculate for compensation. Improving the fire effectiveness of a weapon system needs eliminate or reduce the effect above errors types as depicted in the figure bellow.

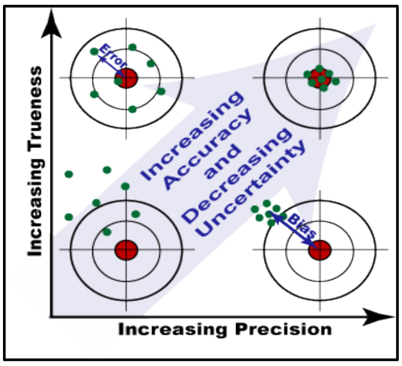

Figure 3: Improving the Firing Accuracy
Source: slideshare.com

D. *Weaponeering*

Weaponeering can be defined as the process of determining the quantity of a specific weapon required to achieve a defined level of target damage, considering target vulnerability, weapon effects, munitions delivery error, damage criteria, probability of kill, weapon reliability, etc. In the operational arena, where planners are striving for the most effective use of limited resources, efficiency is a critical factor that must be considered in the weaponeering process.

The principle mission of the delivery accuracy component of weaponeering is to provide statistics parameters describing the expected error distribution of munitions launched from given conditions against a defined target. In the ideal world, these statistical parameters are obtained from the field and tunnel trials. Practically, however, for many weapon systems this is too expensive to do. So, predictive models are often used for the purpose (Driels 2013).

Problem Statement

Oto Melara 76/62 mm Compact Gun Weapon System (medium caliber indirect fire) installed onboard Fast Missile Vessels (FMVs) was the highest caliber, one and only fire control radar coupled weapon system Sri Lanka Navy (SLN) had by 2019 and This gun is a universally accepted and around 1000 guns are operationally used in the world navies at present yet with different versions. Sri Lanka Navy couldn't use it effectively during the war time mainly due to prolong defects and its effectiveness was never calculated and we don't have such method too. Further, there is not much attention paid on the knowledge and practice of analyzing firing errors in view of improving the fire effectiveness of such of weapon systems.

Figure 4: Oto Melara 76/62 mm Installed Onboard SLN FMVs

Objectives

This study is headed towards three main objectives as follows.

i. To introduce a calculation model for analyzing Fire Effectiveness of an Indirect Fire Naval Weapon System against surface targets.
ii. To Calculate SSHP and Analyze Fire Effectiveness of Oto Melara 76/62 mm Compact Gun Weapon system against various surface target settings.
iii. To influence the future researchers in Sri Lanka to conduct projects for weapon system optimization

Research Design and Methodology

A. *Fire Effectiveness Analysis*

To assess the effectiveness of a ship borne gun against surface (sea) targets, the performance of the total weapon system has to be considered. Hence, we need to determine the effectiveness on the basis of performance of the following factors.

i. Manually or automatically (servo) trained guns
ii. Visually identification of the aim point or sensor driven (radar/thermal)
iii. Engagement range
iv. Fire Control System capability to provide 'Lead'
v. Stabilized or Unestablished ship motion

Whilst various factors affecting the Firing Accuracy, the observable outcome is the deviation of shots from the target Or the Desired Point of Impact (DPI); in Range and Deflection. Therefore, we should find or predict the amount of deviation from DPI to determine the accuracy and subsequently the fire effectiveness of the system. A model is an implementation of a methodology, that is, a practical way to obtain a result such as Pk (likelihood of killing) or Hitting (P_h) (Driels, 2013). There are many fire effectiveness calculation methodologies and models used in the present-day world which evaluates; Effects of Target and Shooter motions, Accuracy of Aiming the Gun, Projectile Trajectory, Target Vulnerability, Effectiveness of the Warhead against the Target, as follows.

1) Statistics and Test Method: Obtain large amount of test firing records and then calculate error probability. This is costly.
2) Statistics and Simulation Method: more famous and effectively used with varies models with the help of programming languages and tools like Monti Carlo, Simula, GPSS suited to particular weapon system (Sherif and Kheir 1981). Such models designed to simulate engagement between a surface ship mounted gun and surface targets and method demands use of costly software.
3) Mathematical Analysis Method: Formulas are developed for the firing process included all possible errors and accordingly predict the probable miss distance from the DPI with mathematical expectation. Then, analyze error with the target parameters to find out whether it is a hit or miss. This method is used for analyzing of fire effectiveness in this study considering it can avoid the long time needed to determine statistics using iterative techniques like Monti Carlo.

This predictive method of mathematical analysis uses the Expected Value theorem for computation of fire effectiveness. Expected Value can be considered as the mean value of a function E(x) would take for a large number of independent random selections of 'x' as expressed bellow (Driels 2013).

$$E(x) = \sum_{i=1}^{i=n} xiP(x = xi) \qquad (1)$$

This study calculates the Single Shot Hit Probability (SSHP) for various target parameters and conditions through a calculation model prepared by identified firing errors taking into account. Subsequently the fire effectiveness is analyzed.

Designing the Model

Fall of shots around MPI are recorded as Miss Distances in Range (x) and Deflection (z). x and z are independent variables. Fall of rounds fired from a naval weapon system considered to follow the Bivariate Normal Distribution with an Elliptical base representing the area of dispersion (Driels, 2013).

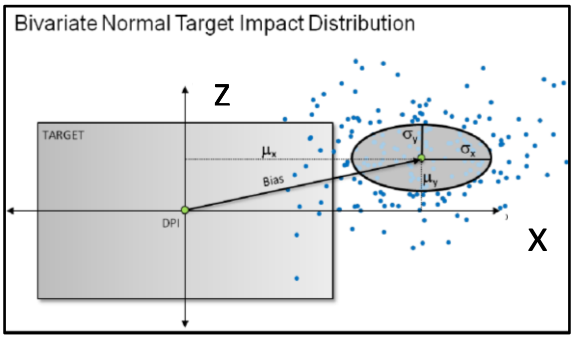

Figure 5: Bivariate Normal Impact Distribution of Shots
Source: (Driels, 2013)

Probability Density Function (PDF) of distribution of shots on the coordinate (x, z) as used in most Weaponeering methods can be expressed as follows (Driels, 2013).

$$f\ (x,y) = \frac{1}{2\pi\sigma_x\sigma_y} exp - [\frac{(x-\mu_x)^2}{2\sigma_x^2} + \frac{(y-\mu_y)^2}{2\sigma_y^2}] \quad (2)$$

In the above equation, $\boldsymbol{\mu_x}$ and $\boldsymbol{\mu_y}$ are 'Means' of shot distribution along each axis. $\boldsymbol{\sigma_x}$ and $\boldsymbol{\sigma_y}$ are standard deviations or the Mean Square Deviations. According to our problem, the Single Shot Hit Probability (SSHP) against a rectangular target, P(x, z) is obtained by formula 3. And It is further expanded in formula 4.

$$P(x,z) = \iint_{\substack{x\in(-lx,\ lx) \\ z\in(-lz,\ lz)}} f(x,z)dxdz$$

$$= \int_{-lx}^{lx} f(x)dx \int_{-lz}^{lz} f(z) \quad (3)$$

P(x,z)=

$$\iint_{\substack{x\in(-lx,\ lx) \\ z\in(-lz,\ lz)}} \frac{1}{2\pi\sigma_x\sigma_y} exp - [\frac{(x-\mu_x)^2}{2\sigma_x^2} + \frac{(y-\mu_y)^2}{2\sigma_y^2}]\ dxdz \quad (4)$$

Here the. $\boldsymbol{lx}$, ***and*** $\boldsymbol{lz}$ denotes length and width of a Rectangular target. $\boldsymbol{\mu_x}$ and $\boldsymbol{\mu_z}$ can be considered as zero for this case, as there is no'Mean' for such shot distribution on x, z plane (Xing Changfeng, 2007).

Matlab based calculation model for Single Shot Hit Probability (SSHP) for a surface to sea target can be formed in the Laplace form as follows.

$$P(x,y) = \frac{1}{4}[\phi(\frac{mx+lx}{\sqrt{2}\,\sigma x}) - \phi(\frac{mx-lx}{\sqrt{2}\,\sigma x})].[\phi(\frac{mz+lz}{\sqrt{2}\,\sigma z}) - \phi(\frac{mz-lz}{\sqrt{2}\,\sigma z})] \quad (5)$$

Then, the single shot hit probability can be represented as,

$$P(x,y)=\frac{1}{4}[\bar{\phi}(x_1)\text{-}\bar{\phi}(x_2)].[\bar{\phi}(x_3)\text{-}\bar{\phi}(x_4)] \quad (6)$$

In this equation,

$$x_1=\frac{mx+lx}{\sqrt{2}\,\sigma x};\quad x_2=\frac{mx\text{-}lx}{\sqrt{2}\,\sigma x};\quad x_3=\frac{mz+lz}{\sqrt{2}\,\sigma z};\quad x_4=\frac{mz\text{-}lz}{\sqrt{2}\,\sigma z}$$

(Xing Changfeng 2007)

A. *Coordinate System*

A coordinate system is introduced as depicted in the following figure to best understand the Single Shot Hit Probability (SSHP) calculation method used in this study.

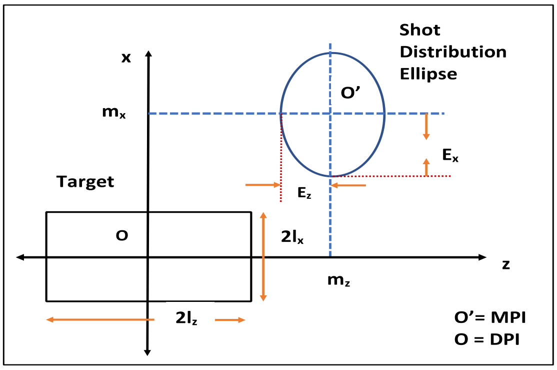

Figure 6: Coordinate System Designed for Analyzing the Hit Probability

The Ellipse formed with the center 'O' as per above figure, represents the Base of the Bivariate Normal Distribution. 2lx and 2lz are target width and length respectively. m_x, m_z are overall systematic errors. Once the Ellipse touches the Rectangle means a successful Hit.

Single Shot Hit Probability (SSHP) Calculation Model for 76/62mm Compact Gun Mounting Weapon System

Here, the Single Shot Hit Probability (SSHP) considered as the measurement for fire effectiveness calculation and analysis of the subject weapon system. SSHP is assumed to be similar to Probability of Kill (Pk) due to this study is mainly focused on effectiveness against small attack craft and suicide boats which a single hit with impact detonating projectile would incapacitate the target. Computation method for analyzing the fire effectiveness of Oto Melara 76/62mm Compact Mounting Weapon System against steady surface (sea) targets introduced following errors (Xing Changfeng 2007).

i. Dispersion Error
ii. Shooting Errors (MPI)
   a. Servo System error
   b. Fire Control error
   c. Observation error
   d. Ballistic Meteorological error

A. *Calculation Model for Precision Errors*

The precision (dispersion) error values of parallel and cross (range and deflection) for maximum range is given in the particular firing table. These values can be adjucted/estimated using following equations for a given range (Lim 2016).

Parallel≤1/180m(for range), Ex(pre)=dp/180 (7)

Cross ≤1 mil(for deflection),Ez(pre)=1*dp/955 (8)

Here the Deflection error to be converted from mil to meter and done by multiplying 1/955. The 'dp' is the Target range.

B. *Calculation Model for MPI Errors*

1) Calculation of the Servo System Error: Due to the transmission error of the ship gun follow up system, the actual firing of the naval gun and the fire control solution for the predicted point of the target can be different. This difference is the servo system error. It includes the Direction (Training) tracking aiming error (**$\Delta\beta_m$**) and the Range (elevation) tracking aiming error (**$\Delta\varphi_m$**).

i. Calculation of Probability of Tracking Error in Direction (Ezm)
   Ezm = Cm. .dp .Eβm (m) (9)
ii. Calculation of Probability of Range Tracking Error at the Predicted Point (Edm)
   Edm = ʃdθ . Eφm (m) (10)

<u>Note:</u>

Here, the Cm = $2\pi/6000$ = 1/955 (coefficient for converting Radian to Mills), ʃdθ is the range change coefficient caused by the change of elevation angle. It is a constant, ʃdθ = 67.71m. Eβm = Eφm = 4 (mil) Known Error Probabilities (system)

2) Calculation of Observation Equipment Error: Observation equipment includes the Radar and the Optical Range Finder. Observation equipment measurement error refers to the deviation of the measured target position parameter values through the observation device from the actual target position parameter values. This includes the target range and direction errors as follows.

i. Observation equipment ranging mean squared error (Laser $Range\ finder - \sigma_{dg}$, Radar - σ_{gd}) and the respective systematic errors, m_{dg} and m_{gd} are:

$$\boldsymbol{\sigma}_{dg} = \boldsymbol{\sigma}_{gd}(m) \quad (11)$$
$$m_{dg} = m_{gd}\,(m) \quad (12)$$

ii. Mean square error in direction for given target range: **σ**zg and the systematic azimuth error caused by the observation equipment, mzg can be found by:

$$\boldsymbol{\sigma}_{zg} = \mathbf{C}m.dp.\,\boldsymbol{\sigma}_{gq}(m) \quad (13)$$
$$m_{zg} = Cm.\,dp.\,\boldsymbol{m}_{gq}(m) \quad (14)$$

σ_{gq} - Direction measuring MSE of EOD is known as 1.6 mil

m_{gq} - EOD System Direction measuring error is known be 1.6 mil

3) *Calculation of Fire Control Error*:Fire Control error of the Gun director includes both System Error and Random Errors. In this case, the System Error $m\boldsymbol{\beta}_c = m\boldsymbol{\varphi}c$ and the Random Error $E\boldsymbol{\beta}_c = E\boldsymbol{\varphi}_c$.

$\Delta\varphi c$, the range tracking error causes the range error Δdc and the Probability error $E\boldsymbol{d}c$ and mathematical expectation m_{dc}.

$E\boldsymbol{d}c = \int d\theta .\ E\boldsymbol{\varphi}_c$ (15)

$m_{dc} = \int d\theta .\ m\boldsymbol{\varphi}_c$ (16)

$\Delta\boldsymbol{\beta}_c$, the direction tracking error causes the direction error Δz_c, the probability error $E\boldsymbol{z}_c$ and the mathematical expectation mzc.

$E\boldsymbol{z}_c = Cm.\ dp\ .\ E\boldsymbol{\beta}_c$ (17)

$mz_c = Cm.\ dp\ .\ m\boldsymbol{\beta}_c$ (18)

4) *Calculation of Ballistic Meteorological Error:*

i. *Error Caused by Muzzle Velocity Deviation:*When firing to sea targets from a surface ship, the muzzle velocity deviation $\Delta\boldsymbol{V}_0$ is possible due to variations in ammunitions provided and cause the distance (range) error $\Delta\boldsymbol{d}_{V_0}$. Its Probability error at the predicted point (Edv0) can be calculated by,

$Edv_0 = 0.1\ \int d_{V0}.\ E_{V0}$ (19)

fdV0 - The Range Change coefficient caused by the muzzle velocity. Change of distance in meters when initial velocity V0 change by 1%. EV0 - Probability Error of the Initial Velocity.

ii. *Error Caused by the Air Density Deviation*: When fire to surface, the air density deviation $\Delta\boldsymbol{\rho}$ just cause the distance error $\Delta\boldsymbol{d\rho}$. Its probability error $E\boldsymbol{d\rho}$, can be calculated by,

$E\boldsymbol{d\rho} = 0.1\ \int dp\ .\ E\boldsymbol{\rho}$ (20)

fdp - The range change coefficient caused by the change of air density, fdp = Range change in mtr when $\boldsymbol{\rho}$ change by 10% , $E\boldsymbol{\rho}$ – Probable Air Density Error.

iii. *Error Caused by Ballistic Wind Deviation*: Error caused by Ballistic wind deviation can be divided in to vertical wind error $\Delta\boldsymbol{W}_d$, and Horizontal wind error $\Delta\boldsymbol{W}_z$ .When fire to surface, $\Delta\boldsymbol{W}_d$, causes the distance error, $\Delta\boldsymbol{d}_w$ at the predicted point. Its probability error $E\boldsymbol{d}_w$, can be calculated using following equation.

$E\boldsymbol{d}_w = 0.1\ \int d_w\ .\ EW_d$ (21)

$\int d_w$ – The Range change coefficient when vertical wind is 10ms-1
EW_d – Probability of Vertical Wind error (changing amount), EW_d is normally, 2 ~4 (m/s).

Horizontal wind error $\Delta\boldsymbol{W}_z$, will cause the direction error $\Delta\boldsymbol{Z}_w$ at the predicted point. Its probability error Ez_w can be calculated by,

$Ez_w = 0.1\ Cm.\ dp\ .\ \int z_w\ .Ew_z\ (m)$ (22)

$\int zw$ -The direction change coefficient when horizontal wind is $10ms^{-1}$, Ewz - Probability of Horizontal Wind error (Xing Changfeng, 2007).

C. *Error Combination*

Dispersion and Aiming errors are combined using Root Sum Square (RSS) method.

$$\textbf{RSS}= \sqrt{(\boldsymbol{x^2}_1 + \boldsymbol{x^2}_2 + \cdots + \boldsymbol{x^2}_n)} \quad (23)$$

Hence, the calculation model:

$$\boldsymbol{a}_{\Sigma}\boldsymbol{a}_{\Sigma} = (\textstyle\sum_{i=1}^{n} \boldsymbol{a}_i{}^2)^{1/2} \quad (24)$$

Conversion of Error probabilities; Ex and Ey to MSE is done through,

$Ex = \rho\ \sqrt{\mathbf{2}}\sigma_x$ (25)

'ρ' means the transformation coefficient and equal to 0.4769 (Xing Changfeng, 2007).

Analysis of the Fire Effectiveness against Surface Targets

Analysis of the fire effectiveness of the Oto Melara 76/62mm Compact Mounting

Weapon System has been carried out using above model and applying various conditions for targets of LTTE's Suicide craft and attack craft to denote change of target length, width and height. Target range, Relative Bearing and Falling Angle of the Projectile will be changed one at a time for SSHP calculation for each target type.

A. *Single Shot Hit Probability Against Attack Craft*

1) *Probability Change with Target Range*:

Table 1- Probability Change with Target Range

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	500	170	60	12x3x3	26.57015	0.00243152
2	1000	170	60	12x3x3	26.57013	0.00123152
3	1500	170	60	12x3x3	26.57013	0.0008229
4	2000	170	60	12x3x3	26.57013	0.00061774
5	2500	170	60	12x3x3	26.57013	0.00049437
6	3000	170	60	12x3x3	26.57013	0.00041205
7	3500	170	60	12x3x3	26.57013	0.00035321
8	4000	170	60	12x3x3	26.57013	0.00030907
9	4500	170	60	12x3x3	26.57013	0.00027473
10	5000	170	60	12x3x3	26.57013	0.00024726

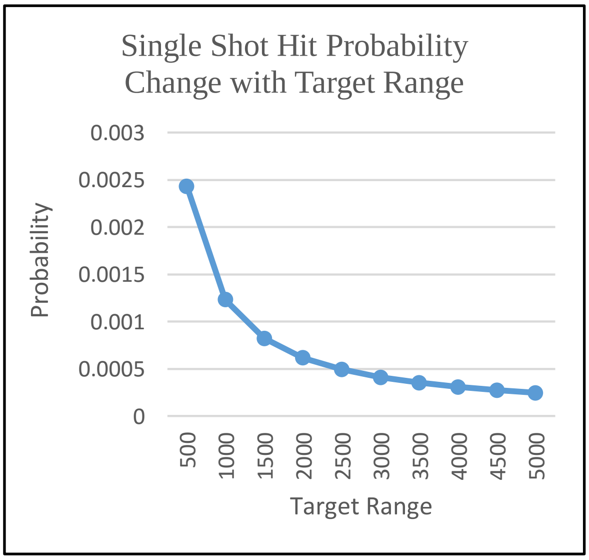

Figure 7: Single Shot Hit Probability Change with Target Range

It is observed that the probability is significantly changed (decreased) with the increase of range up to 1500m and then the rate of change of probability is constant.

2) *Probability Change with Target Relative Bearing*:

Table 2 - Probability Change with Target Relative Bearing

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	2000	000	60	5x1.5x1	6.866025	0.00015957
2	2000	015	60	5x1.5x1	7.434233	0.00017233
3	2000	030	60	5x1.5x1	7.904700	0.00018268
4	2000	045	60	5x1.5x1	8.245365	0.00019003
5	2000	060	60	5x1.5x1	8.433012	0.00019402
6	2000	075	60	5x1.5x1	8.454854	0.00019448
7	2000	090	60	5x1.5x1	8.309401	0.00019139
8	2000	105	60	5x1.5x1	8.006566	0.00018489
9	2000	120	60	5x1.5x1	7.566987	0.00017527
10	2000	135	60	5x1.5x1	7.020620	0.00016307
11	2000	150	60	5x1.5x1	6.404700	0.00014902
12	2000	165	60	5x1.5x1	5.761200	0.00013407
13	2000	180	60	5x1.5x1	5.133974	0.00011931

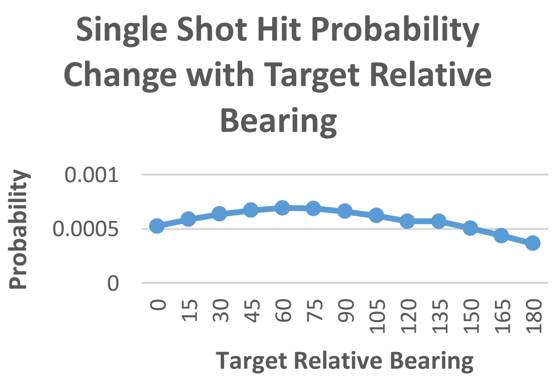

Figure 8: Single Shot Hit Probability Change with Target Relative Bearing

Results of the calculation denotes that the probability of single shot hit the target and therefore fire effectiveness is highest when the target relative bearing is 060^0 in respect to other conditions as indicated above.

3) *Probability Change with Falling Angle:* Next, the Falling angle changed from the 000 degrees to 090 degrees whilst keeping other parameters constant as per the table below for calculation of Single Shot Hit Probability.

Table 4 - Hit Probability Change Pattern with Falling Angle

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	3000	060	000	12x3x3	Inf	NaN
2	3000	060	015	12x3x3	138.6772	0.00209295
3	3000	060	030	12x3x3	79.79422	0.00120428
4	3000	060	045	12x3x3	58.24153	0.00087900
5	3000	060	060	12x3x3	45.79807	0.00069120
6	3000	060	075	12x3x3	36.68883	0.00055372
7	3000	060	090	12x3x3	28.80000	0.00043466

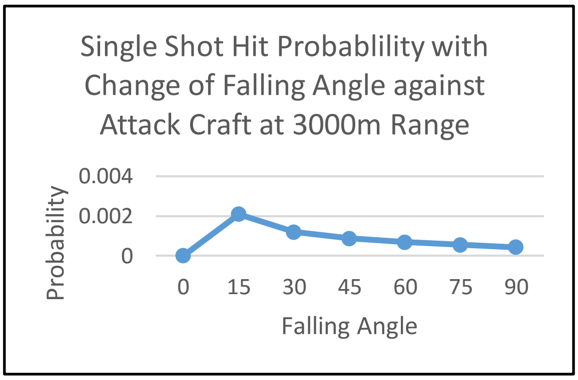

Figure 9: Probability Change with Falling Angle

Single shot hit probability is maximum when the falling angle is 15^0 subjected to other conditions as indicated above. Therefore, it is best to set/arrange falling angle to that amount when designing the ammunition and weapon system.

B. *Single Shot Hit Probability Against Suicide Craft*

1) *Probability Change with the Range*:

Table 5 - Probability Change with the Range

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	400	090	60	5x1.5x1	8.309401	0.00076385
2	800	090	60	5x1.5x1	8.309401	0.00045367
3	1200	090	60	5x1.5x1	8.309401	0.00031322
4	1600	090	60	5x1.5x1	8.309401	0.00023786
5	2000	090	60	5x1.5x1	8.309401	0.00019139
6	2400	090	60	5x1.5x1	8.309401	0.00016000
7	2800	090	60	5x1.5x1	8.309401	0.00013740
8	3200	090	60	5x1.5x1	8.309401	0.00012037
9	3600	090	60	5x1.5x1	8.309401	0.00010708
10	4000	090	60	5x1.5x1	8.309401	0.00009643

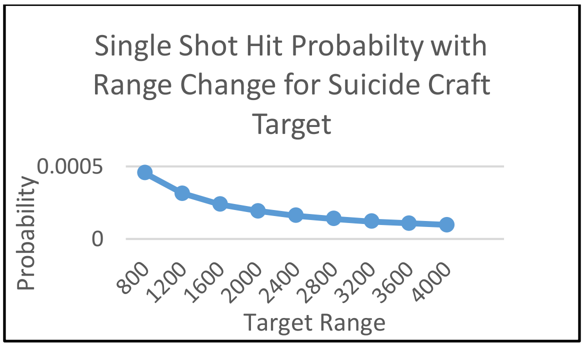

Figure 10: Single Shot Hit Probabilty with Range Change for Suicide Craft Target

It is observed a drastic change (decrease) of hit probability with increase of range. Single shot hit is not assured even with a closer range of 400m for suicide craft.

2) *Probability Change with the Target Relative Bearing*:

Table 6. Probability Change with the Target Relative Bearing

Sr. No	Target Range (m)	Tgt Relative Brg (Qm)	Falling Angle (Deg)	Tgt Size (m^3)	Effective Tgt Area A_j	Single Shot Hit Probability
1	2000	000	60	5x1.5x1	6.866025	0.00015957
2	2000	015	60	5x1.5x1	7.434233	0.00017233
3	2000	030	60	5x1.5x1	7.904700	0.00018268
4	2000	045	60	5x1.5x1	8.245365	0.00019003
5	2000	060	60	5x1.5x1	8.433012	0.00019402
6	2000	075	60	5x1.5x1	8.454854	0.00019448
7	2000	090	60	5x1.5x1	8.309401	0.00019139
8	2000	105	60	5x1.5x1	8.006566	0.00018489
9	2000	120	60	5x1.5x1	7.566987	0.00017527
10	2000	135	60	5x1.5x1	7.020620	0.00016307
11	2000	150	60	5x1.5x1	6.404700	0.00014902
12	2000	165	60	5x1.5x1	5.761200	0.00013407
13	2000	180	60	5x1.5x1	5.133974	0.00011931

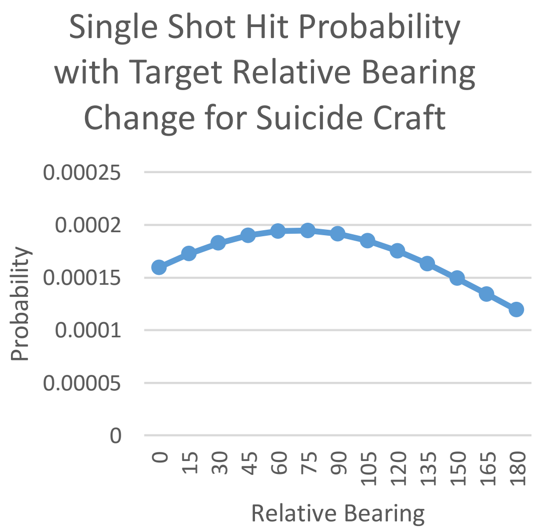

Figure 11: Single Shot Hit Probabilty with Relative Bearing for Suicide Craft Target

When the Target Relative Bearing is reaching 75^0, the single shot hit probability observed to be the highest against Suicide Craft concerned at a range of 2000m.

Conclusion

Choice of suitable method for calculating and analyzing the fire effectiveness of a weapon system, out of various methods available is depend upon the amount of accuracy needed to achieve, how fast it needs to compute results and availability of parameters, weapon system and target data. In view of fire effectiveness calculation, first you have to identify sources of all errors. Not only the Gun's accuracy but also the errors of weapon sub systems like servo, observation equipment, FCS and meteorological /environmental also to be considered. This study aimed to choose a suitable mathematical model and analyze the fire effectiveness of OTO Melara 76mm/62 Compact Mounting Weapon System with reference PLA (Chinese) Navy's practice (Xing Changfeng 2007).

Hit Probability is largely depended upon target range. Hit area of the target is a crucial factor and that is decided by the angle of attack (Rel. Brg) and the angle of fall. There is a pattern of SSHP change related to Target Range, Relative Bearing and the Falling Angle of the Projectile. Knowing that, is beneficial before planning any firing mission. It is important to know the inherent errors of the associated systems and due consideration should be given for mechanical errors and equipment alignment. Accuracy of MET message is very important factor especially in long range firing. Better to have systems to obtain real time weather parameters.

Following issues found with this Study.

i. Firing Table data, probable equipment errors are from other sources (PLA Navy) due to none availability same under SLN.
ii. Status of both Firing platform and target moving was not considered.
iii. No impact records or Proving ground/laboratory test records available for comparison.

Recommendations for Future Researchers

This can be taken as just a basement and researchers in the Gunnery field (specially Sri Lanka Navy) can try for following works.

i. Design a Matlab based calculation model for similar weapon system to analyze fire effectiveness against fast moving and air targets as it induced some additional error sources.
ii. Design a Computer based programme for simulating the Gun Projectile Trajectory

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Author Biography

The author is specialized in Naval Gunnery in India with award of the best International Student officer in year 2015. Afterwards he had the opportunity to follow a Gunnery Engineering course in PRC China which would emensely benifited in enhancing the knowledge on Naval Weapon Systems. During this course Author again awarded as the Excelent Trainee of the course with a value addition of Master of Engineering degree (MEng) in Naval Weapon Science and Technology completed in year 2019