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Assessment of Possibility to Conduct Fire for Effect without Adjust Fire according to Observational Distance of a Target in Artillery Automated Fire Control Systems

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***Abstract*—The article deals with assessing the possibility to conduct fire for effect without adjust fire. The proposed method is a new, and more precise way of the assessment of possibility to conduct fire for effect without adjust fire, being available to be utilized in artillery automated fire control systems. The authors derive mathematical apparatus, based on the defined starting points, with the use of which this assessment can be implemented.**

***Keywords*—adjust fire, artillery, circular probable error of target orthogonal coordinates determination, fire for effect, observational distance**

I. Introduction

In artillery of most armies the possibility to conduct fire for effect without adjust fire is assessed through an estimated value of the circular probable error of the target orthogonal coordinates determination (E_{TLE}). E_{TLE} is also used by the artillery reconnaissance equipment that then allows finding the polar coordinates of the target only. The polar coordinates must then be converted to the orthogonal coordinates and the altitude of the target (using a goniometer, an automated fire control system, manual recalculation, etc.).

Fire for effect without prior adjust fire is permitted to begin when the value of E_{TLE} is smaller then the maximum acceptable value of E_{TLE} for conduct of fire for effect without adjust fire. The maximum acceptable value of E_{TLE} for conduct of fire for effect without adjust fire is stated with respect to the fragmentational effect of the ammunition used (for example in the Army of the Czech Republic conduct of fire for effect without adjust fire is conditioned by the value of the target location error: $E_{TLE} \leq 50\ m$)[1], [2].

The real E_{TLE} value is not calculated during artillery training and conduct of combat operations. Then, merely an estimated value of E_{TLE} is stated. The estimated value of E_{TLE} is usually determined via the reconnaissance equipment used, measuring conditions and the method of topographic-geodetic connection of an observation post (according to the methods of determination of our own location and the determination of orientation direction bearings). To determine the estimated E_{TLE} value there are simple tables processed for the sake of the artillerists.

Determination of the E_{TLE} value and subsequent assessment of the possibility to conduct fire for effect without adjust fire are similarly realized also in the artillery automated fire control systems. In an automated way only the comparison of E_{TLE} indicated by an artillery observer and maximum acceptable value of E_{TLE} for conduct of fire for effect without adjust fire is performed. However, where the manual calculation would be quite complicated and time consuming much more accurate ways of assessing the possibility of fire for effect without adjust fire can be used in the automated fire control systems. One of them is the method proposed in this article. The observational distance of the target is appropriate to be used due to the influence of some angular errors on the E_{TLE} value.[3]

Most of the variables used below do n ot have their standardized signs; therefore authors´ symbology has been used.

II. Starting Points

The target position is determined by the polar or orthogonal coordinates and the altitude. Means of artillery reconnaissance, identifying the orthogonal coordinates and the altitude of the target, determine the orthogonal coordinates and the altitude of the target through conversion of the orthogonal coordinates and the altitude of their own position and the polar coordinates of the target (some radar means are the exceptions which determine the orthogonal coordinates and the altitude of the target through extrapolation of the measured section of the projectile trajectory). The orthogonal coordinates of the target represent the solution of the First Geodetic Task. The altitude of the target is calculated from an angle of sight of the target and the altitude of the artillery reconnaissance mean post. The total circular probable error of the target orthogonal coordinates determination is then the same in both ways of the target location determination.[4], [5], [6], [7] The circular probable error of the target orthogonal coordinates determination performs diversion in the horizontal plane. Deviation in the vertical plane is ignored because it is negligible. If the target centre fits the horizontal xy-coordinatesystem – artillery has been used to sign the distance by „*x*“ and direction by „*y*“ (which is in contrast to the habits practiced in the Cartesian coordinate system) – and the line representing the observing distance lays on the x-axis then the circular probable error of the target orthogonal coordinates determination consists of the probable errors of the target orthogonal coordinates determination in distance (on the x-axis) and in direction (on the y-axis) and it is calculated from a right-angled triangle (Fig. 1):

$$E_{TLE} = \sqrt{E_{TLE(x)}^{2} + E_{TLE(y)}^{2}}, \quad (1)$$

where:

E_{TLE} - circular probable error of the target orthogonal coordinates determination [m],

$E_{TLE(x)}$ - probable error of the target location determination in distance [m],

$E_{TLE(y)}$ - probable error of the target location determination in direction [m].

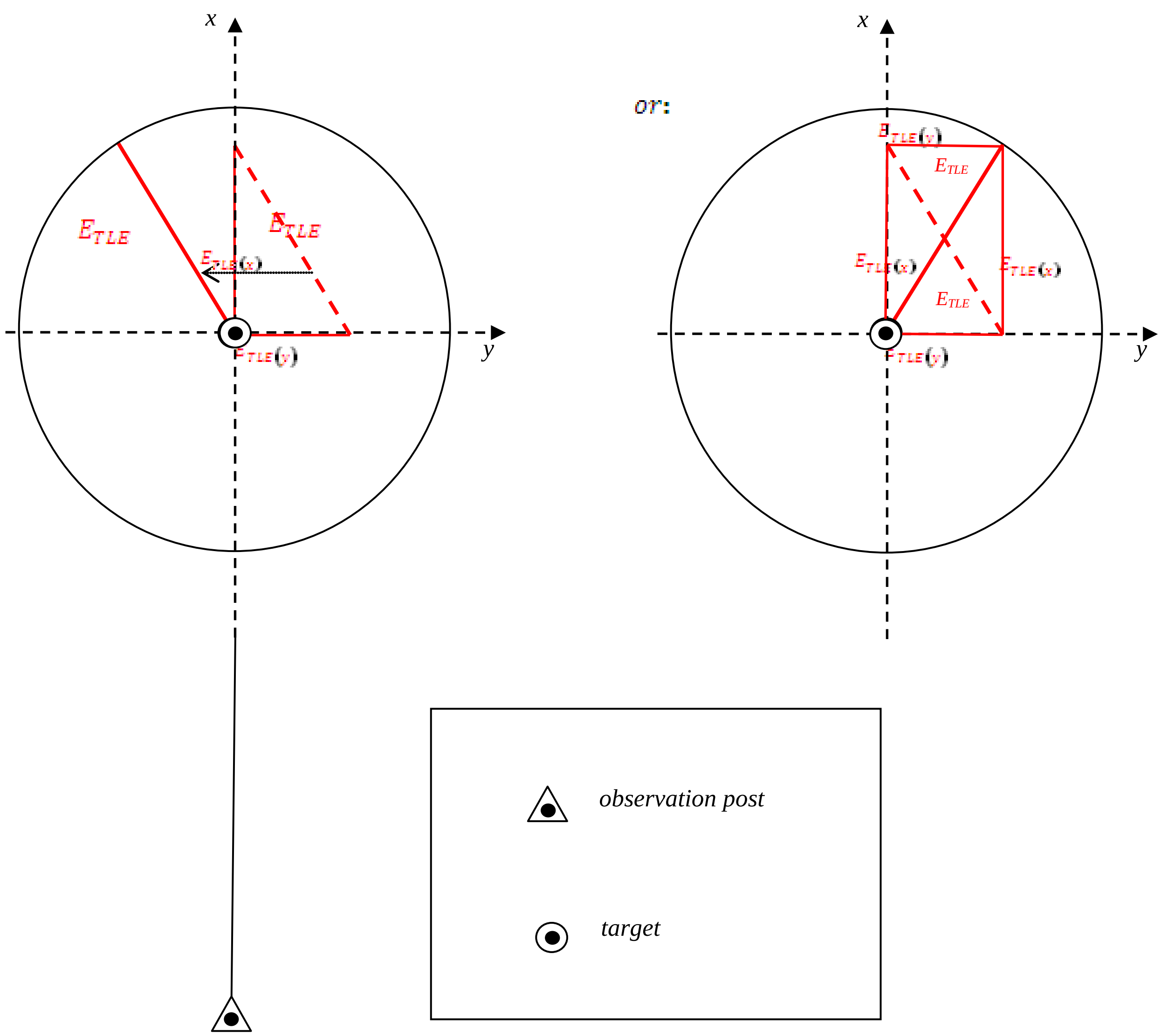

Fig. 1. Circular probable error of the target orthogonal coordinates determination

The E_{TLE} value equals to the radius of the circle (Fig. 1). In fire, the E_{TLE} value is manifested by the deviation of the artillery fire range point of the projectile (in the coordinates E and N) and the explosion occurs just on the circle with the center in the target and with the radius equalled E_{TLE} .

E_{TLE} arises due to the following partial errors (while neglecting the vertical deviation):

- circular probable error of the observation post orthogonal coordinates determination (E_{poz}),
- probable error of the mean orientation (E_o),
- probable error of the azimuth measurements (E_m)(when determining the position of the target is the bearing of the target determined. Initial magnetic or gyroscopic orientation is usually carried out for the means of artillery reconnaissance. Magnetic or geographic azimuths are measured from the magnetic or geographic norths. To obtain the bearing it is then necessary to include appropriate correction (grivation or meridian convergence) in this azimuth. For this reason, the probable error of the azimuth measurements (E_m), is related to the azimuth detection.),
- probable error of the distance measurement (E_{ld}).

The circular probable error of the observation post orthogonal coordinates determination (E_{poz}) is defined in meters. It affects the target position determination both in distance and in direction (orthogonal coordinates). The E_{poz} value is determined as the maximum probable error of the artillery reconnaissance mean post orthogonal coordinates determination in accordance with the type of topographic-geodetic connection used and the means and methods used, or in accordance with the technical documentation (manuals) of the means used to identify the location (orthogonal coordinates) of our own post, or by the distance covered from the starting point when using the inertial navigation system.

The probable error of the mean orientation (E_o) is given in artillery angular units. Its value is equal to the maximum probable error of orientation direction bearing determination for given way of orientation and the means and methods used, or it e quals to the maximum values of the particular mean stated in its technical documentation. $E_o$affects determination of the target location in distance (on y-axis, Fig. 1).

The probable error of the azimuth measurements (E_m) is given in artillery angular units. Its value is equal to the maximum probable error of bearings (or azimuths) measurements by the given artillery reconnaissance mean. The E_m values are usually stated in the technical documentation of the particular artillery reconnaissance mean. E_m implies from accuracy of the technology. It burdens every measurement. E_m affects the determination of the target location in direction (on y-axis, Fig. 1).

The probable error of the distance measurement (E_{ld}) is given in meters. It corresponds to the maximum error of the distance measurement (by a laser range finder) done by the artillery reconnaissance mean given. The E_{ld} values are usually stated in the technical documentation of the mean. Also, E_{ld} implies from accuracy of the technology used, burdens every measurement and affects the determination of the target location in distance (on x-axis, Fig. 1).

III. Mathematical Solution

For the following calculations it is necessary to express both the probable errors of the mean orientation (E_o) and the probable errors of the azimuth measurements (E_m) in meters depending on the observing distance *(d)*. Particular equations are derived from the right-angled *ABC* triangle (Fig. 2).

An *A*-vertex of the *ABC* triangle represents the post of the artillery reconnaissance mean. A *C*-vertex represents the centre of the target. An *AC* line segment represents the distance of the target (*d*) and an $\mapsto AC$ half-line performs orientation direction bearing from the observation post at the center of the target. Size of a BC line segment represents the value of the probable error of the target location determination in direction (in metres) caused by the probable error of the mean orientation (E_o) and the probable error of the azimuth measurements (E_m) in given observational distance *d* (the *AC* line-segment). The BC line segment lays on the y-axis of the coordinate system.

Then *d*, the observing line (line segment *AC*), is just a leg of an angle of the probable error of the mean orientation (E_o), because the orientation of the artillery reconnaissance mean is made initially. That is why the probable error of the azimuth measurements (E_m) takes effect merely during the actual measurement by the artillery reconnaissance mean.

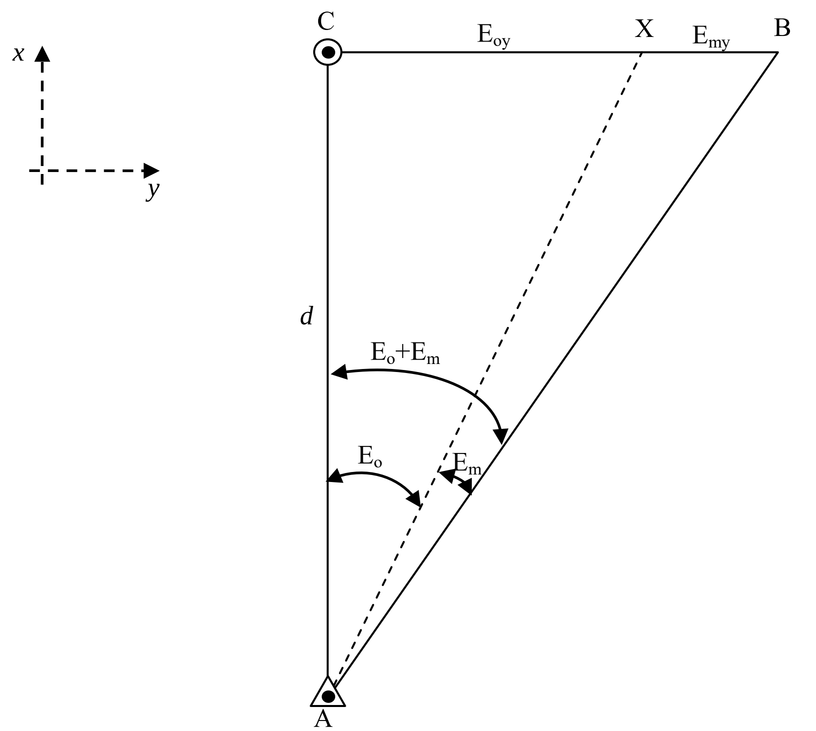

Fig. 2. Representation of the probable error of the mean orientationand the probable error of the azimuth measurements in a right-angled triangle

The probable error of the mean orientation (E_o) causes, in given observing distance of d, the probable error of the mean orientation in direction E_{oy} (CX line segment). The value of E_{oy} equals:

$$E_{oy} = d \cdot \tan E_o \, , \tag{2}$$

where:

E_{oy} - probable error of the mean orientation in direction [m],

d - observing distance of the target (Figure 2: AC line segment) [m],

E_o - probable error of the mean orientation (converted to degrees) – it is necessary to convert the probable error of azimuth measurements (E_m) into degrees, because of calculation with the tangents function.

The probable error of the azimuth measurements (E_m) causes, in given observing distance of d, the probable error of the azimuth measurements in direction (E_{my}) in metres (line segment XB). The value of E_{my} equals:

$$E_{my} = d \cdot \tan(E_o + E_m) - E_{oy} \, , \tag{3}$$

After substitution (2) to (3):

$$E_{my} = d \cdot \tan(E_o + E_m) - d \cdot \tan E_o \, . \tag{4}$$

Modified:

$$E_{my} = d \cdot [\tan(E_o + E_m) - \tan E_o] \, , \tag{5}$$

where:

E_{my} - probable error of the azimuth measurements in direction [m],

E_m - probable error of the azimuth measurements [degrees].

The probable error of the target location determination in direction $\left(E_{TLE(y)}\right)$ arises due to the following partial errors:

- probable error of the mean orientation in direction (E_{oy}) [m],
- probable error of the azimuth measurements in direction (E_{my}) [m],
- circular probable error of the observation post orthogonal coordinates determination (E_{poz}) [m].

The probable error of the target location determination in direction ($E_{TLE(y)}$) can be then calculated as:

$$E_{TLE(y)} = E_{oy} + E_{my} + E_{poz} \quad (6)$$

After substitution (2) and (5) to (6):

$$E_{TLE(y)} = d \cdot \tan E_o + d \cdot [\tan(E_o + E_m) - \tan E_o] + E_{poz} \quad (7)$$

Modified:

$$E_{TLE(y)} = d \cdot [\tan(E_o + E_m)] + E_{poz} \quad (8)$$

The probable error of the target location determination in distance ($E_{TLE(x)}$) arises due to the following partial errors:

- probable error of the distance measurement (E_{ld}) [m],
- circular probable error of the observation post orthogonal coordinates determination (E_{poz}) [m].

The probable error of the target location determination in distance ($E_{TLE(x)}$) can be then calculated as:

$$E_{TLE(x)} = E_{ld} + E_{poz} \quad (9)$$

After substitution (8) and (9) to (1):

$$E_{TLE} = \sqrt{(E_{ld} + E_{poz})^2 + \{d \cdot [\tan(E_o + E_m)] + E_{poz}\}^2} \quad (10)$$

The relation (10) shows the dependence of the probable error of the target location determination value (E_{TLE}) on the partial probable errors and the observational distance. The longer is the observational distance, the bigger are effects of both the probable error of the mean orientation (E_o) and the probable error of the azimuth measurements (E_m).

The *d* variable, expressed from (10):

$$d = \frac{\sqrt{E_{TLE}^2 - (E_{ld} + E_{poz})^2} - E_{poz}}{\tan(E_o + E_m)}, \quad (11)$$

where:

d - observing distance of the target [m],

E_{TLE} - circular probable error of the target orthogonal coordinates determination [m],

E_{ld} - probable error of the distance measurement [m],

E_{poz} - circular probable error of the observation post orthogonal coordinates determination [m],

E_o - probable error of the mean orientation [degrees],

E_m - probable error of the azimuth measurements [degrees].

IV. Method of Assessment of the Possibility to Conduct Fire for Effect without Adjust Fire in the Automated Fire Control System

When assessing the possibility to conduct fire for effect without adjust fire in the automated fire control system the relation (11) is to be exploited. The automated fire control system determines the E_{poz} and E_o values in accordance with the specific conditions, the method of work, and the means used in the topographic-geodetic connection. The E_m a E_{ld} values are set in accordance with the artillery reconnaissance means used. The E_{TLE} value is substituted for the maximum permissible E_{TLE} value for conduct of fire for effect without adjust fire (for example in the Army of the Czech Republic: $E_{TLEmax} = 50\ m$).

In the automated fire control systems, the possibility to conduct fire for effect without adjust fire is assessed by comparing the observational distance of the target identified and the observational distance of the target calculated by the equation (11). If the observational distance of the target identified is smaller than the observational distance of the target calculated by the equation (11), the automated fire control system recommends (if other necessary conditions are fulfilled) to execute fire for effect without adjust fire. If the observational distance of the target identified is larger than the observational distance of the target calculated by the equation (11), the automated fire control system recommends adjust fire.

V. Conclusion

Information technology used in the automated fire control systems enables to use the highly accurate methods of calculation which would be highlytime consuming in manual calculations. The proposed procedure of assessing the possibility to conduct of fire for effect without adjust fire by observing distance of the target in the automated fire control systems allows commanders, contrary to the existing method (by the expected value of the circular probable error of the orthogonal coordinates of the target determination), easier and more accurate assessment of the conditions for conduct of fire for effect without adjust fire.

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