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Determination of Firing Solution Settings for Engagement of UAVs by a Man-Portable Counter-UAV System

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Abstract. The paper presents the operating principle of the Man-Portable Counter Miniature Unmanned Aerial Vehicles System (MPC-MUAVS), with particular reference to the development of its firing solution settings and the methodology and structure of development of the firing tables implemented in the ballistic calculator of the MPC-MUAVS. This ballistic calculator has been applied in the MPC-MUAVS targeting sight assembly, while the entire MPC-MUAVS is intended to counter UAVs within 50 m of the MPC-MUAVS operator. The MPC-MUAVS is being developed under project DOB-1P/02/18/2016, funded by the Polish National Centre for Research and Development.
Keywords: mechanical engineering, ballistics, unmanned aerial vehicles, drones

1. INTRODUCTION

The Man-Portable Counter Miniature Unmanned Aerial Vehicles System (MPC-MUAVS) developed at the Military University of Technology in Warsaw [1, 2] is designed to intercept and safely ground miniature UAVs (with a maximum wing or rotor span of less than 0.25 m), either hovering or moving at velocities of up to 0.5 m/s within 50 m of the MPC-MUAVS operator. The MPC-MUAVS consists of a launcher (Fig. 1), a targeting sight with a ballistic calculator, (Fig. 2) and intercepting net deployment projectiles (Fig. 3). When fired from the launcher, the unguided projectile disintegrates at an appropriate distance from the target, ejecting and deploying the intercepting net which snags the targeted UAV and grounds it in a controlled manner by deploying a parachute.

Fig. 1. MPC-MUAVS launcher

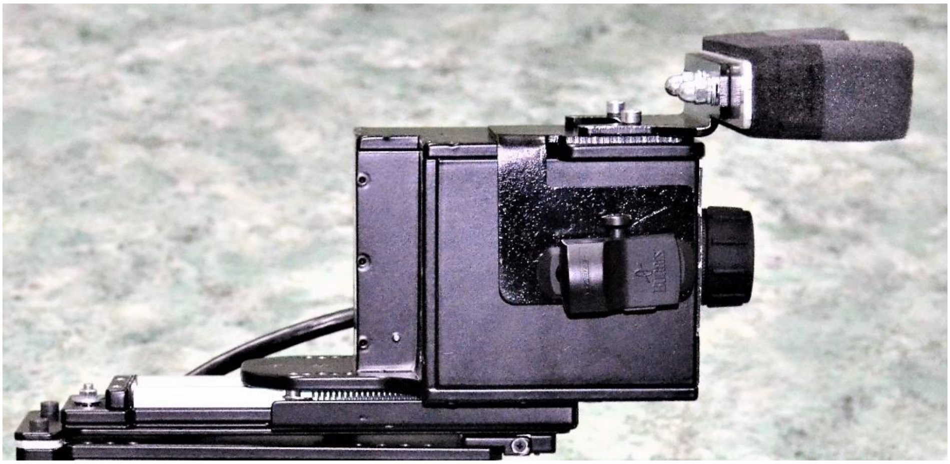

Fig. 2. MPC-MUAVS targeting sight with the ballistic calculator

Fig. 3. Interception net deployment projectiles ready for use

It is extremely important for the system that the projectile disintegrates and deploys (eject the interception net towards the target and deploy the parachute) at the correct point along the trajectory to guarantee successful interception of the UAV. To determine the projectile disintegration (deployment) point, it is necessary to establish the correct trajectory of the projectile, by setting the launcher to a certain elevation angle and define the time delay between launch and initiation of projectile deployment. For this purpose, the system uses the following: targeting sight containing a ballistic calculator, and programmable fuzes housed in the interception net deployment projectiles. The targeting sight allows observation of a portion of the airspace and, when the operator detects an object to be intercepted, measurement of the target's elevation angle and distance is performed. These parameters allow the determination of target position relative to the launcher and to upload the appropriate targeting sight elevation angle and the deployment time delay values, developed and uploaded to the ballistic calculator's memory, from the firing tables to the projectile fuze. Once the targeting sight elevation angle is achieved and the projectile fuze is programmed with the correct deployment time delay, the system is ready to fire [3 - 5].

2. OPERATION OF THE MPC-MUAVS

The MPC-MUAVS is prepared for firing by removing the safeties from the interception net deployment projectile and loading the stabilizer assembly boom into the launcher barrel.

When the projectile is loaded into the barrel bore, the retaining ring which holds the stabilizer fins folded around the boom slides forward. This enables the stabilizer fins to deploy by the elastic energy of their material once the projectile clears the barrel bore. In the final loading phase, the control data connectors of the projectile and the launcher mate. These connectors are used, among other things, for programming the projectile fuze, charging the detonator capacitor, and initiating the shot.

When the launcher is turned on, the optical system integrated in the targeting sight allows visual monitoring of the airspace. The optical system is provided with a sight reticule which is to be aimed at the detected aerial target, followed by pressing the distance measurement command button – located on the forward grip of the launcher – to determine the distance to the target. The measured distance and elevation angle of the target are stored in memory by the ballistic calculator and if the values are within the operating range of the MPC-MUAVS, the calculator attempts to solve the firing settings necessary to successfully intercept the targeted UAV. When the operator presses the fuze programming command button – located under the right-hand thumb on the pistol grip – the elevation angle of the launcher is set by the operator correcting the aim of the launcher according to the guidance indications provided by the targeting sight. The launcher elevation angle is determined with the first of the settings read from the firing tables, the targeting sight elevation angle. The targeting sight elevation angle is automatically added to the target's elevation angle and set manually by the operator as the launcher elevation angle, who follows the modulated guidance indication sounds output by the targeting sight (with long sounds indicating an angle too low, short sounds indicating an angle too high, and the continuous sound indicating the correct elevation angle). If the elevation angle correction to be made by the operator is outside of the FOV (field of vision) of the primary optical sight, the operator can use the auxiliary optical system, which provides a very wide FOV created by a microcollimator mounted on the side of the targeting sight. Operating the fuze programming command button programs the projectile fuze with a deployment time delay – this is the time between the firing of the projectile (being the separation of the control data connectors between the projectile and the launcher) to the initiation of the projectile disintegration/deployment along the flight trajectory. The correct programming of the fuze is indicated by a green LED on the targeting sight housing.

Once the fuze is correctly programmed, the operator presses the launch trigger with his right-hand index finger or if the operator decides not to fire the projectile, e.g. the shot is impossible or unrealistic, then the fire solution reset command button should be pressed. Pressing the launch trigger initiates the shot, while pressing the reset command button disarms the fuze and mutes the sound guidance indications output by the targeting sight. Figure 4 shows the MPC-MUAVS ready to fire a projectile.

Fig. 4. MPC-MUAVS ready to fire

3. FIRING TABLES FOR THE MPC-MUAVS

The PRODAS v3 Main Analysis Package computer software was used to create the firing tables for the MPC-MUAVS and then implemented in the ballistic calculator of the launcher's targeting sight. To develop the firing tables, it was necessary to develop a physical model of the projectile (Fig. 5) in PRODAS environment, reproducing the structure of actual interception net deployment projectiles with their geometric and mass characteristics mapped to the model [6].

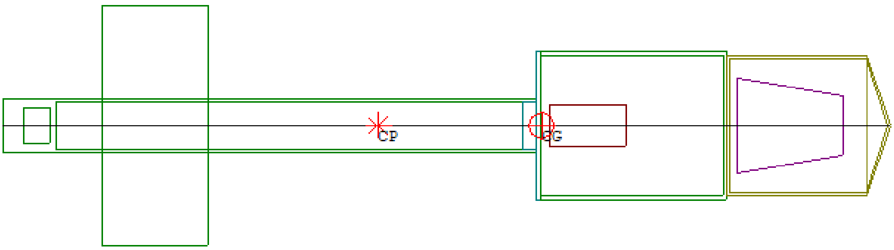

Fig. 5. Physical model of the projectile:
CP – centre of pressure; CG – centre of gravity

The model was characterized by a simplified internal structure, because the mechanisms contained in the projectile do not affect its flight trajectory, and for the purposes of simulation, only the external shape and mass distribution were important and which were recreated from the technical documentation and measurements of actual projectiles.

The firing tables were characterized by a specific structure imposed from the intended use and operation of the MPC-MUAVS. The targeting sight elevation angle was not calculated for the distance from the barrel muzzle to the target measured at the height of the muzzle (topographic distance) as in traditional firing tables, but for selected points of the interception of the target by the projectile in the airspace around the launcher operator. The upper hemisphere was divided into sectors to be selected according to the actual elevation angle of the target. For these sectors, the firing solution settings calculated for a fixed elevation angle of the target in the same sector would apply. They were calculated for these elevation angles: 7.5°, 15°, 22.5°, 30°, 37.5°, 45°, 52.5°, 60°, 67.5°, 75°, and 82.5°. It was assumed that for the elevation angles of the launcher aimed at a target between 0° to 11.25°, the ballistic calculator would fetch the targeting sight elevation angle applicable to the target elevation angle of 7.5°. For the launcher elevation angles:

- 11.26° to 18.75°, calculated for a target elevation angle of 15°;
- 18.76° to 26.25°, calculated for a target elevation angle of 22.5°;
- 26.26° to 33.75°, calculated for a target elevation angle of 30°;
- 33.76° to 41.25°, calculated for a target elevation angle of 37.5°;
- 41.26° to 48.75°, calculated for a target elevation angle of 45°;
- 48.76° to 56.25°, calculated for a target elevation angle of 52.5°;
- 56.26° to 63.75°, calculated for a target elevation angle of 60°;
- 63.76° to 71.25°, calculated for a target elevation angle of 67.5°;
- 71.26° to 78.75°, calculated for a target elevation angle of 75°;
- 78.76° to 90°, calculated for a target elevation angle of 82.5°.

The adopted resolution of the firing tables was considered to be sufficient and any errors resulting from the resolution would be compensated for by the size of the interception net deployed by the projectile.

The matrix of intercept points was then developed. The matrix consisted of points inside the upper hemisphere where the UAVs would be intercepted. These points were located on the axes determined by the target position lines for the selected elevation angles between 0° and 90° with an increment of 7.5° and were spaced every 5 m from the barrel muzzle for a range from 5 to 50 m. The distribution of the intercept points is shown in Fig. 6.

The development of the firing tables required running the simulation so that for every individual interception point a trajectory can be found to intersect the same point or as close to that point as possible. The trajectory parameters and its characteristics allowed the determination of the values to populate the firing tables. The values included the time of flight to the anticipated interception point, used to determine the projectile's disintegration (deployment) time delay, and the launcher barrel elevation angle required to hit the anticipated interception point, used to determine the targeting sight elevation angle. A part of the firing tables for the lower elevation angle group (0° to 45°) is shown in Table 1.

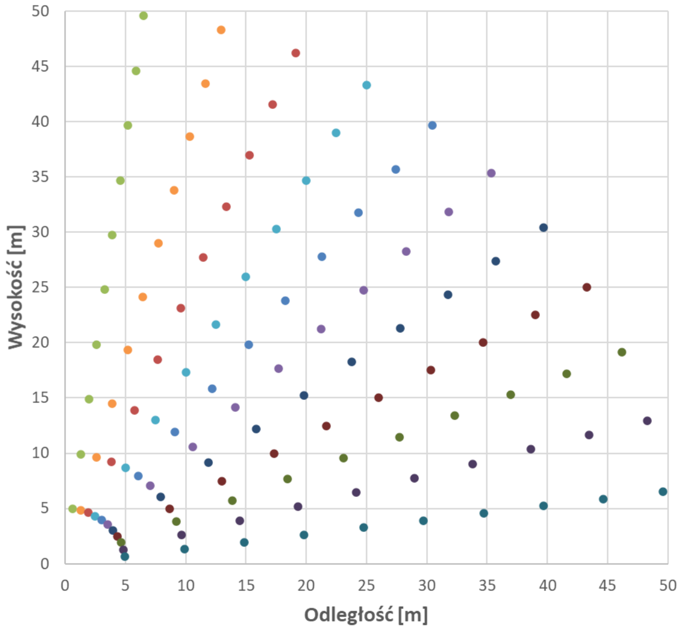

Fig. 6. Distribution of the target interception points for the projectile specified for the development of the firing tables

Table 1. Firing tables for the lower elevation angle group (0° to 45°)

Distance to target	Target elevation angle [°]		Target elevation angle [°]		Target elevation angle [°]		Target elevation angle [°]		Target elevation angle [°]		Target elevation angle [°]	
	7.5		15		22.5		30		37.5		45	
	Sight elevation angle [°]	Disintegration delay time [s]	Sight elevation angle [°]	Disintegration delay time [s]	Sight elevation angle [°]	Disintegration delay time [s]	Sight elevation angle [°]	Disintegration delay time [s]	Sight elevation angle [°]	Disintegration delay time [s]	Sight elevation angle [°]	Disintegration delay time [s]
5	0.7	0.000	0,6	0.000	0.6	0.000	0.6	0.000	0.5	0.000	0.5	0.000
10	1.3	0.046	1.3	0.047	1.2	0.048	1.1	0.048	1.1	0.049	0.9	0.050
15	2.0	0.192	1.9	0.194	1.9	0.197	1.8	0.199	1.6	0.201	1.4	0.203
20	2.7	0.340	2.6	0.345	2.5	0.350	2.4	0.355	2.2	0.329	2.0	0.363
25	3.4	0.491	3.3	0.500	3.2	0.509	3.0	0.518	2.8	0.526	2.5	0.536
30	4.1	0.647	4.0	0.661	3.9	0.675	3.7	0.689	3.4	0.702	3.1	0.718
35	4.8	0.807	4.8	0.827	4.6	0.884	4.4	0.87	4.1	0.891	3.7	0.911
40	5.6	0.971	5.5	1.001	5.4	1.031	5.1	1.063	4.8	1.095	4.3	1.126
45	6.4	1.143	6.3	1.183	6.2	1.226	5.9	1.272	5.5	1.320	5.0	1.370
50	7.2	1.319	7.2	1.376	7.0	1.437	6.7	1.505	6.3	1.579	5.8	1.660

The targeting sight elevation angle is the difference between the elevation angle of the launcher barrel necessary to hit the target area with the projectile (as determined by simulation) and the target elevation angle (angle between the height of the barrel muzzle and the target position line between the target and the muzzle).

The disintegration delay time is the flight time of the projectile to the target, determined by simulation and reduced by the time constant required to initiate the proper disintegration of the projectile ahead of the target (and to fully deploy the interception net). The time constant was set to 0.1 seconds from the test firing. The ballistic calculator uses the data from the firing tables as follows:

1. The measurement triggered with the launcher provides the target distance and elevation angle.
2. Based on the measured values, the software chooses the correct firing table column (from the target elevation angle) and row (from the target distance).
3. The elevation angle correction value (which is the targeting sight elevation angle) is sent to the targeting sight, and the projectile disintegration time delay is sent to the fuze.

The measured target elevation angle and distance would very rarely match the firing table data; hence the ballistic calculator assumed the data as approximate to the measurement results. For example: with a target elevation angle of 35° and a target distance of 32 m, the firing table data is assumed from column 37.5° and row 30 m.

4. CONCLUSIONS

The determination of the firing solution settings for engagement of UAVs is a complex problem and can be implemented in various, more or less complicated ways. This paper presents a proposal for determination of the fire solution settings for engagement of UAVs with the Man-Portable Counter Miniature Unmanned Aerial Vehicles System, which is dedicated to neutralization of aerial objects moving at velocities of up to 0.5 m/s and within 50 m of the operator. The development of the firing tables from live-range test firing very often requires considerable financial expenditure and disposal of a sufficient number of projectiles, both of which is just as often infeasible during scientific research. However, a simpler solution is required to complete a project which aims to design and develop a system that meets the prerequisites of the predesign stage. Provided they are developed with due diligence; theoretical firing tables can become a preliminary alternative to traditional firing tables. However, it should be remembered that theoretical firing tables must ultimately be verified experimentally and modified if necessary.

The method proposed in this paper for the determination of firing solution settings for engagement of UAVs with the Man-Portable Counter Miniature Unmanned Aerial Vehicles System enabled the development of a ballistic calculator-operated targeting sight and the experimental testing of both the test models of the interception net deployment projectiles, the launcher, and finally an entire model of the MPC-MUAVS.

The tests ended with the interception of a UAV, which demonstrates that, given the project assumptions, the presented method of development of firing solution settings and the development methodology and structure of the firing tables were correct.

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Określanie nastaw do strzelania do bezzałogowych statków powietrznych z przenośnego systemu do ich przechwytywania

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Streszczenie. W pracy przedstawiono sposób działania Przenośnego Systemu do Przechwytywania Miniaturowych Bezzałogowych Statków Powietrznych (PSP-MBSP), ze szczególnym uwzględnieniem wypracowania nastaw do strzelania oraz metodyki opracowania i struktury tabel strzelniczych, zastosowanych w przeliczniku balistycznym. Przelicznik ten wykorzystano w celowniku PSP-MBSP, a cały system służy do przeciwdziałania BSP, które znajdują się w odległości do 50 m od operatora. PSP-MBSP powstaje w ramach projektu DOB-1P/02/18/2016, finansowanego przez Narodowe Centrum Badań i Rozwoju (NCBR).

Słowa kluczowe: mechanika, balistyka, bezzałogowe statki powietrzne, drony.