PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

ISSN 2081-5891 **10, 1 (35), 2019, 59-74**

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

Use of Standard Meteorological Messages to Simulate the Flight of 35 mm TP-T Projectile Under Actual Conditions

Leszek BARANOWSKI*, Zbigniew LECIEJEWSKI

Military University of Technology, Faculty of Mechatronics and Aerospace,
2 gen. Witolda Urbanowicza St., 00-908 Warsaw, Poland
**Corresponding author's e-mail address and ORCID:*
leszek.baranowski@wat.edu.pl; https://orcid.org/0000-0002-5239-0659

Received by the editorial staff on 28 December 2016
The reviewed and verified version was received on 1 March 2019

DOI 10.5604/01.3001.0013.0797

Abstract. The paper presents a method of using actual atmosphere parameter data contained in meteorological messages, necessary for numerical calculation of a spin-stabilised projectile trajectory. Three standard meteorological messages are considered: message METB3 compliant with STANAG 4061, message METCM compliant with STANAG 4082, and message METEO11, so called meteoaverage, currently used in the Polish Armed Forces. The purpose of verifying the correctness of the prepared algorithms of using meteorological messages, a computer program simulating the flight of the 35 mm TP-T anti-aircraft projectiles under actual atmospheric conditions was developed, and appropriate calculations were performed.
Keywords: standard meteorological message, METB, METCM, Meteo11, meteoaverage, projectile flight simulation

This work has been compiled from the paper presented during the 11th International Armament Conference *on Scientific Aspects of Armament and Safety Technology*, Ryn, Poland, September 19-22, 2016.

1. INTRODUCTION

Modern fire control systems use in their setting calculation algorithms for calculations of projectile trajectory under actual, not standard shooting conditions [1]. Calculating an actual trajectory requires data on the atmospheric conditions surrounding a projectile in flight, such as:
- wind direction and speed vector modulus,
- air temperature and density.

For projectile trajectory calculations to carry as little error as possible, the atmosphere parameters must be determined along the predicted projectile trajectory. Currently, the only information source that artillery subunits have to determine atmospheric parameters, which markedly affect projectile trajectories, are standard meteorological messages.

Having regard to the above, this paper presents a method of using meteorological data included in meteorological messages, necessary to simulate the trajectory of a spin-stabilised projectile, treated as a rigid body with six degrees of freedom. Three standard meteorological messages are considered:
- ballistic meteorological message (METB) compliant with STANAG 4061 [7],
- meteorological message for artillery computers (METCM), compliant with STANAG 4082 [8],
- message Meteo11, so-called "meteoaverage", currently used in the Polish Armed Forces field artillery [12].

2. STRUCTURE OF STANDARD METEOROLOGICAL MESSAGES

Standard meteorological messages are prepared based on actual air parameters measured by a radiosonde (suspended under a meteorological balloon), tracked by a meteorological radar [10].

2.1. Standard ballistic meteorological message (METB)

The current version of the ballistic message is included in STANAG 4061, Edition no. 4 of 3 October 2010 [7].

The message comprises two parts:
- introduction containing information on the message type, meteorological station position and message expiry date; this information is divided into four six-item groups (group 1, group 2, group 3, group 4)
- the main part containing information on atmosphere parameters; this information is provided in two six-item groups (group 5, group 6) shown cyclically for 21 lines of the message, which are consecutive zones of the Earth’s atmosphere.

The message is structured as follows:

group 1	METBKQ		
group 2	$L_a L_a L_a L_o L_o L_o$	or	XXXXXX
group 3	$YYG_oG_oG_oG$		
group 4	hhhPPP		
group 5	ZZddFF		
group 6	TTTΔΔΔ		

Groups 5 and 6 are repeated for each message line (each consecutive zone).

group 1

MET meteorological message
B ballistic
K type of message
K=2 – message for anti-aircraft fire
K=3 – message for the surface to surface fire
Q code of Earth globe part where the message applies

group 2

if Q= 0, 1,2,3,5,6,7,8 then $L_a L_a L_a L_o L_o L_o$

$L_a L_a L_a$ latitude

$L_o L_o L_o$ longitude

if Q=9 then XXXXXX

XXXXXX name of a region on the Earth's globe

group 3

YY day of the month when the message is valid for the stated period,

$G_oG_oG_o$ time with accuracy to tens of minutes in a 24-hour format (from 000 to 239), starting from which the message is valid for the stated period,

G number of hours for which the message is valid, for the digit 9 the message is valid for 12 hours.

group 4

hhh Meteorological Datum Plane (MDP) - in tens of metres,

PPP pressure at the MDP, expressed in percentage of standard pressure, with an accuracy of up to 0.1%. For pressures greater than the standard pressure, the first character is omitted.

group 5

ZZ message line number

dd direction from which the ballistic wind is blowing, expressed in hundreds of mils (dd - may take a value from 00 to 64),

FF ballistic wind speed for the zone, with an accuracy of up to 0.1 kt.

group 6

TTT ballistic air temperature, with an accuracy of up to 0.1%. For temperatures greater than the standard, the first character is omitted.

ΔΔΔ ballistic air density, with an accuracy of up to 0.1%. For densities greater than the standard, the first character is omitted.

Ballistic temperature is calculated based on the weighted average of relative temperature values in consecutive zones; the average temperature value in each zone is the measured or predicted average value of virtual temperature in the zone relative to standard temperature for the zone; ballistic temperature is expressed as a percentage.

Ballistic density is calculated in a similar manner, i.e. by calculating the weighted average of relative values in consecutive zones; the average value in each zone is obtained by first calculating the density in the given zone based on the average virtual temperature in the zone and atmospheric pressure in the centre of the zone, then by expressing density in the zone as a percentage of standard density for the zone. Alternatively, ballistic density can be expressed by the weighted value of temperature and ground-level pressure using the method given in appendix H to STANAG 4061.

The direction and speed of ballistic wind are obtained by calculating the weighted average of average wind speeds and directions in consecutive zones.

When calculating METB messages, it is assumed that standard temperature and density curves in time are consistent with the ICAO standard atmosphere [11].

2.2. Standard meteorological message for artillery computers (METCM)

The meteorological message for artillery computers is defined in STANAG 4082, Edition no. 3 of 6 April 2010 [8]. Similar to METB, the message comprises two parts:

- introduction containing information on the message type, meteorological station position and message expiry date; this information is divided into four six-item groups (group 1, group 2, group 3, group 4), forming line one of the message,
- the main part containing information on atmosphere parameters; this information is provided in two eight-item groups (group 5, group 6) shown cyclically for 32 lines of the message, which are consecutive zones of the Earth’s atmosphere (Table 1).

Table 1. Summary of zones for which the METCM meteorological message is compiled

zone number Z_nZ_n	Altitude of zone central point	Altitude above MDP of lower and upper zone boundary	zone number Z_nZ_n	Altitude of zone central point	Altitude above MDP of lower and upper zone boundary
[-]	[m]	[m]	[-]	[m]	[m]
00	0	0	16	9500	9000 - 10000
01	100	0 - 200	17	10500	10000 - 11000
02	350	200 - 500	18	11500	11000 - 12000
03	750	500 - 1000	19	12500	12000 - 13000
04	1250	1000 - 1500	20	13500	13000 - 14400
05	1750	1500 - 2000	21	14500	14000 - 15000
06	2250	2000 - 2500	22	15500	15000 - 16000
07	2750	2500 - 3000	23	16500	16000 - 17000
08	3250	3000 - 3500	24	17500	17000 - 18000
09	3750	3500 - 4000	25	18500	18000 - 19000
10	4250	4000 - 4500	26	19500	19000 - 20000
11	4750	4500 - 5000	27	21000	20000 - 22000
12	5500	5000 - 6000	2S	23000	22000 - 24000
13	6500	6000 - 7000	29	25000	24000 - 26000
14	7500	7000 - 8000	30	27000	26000 - 28000
15	3500	8000 - 9000	31	29000	28000 - 30000

The message is structured as follows:

METCMQ $L_a\,L_a\,L_a\,L_o\,L_o\,L_o$ $YYG_oG_oG_oG$ $hhhP_dP_dP_d$ – (groups 1, 2, 3, 4)

$Z_nZ_n$dddFFF TTTTPPPP – (groups 5 and 6)

Groups 5 and 6 are repeated for each message line (each consecutive zone).

<u>Introduction part of the message</u>

group 1

METCMQ

- MET meteorological message,
- CM artillery computer,
- Q code of the Earth’s globe part where the message applies

group 2

if Q= 0, 1,2,3,5,6,7,8 then

$L_a\,L_a\,L_a\,L_o\,L_o\,L_o$

- $L_a\,L_a\,L_a$ latitude in tens, units and tenths of degrees,
- $L_o\,L_o\,L_o$ longitude in tens, units and tenths of degrees,

if Q=9 then
XXXXXX

XXXXXX name of a region on the Earth's globe.

group 3

$YYG_oG_oG_oG$

- YY — day of the month when the message is valid for the stated period,
- $G_oG_oG_o$ — time in a 24-hour format (from 000 to 239), starting from which the message is valid for the stated period, in tens, units and tenths of hours,
- G — number of hours for which the message is valid, for the digit 9 the message is valid for 12 hours.

group 4

$hhhP_dP_dP_d$

- hhh — Meteorological Datum Plane (MDP) above sea level, in tens of metres
- $P_dP_dP_d$ — pressure at MDP, expressed in tens, units and tenths of hectopascals (hPa). For pressures equal to or exceeding 1000 hPa, the digit denoting the thousand is omitted.

<u>Main part of the message</u>

group 5

$Z_nZ_ndddFFF$

- Z_nZ_n — number corresponding to a zone in Table 1, e.g. zone number 04 corresponds to the zone between 1000 and 1500 m,
- ddd — direction from which mean vector wind in the given zone is blowing, expressed in thousands, hundreds and tens of mils (ddd – may take values from 001 to 640, 000 means that wind speed is zero),
- FFF — speed of mean vector wind in the given zone, expressed in hundreds, tens and units of knots (1 knot = 0.51444 m/s).

group 6

TTTTPPPP

- TTTT — mean virtual temperature in the given zone, expressed in hundreds, tens, units and tenths of degrees Kelvin,
- PPPP — air pressure at the mid-point of the zone (see Table 1), expressed in thousands, hundreds, tens and units of hectopascals (hPa), (1 hPa = 1 mBar).

2.3. Meteo11 message, so called "meteoaverage"

The "meteoaverage" message contains wind speed and direction values and average temperature deviations from the normal temperature in a zone from the Earth's surface to the altitude stated in the message.

Furthermore, it contains the ground-level pressure deviation at the meteorological station location. Based on the data from the "meteoaverage" message, the so-called ballistic wind and ballistic temperature deviation [6, 7] are determined, which are then used directly to calculate firing range and direction corrections [5].

The "meteoaverage" meteorological message is communicated in the following telephonogram form (example) [12]:

"Meteo: 1103 – 05074 – 0080 – 50668 – 0206 – 671908 – 0405 – 661909 – 0804 – 642210 – 1203 – 622410 – 1603 – 602511 – 2002 – 602511 – 2402 – 592812 - ... – 1827 – 5624 - 3514".

The meaning of the digits is based on their position in each group and the group's position within the message:

group one (l word and 4 digits) - **Meteo 1103**

Meteo 11 - arbitrary designation of the "meteoaverage" message;
03 - arbitrary number of the meteorological station - no. 3;

group two (5 digits) - **05074**

05 - day of the month the message was compiled - 5th day of the month;
07 - hour when atmosphere sounding was completed - 7th hour;
4 - minutes (in tens) when sounding was completed - 40 minutes;

group three (4 digits) – **0080**

0080 - altitude of the meteorological station above sea level in metres - 80 m;

group four (5 digits) **- 50668**

506 - air pressure deviation in the ground-level layer from the tabular value at the meteorological station altitude, in millimetres of mercury (mm Hg) - negative 6 mm;
68 - virtual air temperature deviation in the ground-level layer from the tabular value in degrees - negative 18°C;

group five (4 digits) – **0206**

02 - altitude specified in hundreds of metres - 200 m;
06 - average air density deviation from the tabular value in the atmosphere layer from the Earth's surface to the specified altitude, in percent - +6%;

group six (6 digits) - **671908**

67 - average air temperature deviation from the tabular value in the atmosphere layer from the Earth's surface to the specified altitude, in degrees - 17°C;
19 - topographic azimuth of average wind (direction from which wind is blowing) in the atmosphere layer from the Earth's surface to the specified altitude in hundreds of thousandths - 19-00;
08 - average wind speed in the atmosphere layer from the Earth's surface to the specified altitude, in metres per second - 8 m/s.

3. ALGORITHMS OF USING STANDARD METEOROLOGICAL MESSAGES

The atmospheric parameters necessary to calculate projectile trajectory are: wind speed and direction, air density and speed of sound. This section presents the algorithms for obtaining the values of these parameters based on data included in meteorological messages.

3.1. Using the METB message

The algorithm for using data contained in **METB** meteorological messages is as follows:
1. For the given firing distance and specific propellant charge (selected projectile muzzle velocity), calculate gun barrel elevation angle *QE* that ensures a target hit when firing under normal conditions,
2. In Table A, included in the firing table set, find the meteorological message line number corresponding to the given *QE* angle,
3. If the target and the firing position are not at the same altitude, use Table B to correct the meteorological message line number from which atmospheric parameters are read,
4. Read information on ballistic wind speed and direction, as well as ballistic temperature and ballistic density from the METB message for the line determined previously.
5. Read the meteorological station altitude from the message.
6. Correct ballistic temperature and ballistic density for the difference in altitudes between the firing position and the meteorological station, e.g. based on Table D included in the firing table set.
7. Calculate flight trajectory, taking into account wind components and changes of air density with altitude according to ICAO, including ballistic density and changes in speed of sound with altitude based on the temperature chart in ICAO, taking ballistic temperature into account.

3.2. Using the METCM message

The algorithm for using data contained in **METCM** meteorological messages for calculating projectile flight trajectory is as follows:
1. Use Table 1 to determine which zone the projectile is located in at the given moment of flight,
2. Read information on mean wind direction and speed, mean temperature and atmospheric pressure at the centre of the zone from the meteo message for the zone determined previously,

3. Correct mean air temperature and pressure for the difference in altitudes between the firing position and the meteorological station.
4. Take into account in the projectile trajectory calculation the mean wind values, air density and speed of sound from the following equation:

$$\rho(h) = 0.34836764\frac{p}{T}$$

$$a(h) = 20.04680276\sqrt{T}$$

where: p - pressure found for the given zone in the METCM message,
T - virtual temperature found for the given zone in the METCM message.

If it occurs that the meteorological message used to calculate projectile trajectory is incomplete, the missing data are determined as follows:
- wind is considered constant,
- air temperature and density are determined on the basis of ICAO standard atmosphere values.

If, during flight trajectory calculations, the projectile begins to travel below the first data line in the meteo message or above the last data line in the message - extrapolate the data to continue the calculations.

3.3. Using the Meteo11 message

Data concerning ballistic air temperature and wind deviations are drawn from the meteorological message not based on the actual apex of the trajectory *(y)*, corresponding to the topographical distance to the target, but from a certain arbitrary altitude (*Y*k - input height for the message) stated in firing tables (section II) or from a relevant nomogram [9]. Ballistic temperature deviation, topographic azimuth and ballistic wind speed are taken from the message for the altitude closest to the arbitrary value (*Y*k).

4. DISCUSSION OF SIMULATION TEST RESULTS

Using algorithms with atmosphere parameters from meteorological messages, and the mathematical flight model of a projectile as an axially spinning oblong rigid body, presented in papers [1, 2], and the characteristics of a physical model of the 35 mm TP-T training projectile and 35 mm FAPDS-T sabot projectile, shown in paper [3], a computer program simulating the firing of the 35 mm anti-aircraft gun of the LOARA gun system under actual atmospheric conditions was developed. The program, an application running in the Windows environment, was written in Visual Basic. It enables calculating projectile trajectories in four variants:
- flight in the ICAO standard atmosphere,
- flight under actual atmospheric conditions read from a METCM message,

- flight under actual atmospheric conditions read from a METB2 or METB3 message,
- flight under actual atmospheric conditions read from a Meteo11 message,

To verify the correctness of the algorithms that use data included in meteorological messages to calculate projectile trajectory under actual atmospheric conditions, the structures of METCM and METB3 messages, discussed in paper [4] and summarised in Table 2, were used.

Table 2. Meteorological message structure: METCM and METB3

METCM0 329114 062150 024986	METB30 329114 062150 024986
00505007 29230986	005007 014959
01507008 29160975	015108 014960
02511009 28940946	025109 013961
03519008 28600902	035208 011963
04513006 28260850	045107 010964
05540006 27920800	055307 010965
06546009 27640752	065310 011965
07534014 27370707	075215 012965
08520018 27060664	085218 011966
09515022 26710623	095122 010967
10518024 26350584	105030 010972
11519027 26000547	114936 010974
12508031 25430495	124943 010969
13497036 24600432	134846 010971
14494042 23770375	144846 010974
15487050 23100324	154844 010976
16485060 22680279	999999
17483068 22500240	
18480073 22380206	
19473074 22190177	
20465072 21880151	
21459068 21440129	
22455063 21030110	
23452056 20700093	
24450047 20450079	
99999	

The METB3 message in paper [4] was compiled on the basis of a METCM message, so both messages reflect the same atmospheric conditions. Sample results of trajectory calculations for a 35 mm TP-T training projectile fired at an angle *QE* = 800 mils in the ICAO Standard Atmosphere are shown in Fig. 3, while Fig. 4 shows the calculation results when using atmospheric data from a METCM message, and Fig. 5. shows the calculation results when using atmospheric data from a METB3 message.

Selected calculation results: projectile impact coordinates (X_{kon}, Z_{kon}), trajectory apex (Y_w) and projectile flight time (T_{kon}) are also summarised in Table 3.

Fig. 1. Round type selection window

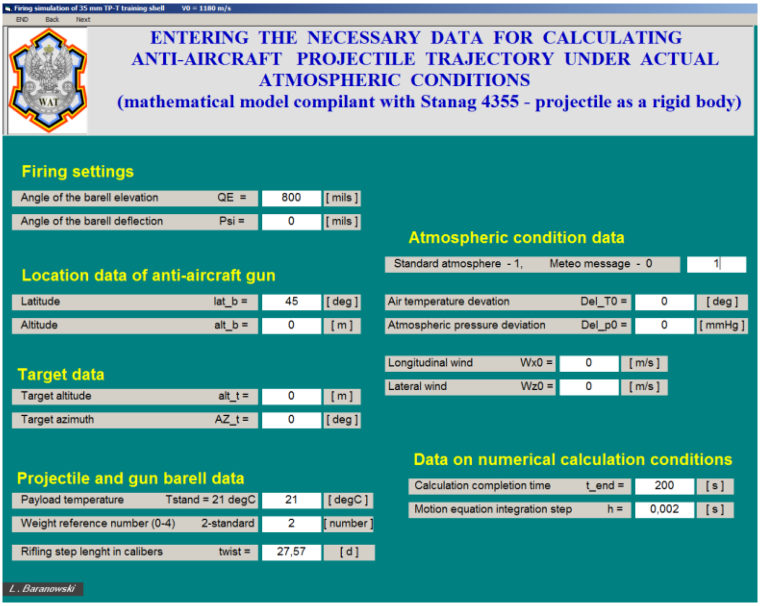

Fig. 2. Window for entering calculation conditions data

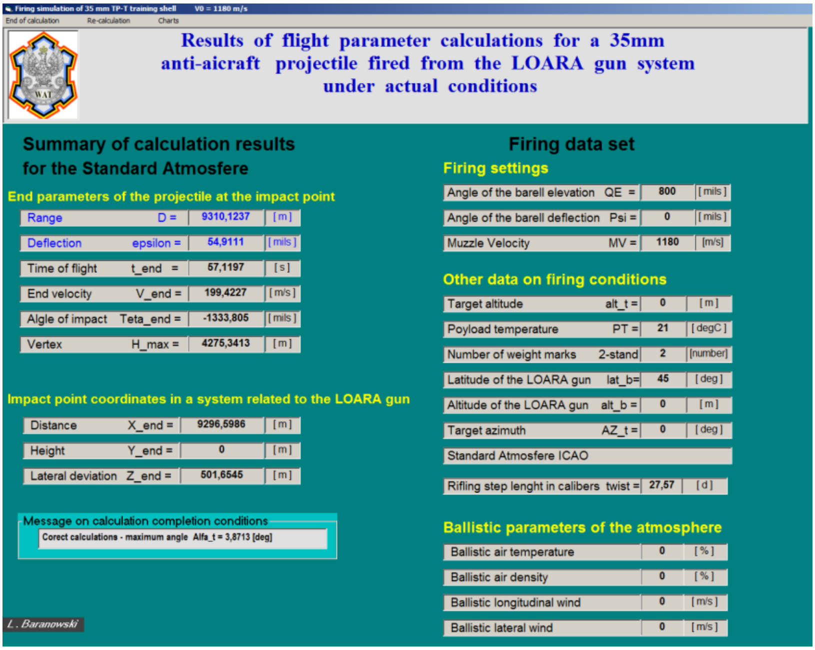

Fig. 3. Results window for calculations in ICAO Standard Atmosphere

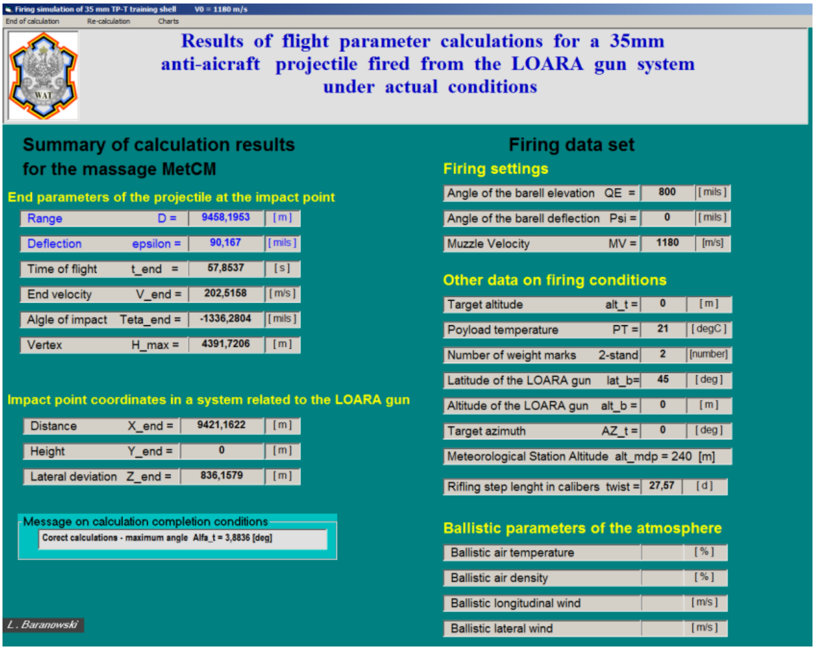

Fig. 4. Results window for calculations using a METCM message

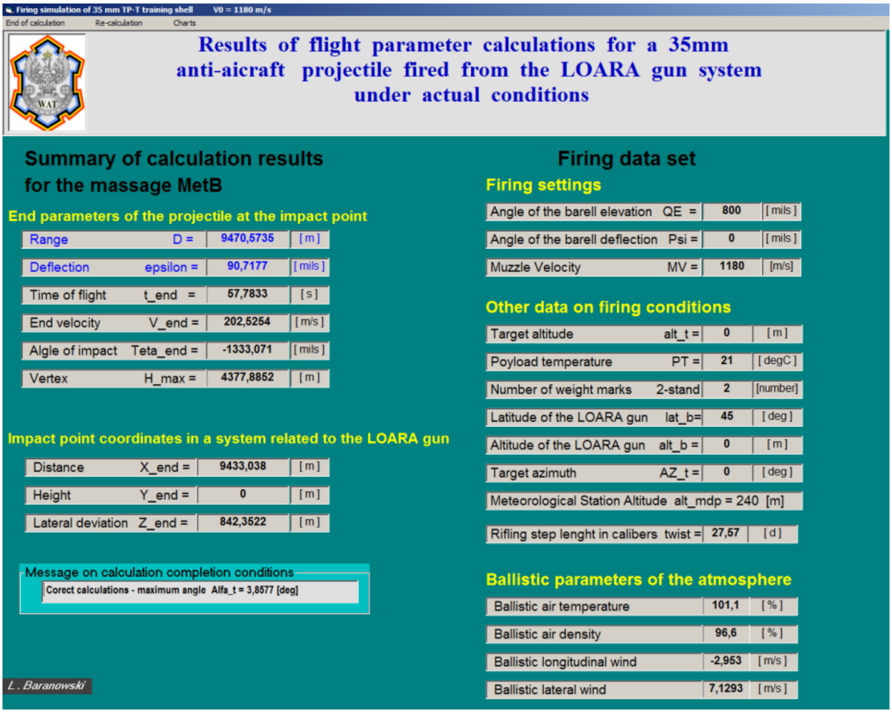

Fig. 5. Results window for calculations using a METB3 message

Table 3. Summary of projectile impact point coordinates (X_{kon}, Z_{kon}), apex (Y_{w}) and flight time (T_{kon}) for three calculation cases: flight in ICAO standard atmosphere, and with two meteo messages: METCM and METB3 taken into account

	X_{kon} [m]	Y_{w} [m]	Z_{kon} [m]	$\mathrm{T}_{\mathrm{kon}}$ [s]
ICAO	9296.6	4275.3	501.7	57.12
METCM	9421.2	4391.7	836.2	57.85
METB3	9433.0	4377.9	842.4	57.78

Having analysed the atmospheric parameters provided in the meteorological messages used in the calculations, and their impact on projectile trajectory as compared to the trajectory in the standard atmosphere, the calculation results summarised in Table 3, and consequently the algorithms developed, can be considered correct.

The 35 mm anti-aircraft gun firing simulation software was also used to perform preliminary qualitative tests of the impact of atmospheric conditions (expressed in properly compiled meteorological messages) on fire accuracy.

5. SUMMARY AND FINAL CONCLUSIONS

The purpose of this paper was to present the tested algorithm uploading data on atmosphere parameters, coded in standard meteorological messages, to the projectile trajectory calculation software. For the purpose of testing the algorithm's correctness, a computer program enabling simulation of the flight of a 35 mm anti-aircraft projectile under actual atmospheric conditions, described in a relevant meteorological message, was developed.

Additional preliminary calculations of the impact of atmospheric condition deviation from standard atmospheric conditions on projectile flight, and the resulting firing errors, enabled the following general conclusions to be made:

- firing error magnitude caused by atmospheric conditions increases with firing range *R*c (angular distance to target),
- accuracy is affected the most by lateral wind, followed by longitudinal wind,
- the impact of air temperature and atmospheric pressure deviations on anti-aircraft gun accuracy (within the firing ranges in question, up to *R*c = 4000 m) is significantly lower than the effects of wind,
- firing error caused by longitudinal wind increases with increasing target altitude, assuming *R*c = const,
- firing error caused by air temperature and atmospheric pressure deviations decreases with increasing target altitude, assuming *R*c = const,
- firing error caused by lateral wind is essentially independent of target altitude, assuming *R*c = const,

A detailed quantitative analysis of the impact of atmospheric conditions on firing errors will be the subject of further studies and will be presented in a future paper.

The study was financed from science funds in the years 2013–2016
as the research and development project no. O ROB 0046 03 01

REFERENCES

[1] Baranowski Leszek. 2013. "Effect of the mathematical model and integration step on the accuracy of the results of computation of artillery projectile flight parameters". *Bulletin of the Polish Academy of Sciences – Technical Sciences* 61(2) : 475-484.

[2] Baranowski Leszek, Wojciech Furmanek. 2013. „Problem walidacji modelu trajektorii lotu 35mm pocisku TP-T w warunkach normalnych". *Problemy Techniki Uzbrojenia* 125 : 35-44.

[3] Baranowski Leszek. 2014. *Opracowanie modeli matematycznych i symulacje parametrów toru lotu 35 mm pocisków: podkalibrowego i ćwiczebnego, dla warunków normalnych*. Sprawozdanie częściowe z realizacji projektu NR O ROB 0046 03 001. Warszawa: Instytut Techniki Uzbrojenia WML WAT.

[4] Cogan J., D. Sauter. 2013. *Generation of Ballistic Meteorological Messages - Surface to Surface (METB3s) from Computer Meteorological Messages (METCMs)*, Army Research Laboratory, Report number ARL-TN-0550.

[5] Pogorzelski Feliks. 1980. *Teoria strzelania artylerii naziemnej*. Warszawa: Wydawnictwo WAT.

[6] Szapiro J. 1956. *Balistyka zewnętrzna*. Warszawa: MON.

[7] *Adoption of a standard ballistic meteorological message*. STANAG 4061 (Edition 4), 2000.

[8] *Adoption of a standard artillery computer meteorological message*. STANAG 4082 (Edition 3), 2010.

[9] *Balistyka zewnętrzna – Podręcznik*. 1979. Warszawa: Wydawnictwo Ministerstwa Obrony Narodowej.

[10] *Instrukcja zabezpieczenia meteorologicznego wojsk rakietowych i artylerii*. 1981. Warszawa: Wydawnictwo Ministerstwa Obrony Narodowej.

[11] ISO 2533, *The ISO Standard Atmosphere*, 1975.

[12] *Tabele strzelnicze do 122 mm Haubicy Samobieżnej 2S1*. 1979. Warszawa: Wydawnictwo Ministerstwa Obrony Narodowej.

Wykorzystanie standardowych komunikatów meteorologicznych do symulacji lotu 35 mm pocisku TP-T w warunkach rzeczywistych

Leszek BARANOWSKI, Zbigniew LECIEJEWSKI

Wojskowa Akademia Techniczna, Wydział Mechatroniki i Lotnictwa,
Instytut Techniki Uzbrojenia
ul. gen. Witolda Urbanowicza 2, 00-908 Warszawa

Streszczenie. W artykule przedstawiono sposób wykorzystania danych o rzeczywistych parametrach atmosfery, zawartych w komunikatach meteorologicznych, niezbędnych do numerycznego obliczenia toru lotu pocisku stabilizowanego obrotowo. Rozpatrzono trzy standardowe komunikaty meteorologiczne: komunikat METB3 zgodny ze Stanagiem 4061, komunikat METCM zgodny ze Stanagiem 4082 oraz komunikat METEO11 tzw. meteośredni, stosowany aktualnie w Wojsku Polskim. Celem sprawdzenia poprawności opracowanych algorytmów wykorzystania komunikatów meteorologicznych opracowano program komputerowy symulacji lotu 35 mm pocisku przeciwlotniczego TP-T w rzeczywistych warunkach atmosferycznych i dokonano stosownych obliczeń.
Słowa kluczowe: standardowy komunikat meteorologiczny, METB, METCM, Meteo11, meteośredni, symulacja lotu pocisku