INTERIOR BALLISTIC STUDIES OF POSSIBILITIES FOR LAUNCHING AIRCRAFTS ROCKETS FROM GROUND

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In last years happens that some type of aircrafts are no more in use from different reasons, but the stocks of ammunition for them are enormous. In some cases the question of possibilities of launching aircraft rockets from ground arises. Commonly, for ground launching of aircraft rockets the need appears for increase of initial launching velocity in order to provide required rocket range and precision. In this paper different interior ballistic possibilities are studied as candidates for appropriate launching. Interior ballistic concepts of open-aft launcher, close-aft launcher, close-aft launcher with additional charge, open-aft launcher with additional charge and countermass and launcher with nozzle and additional propellant charge are analyzed. Appropriate mathematical models and computer codes are developed. Results for 57mm aircraft rocket show possibilities of different interior ballistic concepts to fulfill specified requirements.

INTRODUCTION

Today some types of aircrafts are no more in use from different reasons, but the stocks of ammunition for them are enormous. Then the question of possibilities of aircraft rockets launching from ground (for example, for light multi tube rocket launcher) arises. Commonly for ground launching of aircraft rockets the need appears for increase of initial launching velocity in order to provide required rocket range and precision.

In this paper different ballistic possibilities are studied as candidates for launching of 57mm aircraft rocket BR-20/57 (rocket initial mass - 3.380 kg, mass of double base propellant - 1,12kg) with increased initial velocity. Following interior ballistic concepts are analyzed:

- open-aft launcher,
- close-aft launcher,

- close-aft launcher with additional propellant charge,
- open-aft launcher with additional propellant charge and countermass, and
- launcher with nozzle and additional propellant charge.

For all these interior ballistic concepts influence of launcher length is studied.

MATHEMATICAL MODEL

The mathematical model for open-aft launcher with additional propellant charge and countermass is given in this paper. All other models for different interior ballistic concepts can be treated as special cases of this model.

The schematic representation of open-aft launcher with additional propellant charge and countermass is given in figure 1.

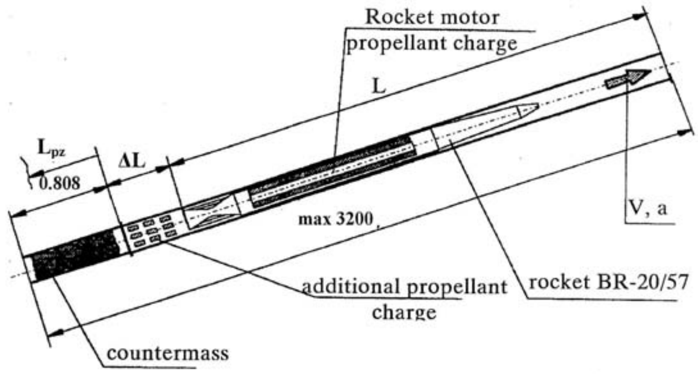

Figure 1. Schematic representation of open-aft launcher with additional propellant charge and countermass

The mathematical model [1] is composed from following equations:

- equation for formation of propellant gases due to combustion of additional propellant charge

$$\frac{dm_{ac}}{dt} = \rho_{ac} S_{ac} u_{1ac} p_l^{nl} \qquad (1)$$

where are: m_{ac} - mass of additional propellant charge, t - time, ρ_{ac} - density of additional propellant charge, S_{ac} - instanteneous burning surface of additional propellant charge, u_{1ac} - coefficient in burning law of additional propellant charge, p_l - pressure in launcher, n_{ac}- exponent in burning law of additional propellant charge,

- flow through the rocket nozzle

case a) $\frac{p_l}{p_{rm}} \langle (\frac{2}{k+1})^{\frac{k}{k-1}}$

where are: p_{rm} - pressure in rocket motor, k - specific heat ratio of products of rocket propellant,

1. Determination of location of normal shock wave in nozzle using assumption $p_l = p_2$ (p_2- pressure behind the wave)

$$\frac{p_l}{p_{rm}} = \frac{2kM_1^2 - (k-1)}{k+1}\left[1 + \frac{k-1}{2}M_1^2\right]^{\frac{k}{k-1}} \tag{2}$$

where is: M_1 - Mach number in front of the shock wave in the rocket nozzle. Based on known p_l/p_{rm}, M_1 is determined by iterative procedure.

2. In the case of shock wave location outside the nozzle, we assume that it is in the nozzle exit section. The maximum value of M determines by iterative procedure from the expression:

$$\frac{S_{sh}}{S_t} = \frac{1}{M_m}\left[\frac{2}{k+1}\left(1 + \frac{k-1}{2}M_m^2\right)\right]^{\frac{k+1}{2(k-1)}} \tag{3}$$

whereare: S_{sh} - area of shock wave, S_t - nozzle throat area, M_m - maximum Mach number,

3. Determination: $M' = \min(M_1, M_m)$.

4. The cross-section area in the nozzle on the place of appearing shock wave

$$S_e = S_t \frac{1}{M'}\left[\frac{2}{k+1}\left(1 + \frac{k-1}{2}M'^2\right)\right]^{\frac{k+1}{2(k-1)}} \tag{4}$$

5. Determination of p_{ex}:

$$\frac{p_{rm}}{p_{ex}} = \left(1 + \frac{k-1}{2}M'^2\right)^{\frac{k}{k-1}} \tag{5}$$

where p_{ex} is pressure in the nozzle exit area,

6. Determination of V_{ex}:

$$V_{ex} = \sqrt{\frac{2k}{k-1}}\sqrt{f\left[1 - \left(\frac{p_{rm}}{p_{ex}}\right)^{\frac{1-k}{k}}\right]} \tag{6}$$

where are: V_{ex} - gas velocity in the nozzle exit area, f - rocket propellant force,

7. Determination of mass flow rate through the nozzle $\dot{m}_{rm}$:

$$\dot{m}_{rm} = \sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} p_{rm} S_t \sqrt{\frac{1}{f}} \tag{7}$$

case b) $\frac{p_l}{p_{rm}} > \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$

$$p_{ex} = p_l \ , \ S_e = S_t \tag{8}$$

$$V_{ex} = \sqrt{\frac{2k}{k-1}} \sqrt{f\left[1 - \left(\frac{p_l}{p_{rm}}\right)^{\frac{k-1}{k}}\right]} \tag{9}$$

$$\dot{m}_{rm} = \sqrt{\frac{2k}{k-1}} p_{rm} S_t \sqrt{\frac{1}{f}\left[\left(\frac{p_l}{p_{rm}}\right)^{\frac{2}{k}} - \left(\frac{p_l}{p_{rm}}\right)^{\frac{k+1}{k}}\right]} \tag{10}$$

- equation for formation of propellant gases due to combustion of rocket charge

$$\frac{dm_{rm}}{dt} = \rho_{rm} S_{rm} u_{1rm} p_{rm}^{nrm} \tag{11}$$

where are: ρ_{rm} - density of rocket propellant, S_{rm} - instanteneous burning surface of rocket propellant, u_{1rm} - coefficient in burning law of rocket propellant, n_{rm}- exponent in burning law of rocket propellant,

- equation of conservation of mass in the launcher

$$\frac{d\rho_m}{dt} = \frac{1}{W_l}\left[\omega^* \frac{dz}{dt} - \dot{m}_{out} + \dot{m}_{rm} - \rho_m \frac{dW_l}{dt}\right] \tag{12}$$

where are: ρ_m - density of gas mixture in launcher, W_l- launcher volume between rocket and countermass, z- relative burnt web of additional propellant charge,

- mass of additional propellant charge and igniter

$$\overset{*}{\omega} = \omega_{ac} + \omega_i \tag{13}$$

where are: ω_{ac} - mass of additional propellant charge, ω_i - mass of igniter of additional propellant charge,

- equation of change of free volume in the launcher

$$\frac{dW_l}{dt} = \frac{\overset{*}{\omega}}{\rho_{ac}} \frac{dz}{dt} + S_l\left[\frac{dx}{dt} + \frac{dx_{cm}}{dt}\right] \tag{14}$$

where are: S_l - cross-section area of launcher, x - rocket path in launcher, x_{cm} - countermass path in launcher,

- equation of energy conservation in the launcher

$$\frac{dT_l}{dt}=\frac{1}{c_{vm}\rho_m W_l}\left[c_{pp}\frac{f_p^*}{R_{gp}}\omega^*\frac{dz}{dt}-c_{pm}\dot{m}_{out}T_l+c_{prm}T_{rm}\dot{m}_{rm}-p_l S_l\left(V+V_{cm}\right)\right]-$$
$$T_l\left[\frac{1}{c_{vm}}\frac{dc_{vm}}{dt}+\frac{1}{\rho_m}\frac{d\rho_m}{dt}+\frac{1}{W_l}\frac{dW_l}{dt}\right] \tag{15}$$

where are: T_l - temperature of gas mixture in launcher, c_{vm} - specific heat under constant volume for gas mixture in launcher, c_{pp} - specific heat under constant pressure for products of burning of additional propellant charge, c_{pm} - specific heat under constant pressure for gas mixture in launcher, V - rocket velocity, V_{cm} - velocity of countermass,

- combined force of additional charge and its igniter

$$f_p^*=\frac{\omega_{ac}f_{ac}+\omega_i f_i}{\omega^*} \tag{16}$$

where are: f_{ac} - force for propellant of additional charge, f_i - force for igniter of additional propellant charge,

- mass flow rate through the aft-end of launcher when the countermass leaves the launcher

$$\dot{m}_{out}=\varphi p_l S_l\sqrt{k_m\left(\frac{2}{k_m+1}\right)^{\frac{k_m+1}{k_m-1}}\frac{1}{R_{gm}T_l}} \tag{17}$$

where are: φ - nozzle coefficient, k_m - ratio of specific heats for gas mixture in launcher,

- change of burnt web

$$\frac{dz}{dt}=\left[f_1+2f_2\frac{e}{e_0}+3f_3\left(\frac{e}{e_0}\right)^2\right]\frac{d\left(e/e_0\right)}{dt} \tag{18}$$

where are: f_1, f_2,f_3 - coefficient of geometry shape of propellant of additional charge, e - burnt web of propellant of additional charge, e_0 - initial web of propellant of additional charge,

- equations for mixture of gases in the launcher

$$\frac{dc_{vm}}{dt}=\frac{d\varepsilon_*}{dt}c_{v*}+\frac{d\varepsilon_{rm}}{dt}c_{vrm}=\frac{d\varepsilon_*}{dt}(c_{v*}-c_{vrm}) \tag{19}$$

where is ε_{rm} - mass share of rocket propellant gas in gas mixture in launcher,

$$\varepsilon_*=\frac{\omega^* z}{\omega^* z+m_{rm}} \tag{20}$$

$$\varepsilon_{rm} = \frac{m_{rm}}{\omega^* z + m_{rm}} \tag{21}$$

$$c_{pm} = \varepsilon_* c_{p*} + \varepsilon_{rm} c_{prm} \tag{22}$$

$$c_{vm} = \varepsilon_* c_{v*} + \varepsilon_{rm} c_{vrm} \tag{23}$$

$$\frac{dc_{vm}}{dt} = \frac{\omega^* \left[m_{rm} \frac{dz}{dt} - z\dot{m}_{out} \right]}{\left(\omega^* z + m_{rm} \right)^2} \left(c_{v*} - c_{vrm} \right) \tag{24}$$

$$R_{gm} = \varepsilon_* R_{g*} + \varepsilon_{rm} R_{grm} \tag{25}$$

- equation of state for mixture of gases in launcher

$$p_1 = \rho_m R_{gm} T_1 \tag{26}$$

- equations of rocket and countermass motion

$$\frac{dV}{dt} = \frac{F + p_1 S_1}{m(t)} \tag{27}$$

where is m(t) - instanteneous rocket mass,

$$\frac{dV_{cm}}{dt} = \frac{p_1 S_1}{m_{cm}} \tag{28}$$

where is m_{cm} - mass of countermass,

$$\frac{dx}{dt} = V \tag{29}$$

$$\frac{dx_{cm}}{dt} = V_{cm} \tag{30}$$

- equation for rocket thrust force

$$F = \eta_{ef} \frac{1 + \cos\beta}{2} \dot{m}_{rm} V_{ex} + S_1 p_1 - S_e \left(p_1 - p_{ex} \right) \tag{31}$$

where are: η_{ef} - coefficient of loss of total pressure in rocket motore, β - angle of divergent part of nozzle.

Based on these equations the computer program ROMOCM is created. For solution of system of ordinary differential equations of developed system the fourth-order Runge-Kutta method is used.

COMPUTATIONAL RESULTS

During evaluation of possibilities of different interior ballistic concepts for aircraft rocket 57 mm BR-20/57 the following limitations are introduced:

■ maximum pressure in launcher must not exceed the value of 120 bar; on that way we provide the conditions for regular work of rocket motor for all interior ballistic concepts,

■ launcher length was limited on 3.2 m; this length was consequence of demands for placing rocket and elements of different concepts and acheivement of required initial rocket velocity, fom one side, and system mass, from other side,

■ for additional charge can be used only already developed domestic types of propellants.

Typical results for the interior ballistic concept of open-aft launcher with additional propellant charge and countermass are given in figures 2 and 3. These results are obtained for countermass mass of 3 kg and additional charge compose of 30 g of tubular, nitrocellulose propellant.

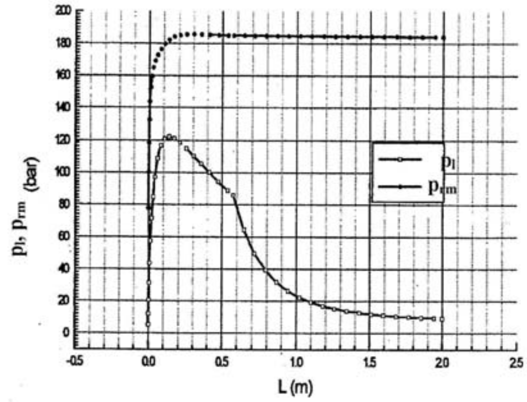

Figure 2. Change of pressures in launcher and rocket motor for open-aft launcher with additional propellant charge and countermass

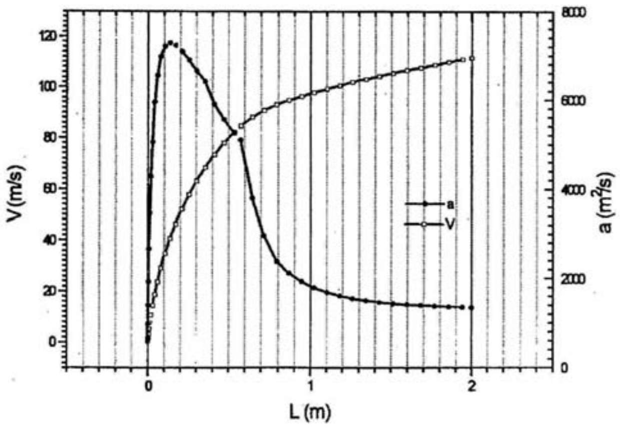

Figure 3. Change of rocket velocity and acceleration for open-aft launcher with additional propellant charge and countermass

Similar curves are obtained with ather interior ballistic concepts. Some of computatitional results are comfirmed by experimental data.The highest initial rocket velocity is obtained with the concept of close-aft launcher with additional propellant charge (170 m/s). In the case of recoiless concepts the highest initial velocity is acheived with the concept of launcher with nozzle and additinal propellant charge (165 m/s).

CONCLUSIONS

Based on previous considerations we can make following conclusions:

1. In last years happens that some type of aircrafts are no more in use from different reasons, but the stocks of ammunition for the them are enormous.
2. Commonly for ground launching of aircraft rockets the need appears for inccrease of initial launching velocity in order to provide required rocket range and precision.
3. Following interior ballistic concepts are analysed:
   - open-aft launcher,
   - close-aft launcher,
   - close-aft launcher with additional propellant charge,
   - open-aft launcher with additional propellant charge and countermass, and
   - launcher with nozzle and additinal propellant charge.
4. The mathematical model for open-aft launcher with additional propellant charge and countermass is given in this paper. All other models for different interior ballistic concepts can be treated as special cases of this model.
5. The highest initial velocity for aircraft rocket 57 mm BR-20/57 is obtained with the concept of close-aft launcher with additional propellant charge (170 m/s). In the case of recoiless concepts the highest initial velocity is acheived with the concept of launcher with nozzle and additinal propellant charge (165 m/s).

REFERENCES

[1] S. Jaramaz, D.Mickovic, *Interior Ballistics*, Faculty of Mechanical Engineering, Belgrade, (2002)