

# Flow Field Simulation and Efficiency Calculation of Muzzle Brake Based on ANSYS Fluent

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**Abstract.** The development of advanced artillery needs to be combined with simulation means, so, traditional calculation method and the flow field simulation method was employed to calculate the efficiency of a large-caliber muzzle brake we designed, and the results achieved by these two methods were 47.8% and 49.3%, respectively. Further, the overpressure value 1 m away from the muzzle was obtained through flow field simulation, and the far-field overpressure value was calculated using blast wave attenuation equations. The result suggests that the blast wave from the designed muzzle brake has little harmful impact. This paper provides an intuitive calculation method of muzzle brake efficiency, also, it provides theoretical support for research of high efficiency muzzle brake and personnel protection onboard.

## 1 Introduction

The artillery, as major arms engaged in firepower coverage and firepower suppression, is hailed as “the god of war”. Moreover, artillery still plays an irreplaceable role in wars these days, even if information technologies are developing rapidly. The birth of muzzle brakes in the 1940s alleviated the contradiction between the power and mobility of the army and promoted the development of artillery [1]. Muzzle brakes can be divided into three types by structure — impact muzzle brakes, reaction muzzle brakes, and impact-reaction muzzle brakes. At present, most of the active artillery is equipped with impact-reaction muzzle brakes, which possess characteristics of both impact muzzle brakes and reaction muzzle brakes. Specifically, impact-reaction muzzle brakes have chambers that expand with a certain angle and retroverted side holes. Once the explosive gas enters the chamber, it expands and flows fast, and holes on both sides of the chambers play a role in flow distribution and gas expansion for the second time, so as to significantly reduce the recoil. For naval artillery, the installation of muzzle brakes can effectively reduce their weight, thus the large-caliber naval artillery can also be available on relatively small tonnage frigates and the strike capability of the whole fleet will be improved.

The more efficient the muzzle brake is, the more recoil of the artillery will be reduced. However, there is conflicts between the muzzle brake’s efficiency and the intensity of the muzzle blast wave. The excessive muzzle blast wave will harm the soldiers and equipment. Therefore, it is necessary to balance the efficiency of the muzzle brake with the blast wave intensity, and to reduce the blast wave intensity as much as possible based on the assurance that the efficiency meets the demand. ANSYS Fluent is a

professional flow field simulation software, which has been widely used in simulation of automobile flow fields and oil pipeline transportation. Simulation of the flow field of muzzle brakes by ANSYS Fluent cannot only present the intensity of blast waves near the muzzle, but obtain the extent of force of the artillery barrel and the muzzle brake to calculate the efficiency of the muzzle brake.

## 2 Calculation Methods of the Muzzle Brake’s Efficiency and Model Construction

Traditional calculation methods of muzzle brakes’ efficiency include the improved Orlov’s method, Sphusky’s method, and method from American Engineering Design Manual [3]. The aforementioned methods are based on both theories and experience, and their application entails complex calculation process since various structural parameters of muzzle brakes need to be calculated. The flow analysis software, however, does not require calculation of these complex structural parameters in simulation and analysis of the flow field of muzzle brakes, and hence makes it much easier to calculate the efficiency of muzzle brakes.

In this paper, a muzzle brake applicable to large-caliber artillery was designed. Table 1 shows the structural parameters of the designed muzzle brake.

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**Table 1** Structural parameters of the designed muzzle brake

Total length of muzzle brake (L)	620 mm
Maximum outer diameter of muzzle brake (D <sub>Max</sub> )	279.4 mm
Number of chambers	3
Number of side holes	3 in each of the 2 lines
Central bullet hole diameter (D <sub>c</sub> )	165 mm
Side holes' angle of inclination	135°
Expansion angle of chambers	20°
Maximum cross-sectional area of chambers	46224.4 mm <sup>2</sup>
Axial length of each chamber (l <sub>q</sub> )	127 mm
Size of muzzle's entrance side holes (A <sub>in</sub> )	10846.2 mm <sup>2</sup>
Size of muzzle's exit side holes (A <sub>out</sub> )	17555.2 mm <sup>2</sup>

### 3 Calculation of the Muzzle Brake's Efficiency

#### 3.1 Improved Orlov's method

The calculation process using the improved Orlov's Method is as follows:

- (1) The area ratio of each chamber (v<sub>ci</sub>), i.e., the ratio of the cross-sectional area of each chamber to the area of the central bullet hole in the front chamber, is calculated:

$$v_{ci} = \frac{A_{ki}}{A_{cpi-1}}$$

- (2) The following parameters are calculated: the ideal velocity coefficient (λ<sub>ci</sub>'), the ideal reaction coefficient (K<sub>ci</sub>'), modified reaction coefficient (K<sub>ci</sub>), actual nozzle velocity coefficient (λ<sub>cpi</sub>), central bullet hole velocity coefficient (λ<sub>cpi</sub>), and central bullet hole reaction coefficient (K<sub>ci</sub>).

$$v_{ci} = \frac{\lambda_{cpi-1} \left(1 - \frac{k-1}{k+1} \lambda_{cpi-1}^2\right)^{\frac{1}{k-1}}}{\lambda'_{ci} \left(1 - \frac{k-1}{k+1} \lambda'^2_{ci}\right)^{\frac{1}{k-1}}}$$

$$K'_{ci} = \frac{1}{2} \left( \lambda'_{ci} + \frac{1}{\lambda'_{ci}} \right)$$

$$K_{ci} = \chi_{\mu} [1 + \chi_{\theta ci} (K'_{ci} - 1)] \text{ or } K_{ci} = K'_{ci}$$

$$\lambda_{ci} = K_{ci} \pm \sqrt{K_{ci}^2 - 1}$$

$$\lambda_{cpi} = \frac{1}{\lambda_{ci}} \text{ or } \lambda_{cpi} = \lambda_{ci}$$

$$K_{cpi} = \frac{1}{2} \left( \lambda_{cpi} + \frac{1}{\lambda_{cpi}} \right)$$

- (3) The chamber's flow distribution ratio (σ<sub>i</sub>) is calculated, and the angle of each side hole respectively during the process is considered.

$$\sigma_i = \frac{1}{1 + \delta_i \frac{A_i}{A_{cpi}} \cos(90^\circ - \psi_i + \alpha_i)}$$

- (4) The area ratio of each chamber's side hole ratio (v<sub>ei</sub>), the ideal velocity coefficient of muzzle's exit side hole (λ<sub>i</sub>'), the ideal reaction coefficient of muzzle's exit side hole (K<sub>i</sub>'), and the actual reaction coefficient of muzzle's exit side hole (K<sub>i</sub>) are calculated.

$$v_{ei} = \frac{A_{ci} \cos(\alpha_{ci} + 90^\circ - \psi_i)}{(1 - \sigma_1) A_{cpi-1}}$$

$$v_{ei} = \frac{\lambda_{cpi-1} \left(1 - \frac{k-1}{k+1} \lambda_{cpi-1}^2\right)^{\frac{1}{k-1}}}{\lambda'_i \left(1 - \frac{k-1}{k+1} \lambda'^2_i\right)^{\frac{1}{k-1}}}$$

$$K'_i = \frac{1}{2} \left( \lambda'_i + \frac{1}{\lambda'_i} \right)$$

$$K_i = \chi_{\mu} [1 + \chi_{\theta ci} (K'_i - 1)] \text{ or } K_i = K'_i$$

- (5) The flow deviation angle through the side holes (Δψ<sub>i</sub>) is caused by the fact that when the gas flows from side holes of the muzzle brake, the direction it aims is not perpendicular to the surface of the muzzle's exit side holes.

$$\frac{\sin(\psi + \Delta\psi)}{\sin \psi} = \frac{K_0 + \sqrt{K_0^2 - 1}}{\frac{K_0}{\cos \Delta\psi} + \sqrt{\frac{K_0^2}{\cos^2 \Delta\psi} - 1}} \left[ \frac{k - (k-1)K_0 (K_0 + \sqrt{K_0^2 - 1})}{k - (k-1) \frac{K_0}{\cos \Delta\psi} \left( \frac{K_0}{\cos \Delta\psi} + \sqrt{\frac{K_0^2}{\cos^2 \Delta\psi} - 1} \right)} \right]^{\frac{1}{k-1}}$$

- (6) The structural characteristic quantity (α), gas

reaction coefficient (βT), and the muzzle brake's

efficiency ( $\eta_T$ ) are calculated.

$$\alpha = K_{cpm}\sigma_1\sigma_2 \dots \sigma_m + \sum_{i=1}^m \sigma_1\sigma_2 \dots \sigma_{i-1}(1 - \sigma_i)K_i \frac{\cos(\psi + \Delta\psi_i)}{\cos \Delta\psi_i}$$

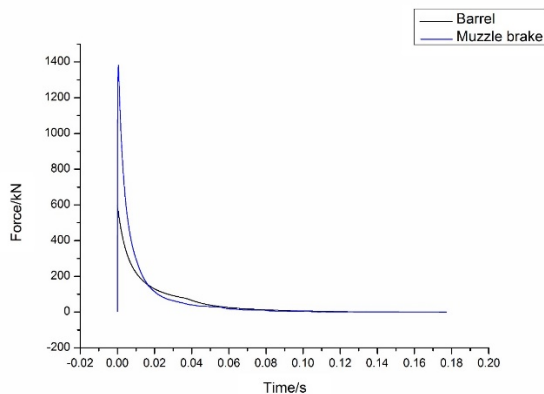
$$\beta_T = 0.5 + \frac{4\alpha - k}{4 - k}(\beta - 0.5)$$

$$\eta_T = 1 - \left( \frac{m + \beta_T \omega}{m + \beta \omega} \right)^2$$

According to the above equations, programming calculation is conducted with Matlab. Further, structural parameters are put into the equations, and the calculation result of the muzzle brake's efficiency ( $\eta_T$ ) is obtained, which is 47.8%.

### 3.2 Flow field simulation and efficiency calculation

ANSYS Fluent is applied to numerical simulation of the muzzle flow field. First, grid division of the muzzle flow field model using ICEM is conducted, and the whole model adopts structural grid division. In detail, grids near the muzzle and in the axial direction along the muzzle are densified, and grids in the far field are sparser. Thus, the number of grids is reduced, the calculation speed is raised, and the calculation accuracy is improved. The two-dimensional axisymmetric model is used, and the first-order upwind scheme and density-based coupled solver are adopted to solve the equations. Further, the results p-t and v-t of the internal ballistics obtained from the experiment serve as the input when simulating the muzzle flow field of the brake. By setting up the software to monitor the extent of force of the muzzle brake and the barrel, the time-varying curves of the barrel and muzzle brake's force at the bottom of the barrel and the reacting force at the muzzle are concluded, which are shown in Figure 1.



**Figure 1** Changes in the bottom force of barrel and reacting force of the muzzle brake with the time

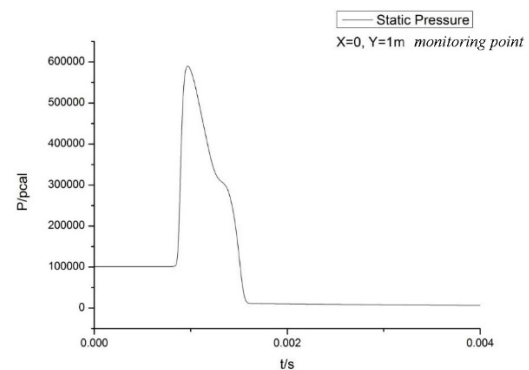
Figure 1 shows that the bottom force reaches the maximum at the initial stage of launch, then it attenuates rapidly and becomes stable gradually; while the reacting force of the muzzle brake reaches its peak at some time after the launch, then it also attenuates rapidly and finally the bottom force value of barrel and reacting force of muzzle brake become closer and closer to zero.

The average value of the above two forces is obtained by conducting a curvilinear integral of the two curves and dividing by the total time, and  $\beta_T$  can be obtained based on the equation  $\chi = \frac{F_{pt} - F_N}{F_{pt}} = \frac{\beta_T - 0.5}{\beta - 0.5}$ , where  $\chi$  refers to the impulse characteristic quantity,  $F_{pt}$  and  $F_N$  refer to the average values of the bottom force of barrel and reacting force of the muzzle brake, respectively ( $F_{pt}=48.627$  kN,  $F_N=61.085$  kN), and  $\beta_T$  and  $\beta$  are the gas reaction coefficients of the situation when with and without the muzzle brake, respectively. As for the equation  $\beta=A/v_0$ , for large-caliber and medium-caliber cannons, the value of  $A$  is set at 1250.

The muzzle brake's efficiency can be obtained by the equation  $\eta_T = 1 - \left( \frac{m + \beta_T \omega}{m + \beta \omega} \right)^2$ , where  $\eta_T$  refers to the muzzle brake's efficiency,  $m$  refers to the projectile mass, which is 45.5 kg, and  $\omega$  refers to the explosive mass, which is 26.7 kg. The value of  $\eta_T$  is 49.3%, obtained by putting the data into the equation, is relatively consistent with the efficiency calculated using traditional methods and within the margin of allowed errors. Therefore, the muzzle brake's efficiency is approximately 50%.

### 4 Overpressure near the muzzle

In the simulation of the flow field of the muzzle brake, a monitoring point is set 1 m away from the left side of the muzzle to observe the blast wave pressure near the muzzle during the launch of the projectile and the aftereffect period, and the results show that the blast wave pressure attenuates very rapidly with time. At the monitoring point, the blast wave pressure attenuates rapidly from the maximum to the atmospheric pressure value within 0.002 s. The maximum pressure value is approximately 0.6 MPa, and the overpressure value is 0.5 MPa.



**Figure 2** Simulation result of blast wave pressure 1 m away from the left side of the muzzle

The peak overpressure of high explosives' blast wave ( $P_{s0}$ ) can be expressed as follows [4]:

$$P_{so} = \begin{cases} \frac{1.059}{Z^{2.56}} & 0.1 \leq Z \leq 1 \\ \frac{1.008}{Z^{2.01}} & 1 < Z \leq 10 \end{cases},$$

where  $Z$  is the proportional distance ( $Z=R/W^{1/3}$ ),  $R$  is the distance between the monitoring point and the blast point (m), and  $W$  is the equivalent mass of explosives (kg).

If the muzzle serves as the blast point, the overpressure value will be 0.5 MPa when  $R=1$ , and in this case  $W^{1/3}=0.7055$ . Thus,  $Z=7.087$  and  $P_{so}=0.0197$  when  $R=5$ . Zhang [5] found that the overpressure of the muzzle brake of an 85mm-long cannon was 0.0225 MPa when  $R=5.5$ . The muzzle brake in Zhang's work has a much smaller caliber than that of our designed muzzle brake, but its overpressure at the same monitoring point as ours is higher. It reveals that our designed muzzle brake not only has high efficiency, but also limits the harm of the overpressure within a small range.

## 5 Conclusion

Calculation of the efficiency of muzzle brakes by traditional methods entails computation of multiple complex structural parameters; the flow field simulation method, however, cannot only dispense with these complex parameters in calculation of the efficiency, but also simulate the blast wave pressure, and speed and other parameters of the flow field near the muzzle brake. In the present work, an impact-reaction muzzle brake was designed, and its efficiency was calculated using the traditional method and the flow field simulation method. The two methods yielded similar results, and the flow field simulation indicated that the blast wave pressure of the muzzle brake had little negative impact. Advances in the flow field simulation technology have made it more convenient to measure the efficiency and blast wave overpressure of muzzle brakes with different structural parameters, reducing the time and workload of the designers.

## Author information

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