MUZZLE BRAKES AND THEIR PERFORMANCE

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ABSTRACT

A criteria for the usefulness of a muzzle brake on any equipment is discussed and applied to existing weapons. Efficiencies of the existing muzzle brakes are also calculated. Design considerations for a muzzle brake are summarized.

Introduction

A muzzle brake is a fitting at the muzzle end which deflects a part of the gases which emerge from the muzzle after shot ejection to the side or rear thus reducing the backward momentum of the recoiling mass. This advantage is often utilized when 'upgunning' an existing vehicle using the existing recoil system with minor modifications or to reduce the recoil energy or when making use of a buffer of smaller capacity thus saving space etc. It is therefore, necessary to know if a muzzle brake can effectively be used on any equipnent, and to design one with optimum efficiency.

Usefulness of a Muzzle brake

Fig. 1 shows roughly the effect of a muzzle brake on the velocity and distance of recoil and is self-explanatory. Curve (*a*) shows variation of velocity of free recoil *i.e.* without any retarding force to destroy momentum of the recoiling mass. Curve (*b*) shows the variation of velocity under a constant retarding force provided by buffer and recuperator. Curve (*c*) shows the final relationship between distance of recoil & the velocity of recoil for a gun with out a muzzle brake.

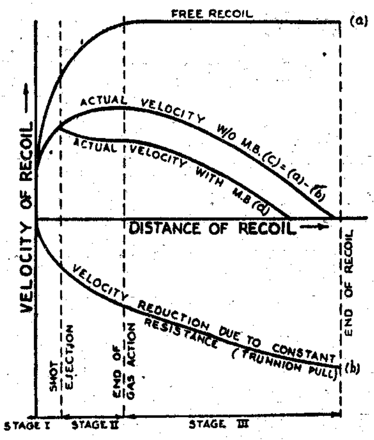

FIG:-1

In the case of an ideal muzzle brake in which all the gases are deflected through 180°, the effect of the gases during stage II (indicated in the figure) will provide forward momentum thus giving the curve (*d*). It is therefore evident that the greater the momentum supplied to the gun after shot ejection when there is no muzzle brake, the greater the braking momentum that can be reversed by a given brake. Therefore, the effectiveness of a muzzle brake on any equipment depends upon the ratio :—

$$\frac{\text{Momentum imparted after shot ejection}}{\text{Total momentum imparted}}$$

which is given by the expression :

$$\frac{(MV_4 - MV_3)}{MV_4} = \left(1 - \frac{V_3}{V_4}\right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where V_4 = velocity of free recoil at the end of gas action

V_3 = velocity of free recoil upto shot ejection

and M = Recoiling mass.

If a gun is allowed to recoil freely in a horizontal plane, then from conservation of momentums:

$$MV - mv - c\overline{v} = 0 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1a)$$

where m and c are the masses of the shot and charge respectively and $\overline{v}$ the mean velocity of the propellant gases.

The problem of the motion of the propellant gases is exceedingly complicated but as a first approximation and one which is found to give good results in practice, the gas is assumed to be distributed uniformly throughout the available space, hence

$$\overline{v} = \tfrac{1}{2}(v - V)$$

and therefore from (1a), $V = \left(\dfrac{m + c/2}{M + c/2}\right) v \quad \ldots \quad \ldots \quad (1b)$

The assumption that the gases are uniformly distributed is valid only whilst they are confined in the gun. Thus the equation (1b) applies upto shot ejection and therefore :

$$V_3 = \left(\frac{m + c/2}{m + c/2}\right) v_3 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1c)$$

If v_4 is the velocity of the shot at the instant when the propellant gases cease to act, the relationship between V_4 and v_4 which has been investigated experimentally can be expressed by the formula :

$$V_4 = \left(\frac{m + kc}{M + c/2}\right) v_4 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1d)$$

where k is number known as Krupps Constant and theoretically equal to

$$\tfrac{1}{2} + \frac{1{\cdot}35\,\beta\sqrt{RT_0}}{v_4}$$

where $\beta^2 = \dfrac{\text{Gas pressure at breech}}{\text{Mean gas pressure}} = (1 + c/6\,m)$

and $RT_o = RT_o' - 0{\cdot}26 \; v_3^2 \left(\frac{1}{6} + \frac{4}{7} \; \frac{m}{c} \right)$*

T_o being the adiabatic flame temperature which is a known constant of the propellant and T_o is the mean temperature of the gas in the gun when the shot leaves the muzzle.

Assuming that v_3 is approximately equal to v_4 which is true for all equipments, the criteria of the effectiveness of a muzzle brake becomes the ratio :

$$(k - \tfrac{1}{2}) \Big/ \left(\frac{m}{c} + k \right)$$

Table No. 1 shows this ratio for various equipments in service use.

TABLE I

Serial No.	Equipment	Mass of shot (m) lbs.	Mass of Charge (C) lbs.	Ratio m/c	Krupps constant k	Percentage momentum added by gas action $(k-\frac{1}{2})/(\frac{m}{c}+k)$
1	6 pdr 7 cwt ..	6·3	2·34	2·7	1·89	30·5
2	17 pdr MK 1 on Carriage.	17·0	8·125	2·1	1·789	33·0
3	95 mm Tank ..	25 HE	8·8	31·0@	3·74	9·3
4	75 mm Tank ..	15·0	2·0	7·5	2·0	15·8
5	25 pdr MK 5 on carriage.	25·0	2·84	8·8	2·58	17.5
6	3·7″ How ..	20·0	0·88	22·7@	3·60	11·8
7	B.L. 5·5″ ..	97·5	9·125	10·7	2·73	16·4
8	B.L. 7·2″ ..	200·0	25·0	8·0	2·22	16·6
9	40 mm A/A ..	2·0	0·63	3·2	1·80	26·0

@ These figures are rather high.

From the above table it may be observed that:

(*i*) A muzzle brake may be usefully employed with equipment 6 pdr 7 cwt and 17 pdr guns only. For 40 mm A/A, the recoil system is already fairly light and the advantage gained by putting a muzzle brake may not be appreciable. Also a certain minimum recoil, as at present, is necessary for its automatic action.

(*ii*) The higher the value of the ratio m/c (Projectile to charge weight ratio), the lesser the momentum that a muzzle brake can reverse.

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* The equation is based on conservation of energy *i.e.*

$$\frac{c\,(RT_o' - RT_o)}{(\gamma - 1)} = \tfrac{1}{2}\, v_3^2\, (8/7m + c/3)$$

taking all losses in friction, recoil, heat etc. as 14 % of the muzzle energy. Assuming the ratio of specific heats (γ) equal to 1·26, the above reduces to

$$RT_o = RT_o' - 0{\cdot}26\, v_3^2 \left(\frac{1}{6} + \frac{4}{7} \cdot \frac{m}{c} \right)$$

Efficiency of a muzzle brake

'Momentum Index'(B) of a brake is defined as the ratio of the forward momentum supplied by the brake to the after effect *i.e.*

$$\left.\begin{array}{l}\text{momentum imparted to the}\\ \text{gun by gases after shot ej-}\\ \text{ection with brake}\end{array}\right\} = (1 - B) \times \left\{\begin{array}{l}\text{After effect momentum}\\ \text{without brake}\end{array}\right.$$

It is therefore obvious that $B=0$ when there is no muzzle brake, $B=1$ when the muzzle brake momentum just balances the after effect momentum and $B>1$ when the brake supplies a resultant forward momentum.

From the definition of Momentum Index and the criteria of usefulness of a brake, it can be shown that:

$$\text{Percentage reduction of momentum} = \frac{(k - \frac{1}{2})\, B}{\left(\frac{m}{c} + k\right)} \times 100 \quad .. \qquad (2)$$

The gross efficiency (G) of amuzzle brake is defined as the Percentage reduction in energy absorbed in the recoil system as a consequence of fitting the brake and intrinsic efficiency (e) is obtained by correcting the gross efficiency for the effect of the mass of the muzzle brake and is given by:

$$\frac{M'}{M}\, G - 100 \left(\frac{M' - M}{M}\right)$$

which is very nearly $\frac{M'}{M}$ G where M'and M are the masses of the recoiling system with and without the muzzle brake.

$$\text{Percentage reduction of energy} = G = 100 \left[1 - \frac{(V_4')^2}{V_4} \right] \quad .. \qquad (3)$$

where V_4' and V_4 are the velocities of recoiling mass with and without the muzzle brake.

From (2) and (3) it can be shown that gross efficiency is given by

$$G = 2\xi - \xi^2 \quad .. \quad ... \quad .. \qquad (4)$$

where $\xi = \dfrac{(k - \frac{1}{2}).B.}{\left(\frac{m}{c} + k\right)}$

Taking a value of $m/c = 5$ and $k = 2{\cdot}5$ (values commonly met with in conventional guns):

$$G = 0{\cdot}53B - {\cdot}071\, B^2 \quad .. \quad .. \quad .. \quad .. \qquad (5)$$

which is modified to get intrinsic efficiency.

From equation (5) it is obvious that for the ratio $m/c = 5$ and $k = 2 \cdot 5$, a maximum value of $G = 1$ occurs, when $B \leq 3 \cdot 8$ beyond which value of reversal of recoil takes place. In practice however, the value of B rarely goes beyond $1 \cdot 9$.

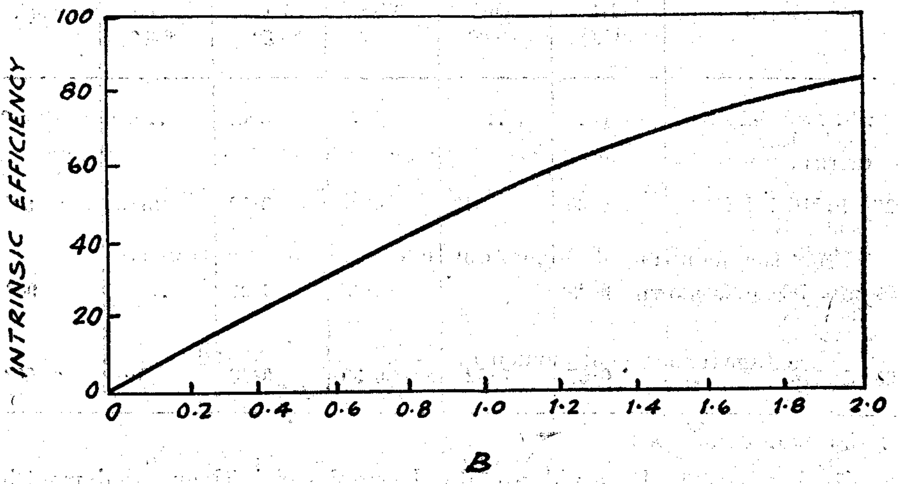

Fig 2

Curve in figure 2 represents the approximate relationship between 'B' and 'e' which may be used in calculations of recoil energy data appended herewith for existing weapons or recoil system design for a new gun.

The numerical value of 'B' is equal to $0 \cdot 697\ \lambda$ for $\gamma = 1 \cdot 26$ where λ is a factor purely dependent on the parameters of the brake and

$\lambda = 1 - n_1 (1 - r) - n_2 r \cos \alpha$

where n_1 and n_2 are the divergences provided in the brake and the baffles, r the fraction of the gases that pass through the baffle and α the angle through which the gases are deflected.

From the above, it therefore follows that the best design of a muzzle brake is such for which the value of λ is high. This is however limited by the following factors :

(*a*) The divergence factor has to be kept within practical limits as a compromise between weight and efficiency. Its value seldom exceeds 5.

(*b*) All gases cannot be trapped since some of them must pass through the central hole.

(*c*) The gases cannot be deflected beyond 135° due to mechanical difficulties and also to avoid the blast coming on to the detachment.

Table II gives calculated values of the portion of the gases trapped the divergence factor, the angle through which the gases are turned for muzzle brake fitted on various equipments.

TABLE II

Equipment with type of M.B.	Portion of gases trapped			Divergence factor		Angle turned through
	1st stage	2nd stage	Total	1st stage	2nd stage	
6 pdr. 7 cwt. MK 2 Single baffle German.	0·7	..	0·7	6·62	..	90°
17 pdr. MK 1 & 2 Double baffle German.	0·667	0·247	0·91	3·52	3·85	90°
75 mm MK 5 & 5A Single baffle German.	0·73		0·73	4·37	..	90°
25 pdr. MK 3 ..	0·67	0·22	0·90	3·48	3·0	90°

Design Considerations

1. A muzzle brake could usefully be employed with an equipment in which percentage momentum added by gas action is sufficiently high say about 30 per cent.

2. The performance of a muzzle brake is an optimum for a particular condition of charge, so that a muzzle brake must be designed for the top charge.

3. Since the percentage of gases trapped is a maximum for the first baffle and goes on decreasing for the subsequent ones, there is little to be gained by complicated design.

4. The performance of a muzzle brake chiefly depends upon its geometry and the value of 'B' and divergence factor seldom exceeding 1·9 and 5 respectively.

5. Since muzzle brakes are subjected to impact loads, it is mechanically unsafe to make them in the form of castings.

6. The maximum stress in the brake occurs at the instant when the projectile is plugging the central hole of the brake so that all gases are deflected. Maximum thrust in actual practice is about 70 per cent higher than the theoretically calculated value at this instant.

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References

1. M.C.S. Publication GM/9/45—Recoil
2. Sirpal J. P. I.A.S. technical Report No. 6004.

TABLE III

Intrinsic Efficiency Data

Name of Equipment	Ord. Q.F. 6-Pr. 7-Cwt	Ord. Q. F. 17-Pr. MK1 on Carr. Mk. 1	Ord. Q. F. 17-Pr. on S. P. Valentine	Ord. Q. F. 75 mm. Mk. 5 or 5A on Churchill 7	Ord. Q. F. 25 -Pr. Mk. 2 on Carr. Mk. 1	Ord. Q. F. 25-Pr. Mk. 3 on S. P. Sexton
Total Wt. of Recoiling Mass (M) (lbs.)	932	2,256	2,091·5	753	1,558	1,558
Wt. of Projectile (m) (lbs.)	6·3	17	17	14·96	25(HE) 20(AP)	25(HE) 25(AP)
Wt. of Charge (c) .. (lbs.)	2·34	8·125	8·125	2·0	2·844(HE) 3·187(AP)	2·844(HE) 3·187(AP)
Nature of Charge ..	N.H. 033	N.H.055	N. H. 055	F. N. H.	NQ/S. 134-040	N.Q.
A constant depending on nature of charge FT/SEC^2 (RTc)	$10{\cdot}60\times10^{6}$	$10{\cdot}60\times10^{6}$	$10{\cdot}6\times10^{6}$	$10{\cdot}09\times10^{6}$	$11{\cdot}26\times10^{6}$	$11{\cdot}26\times10^{6}$
Muzzle Velocity (New Gun)(vo) .. Ft./Sec.^{2}	2,709	2,980	2,980	2,030	2,030	1,750(HE) 2,030(AP)
Krupps Constant (Calculated)(k) ..	1·89	1·788	1·445	2·05	...	2·313(AP)
Momentum Index of Muzzle Brake (Calculated) (B)	·658	0·825	·825	·657	..	·795
Intrinsic efficiency of Muzzle Brake (e) approx. ..	·385	·44	·44	.365		·43
Energy of Recoil = $\frac{1-e}{2g}\,\frac{(m+kc)^2}{M}\cdot v^2$ ft. lbs.	8,660	34,000	36,700	19,600	..	18,150(HE) 17,545(AP)