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# ASSESSMENT OF ERFB-BB PROJECTILE

HASSAN YAKOUT[*] and MOHAMED S. ABDEL-KADER[*]

## ABSTRACT

The development of extended range rounds has followed a clearly
traceable line of evolution starting with the Rocket-Assisted
Projectiles (RAP), passing by Extended Range Sub-Calibre (ERSC)
projectiles and Extended Range Sub-Bore (ERSB) projectiles and
ending with Extended Range Full Bore projectiles with Boat Tail
(ERFB-BT) or Base Bleed (ERFB-BB). The most interesting of all
the extended range projectiles developed so far is undoubtedly
the very long range ERFB-BB ones, which incorporate the best
ballistic features of the other extended range projectiles and
achieve the maximum possible payload capacity.

In this treatise, a historical review of the development of high-
explosive, extended range projectilles is first furnished. The
principle of base bleed is then discussed and its use in modern
projectiles illustrated via a newly designed ERFB-BB projectile.
Necessary calculations of range, accuracy and lethality are per-
formed. In doing so, different base drag reduction ratios are
considered. Effects of delayed ignition and slight variations in
time of burning of the base bleed charge on range are also stu-
died, and maximum range is found to be considerably sensitive to
these variations. Possibility of local production of the proposed
design is investigated. Anticipated technical difficulties are
singled out and possible solutions proposed.

*Asst. Prof., Dept. of Weapons and Ammunition, Military Technical
College, Cairo, EGYPT.

## INTRODUCTION

Today's tactics demand that artillery units be positioned at greater depth behind the front line to insure survivability. Modern battlefield deployment scenarios, with fluid fronts and improved enemy firepower, require longer ranges of friendly fire support units. Extended range is most significant in terms of area coverage. The coverage allows the artillery unit to engage targets earlier, fire on more targets, and provide greater flank coverage. Greater range also necessitates fewer displacements for the atrillery units.

Range extension of conventional munition can be achieved by virtue of different solution strategies [1]. These include : (i) increasing projectile muzzle velocity, (ii) improving its ballistic performance, and (iii) designing rocket-assisted projectiles. Each of these strategies has its own advantages and limitations, and optimized procedures that take into account a number of tactical and economical considerations are usually undertaken to come up with 'optimal' designs.

The development of Extended Range (ER) ammunition has followed a clearly traceable line of evolution since the early 1970's when the United States of America has adopted the Rocket-Assisted Projectile (RAP) solution strategy for range extension. Figure 1 depicts one such design, advanced by BPD of Italy for a series of the 155 mm howitzers. RAPs have two fundamental functional drawbacks, however; the space occupied by the rocket motor reduces the High Explosive (HE) capacity, and accordingly the effect of the projectile by about 30% and the in-flight rocket boost adds more elements of dispersion to the ballistic trajectory, thus reducing accuracy.

A different, fully ballistic approach consists in streamlining the conventional projectile in order to limit its aerodynamic wave drag. This can be achieved by eliminating the cylindrical center section and incorporating a long, full-ogive body, tapering all the way from the driving band at the base to the nose fuze. This reduces aerodynamic wave drag by about 30% and simultaneously improves flight stability. In addition, the frontal area (equivalently the diameter) and the mass can be reduced, which respectively produce a further drag reduction and raise muzzle velocity.

The resulting Extended Range Sub-Calibre (ERSC) projectile requires two sabots to insure regularity of projectile motion inside weapon barrel (the rear sabot carrying the driving band), both of which are to be discarded in flight. One such projectile was produced by Space Research Corporation (SRC) that provided a range of more than 22 Km for the 155 mm, 23-calibre-barrelled M109 self-propelled howitzer, compared to the maximum 14.6 Km of the standard M107 projectiles (i.e. a range extension of about 50%) [2]. However, the ERSCs reduce weight and payload comporised lethality so that it could only be used as special purpose ammunition .

To overcome the deficiencies of the ERSC projectiles, an Extended

Range Sub-Bore (ERSB) projectile, with a nearly full calibre (bore) projectile was developed. This enabled the front sabot of the ERSC to be replaced by four aerodynamically streamlined nubs that provide support at the mid section. A discarding, non-metallic driving band provided the necessary support at the base and transmitted the rotational force. A tapering boat tail was also added behind the driving band to reduce the wake zone behind the shell base, thus cutting down the amount of base drag. Lethality of the ERSB projectile is close to that of the standard projectile.

Difficulties in developing the discarding driving band of the ERSB and its still slightly reduced lethality, shifts emphasis towards Extended Range Full Bore (ERFB) projectiles, which incorporate the best features of the ERSBs, together with the maximum possible payload capacity. The fixed nubs of the early version of the ERFBs were welded on, but those of the new series are machined from the forged body, thus reducing cost, enhancing productivity, and raising reliability. The latest version of the ERFBs achieves a maximum range in excess of 26 Km with the 39-calibre barrel of the American M198 towed howitzer, 8 Km (or about 45%) more than the M107 projectile fired from the same howitzer.

The ERFB's low drag aerodynamic profile reduces flight time, makes the trajectory therefore less susceptible to meteorological perturbations and, in consequence, improves precision. Its hollow base reduces transverse momoent of inertia and shifts centre of gravity forward, thus improving the stability of the projectile.

The most interesting of all the ERFB projectiles developed so far is undoubtedly the very long range, fourth-generation ERFB Base Bleed (or Base Burn) (ERFB-BB) projectile. It is actually a normal ERFB projectile, but with a different boattail containing the base bleed unit. Although it has a lower muzzle velocity, it provides an increase in maximum range of about 15 to 30% depending on the weapon. Figure 2 exhibits the first three generations of the 155 mm ER projectiles, together with the standard M107 HE projectile, whilst Fig.3 shows the fourth generation, i.e. ERFB-BB projectle, along with the components of the base burn unit. Moreover, Table 1 shows the maximum range of standard, RAP, ERFB and ERFB-BB projectiles for a number of 155 mm weapons [3]. In the remainder of this work, more light will be shed on the ERFB-BB projectile, primarily because of its salient features.

### BASIC CONCEPTS

During its flight, the projectile is acted upon by a number of forces. These include the gravitational force, air resistance and Coriolis force accounting for earth rotation. The first one is normally assumed to be constant in exterior ballistic calculations of artillery projectiles, whilst the third one is customarily not considered, because of its negligible effect.

The air resistance force R can be decomposed into three components : (i) head resistance $R_{HR}$, (ii) skin friction $R_{SF}$ and (iii) total base drag $R_{TBD}$, that is

$$R = R_{HR} + R_{SF} + R_{TBD} . \qquad (1)$$

The head resistance experienced by the projectile is caused by compression waves generated ahead of the projectile path due to its motion in air. The magnitude of this component increases rapidly in the supersonic region due to the formation of shock waves at the projectile nose. The skin friction is caued by shear stress developed due to the air viscous effect on the projectile wet area. Its effect on projectile motion, however, is relatively small. The total base drag $R_{TBD}$ consists of two main parts : (i) base pressure drag $R_{BD}$ and (ii) boattail pressure drag $R_{BT}$. The base pressure drag is caused by the formation of wake just behind the projectile tail. This region is characterized by low pressure distribution deviated considerably from that of the upstream conditions, and attributed to the inability of air streamlines to follow the projectile profile. On the other hand, the boattail pressure drag results from the pressure gradient developed along the boattail surface.

Drag prediction represents a major part of the calculation of projectile trajectory, which is the main task of Exterior Ballistics. A common practice is to estimate drag empirically using air resistance laws, such as Siacci, 1930 and 1943. These laws express air resistance in the general form :

$$R = p_d \, S \, C_x(M) , \qquad (2)$$

where $p_d = 1/2 \, \rho \, v^2$ is the dynamic pressure, $\rho$ is the air specific mass, $v$ is the projectile velocity, $S$ is the projectile cross-sectional area, $C_x(M) = i \, C_x^*(M)$ is the total drag coefficient, $M = v/a$ is the Mach number, and $a$ is air sonic velocity. The function $C_x^*(M)$ is the drag coefficient of some standard projectile, which is determined experimentally and varies from one law to another, and $i$ is a constant known as the projectile shape coefficient. It is thus implied that air resistance laws assume that the function $C_x(M)$ has the same form of the chosen law of air resistance and differs only by a constant multiplier $i$. This multiplier is a characteristic of each projectile and is normally determined either by actual firing or in wind tunnels. Experimental work indicates that this multiplier depends only on the projectile firing angle.

Equations (1) and (2) suggest that the total air resistance be written in the alternative form :

$$R = p_d \, S \, ( \, C_{HR} + C_{SF} + C_{TBD} \, ) , \qquad (3)$$

where $C_{HR}$ is the head drag coefficient, $C_{SF}$ is the surface friction drag coefficient and $C_{TBD}$ is the total base drag coefficient, which can be decomposed into a base drag component $C_{BD}$ and a boattail one $C_{BT}$, that is :

$$C_{TBD} = C_{BD} + C_{BT} . \qquad (4)$$

Figure 4 shows the total drag coefficient for a typical HE shell based on Siacci's law, together with its components of Eqs. (3) and (4) . It is clear from this figure that the total base drag

coefficient represents about 75 % of the total drag coefficient at subsonic velocities, about 60 % at transonic velocities and about 50 % in supersonic region [4]. That is probably why research activity concerning range extension has been mostly concerned with reducing base drag, particularly via base bleeding.

### BASE BLEED PRINCIPLE

Firing projectiles with tracers indicates that mass flow out of the base reduces base drag. Wind tunnel tests have also indicated that base drag can be considerably reduced if certain conditions are established for gases flowing out of the base plane. The mass flow rate, for instance, should not exceed certain magnitude, nor should burning take place far from the base plane. Resulting thrust must have negligible effect in relation to the forces due to pressure increase on the base plane. In fact, it has been reported that by burning hydrogen close to the base plane, base drag has been completely diminished [5].

In base bleed projectiles, a base bleed unit is usually employed, which generates hot gases that are expelled into the wake region. Gas flow through the exhaust port is subsonic and provides negligible thrust. However, it increases base pressure and reduces base drag. The amount of reduction depends on the firing and flight conditions, but typically varies between 60 and 80%. There are a number of practical problems, which arise when designing a projectile with a base bleed unit. Large acceleration of projectile during its motion down weapon barrel, the relatively large volume of the unit, type of base bleed charge and its burning characteristics represent some of these problems.

The base bleed charge is ignited by the gases of the main charge inside gun barrel, but due to the sudden pressure drop at the muzzle, it is important to have sustaining igniter to eliminate the possibility of coughing of the base bleed unit. This igniter is also initiated by the propellant gases and burns for about 1 to 1.5 sec, whereas the base bleed charge continues to burn for a time of about 1/3 of the maximum flight time, resulting in a range extension of up to 25 % . Longer bleeding times cause slight increase in range and require larger bleeding units, which affects the lethality of the projectile adversely [1,5].

To further ascertain these arguments, the trajectory of the 155 mm HE shell with a base bleed time, $T_B$, ranging from 0.2 to 0.6 of the flight time at maximum range of the original shell, $T_s$ , has been predicted, as shown in Fig.5. In doing so, it has been assumed that the total drag coefficient was reduced by 40 % due to bleeding (correspondint to a reduction of about 80% in base drag). It is clear from this figure that the maximum range, X, increases with increasing $T_B$. Plotting X with $T_B$ in Fig.6, however, shows that for $T_B$ greater than 0.4 $T_s$, only slight increase in X is achieved.

### PROPOSED DESIGN AND DISCUSSIONS

A number of 155 mm high explosive, base bleed projectiles have been recently designed by international armament firms, such as

BPD (Italy) and SRC (USA), which are shown in Fig.3. A similar version of the standard 155 mm high explosive projectile with base bleed for use with M109 A1 howitzer is proposed herein. In this proposal, both shape and dynamic characteristics of the shell were kept as close as possible to those of the original projectile. Theoretical external ballistic calculations of the trajectory of the 155 mm HE, base bleed projectile proposed herein show that a range extension of about 22% can be achieved, assuming a reduction of 80% in base drag due to bleeding. If the base drag is entirely eliminated, hypothetically, range can be further extended to 23.1 Km ( about 28% extension ). Corresponding trajectories are shown in Fig.7. Further range extension could have been achieved, if the projectile shape had been streamlined and its length increased. In such a case, the ballistic coefficient needs to be determined, essentially via a series of laboratory and field tests.

To study the effect of irrigularity of burning of the base bleed charge, the time of burning $T_B = 0.4 T_s$ was allowed to change to $T_B'$, with the ratio $T_B'/ T_B$ ranging from 0.8 to 1.2. Corresponding variations in maximum range were predicted, and are shown in Fig. 8. It is clear that considerable variations in range are obtained ($\Delta X/X = -2.43:1.98\%$ for fully reduced base drag ), which increase with base drag reduction ratio. This explains why actual firing tests of base bleed projectiles may give unsatisfactory dispersion patterns. Figure 9 illustrates the effect of slight variations in time of ignition and confirms the above arguments.

Predictions of range at different elevation angles for the proposed base bleed projectile with different base drag reduction ratios are depicated in Fig.10. Corresponding flight times and maximum altitudes are respectively shown in Figs. 11 and 12 versus range. Corresponding values for the standard projectile are also included in the three figures for comparison. It is evident that the base bleed projectile reaches longer ranges at all elevation angles. It can also cover any range in a shorter time than the standard projectile. Furthermore, the trajectory summit of the base bleed projectile is reached at longer horizontal distance and flight time. This trend proceeds with increasing base drag reduction, in consistence with previous findings.

Because the bursting charge is reduced by about 10% in the current design, both fragmentation and demolition effects of projectile on target are also reduced. The effect can be improved, however, using a bursting charge with better performance. Stability of the projectile during flight has been checked and was found satisfactory. Real field tests are needed to assess accuracy and consistency.

From a production standpoint, the proposed projectile body can be produced by hot pressing without major difficulties. In this case, however, pressing involves creation of two cavities, a greater one for the bursting charge and a smaller one for the base bleed unit. Design, production and performance of the base bleed composition represent the main difficulty in bringing this proposal into reality. Hard team work involving a relatively great number of laboratory and field tests is expected and suc-

cess is anticipated. The sustaining igniter represents a major part of the aforementioned work. Preparation of firing tables for the proposed projectile is another area of extensive work. No major difficulties are anticipated in this regard.

## CONCLUSION

The 155 mm high explosive projectile with base bleed proposed herein can reach a theoretical maximum range of about 22 Km, thus achieving a range extension of approximately 22% in comparison with the original high explosive projectile. This range is essentially due to base drag reduction of 80%. On the other hand, a slight reduction in projectile effect on target is the trade-off. Irregularity of ignition and subsequent burning of base bleed charge is shown to affect accuracy of fire diversely.

## REFERENCES

1. Yakout,H. and Abdel-kader,M.S., " Range Extension Via Base Bleeding ", AME 4th Conf., M.T.C., Cairo (1990).
2. Furlong,R.D.M., " Extended Range Full Bore and Base Bleed 155 mm Ammunition ", Int. Def. Review, 6, 755-760 (1982).
3. Anon, " Can Your 155 mm Artillery Exceed the 20 Km Range ?",Int. Def. Review, 17, 1773 (1984).
4. El-Ashmawy,A.R., " Drag Prediction Methodology for Missiles at Supersonic Speeds ", M.Sc. Thesis, M.T.C., Cairo (1986).
5. Andersson,K., Gunners,N.E. and Hellgren,R., " Swedish Base Bleed — Increasing the Range of Artillery Projectiles Through Base Flow ", Res. Inst. National Defence, Sweden (1976).

Table 1. Maximum range achieved (in Km) by weapons and by projectile/payload.

| Weapon type | $L_b$ (Cal.) | HE M107 6.6* | HERA (RAP) 6.7* | HE-ERFB/BT 8.16* | HE-ERFB/BB 8.16* |
|---|---|---|---|---|---|
| Conventional M114 | 23 | 14.0 | ** | ** | ** |
| Conventional M109 | 23 | 14.0 | 19.3 | ** | ** |
| Modernized M109 A1 & M109 A2/A3 | 39 | 18.1 | 23.5 | 20.1 | 23.7 |
| M114/39 & new M139 | 39 | 18.1 | 23.5 | 24.0 | 30.6 |
| New M198 | 39 | 18.1 | 30.1 | 25.9 | 30.6 |
| New FH77B | 39 | 18.1 | -- | 25.9 | 31.5 |
| New GC 45 & GHN 45 | 45 | 17.8 | -- | 31.0 | 39.6 |

* Mass of TNT (Kg).          ** Prohibited.

Fig.1. 155 mm Rocket-Assisted Projectile
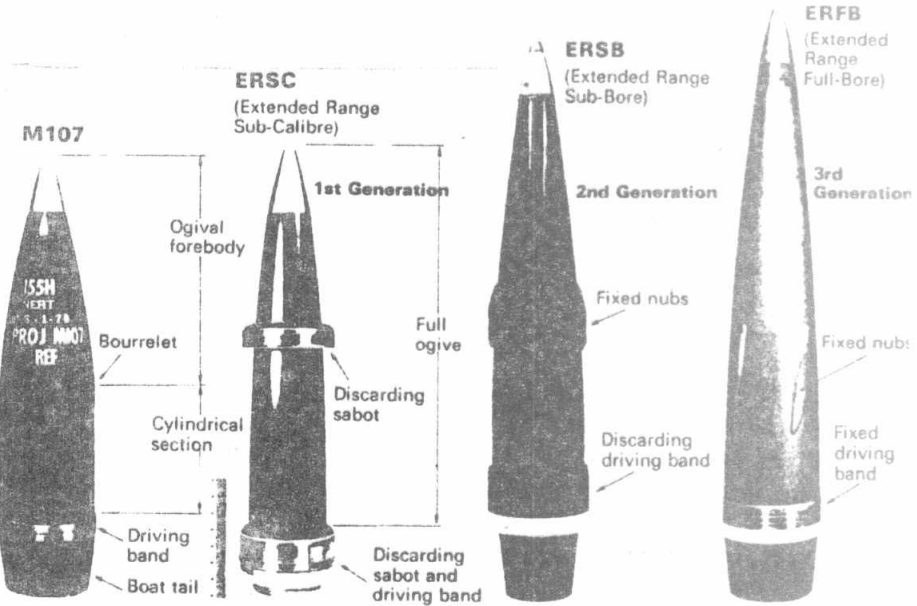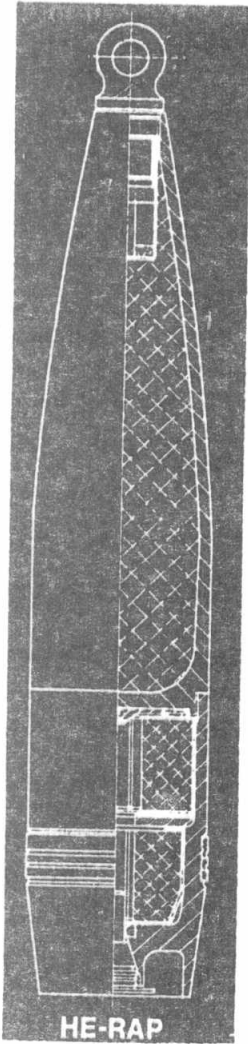RAP, ( BPD, Italy).
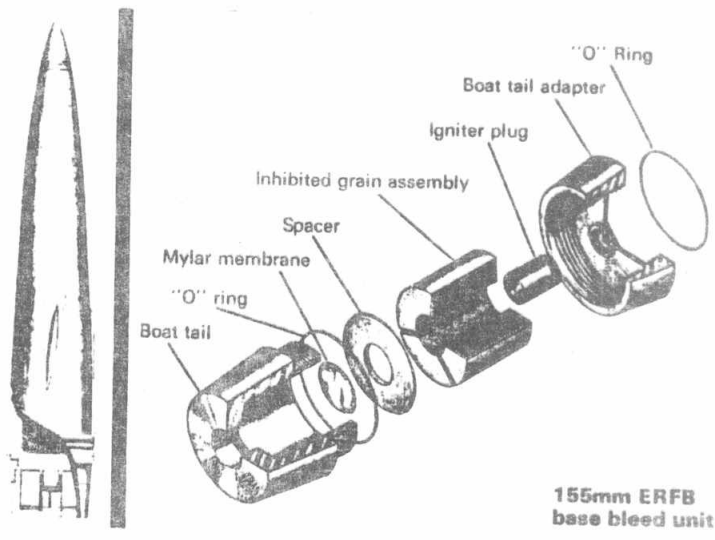
**HE-RAP**

Fig.2. 155mm standard and extended range ammunition

Fig.3. 155 mm Extended Range Full Bore
Base Bleed (ERFB-BB) projectile.

$$C_X = C_{HR} + C_{BDT} + C_{SF} , \quad C_{BDT} = C_{BD} + C_{BT}$$
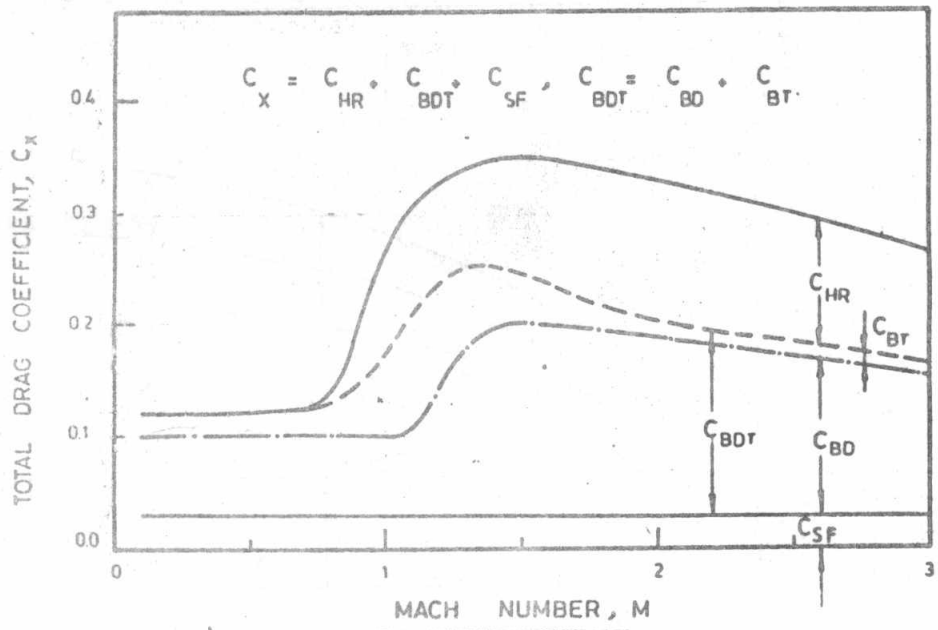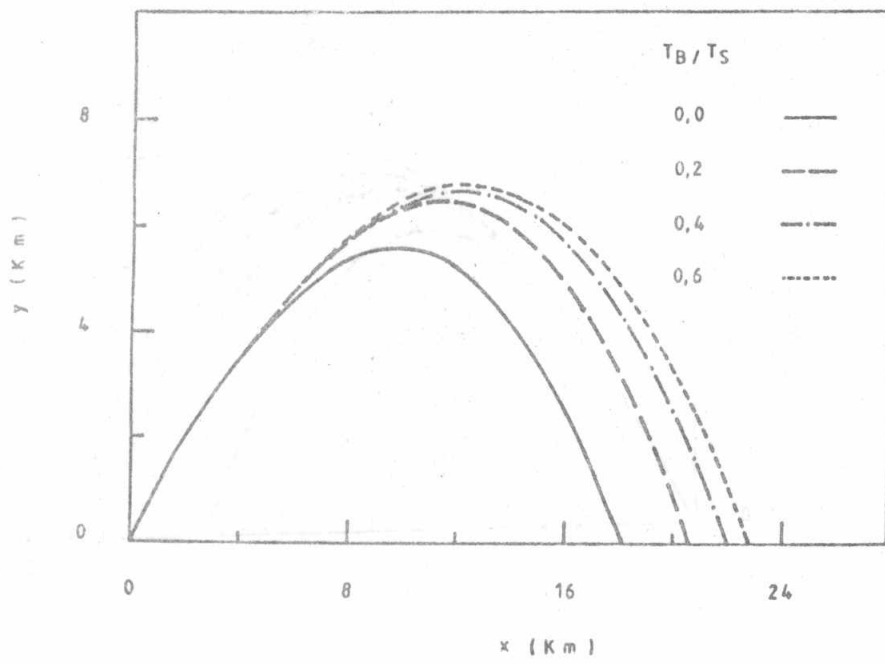
Fig.4. Siacci's total drag coefficient verses
Mach number (for typical HE shell).

Fig.5. 155 mm HE Projectile trajectory at different
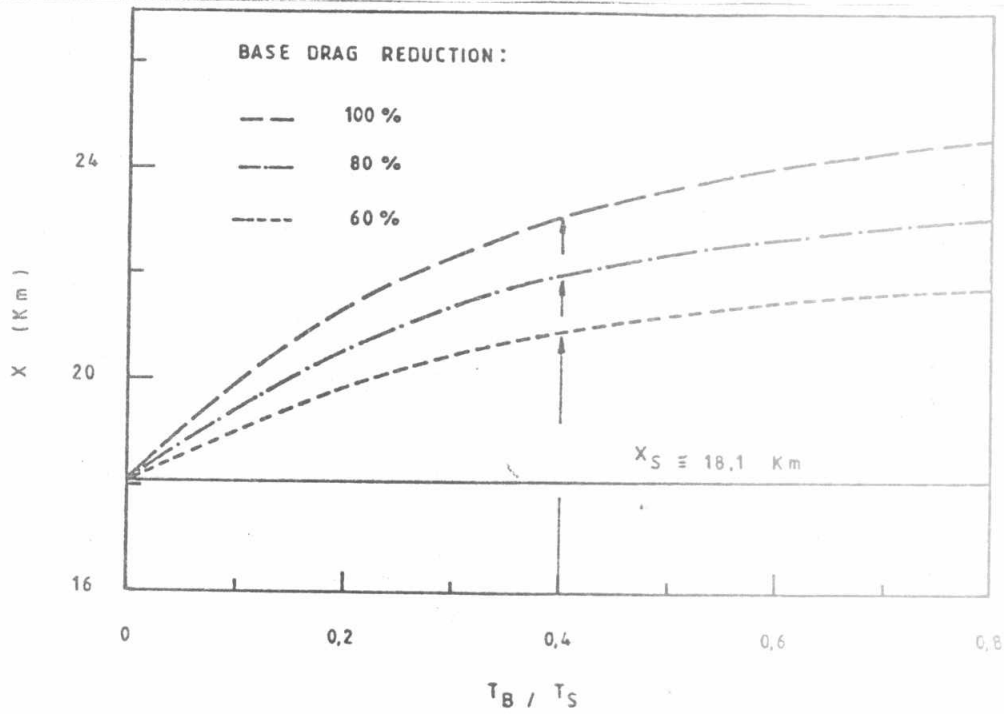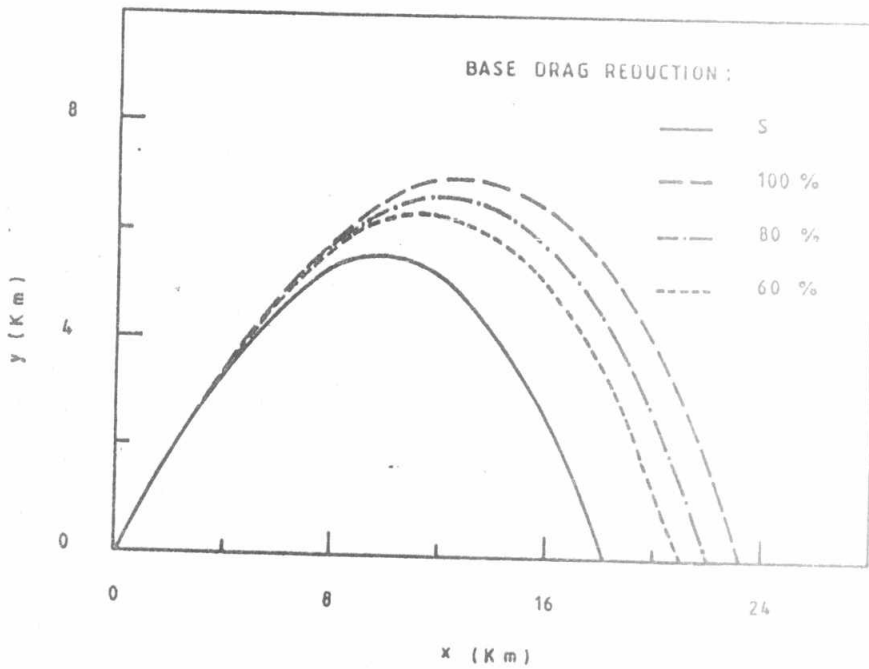bleeding times for 80% base drag reduction.

Fig.6. Dependence of maximum range on bleeding time.



Fig.7. Trajectory of proposed projectile at different
base drag reduction ratios for $T_B/T_S=0.4$.
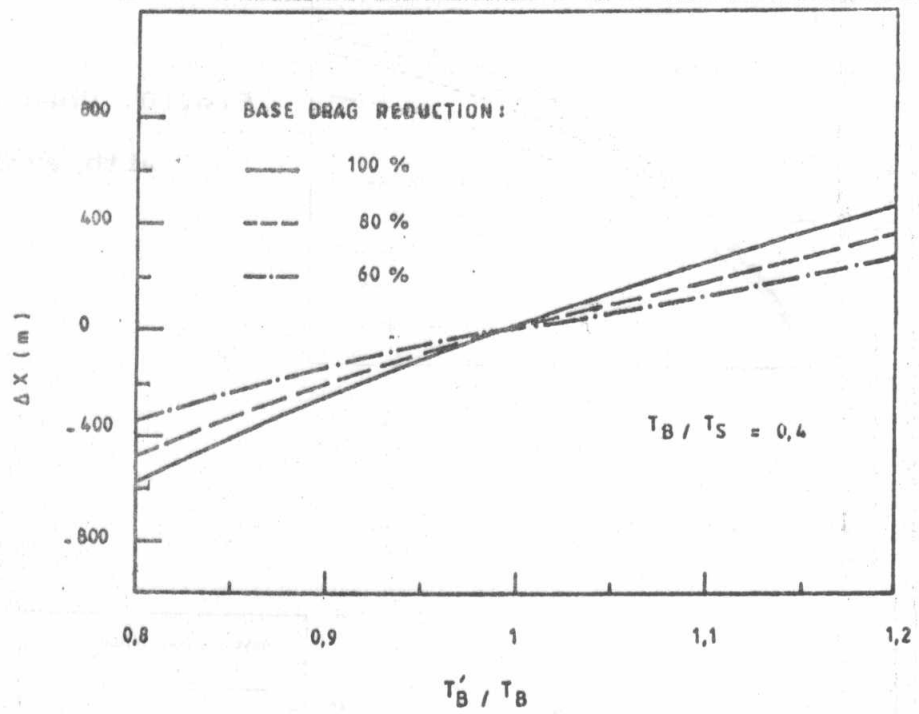
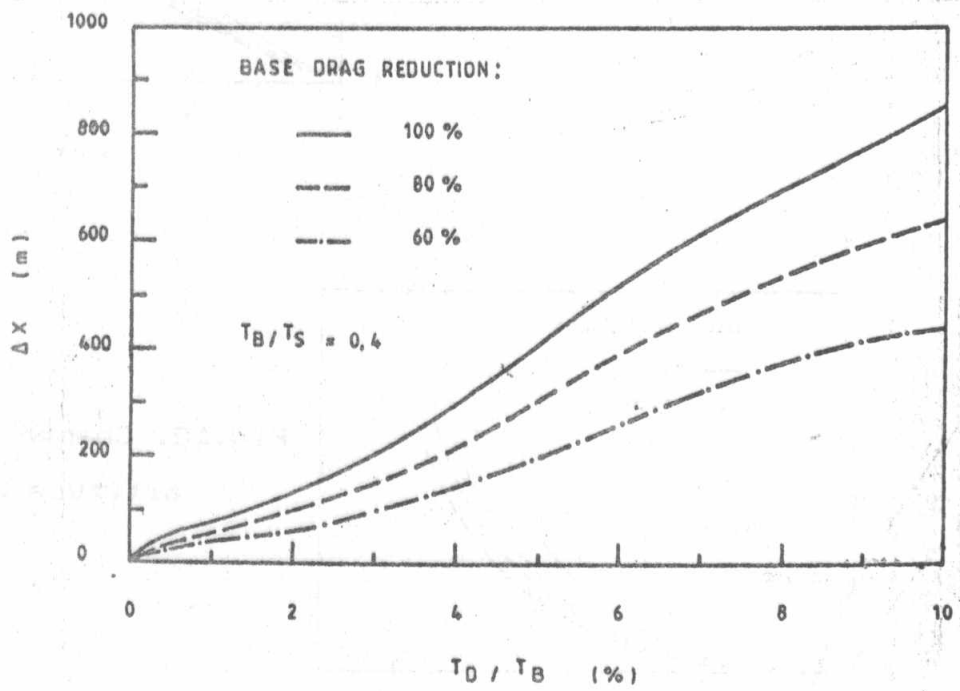Fig.8. Effect of variation in bleeding
time on maximum range.



Fig.9. Effect of irregular ignition of base
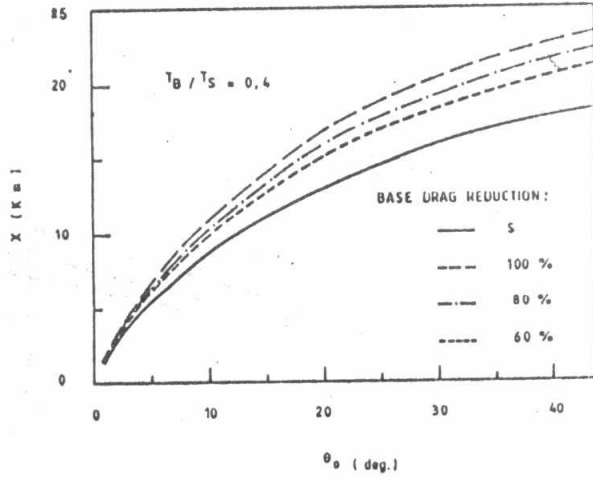bleed charge on maximum range.

Fig.10. Change of range
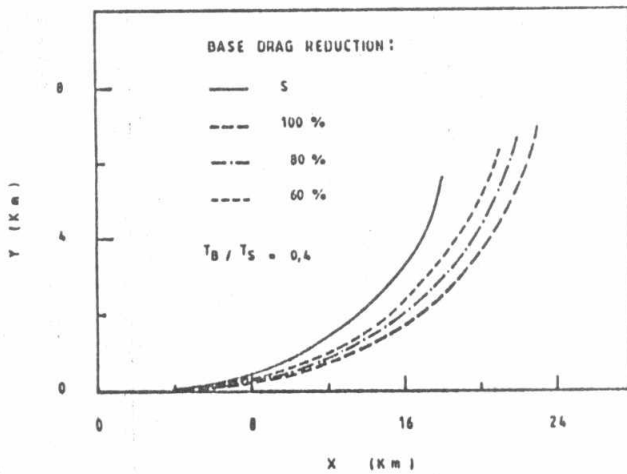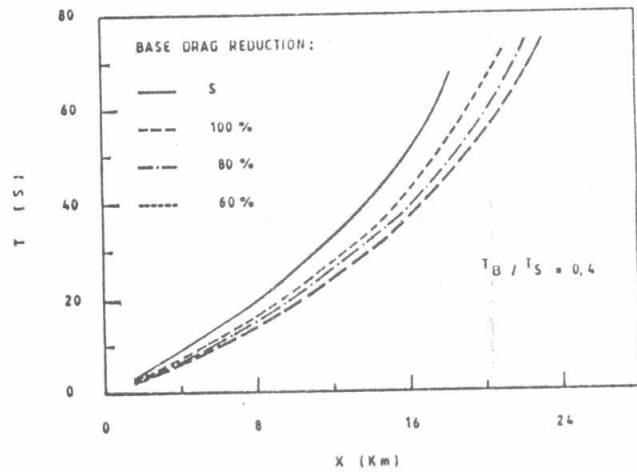with angle of fire.

Fig.11. Change of flight
time with range.

Fig.12. Change of maximum
altitude with range.