ASAT

MILITARY TECHNICAL COLLEGE
CAIRO EGYPT

# AN APPROACH FOR THE EVALUATION OF
# 1- RADIO-FUZE PERFORMANCE

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4- **ABSTRACT**

The problem of target destruction by anti-aircraft guided missiles is not solved only by using an accurate guidance system but also by using a highly-performant fuzing system. Aircrafts are characterized by high flying speeds and great maneuverability that make its destruction, using a guided missile, by a direct hitting is a very difficult mission. Therefore, the target destruction may be realized by a warhead (W.H) which is to be initiated properly according to the missile-target (M/T) encounter conditions.

Up to the moment, there has not been a distinct way for evaluation of a fuze performance (F.P) in a specific M/T encounter conditions.

The present paper provides a graphical method for the evaluation of F.P . The proposed algorithm of such method is developed and the flowchart is included. The program of F.P calculation is elaborated. The results include the evaluation of radio fuze(R.F) performance in different encounter conditions which take into consideration the variation of missile speed, target speed, maneuverability and W.H characteristics. The proposed method and its algorithm are well-suited for further research towards the improvement of R.F performance.

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## 1- Introduction

The fuzing system of anti-aircraft guided missiles determines when the W.H should be activated , according to the encounter conditions , in order to maximize the probability of target destruction. The R.F basic block diagram is shown in figure 1. The sensor may be a transceiver or only a receiver system that detects the presence of a target in the detection zone and the signal processing unit insures fuze operation under certain operating conditions to increase the F.P . The operating circuit treats the signal coming from the signal processing unit in such a manner to increase the fuze immunity from interference and produces a sufficient current to ignite the W.H .

## 2- Parameters of Missile-Target Collision

The M/T collision is fully determined by the W.H characteristics and the parameters of both missile and target. The mutual position of missile and target at the moment of target detection and the fuze inertia determine the fuze activation zone(F.A.Z) while the W.H characteristics and the relative velocity between the missile and target determine the target destruction zone(T.D.Z). Coincidence between F.A.Z and T.D.Z is necessary for a highly-performant fuzing system [1] .

### 2.1- Fuze Activation Zone

A response zone will be defined as the geometrical locus of theoretical target centers related to the missile at the moment of arrival of a minimum signal sufficient to activate the fuze. Due to the time of fuze inertia (propagation delay time in fuze circuits, time of computation, and time of W.H explosion ) a F.A.Z is defined as the geometrical locus of theoretical target centers related to the missile at the moment of W.H explosion . Each point in F.A.Z will be displaced behind its corresponding point in the response zone by a distance D given by [1] :

$$D = v_r * t_{in} \qquad (1)$$

where

$v_r$ ... Relative velocity between the missile and the target.
$t_{in}$ ... The time of fuze inertia.

The shape and position of F.A.Z in space is mainly dependent on the following :

1-Emission characteristics of the fuze antenna (tilting angle , antenna directivity and the shape of beam pattern )
2-Receiver sensitivity
3-Transmitter performance
4-Fuze inertia
5-Range of relative velocity

## 2.2- Target Destruction Zone

The W.H characteristics are the W.H static destruction angle ($\alpha_{st}$) and the fragment speed . Static destruction angle is defined as the angle involving 90 % of destructive agents of the given W.H and measured in the meridian plane of the missile from static explosion point of view as shown in figure 2. The value of $\alpha_{st}$ varies from 5 deg. up to 30 deg. , its inclination ( forward or backward ) depends on the position of pyrotechnique igniter. The fragment speed will be determined empirically according to the following formula [2] :

$$V_{d_o} = 0.353\ D \sqrt{\frac{3\,\beta\, f \lambda}{3 + \beta\, f}} \qquad (2)$$

where

$D$ ... detonation rate (7000-8000) m / s
$\lambda$ ... weight coefficient given by :

$$\lambda = \begin{cases} 0.75 & Q \le 10 \text{ kg.} \\ 0.75 - 1 & 10 \text{ kg.} < Q \le 100 \text{ kg.} \\ 1 & Q \ge 100 \text{ kg.} \end{cases}$$

Q ... total weight of the W.H
$f$ ... coefficient depending on the W.H dimensions and shape
$\beta$ ... coefficient of the W.H explosive material

The fragment speed is perpendicular to the missile longitudinal axis and has initial value of the order 2500-3500 m/s. The fragment speed decreases according to the given formula [2] :

$$V_d = V_{d_o}\, e^{-R * k_h} \qquad (3)$$

where

R ... distance away from the W.H
$k_h$ ... ballistic factor of the W.H fragments referred to the altitude h.

The missile speed (Vm) and the fragment speed (Vd) are vectorially composed to construct the W.H dynamic destruction angle ($\alpha_{dyn}$) as shown in figure 2. In general, $\alpha_{dyn}$ is smaller than $\alpha_{st}$ and as the missile speed increases the central axis of $\alpha_{dyn}$ is inclined forward to the missile axis (X1 - axis ).

The T.D.Z is the area within which the fragments are distributed in space for specific W.H characteristics, missile speed, and target velocity. The target velocity (Vt) will be vectorially added to both fragment and missile speeds to determine the central axis of T.D.Z ,the value of $\alpha_{des}$ determines the whole T.D.Z as shown in figure 3 (the target with velocity Vt will be destroyed if the W.H is activated at the moment when the target crosses the line MR). In space, the fragments disperse in beam of angle $\alpha_{des}$ so the destruction line MR becomes zonal and will be defined as the T.D.Z .

## 3- Radio fuze performance

The identity between the F.A.Z and the T.D.Z is required to cover the largest area of the target by the greatest amount of the effective W.H fragments to increase the probability of target destruction. The F.P is quantitatively defined by the following relation:

$$W = \frac{S}{S_{\max}} * 100\ \% \tag{4}$$

where

$W$ ... F.P

$S_{\max}$ ... maximum vulnerable target area

$S$ ... actual vulnerable target area located in the W.H T.D.Z at the moment of W.H initiation

To calculate the F.P, using the above definition, it is necessary to know the position of the T.D.Z and the F.A.Z for any possible M/T encounter conditions.

## 4- Graphical method of fuze performance calculation

The F.P is calculated graphically for a given W.H characteristics, F.A.Z ,and encounter conditions. The F.A.Z is determined mainly by the characteristics of fuze antenna pattern and throughout the graphical method of performance calculation it will be firmly represented by the central axis of antenna beam pattern. The encounter conditions are controlled by the following parameters of missile, target, and combat situations :

a- Range of missile speed
b- Range of target speed
c- Encounter angle
d- Target dimension
e- Miss distance between missile and target.

The encounter angle is defined as the angle between the target velocity vector and the negation of the missile velocity vector. The target dimension is represented by a target equivalent length.

The F.P is calculated graphically according to the following steps:

A- Construction of relative velocity zone

The relative velocity zone is the geometrical locus of relative velocity vectors between the missile and the target starting from the missile center. For simplicity, this zone is drawn planimetry in X-Y plane as shown in figure 4. The relative velocity zone is drawn using some points that determine the outer frame as follows :

- point 1 corresponds to collinearity of the vectors Vm(max) and Vt(max) with the target moving towards the missile.
- point 2 corresponds to the relative velocity for Vm(max) and Vt(max) making a right angle.
- point 3 corresponds to the relative velocity for Vm(min) and Vt(max) making a right angle.
- point 4 corresponds to Vm(min) and Vt(max) making a particular angle given by the encounter conditions.
- point 5 is similar to point 4 but for Vm(min) and Vt(min).
- point 6 is similar to point 3 but for Vm(min) and Vt(min).
- point 7 is similar to point 1 but for Vm(min) and Vt(min).

where

Vm(max) . . . missile maximum speed.
Vm(min) . . . missile minimum speed.
Vt(max) . . . target maximum velocity.
Vt(min) . . . target minimum velocity.

B- Construction of the encounter zone

The encounter zone (E.Z) is constructed by adding vectorially the fragment speed to each point in the relative velocity zone, as shown in figure 5. If the fuze activation zone makes an angle $\phi$ (beam tilting angle) with respect to the missile velocity vector, the resulting E.Z will be asymmetrical around the missile velocity vector, as shown in figure 6.

C- Calculation of probability of target destruction

For each point (i) in the E.Z, the probability of target destruction $w_i$ is calculated as follows (referred to figure 7) :

1- The F.A.Z is represented by the central axis of the fuze antenna beam pattern (activation line) and makes an angle $\phi$ with the missile velocity vector
2- Draw the static destruction angle $\alpha_{st}$ and use the relative velocity vector to draw the T.D.Z corresponding to the given encounter conditions of point i.
3- From the missile center (point 0) draw a line OR perpendicular to the relative velocity vector, its length $OR = \rho * s_m$ , where $\rho$ is the M/T miss-distance and $s_m$ is a suitable scale of length.
4- From the point R, draw a parallel line to the relative velocity vector that intersects the activation line in point M.
5- The target equivalent length ( line segment L ) lies on the line passing through the point M and perpendicular to the axis of the T.D.Z (line Oi) with its center (point M) located on the activation line.
6- The probability of target destruction is determined by the ratio of the part of line segment L covered by the T.D.Z (part a) to the whole width of the T.D.Z (part b) at the given distance.

$$w_i = \frac{a}{b} * 100 \ \% \qquad \textbf{(5a)}$$

If b > L , then

$$w_i = \frac{a}{L} * 100 \ \% \qquad \textbf{(5b)}$$

D- Calculation of fuze performance

The F.P is calculated by using the following formula :

$$W = \frac{1}{n} \sum_{i=1}^{n} w_i \, p_i \qquad (6)$$

where

W ... fuze performance.
$w_i$ ... probability of target destruction for a given encounter conditions ( i ).
Pi ... probability of occurrence of the encounter conditions ( i ).
n ... selected number of points during the scan over the E.Z

## 5- Algorithm of fuze performance calculation

The algorithm of F.P calculation is based on the graphical method and uses the available information about the W.H characteristics, F.A.Z, and encounter conditions as follows :

a-Determination of the E.Z boundaries
b-Determination of the range of angle that the F.A.Z makes with the missile velocity vector according to the given E.Z.
c-Starting from the minimum angle of F.A.Z, scanning over the angle ange(that has been determined in step b) with a suitable increment value.
d-For a given angle of F.A.Z , scan over the E.Z with sufficient large number of points, the probability of target destruction is calculated.
e-The F.P corresponding to a certain angle of F.A.Z is calculated using equation 6.

The system flowchart of performance calculation based on the above algorithm is shown in figure 8.

## 6- Impact of encounter zone parameters on the fuze performance

The R.F performance is calculated for a general case in which both missile and target are assumed to have a range of velocity and the encounter angle will have a value within a specific range. For the general case, the identity between F.A.Z and T.D.Z is not evident (since we deal with an E.Z each point of which represents a certain missile speed, target velocity and fragment speed, all that construct, with the given static destruction angle, a specific T.D.Z) so, the F.A.Z will be scanned over the E.Z to find the beam tilting angle that makes the F.A.Z involving a maximum T.D.Zs. The effect of the W.H characteristics and the encounter conditions on R.F performance is individually studied using the algorithm that has been formally introduced, over 12000 uniformly selected points to cover the E.Z. The following values will be considered through the calculation of F.P :

| | |
|---|---|
| -Fragment speed | 3000 m/s |
| -Static destruction angle | 10 deg. |
| -Range of missile speed | 550-1100 m/s |
| -Range of target speed | 350-700 m/s |
| -Encounter angle | 120 deg. |
| -Target equivalent length | 10 m |
| -M/T miss distance | 60 m |

The F.P is calculated for the above parameters and, the maximum F.P was found to be 43% at beam tilting of 69 deg.,as shown in figure 9.

### 6.1- Effect of fragment speed on fuze performance

The F.P is calculated for the following values of fragment speed :

Vd1 = 2000 m/s, Vd2 = 3000 m/s, Vd3 = 4000 m/s.

The F.P was found to be 30 % for fragment speed Vd1 at activation line angle of 60 deg., 43 % for Vd2 at 69 deg., and 54 % for Vd3 at 74 deg. as shown in figure 10.

### 6.2- Effect of static destruction angle on fuze performance

The F.P is calculated for the following values of static destruction angle :

$\alpha_{st1}$ = 5 deg., $\alpha_{st2}$ = 12 deg., $\alpha_{st3}$ = 20 deg.

The F.P was found to be 42.2 % for static destruction angle $\alpha_{st1}$, 49.5 % for $\alpha_{st2}$ and 74.5 % for $\alpha_{st3}$ and all of these values occur at activation line angle of 69 deg. as shown in figure 11.

### 6.3- Effect of missile speed range on fuze performance

The F.P is calculated for the following values of the missile speed range :

Vm1 = 500 - 1000 m/s, Vm2 = 700 - 1200 m/s, Vm3 = 900 - 1400 m/s

It has been noted that the missile speed range has no appreciable effect on the F.P. The F.P was found to be 43.9 % for all chosen values of missile speed range at activation line angle of 70 deg. for Vm1, 67 deg. for Vm2 and 63 deg. for Vm3 as shown in figure 12.

### 6.4- Effect of target speed range on fuze performance

The F.P is calculated for the following values of the target speed range :

$Vt1 = 500 - 600$ m/s , $Vt2 = 400 - 700$ m/s , $Vt3 = 300 - 800$ m/s

The F.P was found to be 54.5 % for target speed range Vt1 at activation line angle of 67 deg., 44% for Vt2 at 68 deg. and 38.3 % for Vt3 at 69 deg. as shown in figure 13.

## 6.5- Effect of encounter angle on fuze performance

The F.P is calculated for the following values of the encounter angle($\eta$) :
$\eta 1 = 90$ deg. , $\eta 2 = 105$ deg. , $\eta 3 = 120$ deg.

The F.P was found to be 48.7 % for encounter angle $\eta 1$ , 45.6 % for $\eta 2$ and 42.8 % for $\eta 3$ and all of these values occur at activation line angle of 69 deg. as shown in figure 14.

## 6.6- Effect of target equivalent length on fuze performance

The F.P is calculated for the following values of target equivalent length (L) :
$L1 = 6$ m , $L2 = 12$ m , $L3 = 18$ m .

The F.P was found to be 43.4 % for target equivalent length L1 , 48 % for L2 and 66.1 % for L3 and all of these at activation line angle of 69 deg. as shown in figure 15.

## 6.7- Effect of missile-target miss distance on fuze performance

The F.P is calculated for the following values of M/T miss distance ($\rho$) :
$\rho 1 = 20$ m , $\rho 2 = 40$ m , $\rho 3 = 60$ m .

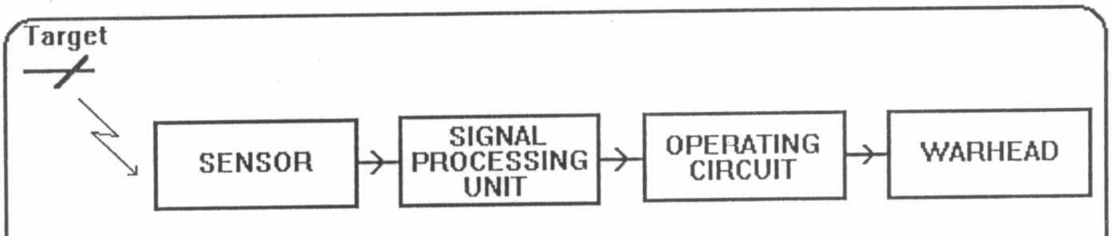
The F.P was found to be 87.3 % for M/T miss distance $\rho 1$ at activation line angle of 72 deg., 57.6 % for $\rho 2$ at 68 deg. and 42.8 % for $\rho 3$ at 69 deg. as shown in figure 16.

## 7- conclusion

The elaborated graphical method provides an efficient tool for evaluating the radio fuze performance. The F.P is mainly dependent on the degree of identity between the F.A.Z and the T.D.Z . The analysis of F.P shows that the fuzing action will be optimum for :

- Short range of both missile and target speeds
- High fragment speed.
- Small encounter angle.
- Wide W.H static destruction angle.
- Small M/T miss distance.
- If it is possible, targets with larger equivalent lengths.

As this is not the case for real M/T encounter conditions ; the performance will be degraded. Therefore , further measures have to be taken for performance improvement .




BASIC BLOCK DIAGRAM OF RADIO FUZE

Fig.1

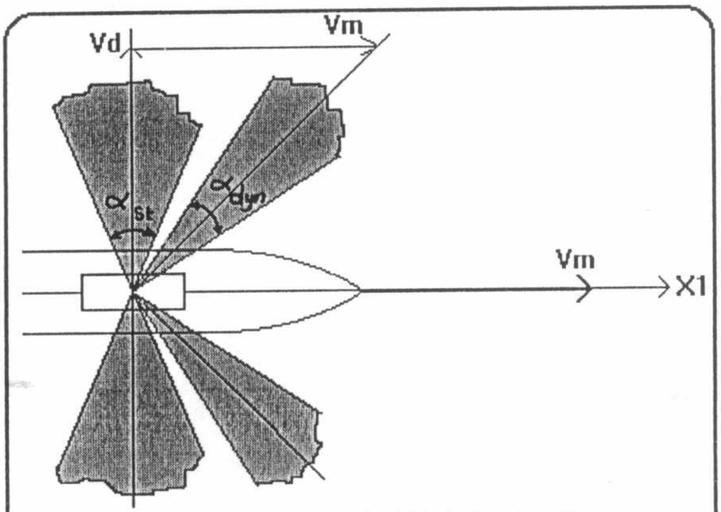



Fig. 2. Static and Dynamic W.H destruction zones

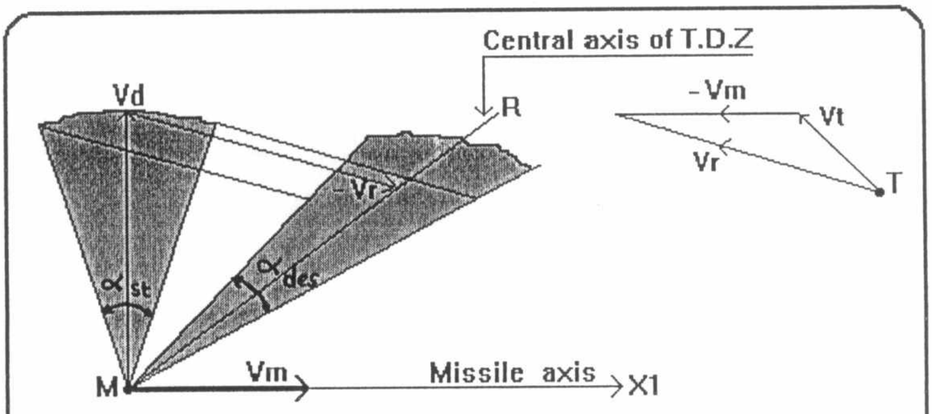



Fig. 3.

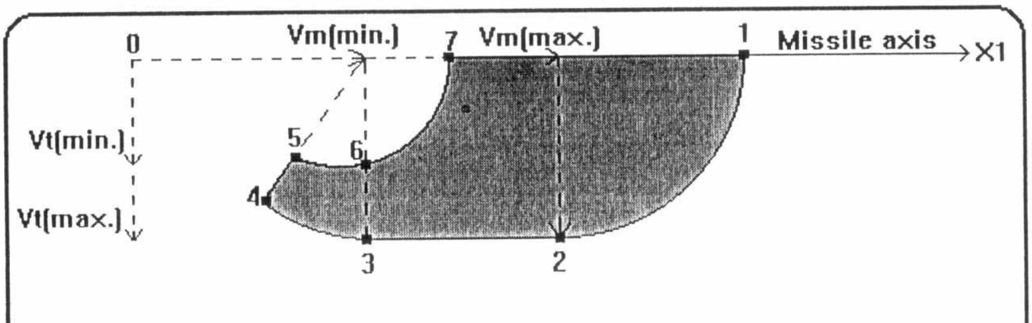



Fig. 4. Relative velocity zone

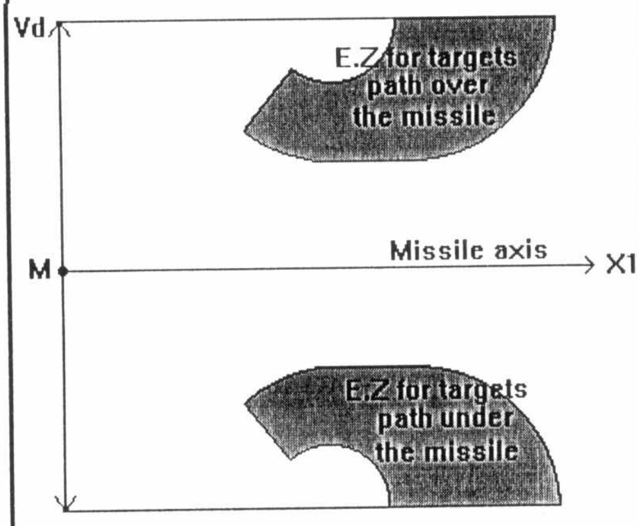



Fig. 5. Encounter zone (E.Z)

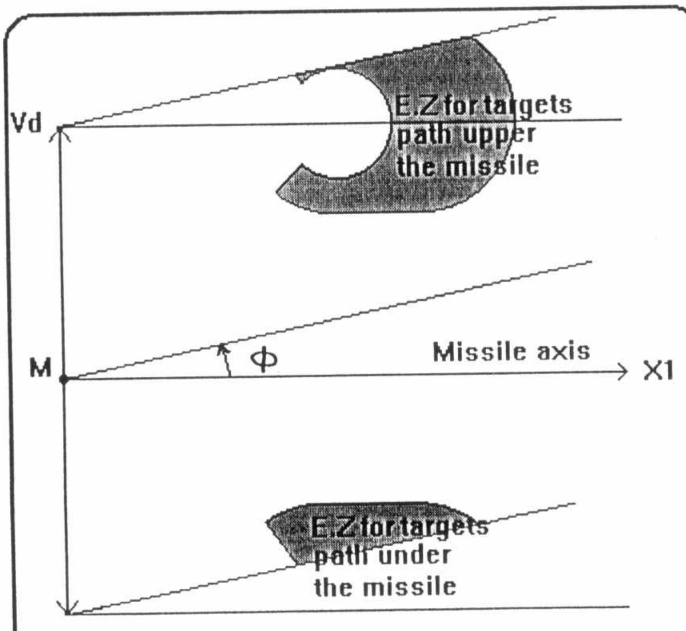



Fig.6. Asymmetrical Encounter zone

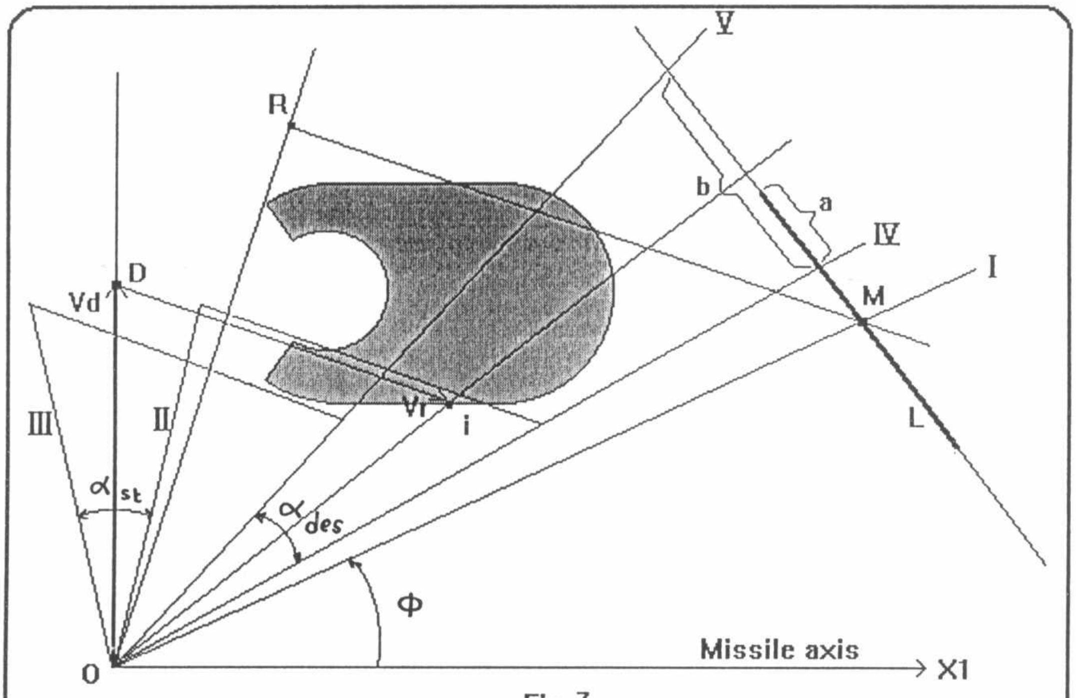



Fig. 7

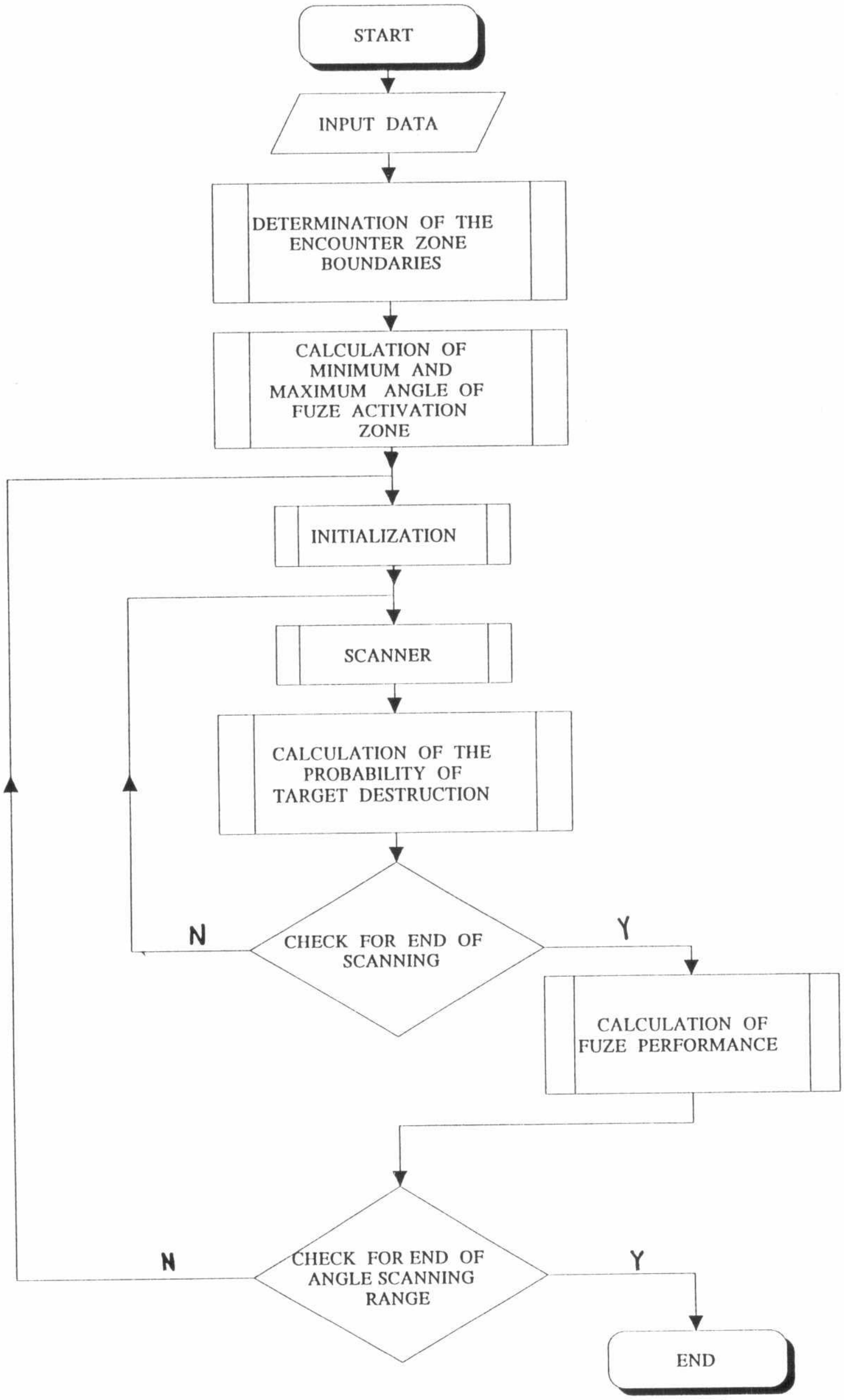

START
INPUT DATA
DETERMINATION OF THE ENCOUNTER ZONE BOUNDARIES
CALCULATION OF MINIMUM AND MAXIMUM ANGLE OF FUZE ACTIVATION ZONE
INITIALIZATION
SCANNER
CALCULATION OF THE PROBABILITY OF TARGET DESTRUCTION
N
CHECK FOR END OF SCANNING
Y
CALCULATION OF FUZE PERFORMANCE
N
CHECK FOR END OF ANGLE SCANNING RANGE
Y
END

**Fig. 8**

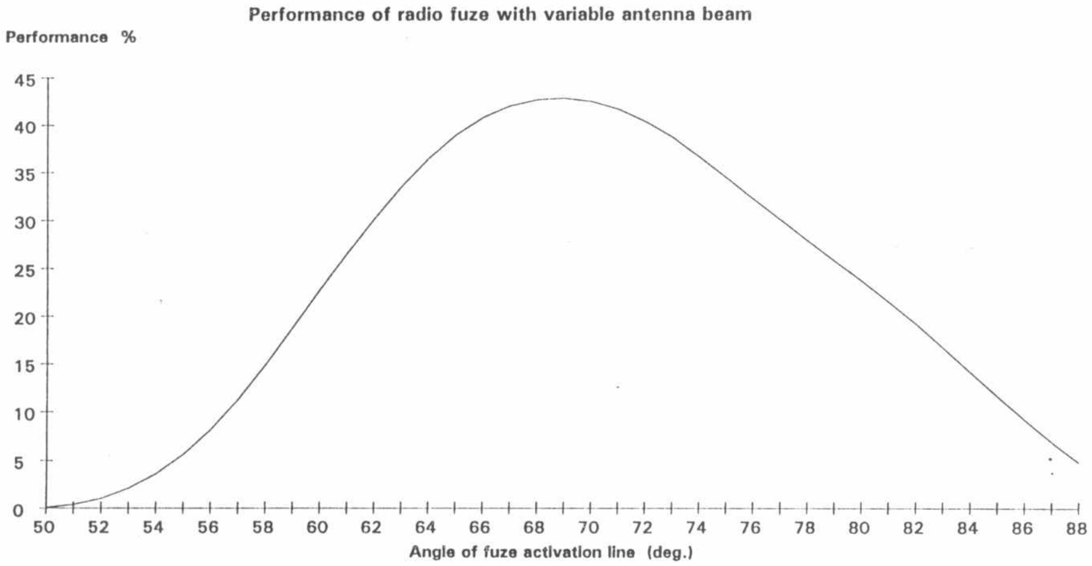

Performance of radio fuze with variable antenna beam
Performance %
45
40
35
30
25
20
15
10
5
0
50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
Angle of fuze activation line (deg.)

Fig. 9

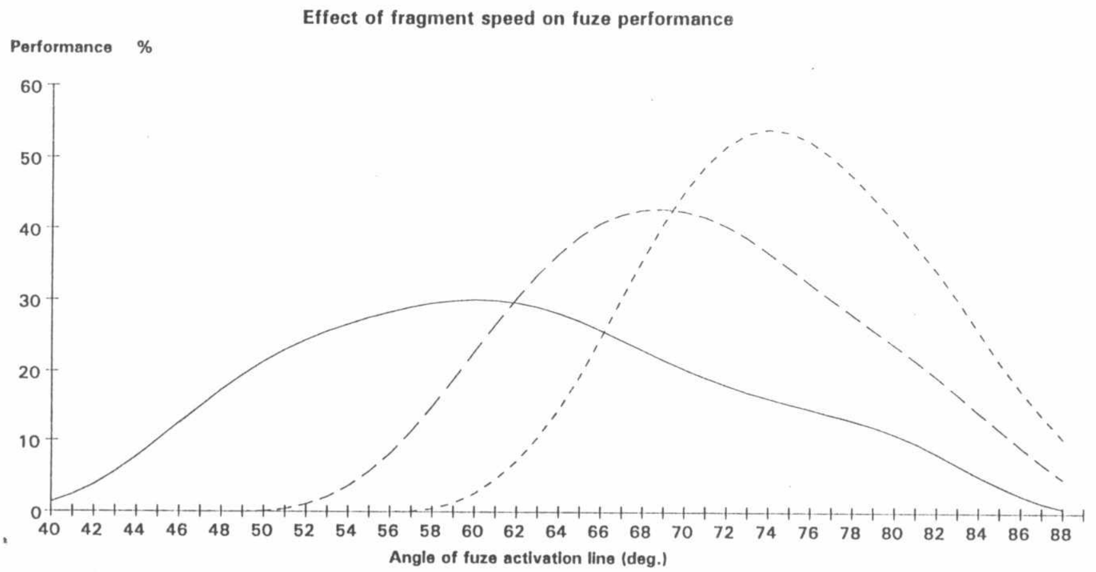
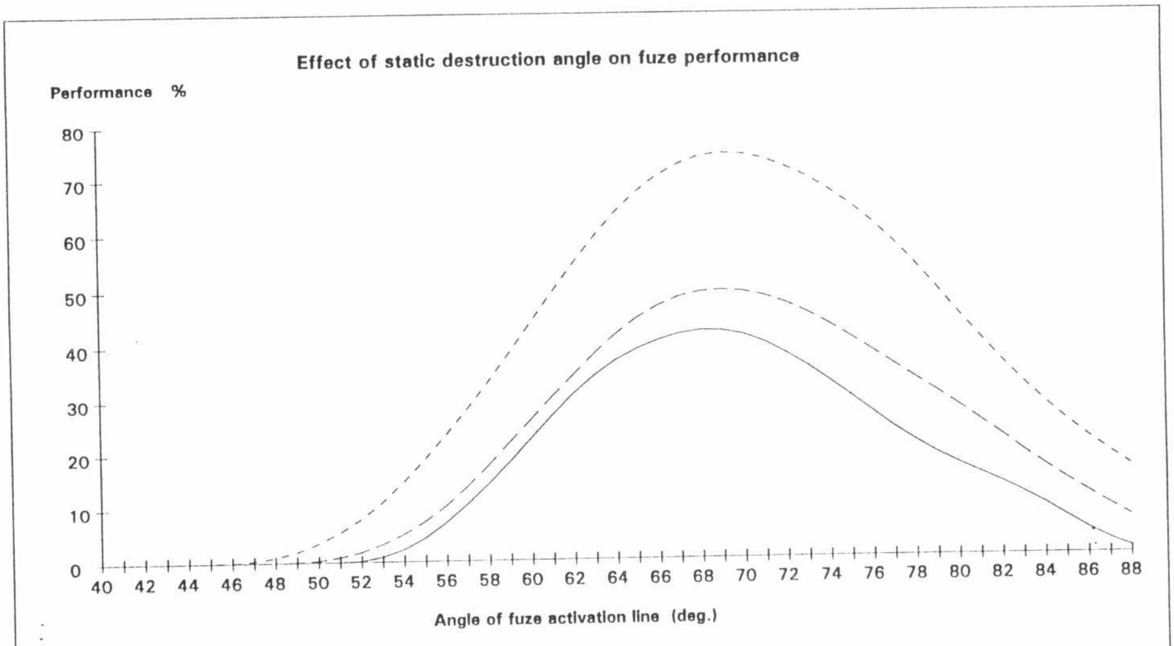

Effect of fragment speed on fuze performance
Performance %
60
50
40
30
20
10
0
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
Angle of fuze activation line (deg.)

Fig. 10


Effect of static destruction angle on fuze performance
Performance %
80
70
60
50
40
30
20
10
0
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Angle of fuze activation line (deg.)

Fig. 11

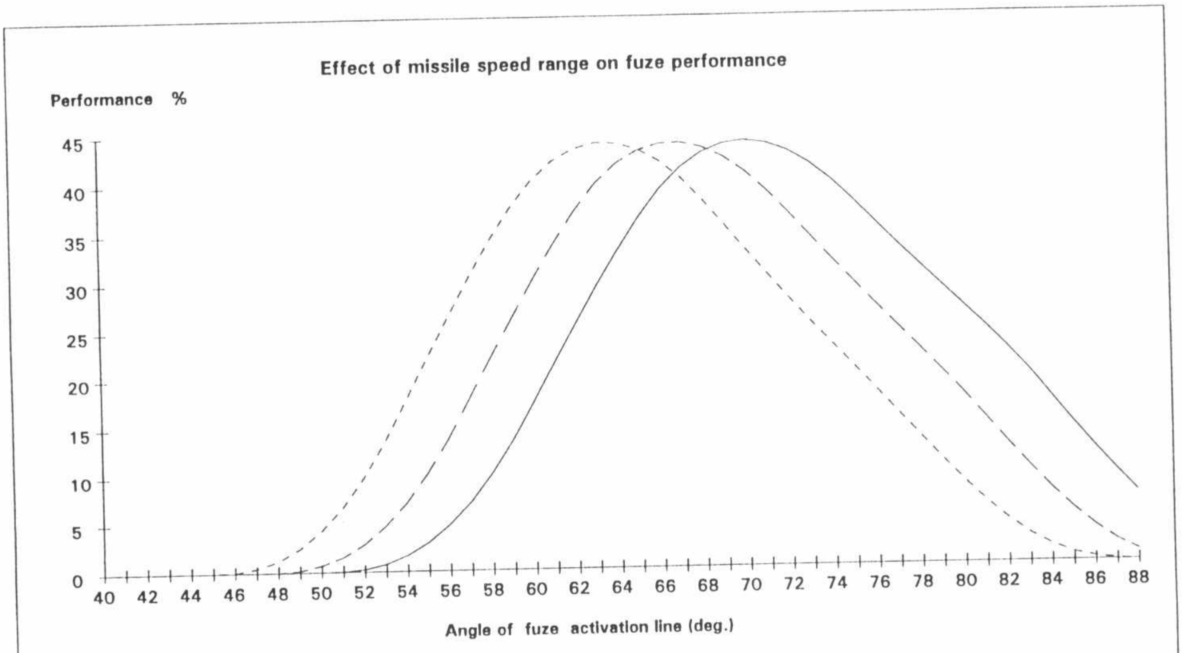
Effect of missile speed range on fuze performance
Performance %
45
40
35
30
25
20
15
10
5
0
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
Angle of fuze activation line (deg.)

Fig. 12

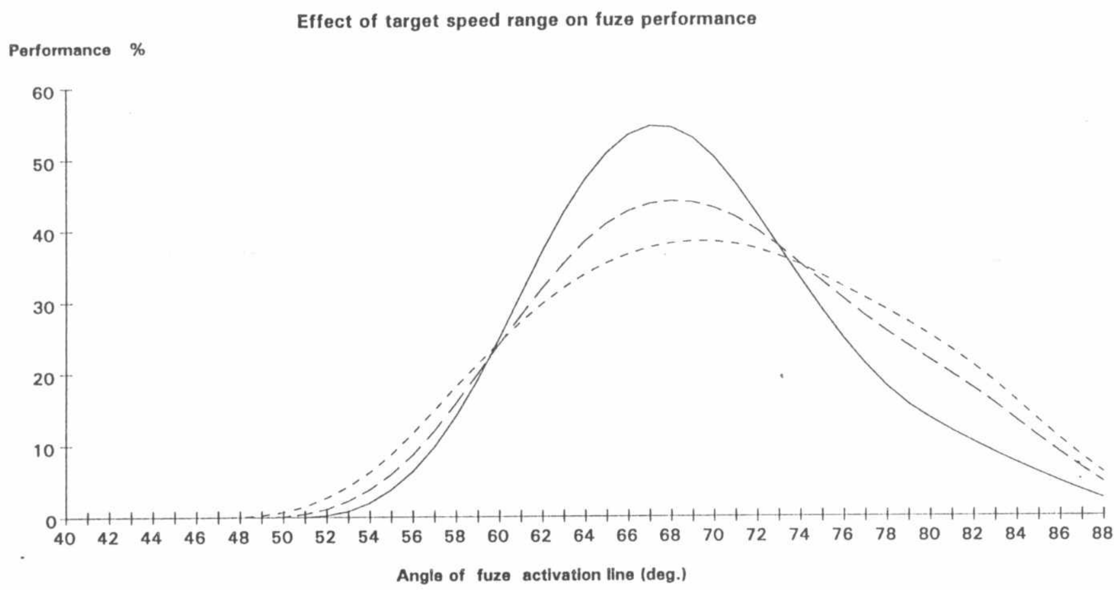
Effect of target speed range on fuze performance
Performance %
60
50
40
30
20
10
0
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
Angle of fuze activation line (deg.)

Fig. 13

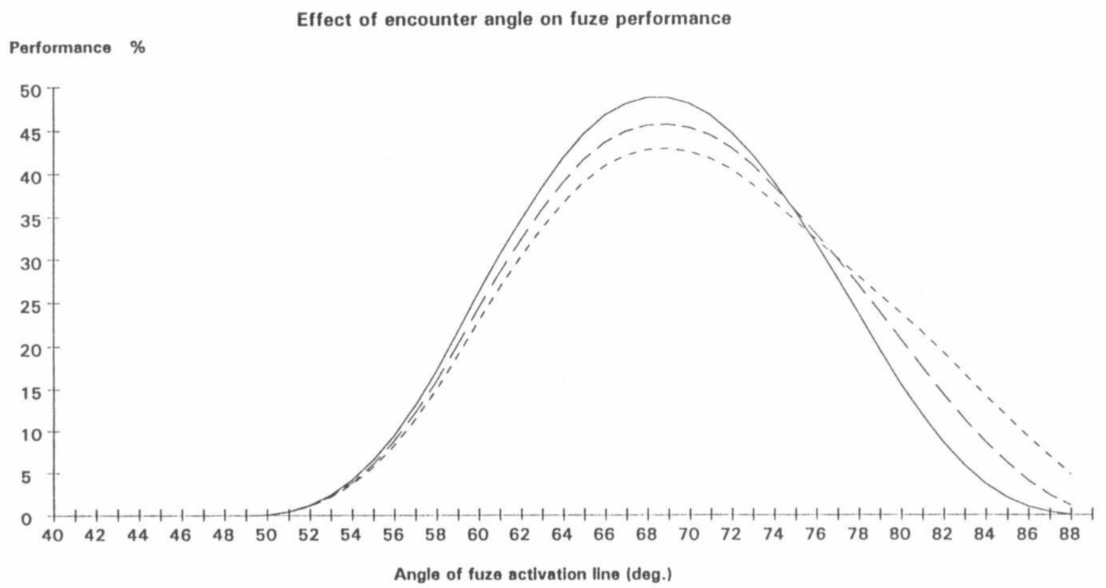
Effect of encounter angle on fuze performance
Performance %
50
45
40
35
30
25
20
15
10
5
0
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
Angle of fuze activation line (deg.)

Fig. 14

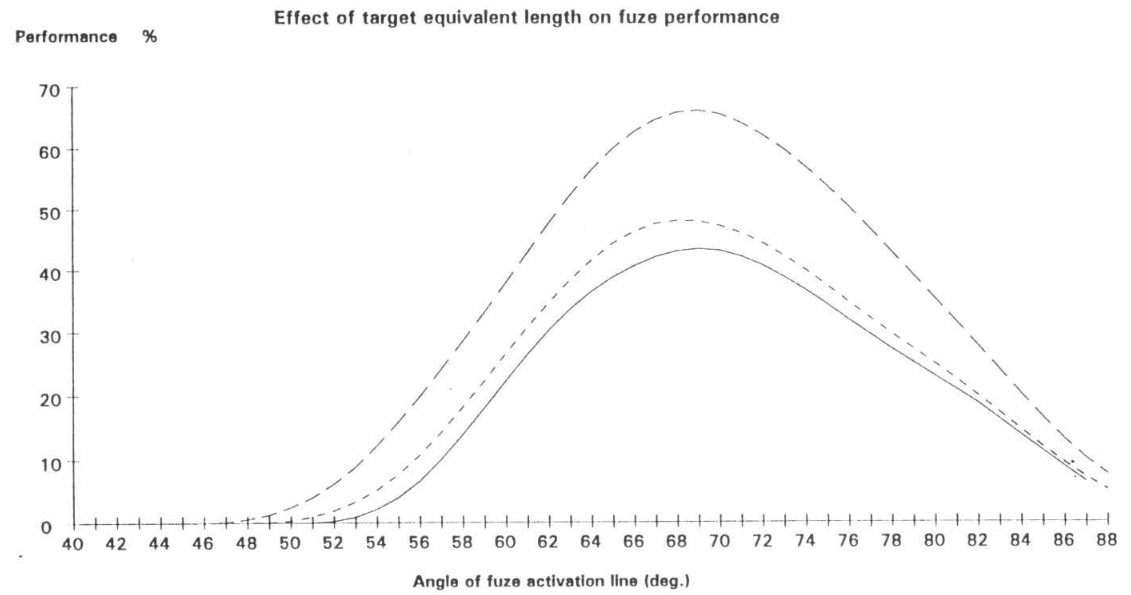
Effect of target equivalent length on fuze performance
Performance %
70
60
50
40
30
20
10
0
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
Angle of fuze activation line (deg.)

Fig. 15

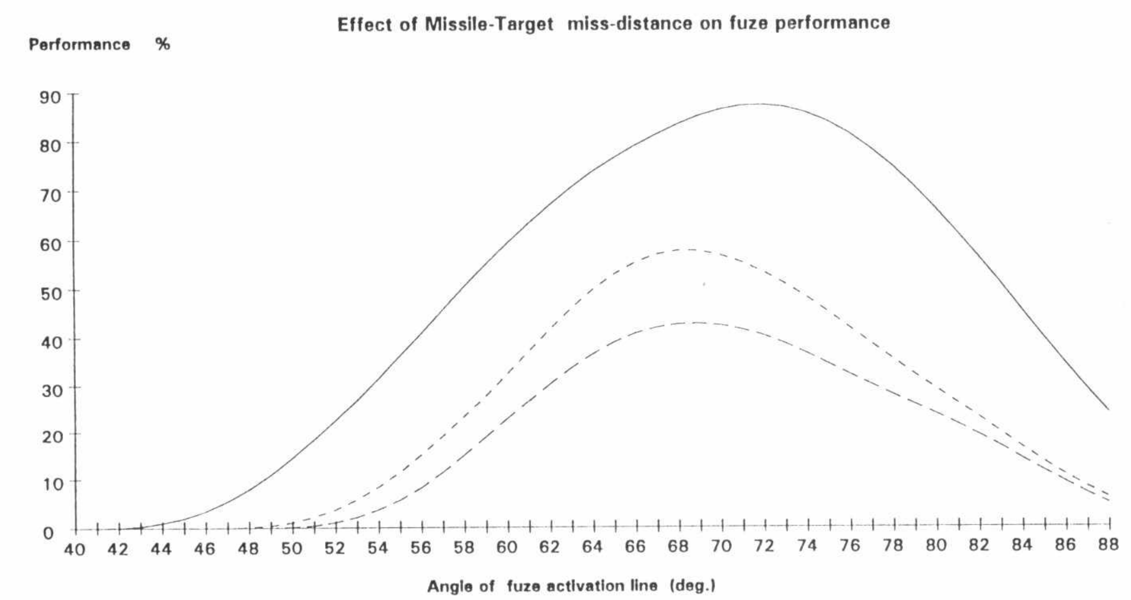
Effect of Missile-Target miss-distance on fuze performance
Performance %
90
80
70
60
50
40
30
20
10
0
40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88
Angle of fuze activation line (deg.)

Fig. 16

## 8- REFERENCES

[1] Otakar Dvorak ,"Theory of radio fuzes for anti-aircraft rockets" Printed lecture 756, M.T.C, 1967 .
[2] Jiri Kuchar ,"Roct wrahead " Printed lecture, M.T.C,1976.
[3] Dusek Josef ,"radio fuze of anti-aircraft guided rocket taking advantage of Doppler effect" Printed lecture TSR 195, M.T.C,1968.
[4] S.J. Parker, "Missile fuzing system" Technical report , March 1988.
[5] M.A. EL-Lithy "Testing device for Radio fuzes" Diploma project report, M.T.C, 1972.