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CLOS GUIDANCE FOR BANK–TO–TURN MISSILE

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ABSTRACT

Bank – to – turn (BTT) control is used to implement a command – to – line – of – sight (CLOS) guidance law. Physical description of the principles involved is given and a 10.th order nonlinear deterministic model proposed. Conventional control is used to design a closed loop controller for the nonlinear system.

Continuous system simulation techniques are employed to explain the effect of bank – to – turn on cross coupling of yaw, pitch and roll channels. Detailed simulation studies are then used for a wide range of engagement sinearieous for trajectory of Missile / Target interception. The target model is considered for three cases: stationary, moving and maneuvering targets. Satisfactory results are obtained for capturing the targets.

الخلاصة

تعرض هذه المقالة استخدام السيطرة بوساطة زاوية العطوف مع قانون التوجيه بوساطة خط النظر. تم استخدام نموذج رياضي من الدرجة العاشرة وباستخدام المسيطر التقليدي. وتبين هذه المقالة تأثير زاوية العطوف على قيم التداخل بين قنوات الصاروخ الثلاثة (التموج ، التعرج ، الرحو) ، تم الحصول على نتائج جيدة ولثلاثة أنواع من الأهداف (الثابتة ، المتحركة ، المناورة).

KEY WORDS

Crosscoupling, BTT, CLOS.

INTRODUCTION

Command – to – line – of – sight (CLOS) guidance is one approach to missile control in short to medium range engagements (Garnell 1980). The controller is based on the ground. and its objective is to try to keep the missile on the line of sight (LOS) between launch point and target by generating suitable guidance command.

In CLOS systems **Fig (1)** the controller tries to drive (θ_e) to zero and keep it zero while the line – of – sight (LOS) moves. There are many types of LOS system, all of which incorporate a separate target tracker which may be either an independent control loop or a manually – operated arrangement.

A typical system would also contain a second tracker, which follows the missile by means of an attached flare. The signals available on the ground are then (θ_e) and (usually) the LOS rate and acceleration. These signals are processed by the guidance controller to produce acceleration commands, which are sent to the missile via a radio link. In response to these, the missile then accelerates in such a way as to remain on the LOS.

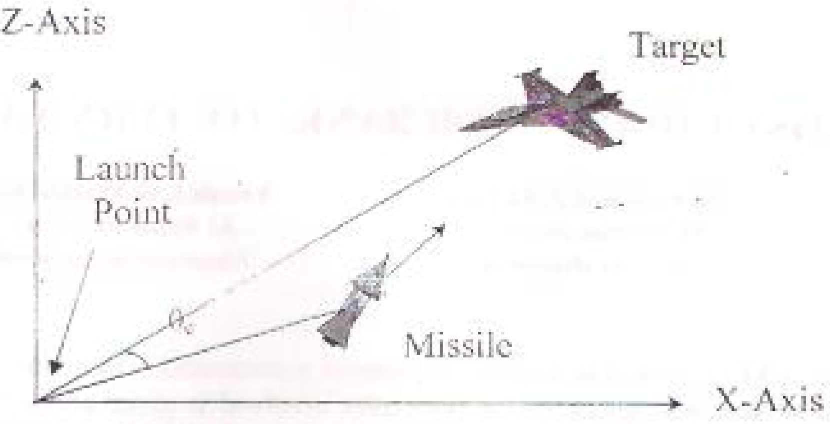
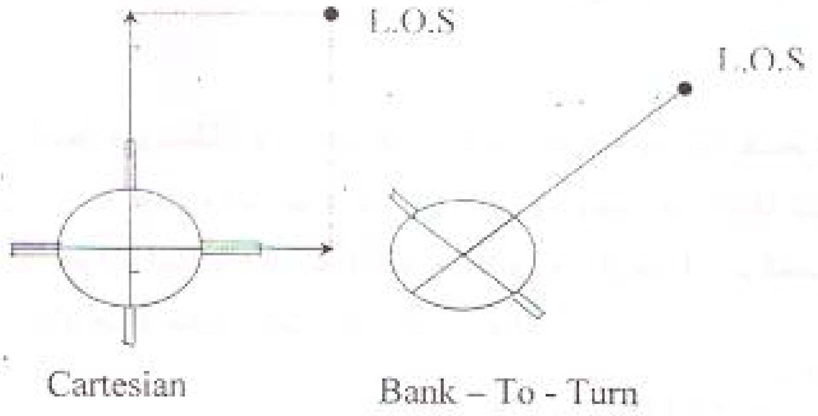


Fig (1) CLOS Guidance for motion in the vertical plane.

The acceleration commands sent to the missile may be either cartesian or polar, for example, if the position of the missile relative to the LOS were as indicated in **Fig (2)**, the cartesian command would tell it to accelerate at ,say,(4g) upwards and (3g) to the right, while the corresponding polar command would be to accelerate at (5g) at an angle of (37) to the vertical (Roddy 1984).



Cartesian

Bank – To - Turn

Fig (2) Cartesian and Bank – To – Turn control.

Two basic methods of controlling the attitude of missile to achieve the acceleration commanded by the guidance law are skid – to – turn (STT) and bank – to – turn (BTT). In the former, the angle may be either held constant or uncontrolled; in which case, the magnitude and orientation of the body acceleration vector is achieved by permitting the missile to develop both an angle of attack and a sideslip angle. The presence of the sideslip imparts a "skidding" motion to the missile; hence the name "skid – to – turn" .A "bank – to – turn" missile on the other hand, should ideally not have any sideslip. To Achieve the desired orientation of the missile, it is rolled (banked) so that the plane of maximum aerodynamic normal force is oriented to the desired direction and the magnitude of the force is controlled by adjusting the attitude (angle of attack) in that plane (Williams 1987).

A bank – to – turn missile maneuvers by means of two sets of control surfaces: elevators and ailerons. The elevators produce pitch motion, causing the missile to accelerate perpendicular to the wing plane under the action of a lift force of magnitude (F) and orientation (ϕ) (see **Fig(3)** Note: the axes and sign convention used here are consistent with reference (Garnell 1980)).

The aileron cause the missile to roll (or bank) until the wing plane (and hence the lift force) is in the correct orientation. The guidance commands consist of the magnitude and orientation of the demanded lift force (Rasheed 1996).

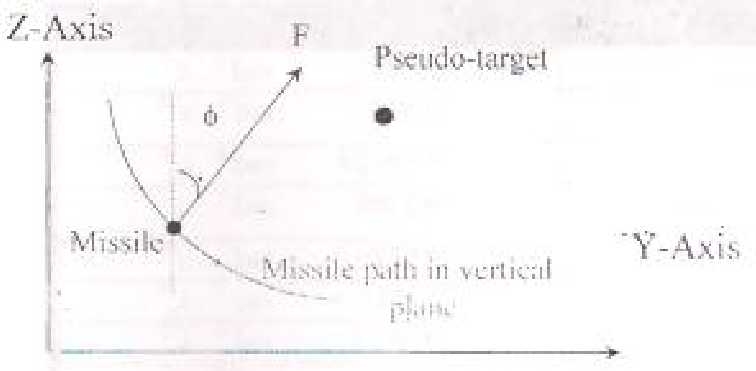


Fig (3) Maneuvering of a BTT Missile.

A BTT missile is controlled to fly in a manner similar to an aircraft. Upon receiving a guidance command, the missile first rolls to an attitude in which the required acceleration vector lies in the pitch plane prior to generating lift in that direction. Fast response is achieved by a combined roll – pitch maneuver, with the roll control system rapidly rotating the missile's maximum lifting orientation into the desired maneuver direction and the pitch control system simultaneously developing the required magnitude of acceleration in the maximum lift orientation (Hussain 1995).

MATHEMATICAL MODEL

Missile Airframe

The model used in this paper for a BTT missile referred to ground axes is tenth – order and nonlinear (Roddy 1984):

$$\left.\begin{aligned}
\alpha &= z_\alpha \alpha + q - p\beta + z_\delta \delta \\
q &= m_\alpha + m_q q + m_\delta \delta \\
\beta &= y_\beta \beta - r + p\alpha \\
r &= n_\beta \beta + n_r r \\
p &= \tfrac{1}{I}\left(L\ p + L_\zeta \zeta\right) \\
\phi &= p \\
z_w &= U\left(z_\alpha \alpha + z_\delta \delta\right)\cos\phi + U\ y_\beta \beta \sin\phi + g \\
y_w &= U\left(z_\alpha \alpha + z_\delta \delta\right)\sin\phi + U\ y_\beta \beta \cos\phi
\end{aligned}\right| \quad (1)$$

Constant aerodynamic derivatives are assumed and numerical values employed, which correspond to a synthetic missile see **Table (1)**.

Table (1). Synthetic missile parameters

z_α	-2.7085	$rad^{-1} . s^{-1}$
z_δ	-0.625	$rad^{-1} . s^{-1}$
m_α	-1939.24	$rad^{-1} . s^{-2}$
m_q	-9.2308	$rad^{-1} . s^{-1}$
m_δ	1234.06	$rad^{-1} . s^{-2}$
y_β	-2.7085	$rad^{-1} . s^{-1}$
n_β	1939.24	$rad^{-1} . s^{-2}$
n_r	-9.2308	$rad^{-1} . s^{-1}$
I	0.0005	$Kg . m^2$
L_p	-0.005	$Nm.s.rad^{-1}$
L_ζ	63.03	$Nm . rad^{-1}$
U	500	$m . s^{-1}$

Realistic constraints will be imposed on the magnitude of the control surface angles (δ & ζ), and the servos driving them will be considered to have infinite bandwidth.

Missile Airframe Transfer Function's

The missile airframe can be represented by the first six equations from eqn (1), where:

$$\left.\begin{aligned}
\alpha(s) &= \frac{-0.625(s-1228.2907)}{s^2+11.9393\,s+1964.2416}\,\delta(s) - \frac{(s+9.2308)}{s^2+11.9393\,s+1964.2416}\,p\beta(s) \\
\beta(s) &= \frac{(s+9.2308)}{s^2+11.9393\,s+1964.2416}\,p\alpha(s) \\
p(s) &= \frac{126050.7}{(s+30)}\,\zeta(s)
\end{aligned}\right\rvert \qquad (2)$$

From above it can be seen that the output of the airframe is represented by angle of attack (α), sideslip angle (β) and roll angle (ϕ). While the input to roll channel the aileron angle. The cross coupling of roll rate (p) and angle of attack (α) is the input to yaw channel and the cross coupling of (roll rate (p) and sideslip angle (β)) and elevater deflection (δ) are input to pitch channel see **Fig (4)** (Ching 1984 , Majed 1996).

Fig (4) illustrates the controller system, which is identical in (y) and (z) channels, is double lead-lag-network :

$$F(s) = k\left(\frac{1+Ts}{1+\alpha Ts}\right)^2$$

where: $k=0.035$; $T=0.1$; $\alpha=0.3$.

The controller for roll loop is:

$$F_R(s) = 0.054\left(\frac{1+0.015\,s}{\quad}\right)$$

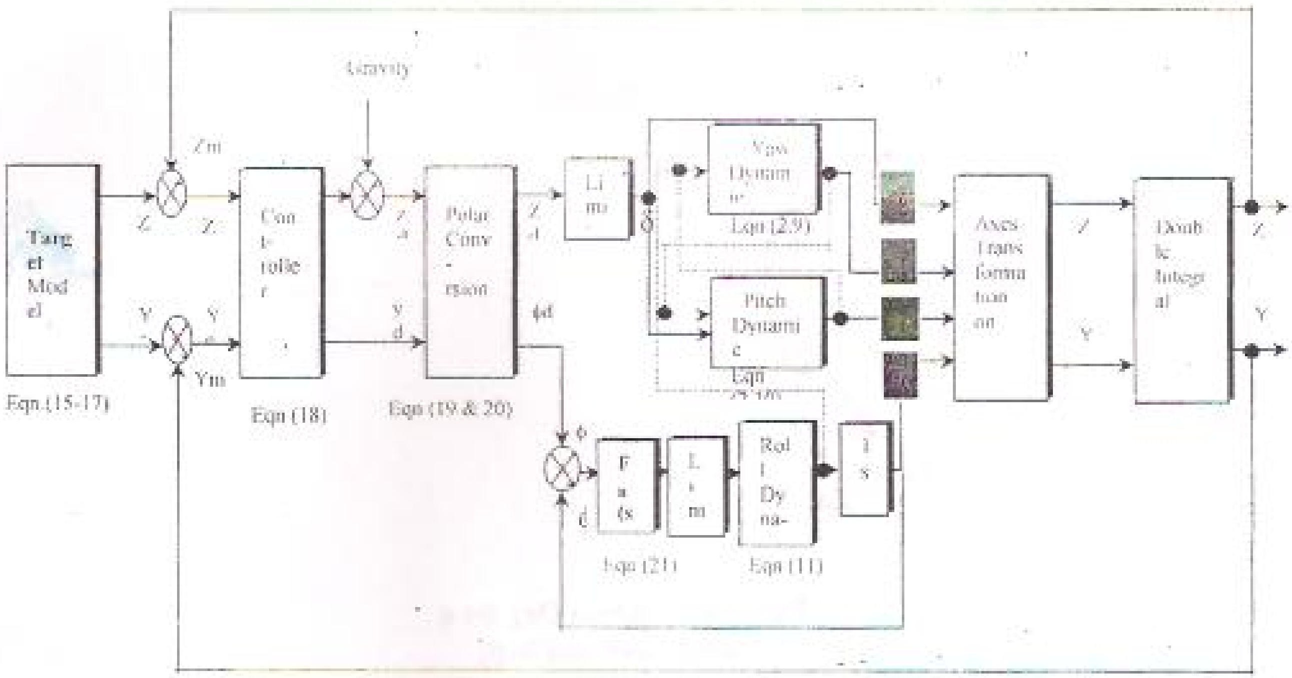


Fig (4) Controller / Autopilot In BTT Missile Guidance Loop.

A polar conversion can then be used to produce acceleration commands compatible with a BTT system:

$$\left.\begin{aligned} \ddot{Z}\mathrm{d} &= \sqrt{\ddot{z}\mathrm{d} + \ddot{y}\mathrm{d}} \\ \phi\mathrm{d} &= \Pi - \tan^{-1}\left(\frac{\bar{y}\mathrm{d}}{\bar{z}\mathrm{d}}\right) \end{aligned}\right\} \qquad (3)$$

AXES TRANSFORMATION

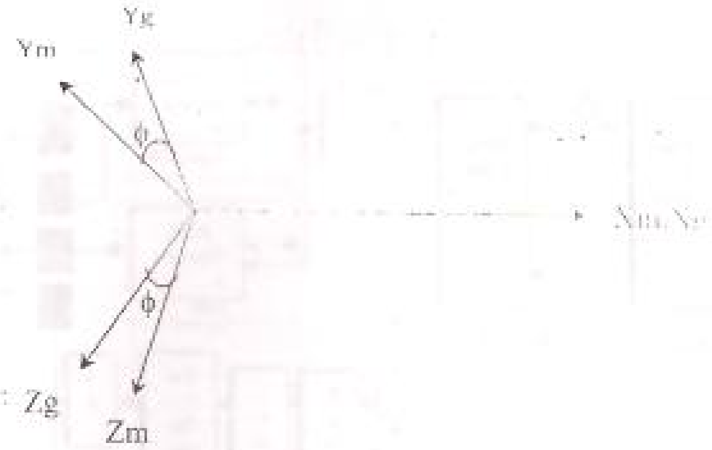
It is then necessary to transform the motion with respect to the missile axes down to the ground axes. This transformation can be achieved using Euler angles made straighter forward by the assumption that the missile and ground x-axis are parallel. Assuming that acceleration due to gravity is (g), then the cartesian accelerations of the missile with respect to the ground axes is described by **Table (2)**, **Fig (5)** and eqn (4), (Jack 1960 , Lightbody 1995).

Table 2: Direction Cosines of Roll

From / To	OXg	OYg	OZg
OXm	1	0	0
OYm	0	Cosϕ	-Sinϕ
OZm	0	Sinϕ	Cos□

(4)

$$\left.\begin{array}{l} Z_m = Z_g \cos\phi + Y_g \sin\phi \\ Y_m = -Z_g \sin\phi + Y_g \cos\phi \end{array}\right\}$$



Fig(5) Roll About Oxg By φ .
(where ψ=0 and θ=0)

TARGET MODEL

The general maneuvering target model is shown in **Fig (6)** . eqn (5). (Tang 1984).

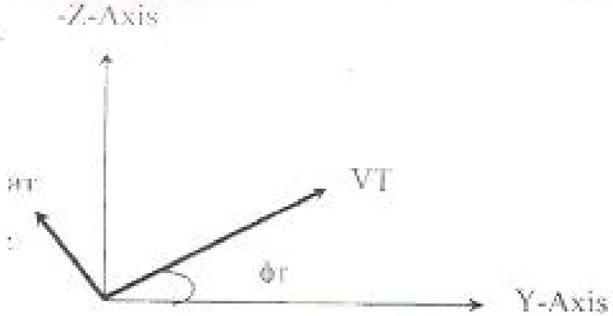


Fig (6): Maneuvering Target.

$$\left.\begin{array}{l} \dot{Y}_T = V_T * \cos\phi_T \\ -\dot{Z}_T = V_T * \sin\phi_T \\ \dot{\phi}_T = \dfrac{a_T}{V_T} \end{array}\right\} \qquad (5)$$

RESULTS AND DISCUSSIOIN

The system in **Fig (4)** including the tenth – order nonlinear model of eqn (1) and **Table (1)** has been simulated on a computer by using Matlab 5.1 1997 package [6] . Three cases of target model are considered ;

From **Fig (7)** and **Table (3)** it can be seen that the missile has smooth trajectory and achieved the target by fast banking to the target plane and oriented to it. This process is achieved according to the momentary position of missile, therefore the missile hit the target in short time (3.26 sec) . The time of capturing depends on target and missile velocities and initial range between them.

Case (2). Moving Unmaneuvering Target

Figs. (8) and (9) demonstrate the two cases for approaching and departing targets . from which it can be seen the affect of roll loop on airframe missile by cross coupling between the yaw – roll channel , yaw – pitch channel and pitch – roll channel. The missile trajectory is severe and this usually from the affect of cross coupling which the target and missile in one plane, the trajectory is smooth but, in cross coupling the roll rate affect on the angle of attack and sideslip angle ($\pi\alpha$ & $\pi\beta$) which is included in missile model. The most affect parameter is the range of target , where by banking will decrease the affect of cross coupling and the last task is decrease the miss distance , depends on the range and velocity , therefore the capture time in approaching target is less than as than of departuring target , but with more severe trajectory .

Case (3). Maneuvering Target

Figs. (10 – 14) and **Table (3)** illustrate the different maneuverability for approaching and departuring targets with positive or negative g – load (+ve at or --ve at). In this case the importance of BTT appears where if the missile with using of BTT it can't capature the target where in this case the target changes the, position at each moment, therefore the missile must change its position according to target see **Fig (11).**

Figs. (15) and (16) it can be seen that as the value of sideslip angle (β) oscillaty, the roll rate (p) has a value which cancel the above affected (the affect of cross coupling) i.e. β--- 0 .

Table (3) Target results

Case Parameters	Miss Distance M.D(m)	Capture Time(sec)
(1).$\phi(0)=\pi/4$, $ZT(0)=-200$, $YT(0)=0$.	0.3245	3.26
(2).$\phi(0)=\pi/4$, $ZT(0)=500$, $YT(0)=800$, $YM(0)=0$ $ZM(0)=0$ a).In $\theta T(0)=0$ & $aT=0$; b).In $\theta T(0)=\pi$ & $aT=0$;	 0.1723 0.4607	 11.23 10.48
(3).$\phi(0)=\pi/4$, $ZT(0)=500$, $YT(0)=800$, $YM(0)=0$ $ZM(0)=0$ a).In $\theta T(0)=0$ & $aT=3g$ b).In $\theta T(0)=0$ & $aT=-3g$ c).In $\theta T(0)=\pi$ & $aT=3g$ d).In $\theta T(0)=\pi$ & $aT=-3g$	 0.928 0.4696 0.8078 0.9956	 11.17 11.5 10.3 9.89

CONCLUSIONS

A BBT missile in a CLOS guidance system has the ability of decreasing the affect of cross coupling between missile airframe channels. The process of transfer the movement of missile from three dimension to 2 nd dimension by banking the missile to target plane gives the missile ability to capture any target with any maneuvering, where it deals with target as plane motion only .

The affect of limitation for elevator deflection on the missile trajectory is greater than the affect of limitation of aileron deflection, where the task of roll loop is banking the missile while the elevator enter on the limiting of missile coordinate (Ym & Zm) .
From all considered cases the most attractive case is the case for departure maneuvering target downward (-3g) . where the missile capature the target in minimum time with less severe maneuver see **Fig (11).**

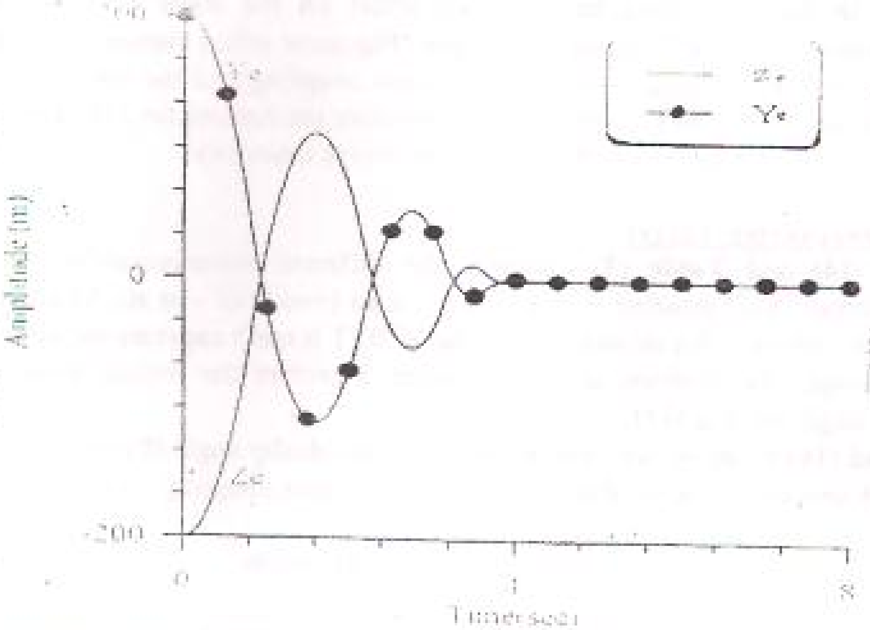


Fig (7) : Error Signal Time Response For Stationary Target .

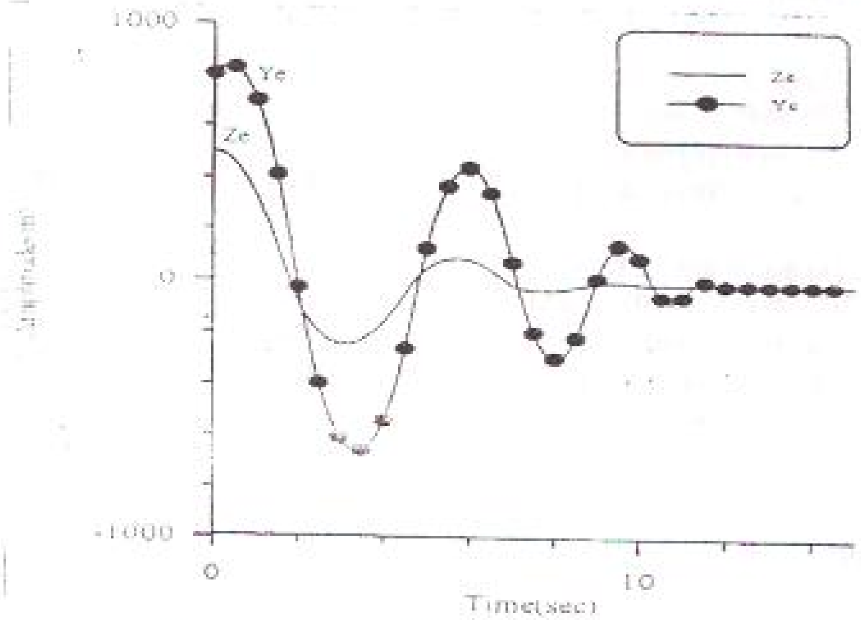


Fig (8) : Error Signal Time Response For Moving (Departuring) Target (case 2,a) .

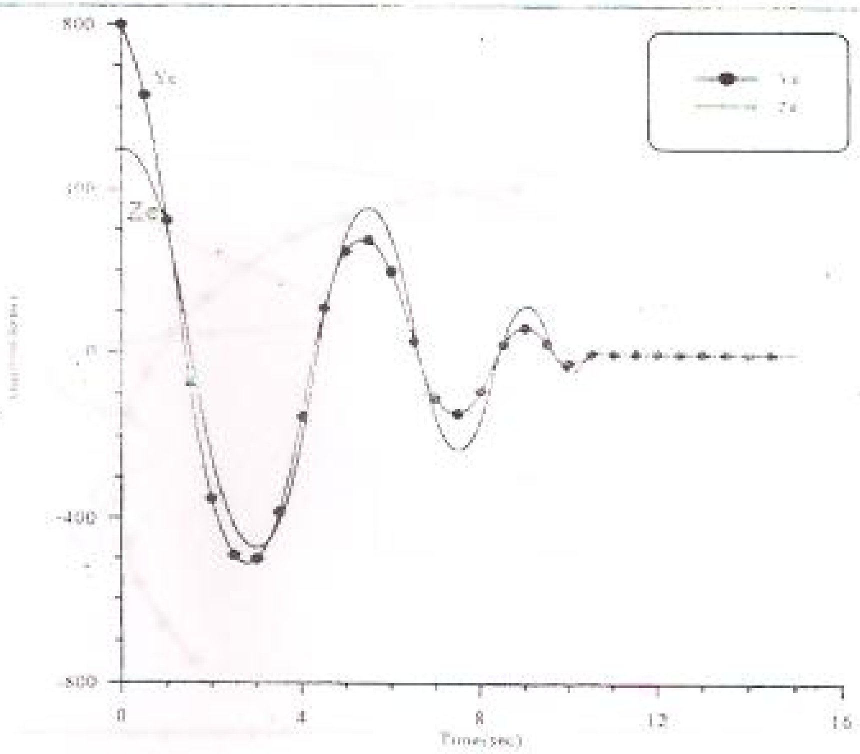


Fig (9) : Error Signal Time Response For Moving (Approaching) Target (case 2.b)

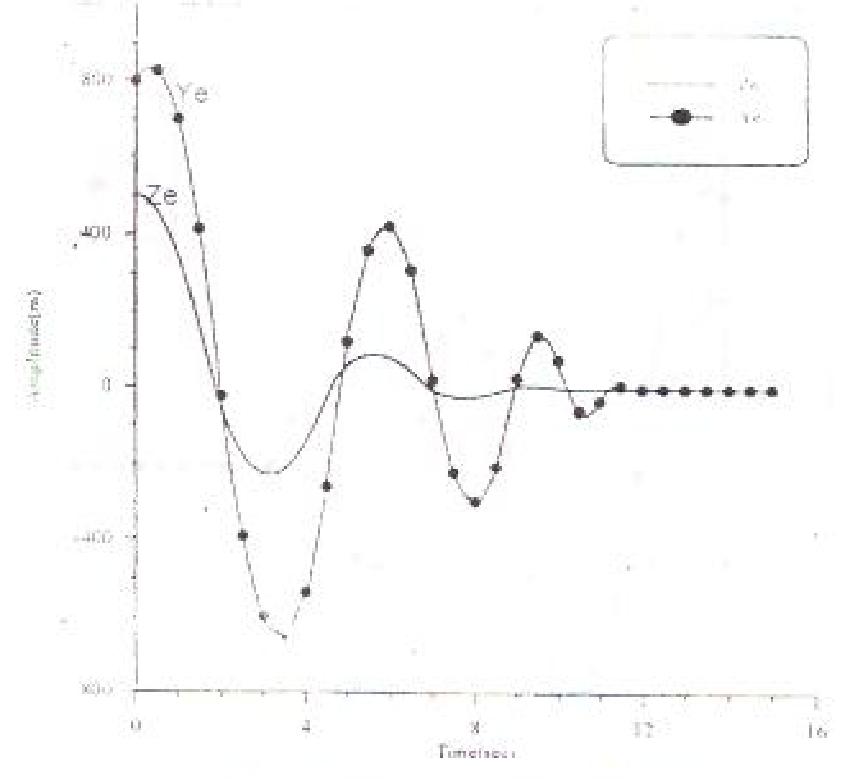


Fig (10) : Error Signal Time Response For Manoeuvering Target (case 3.a)

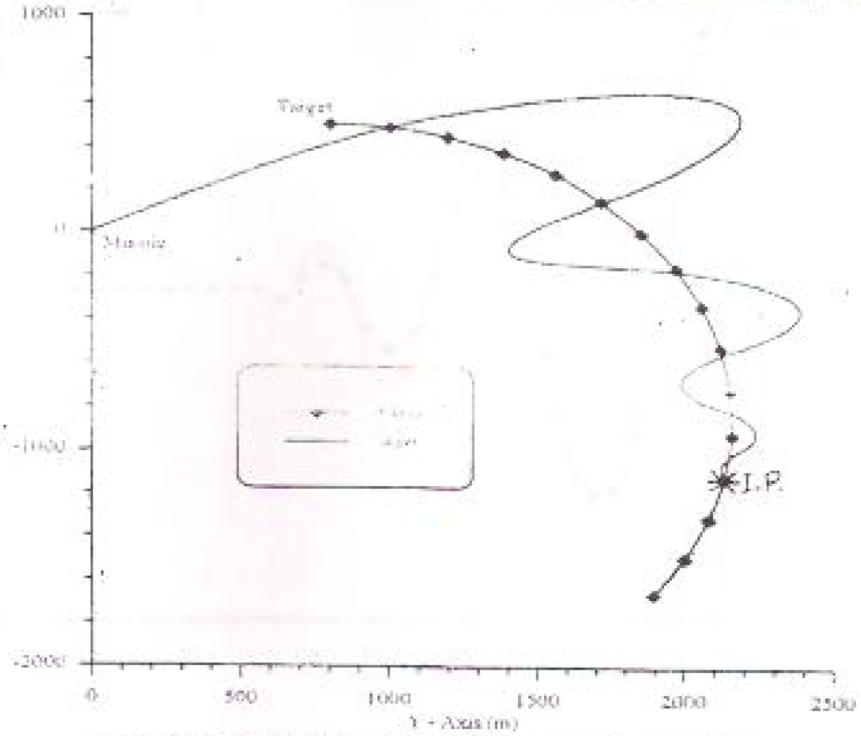


Fig (11) Missile - Target Trajectory For Manoeuvering Target With -3g
(case 3.b)

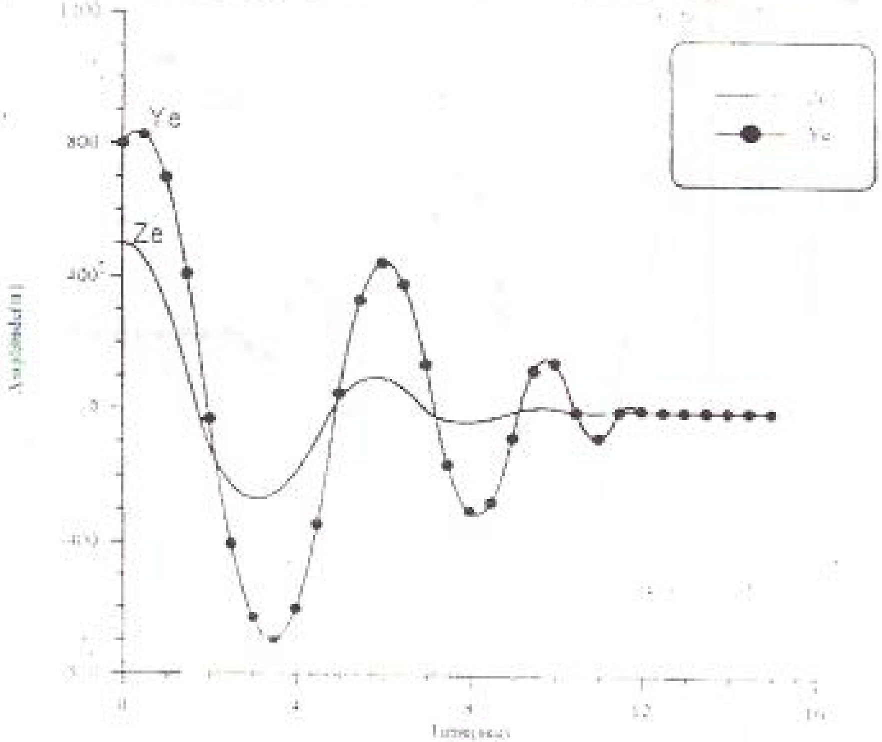


Fig (12) : Error Signal Time Response For Manoeuvering Target (case 3.b)

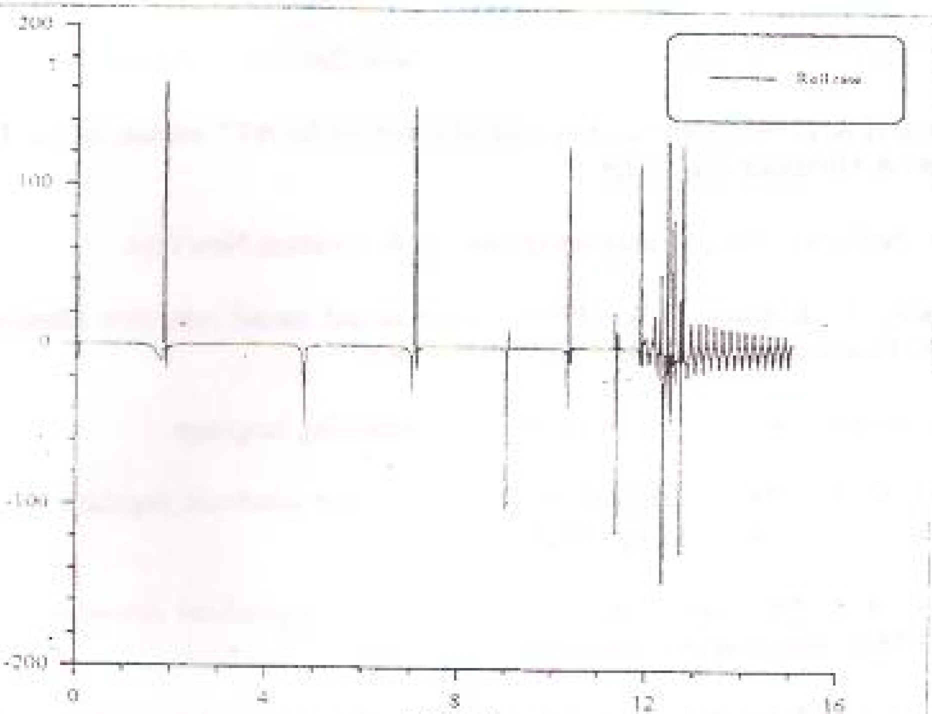


Fig (15) : Time Response of Roll Rate Signal For Manoeuvering Target .

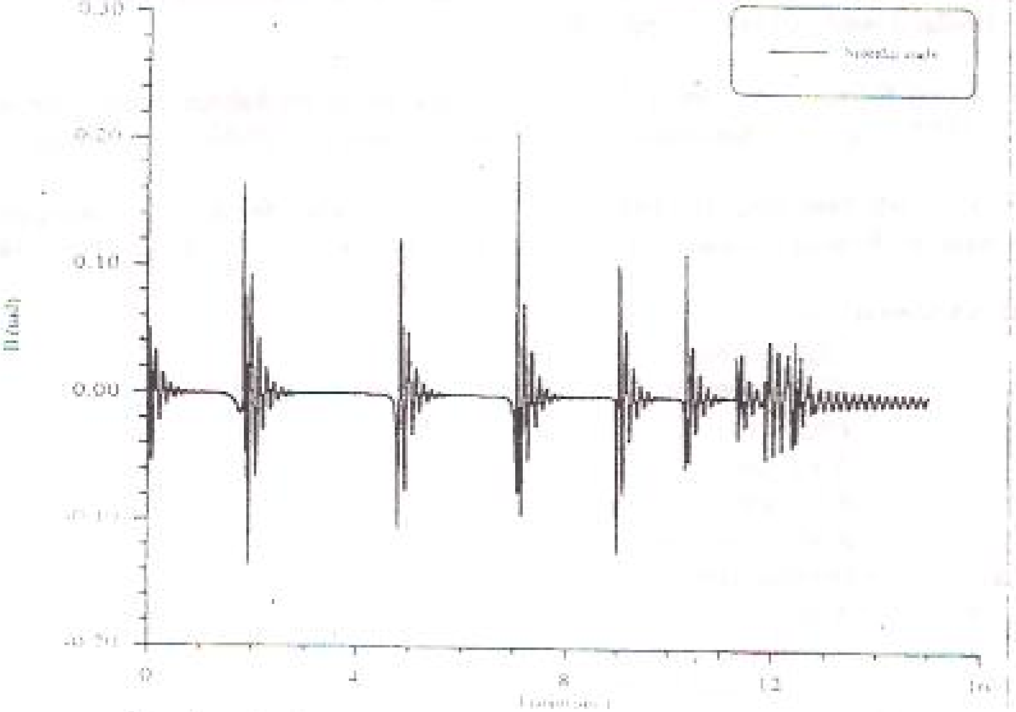


Fig (16) : Time Response of Steering Angle For Manoeuvering Target

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LIST OF SYMBOLES:

α = Angle of attack.
β = Sideslip angle.
q = Pitch rate.
r = Yaw rate.
p = Roll rate.
ϕ = Roll orientation.
Xg,Yg,Zg = Ground axes.
Xm,Ym,Zm = Missile axes.
xm, ym ,zm = Missile position.
xc , yc , zc = Commanded (or pseudo target) position.
δ = Elevator control angle.
ζ = Aileron control angle.
g = Acceleration due to gravity.
m = Missile mass.

I = Roil interia.
z_α , v_β , etc = Aerodynamic derivatives.
F = Lift force magnitude.
ϕ = Lift force orientation.
$\dot{z}d$, $\ddot{Y}d$ = Cartesian acceleration commands.
$\dot{Z}d$, ϕd = Polar acceleration commands.
U = Missile forward velocity.
VT = Target forward velocity.
θT = Target velocity angle.
MD = Miss distance.
aT = Target lateral acceleration (normal acceleration).