Military Technical College
Kobry Elkobbah
CAIRO - EGYPT

8th INTERNATIONAL CONFERENCE
ON AEROSPACE SCIENCES &
AVIATION TECHNOLOGY

Autopilot Design for a LOS Anti-tank Guided Missile

G.A. El-Sheikh and N.A. El.Hamwe***

Abstract

The performance of antitank guided missile systems is measured through the minimum missdistance and the capability of the missile to overcome target maneuver and different sources of errors and disturbance noises. The variety of new missiles with higher performance requirements impulse new problems in structure, effectiveness of control, cost, reliability...etc. One of the most interesting and challenging problem areas for antitank missile is that of the guidance and control. Therefore this paper consider an antitank guided missile system which belongs to the second generation for the design and analysis. Transfer functions representing the missile dynamics in pitch and yaw planes are derived to be considered for investigation. This investigation includes autopilot design and evaluating the system response such that the performance requirements are achieved. The control loop for both pitch and yaw channels of the intended guided missile system with compensation network are designed and investigated for each channel such that the system is stabilized and the performance requirements are satisfied. In addition, an inner loop design is carried out using free gyroscope for the yaw channel to improve its performance against target maneuver. To stay on the robustness of these compensators and their ability to withstand against disturbances, the measurements are corrupted with noise and the system performance is investigated. This investigation leads to the necessary modification or retuning the designed compensators for achieving the required robustness margin.

Keyword: Guidance and Control, Robust Control.

1- Introduction

One of the most important command guidance systems is the antitank guided missiles (ATGM) launched against tanks and armored vehicles. These missiles are classified into three generations: first generation, second generation and third generation. In the first generation both the target and missile are manually tracked using optical telescopes. In the second generation the target is manually tracked using optical telescopes while the missile is automatically tracked by including an infrared sensor in

* Egyptian Army ** PhD Student

the launcher with the telescope to detect the IR radiation from a source strapped on the rear part of the missile. Then the motion parameters are transferred automatically to signals applied to the guidance unit. Finally, the third generation is characterized by manual or automatic target tracking through optical telescopes, TV, laser or radio devices while the missile is automatically tracked by including an infrared sensor in the launcher to detect the IR radiation from a source strapped on the rear part of missile. Then the motion parameters are transferred automatically to signals applied to the guidance unit. However, the guidance commands in this generation are transmitted to the missile through a remote link instead of wires.

Using a command link imposes some limitations upon the guidance system such as data rate of transfer, loop delay and jamming. In addition, the ever-increasing role of armored forces in modern combat directs the designers and manufacturers towards increasing the tank capabilities. These capabilities include tank power and design improvement, armor production, maneuverability of tanks and jamming. Fire efficiency has been increased by newly designed range finders-sights, stabilizing devices, and other appliances allowing the tanks to deliver effective fire during the motion and develop high combat speeds. However, the anti-tank guided missiles are usually following a parallel way for improvement and overcoming the tanks' capabilities. The performance of antitank guided missile systems is measured through the minimum miss-distance, and the capability of the missile to overcome different sources of jamming. One of the most interesting and challenging problem areas for antitank guided missile is that of the guidance and control. Toward this objective an antitank guided missile system that belongs to the second generation is considered for the autopilot design and analysis. Discussions about antitank guided missiles' systems specially those using optical IR tracking devices are given. Transfer functions representing the missile dynamics in pitch and yaw planes are considered for investigating and evaluating the autopilot design upon the system response. The control loop for both pitch and yaw channels of the intended guided missile system with compensation networks is designed and investigated for each channel such that the system is stabilized and the performance requirements are satisfied. In addition, an inner loop design is carried out using free gyroscope for the yaw channel to improve its performance. The robustness of these compensators and their ability to withstand disturbances and measurement noises are investigated through noise sources and unmodeled dynamics. The results obtained show that the classic approaches for design can be made robust with such systems. However, they need tuning from time to time to reject the disturbance and stabilize the system from operating condition to another.

2- Guidance System Errors

The guidance system is a control system where different measuring devices are utilized and never have ideal performance characteristics. Therefore, guidance errors arise during the missile flight due to the curvature of the kinematic trajectory and due to general defects in the system elements. That is, these errors are proportional to the missile crosswinds or normal acceleration. The engine thrust miss-alignment and asymmetry of the aerodynamic moment cause the actual or real missile trajectory to be deviated from the kinematic one. The wind causes accidental and stochastic influence upon the missile motion . The crosswinds cause changes in the angles of attack and side slip and consequently changes in the control forces and moments. The influence of the defects upon the missile motion is diminished or decreased through utilizing negative feedbacks. In addition, this influence can be reduced by selecting accurate measuring instruments and using a robust feedback design. It is desirable for the guided missile to perform on guidance commands with: short settling time, short delay time or fast reaction, and wide range of parameters' change to avoid the loss of system stability and to reduce the dynamic errors and the fluctuation errors.

The **kinematic trajectory** is defined as a space curve to be followed by the guided missile in accordance with the selected guidance method or the guidance law where the dynamic and fluctuation errors can be determined and corrected instantaneously. Moreover, the kinematic trajectory represents a curve on which the missile will fly without random fluctuation errors and without inertia. The **dynamic trajectory** is defined as a space curve along which the guided missile will fly due to inertia of the entire system and without interferences evoking the fluctuation errors. The **magnitude of the dynamic error** is specified by the distance between the kinematic trajectory points and the dynamic trajectory points at the same time instant. The **magnitude of the fluctuation error** is specified by the distance between the actual trajectory points and the dynamic trajectory points at the same time instant. The dynamic error at the instant of target interception with the kinematic trajectory represents the **dynamic component of the miss distance**. While the fluctuation error at the instant of target interception with the kinematic trajectory represents the **fluctuation component of the miss distance**. The sign of the dynamic error is given by the shape of the kinematic trajectory since the dynamic error itself is evoken by the delay of missile reaction and the entire system of steering on the change of motion conditions or parameters. The flatter the kinematic trajectory and the lower the missile speed the smaller the dynamic errors. The value of the dynamic and fluctuation errors changes in different way due to the inertial properties of the system. The dynamic error can be diminished by the proper choice of the guidance method covering the target and missile motion in addition to velocity vectors in an appropriate time and determining the missile kinematic trajectory[4].

3- Anti-Tank Guided Missile Systems

The human operator tracks the target only in the semi-automatic guidance system where the information about the missile is picked from it. The difference (missangle) between optical sight lines(the first line between tracker and target and the second line between tracker and missile)is automatically determined and the guidance commands are generated and transmitted to the missile for correcting its position in the space until hitting the target. The system under consideration belongs to the second generation, where the gunner acquires the target visually through the optical system of the tracking device, and tracks the target rather by optical or electro-optical means, depending on the conditions of visibility in the operating environment. Deviations of the missile from the intended line-of-sight trajectory are sensed by infrared detectors in the launcher. These detectors receive encoded information , from a source in the aft part of missile, which is processed in the launcher to provide azimuth and elevation correction commands. These commands are then sent to the missile over the wire link to bring the missile back on course. The missile performs corrective maneuvers by means of aerodynamic control surfaces which deflect in response to these guidance commands. The actuators respond to control signals from the missile electronics which process the pitch and yaw signals from the wire link as well as the roll and yaw signals from an inboard gyro. The propulsion system for the missile employs two separate rocket motors to keep the exhaust gases a safe distance from the gunner. The missile then coasts to the target as shown in Fig. 1 [11].

The wire command link is a two-wire system wherein single strand, high strength, insulated wire is dispensed from two small diameter bobbins mounted at the aft end of the missile. The wires are wound on the bobbins under tension so that they can be dispensed in a controlled manner which prevents them from becoming tangled or twisted. The circuit to the launcher is completed through the missile case. The command link wires are attached to terminals fitted to the inside of the case. The missile case contains additional wiring that connects the missile to the launcher through an umbilical connector assembled into the top of the case. This connector is mated when the missile is loaded into the launcher and the retaining clamp is closed, completing the circuits between the missile and launcher. The wire command link provides a passive link for the transmission of steering commands from the launcher to the missile. Additional advantages of the wire are its low cost and low electrical power requirement.

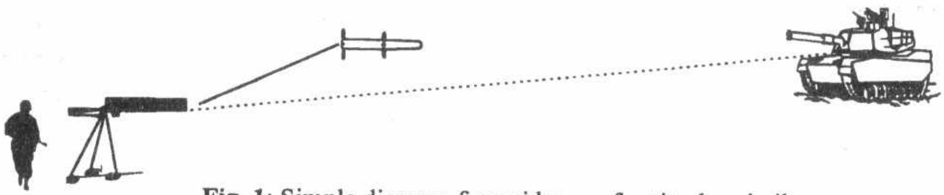

Fig. 1: Simple diagram for guidance of antitank missile

The electronics unit receives missile steering signals from the wire command link and missile attitude signals from the gyro, and applies driving voltages to the four control surface actuators. The signals from the single two-axis displacement gyro are shaped and superimposed on the steering signals to achieve missile roll stabilization and reduce the effect of cross winds on missile accuracy at short range. The gyro is activated by cold compressed gas which is stored in a small tank attached to the gyro case. Electrical power for the electronics, infrared sources, and actuator solenoids is provided by thermal batteries as shown in Fig. 2.

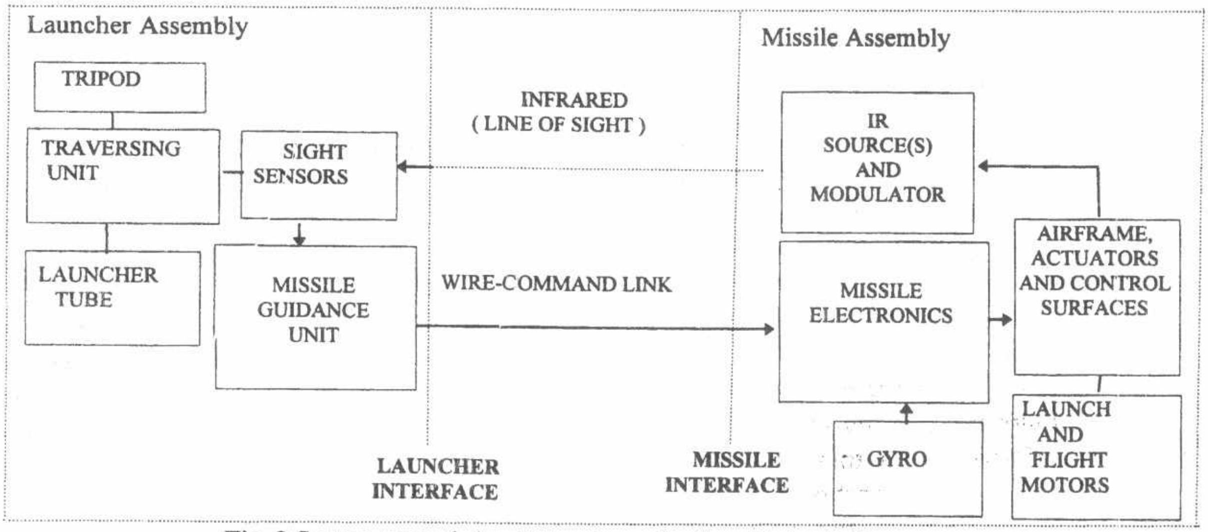

Fig. 2:System control signal flow for antitank guided missile

4- System Performance and Parameters

The underlying guided missile system uses the command-to-line-of-sight (CLOS) guidance method. That is, the missile is commanded to follow the line of sight (LOS) to the target. The operator keeps the sight reticle on the target center and as a result, the target sight data are measured and sent to the missile guidance unit (MGU).The MGU generates the guidance commands and sends them to the missile through the wire link [11]. These commands are applied to the flippers for keeping the missile on the LOS.

Simplified block diagrams representing the dynamics of the pitch and yaw channels are shown in Figs. (3, 4). The two channels are similar in design, except that the yaw channel has an inner stabilization loop. The MGU generates the appropriate guidance commands upon the measurement of target and missile motion parameters. The target angular coordinates are measured using the optical telescope on the tripod. There are two trackers, one senses the infrared (IR) radiation emitted from a modulated xenon lamp, and one senses the IR radiation emitted from a thermal source. Both the xenon lamp and the thermal source are located on the aft section of the missile. The MGU can select either tracker output data to guide the missile based on software selection algorithms. The output signals from the selected tracker are processed and converted into steering signals which are to be used for commanding the missile to return to the LOS. These signals are then summed with a Continuously Varying Amplitude sine wave carrier (CVAC). This composite signal is frequency modulated (FM) and transmitted to the missile through a low bandwidth wire link. The effect of proportional control is obtained by using duty cycle modulation of the pneumatic actuators. This "bang-bang" flipper control is obtained by demodulating the FM signal and passing the commanded signal plus CVAC through zero crossing detectors in the missile electronics package[11].

The guidance system is designed to minimize the missile trajectory deviations from the LOS. There are several error sources which introduce noise into the guidance loop. The predominant error sources are operator jitter, sensor electronics, atmospheric scintillation, flight motor thrust axis misalignment, gusts and crosswinds, variations in launch conditions, system imbalances, and electronic drifts. The system is designed to have adequate control capability to overcome these errors under normal operating conditions. This is accomplished by proper selection of the system time constants, gains, and offset/bias functions. Trade-off studies have been performed to balance the loop stability margins against the amplification of the system noise. The two channels have minimal coupling between them and consequently they are designed and investigated separately. The sensor and error detectors measure the missile angle from the electronic boresight. This is accomplished by either using the error detectors associated with the day sight optics, or using the software algorithms associated with the night sight video thermal sensor. The obtained signals are usually corrupted by noise due to different sources. Therefore a compensation network composed of a series of filters is used to overcome their effects. The performance requirements depend on the missile range. For example; short ranges require a high loop gain and fast response to minimize missile excursion due to initial launch transients, thrust misalignments and control surface imbalances. Long ranges require a lower loop gain and slower response to minimize the effects of IR sensor noise and operator jitter. Therefore, the compensation filters are designed to give the best performance at all ranges by varying the time constants at selected ranges.

The signal from sensor and error detector is filtered by the compensation network. In the pitch channel, then it is summed with the elevation tachometer input and a time varying gravity bias function to produce the missile flipper command. The missile must accelerate laterally and vertically to follow a movable line-of-sight (LOS). Steering commands are summed into the pitch and yaw channels to develop these required accelerations. The pitch and yaw line-of-sight rates are obtained from rate tachometers in the traversing unit. The tachometer outputs are filtered and amplified with the resulting steering commands summed in their respective channels with the closed loop guidance signals. In this way missile can be thought of as being commanded to the instantaneous line of sight. The command signal is introduced prior to the summation of the continuously variable amplitude sine wave carrier. Inputs into this time varying function are the output of tachometer after filtering and amplifying, the elevation and azimuth rate compensations, the gravity bias in the pitch channel and the yaw open loop steering in the yaw channel. The purpose of this limit function is two fold: first, the commanded missile angle of attack must not exceed the structural capabilities of the airframe and second, the commanded signal must be below levels at which excessive coupling between the steering loops and the roll channel could occur.

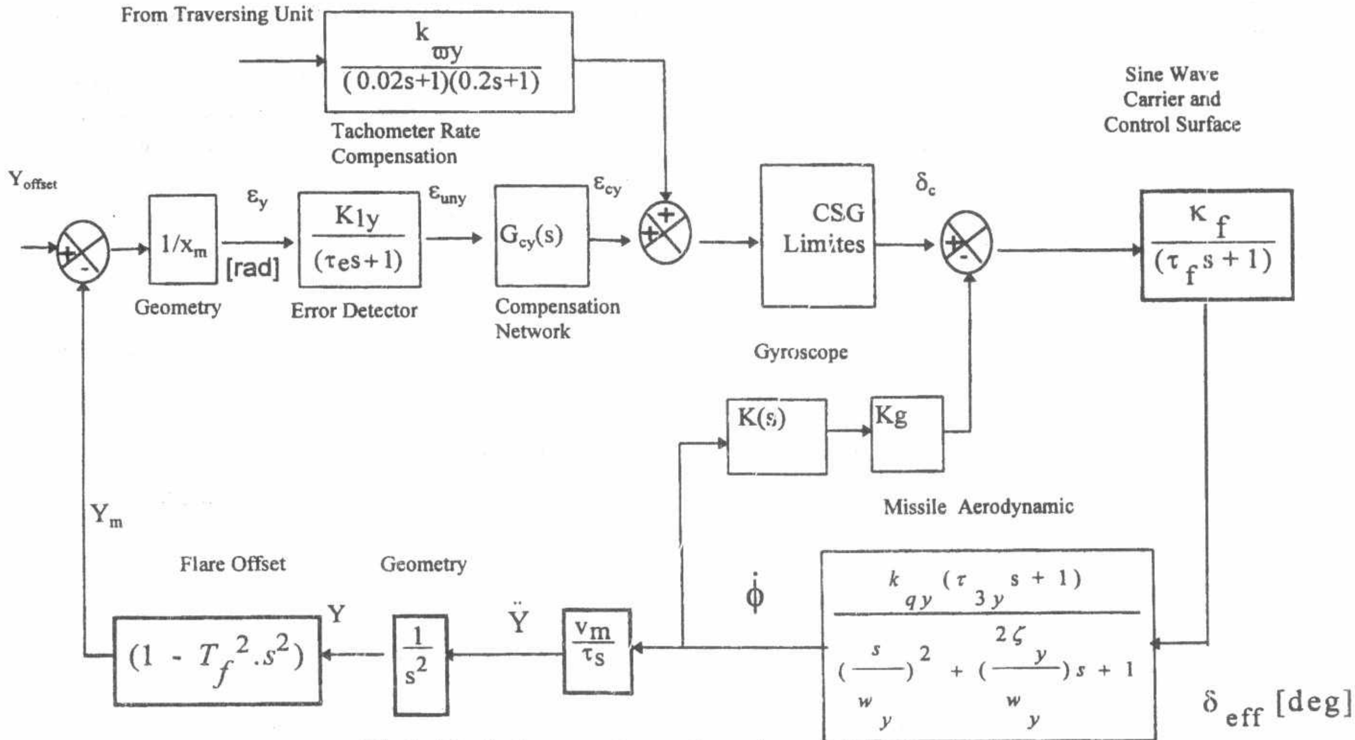

Fig.3: Block diagram of yaw channel

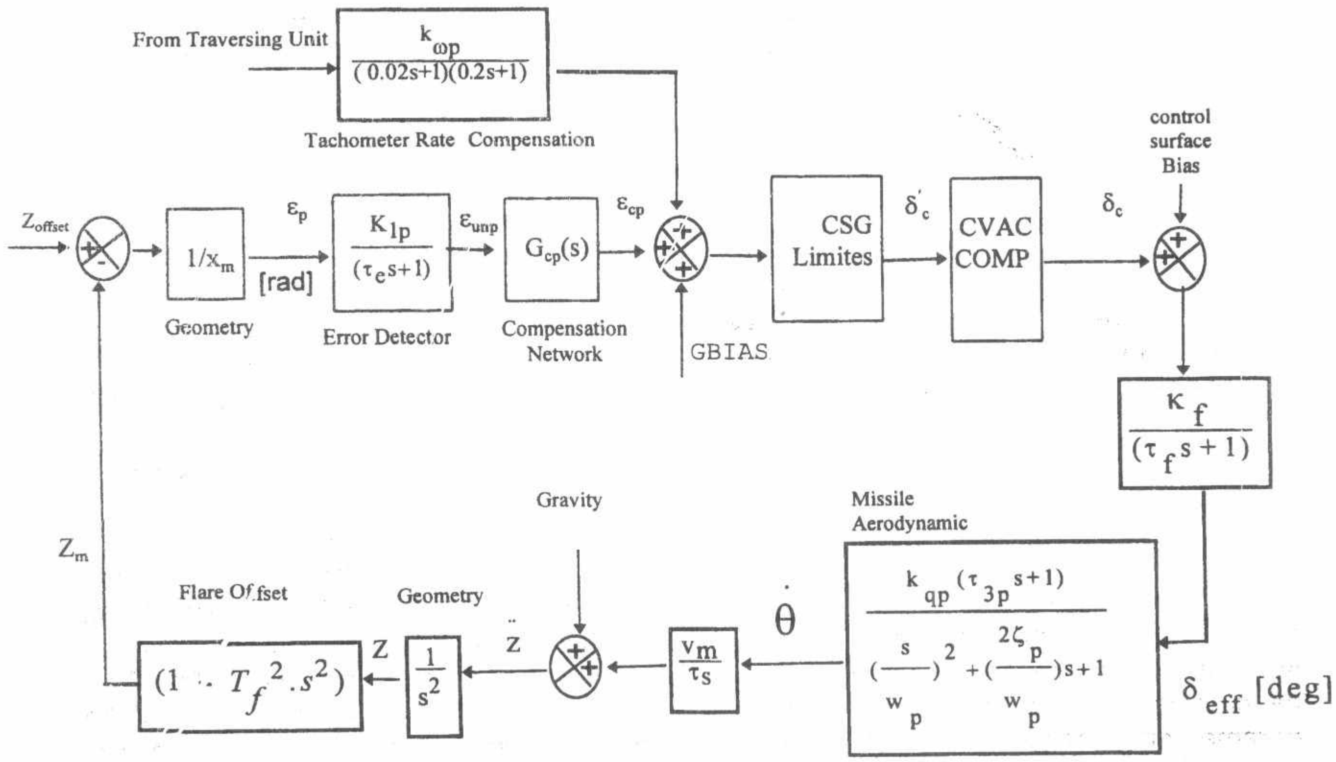

Fig .4: Block diagram of pitch channel

4.1 System parameters

The axial thrust force is a function of time whose profile and values are shown in Fig. 5, while the profile of missile velocity is shown in Fig. 6. [11]:

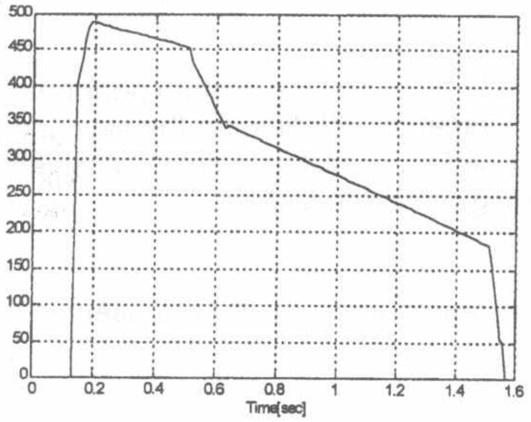

Fig.5: Thrust force profile

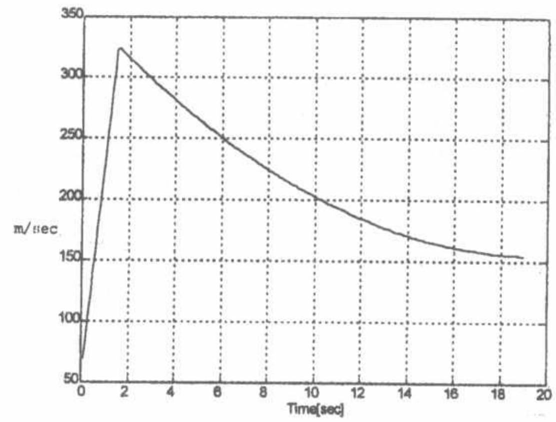

Fig.6: Profile of the missile velocity

These profiles are utilized in extracting the system dynamics needed for autopilot design and analysis, which is the subject of the next section.

4.2 Linearized flipper model

The flipper behaves as a first order system whose the Laplace transform has the following form:

$$\frac{\delta_{eff}(s)}{\delta_c(s)} = \frac{K_f}{\tau_f s + 1} \qquad (1)$$

The general shapes of the continuous varying amplitude carrier K_f for the yaw and pitch channels are shown in Fig. 7. The time constant τ_f =5[msec] is a linear approximation representing the phase lag in the electronics unit and time required for the flippers' actuator to change states. For the purpose of performance investigation a value of K_f is selected at certain time to yield the transfer function corresponding to this operating condition[11].

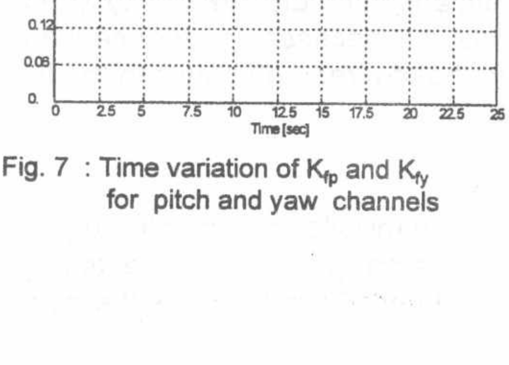

Fig. 7 : Time variation of K_{fp} and K_{fy} for pitch and yaw channels

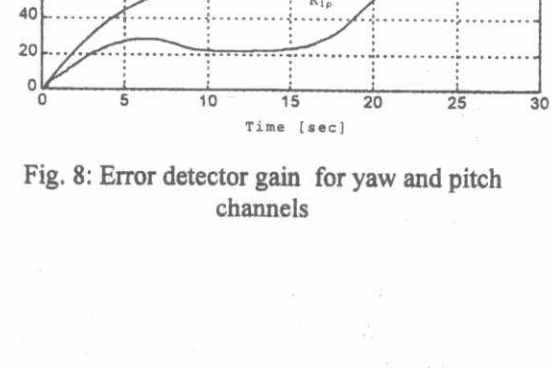

Fig. 8: Error detector gain for yaw and pitch channels

4.3 Linearized model of the error detector

The error detector used to measure the angular error signal can be represented by the transfer function:

$$\frac{\varepsilon_{unc}(s)}{\varepsilon(s)} = \frac{K1}{\tau_e s + 1} \tag{2}$$

This error detector has a time lag equal to 0.031 [sec] and the system performance is optimized by scheduling its gain. The gain variation with time for the yaw and pitch channels is shown in Fig. 8 [11]. Therefore, a certain operating point is considered for the investigation of the error detector functioning within the system.

4.4 Missile aerodynamics

The missile aerodynamics for the pitch or the yaw channel can be represented by the following transfer function[11]:

$$\frac{\alpha(s)}{\delta_{eff}(s)} = \frac{k_q(\tau_3 s + 1)}{(s/\omega_n)^2 + 2s\varsigma_n/\omega_n + 1} \tag{3}$$

where, (ς_n, ω_n) are the damping and natural frequency of the missile aerodynamics, Kq is the aerodynamic gain and τ_j is the lead time constant of either the pitch or yaw channel. Consequently the transfer function representing missile aerodynamics is time varying and therefore, for the purpose of investigation, a certain operating point is to be selected.

5- Autopilot Design and Analysis

Due to the nature of the guidance process, some special requirements are to be imposed on the system stability, system transient response, and on the miss distance. The errors affecting the missile performance are the flight motor thrust misalignment, missile tip-off rates, launch motor impulse, crosswinds, headwinds, wire link balances, and the gunner blinding. These errors can be controlled with close tolerances on error sources and by choosing the loop gain to be as high as possible, yet keeping the system stable. In the case where the target is performing evasive maneuvers, additional errors from target acceleration must be considered. This error suggests choosing the open loop gain as low as possible to average out the noise motion. In addition, the errors in the intended guidance system can arise from various sources such as control surface imbalances, electronic amplifier imbalances, gravity mismatch, and offset commands. The target maneuvers are to be expected only in the azimuth channel, and ground impacts need to be considered only in the elevation channel. Thus, the open loop gain of yaw is roughly twice the elevation value in order to maintain adequate performance against target acceleration. In order to obtain rapid transient response, it is necessary to maintain a high natural frequency with a good damping ratio. However to minimize noise inputs, it is necessary to reduce the natural frequency[3]. Therefore, the autopilot design has to trade off between the transient response and the minimization of noise effects.

5.1 Pitch channel compensation

The objective of guidance process is to correct the missile trajectory through its flight and to overcome the different sources of errors. The navigation equipments determine the position of missile and target at every moment until the missile hits the target. The open loop system performance is characterized by simple construction, easy maintenance and low cost. However, the open loop could not withstand disturbances and noises corrupting the system performance. In addition it could not overcome the effects due to changing operating conditions [2,3,5]. Therefore, the open loop system performance is analyzed first to stay on the motivation for compensated closed loop performance. For the purpose of analysis, an operating point is specified where the variables characterizing the system dynamic are given as follows: gain of pitch channel (K_{op}=9.13), time constant of flare (T_f=0.01), time constant of detector (τ_e=0.031), time constant of missile dynamic in pitch channel (τ_{1_p}=0.02) and aerodynamic turning rate time constant(τ_s=0.2).

It is clear that the open loop performance, Fig. 9, is not satisfactory. Thus, the closed loop is considered with unity compensator G_{cp}, for which the transfer function has the following form:

$$\frac{Z_m(s)}{Z_o(s)} = \frac{k_{op}(1 - T_f^{2}s^{2})(\tau_{3p}s + 1)}{k_{op}(1 - T_f^{2}s^{2})(\tau_{3p}s + 1) + \tau_s s^2(\tau_e s + 1)(\tau_f s + 1)[(\frac{s}{w_p})^2 + (\frac{2\zeta_p}{w_p})s + 1]} \quad (4)$$

Substituting the different variables into (4) yields:

$$\frac{Z_m(s)}{Z_o(s)} = \frac{9.13(1-(0.01)^2 s^2)(0.08s+1)}{9.13(1-(0.01)^2 s^2)(0.08s+1) + s^2(0.031s+1)(0.005s+1)[(\frac{s}{16})^2 + (\frac{2*0.6}{16})s + 1]} \quad (5)$$

Again the performance of the system using a unity compensator is not satisfactory due to its oscillatory behavior as shown from Fig. 9. Thus the compensation network can be considered a lead-lag network whose transfer function has the following form:

$$G_{cp}(s) = \frac{\varepsilon_{cp}(s)}{\varepsilon_{uncp}(s)} = \frac{C_{1p}(T_{1p}s + 1)}{\tau_{1p}s + 1} \quad (6)$$

where, $_{cp}$ and $_{uncp}$ are the electrical compensated and uncompensated missangle signal in pitch plane, C_{1p} = 2.5 is the gain of the pitch compensator and T_{1_p}, τ_{1_p} are time constants of the Lead-Lag network and selected to be (0.46, 0.04), respectively. The time constants T_{1p} and τ_{1_p} could be time varying to be appropriate for the varying conditions of system operation. However, for the purpose of the design analysis, it is enough to design a value for each of them to yield the appropriate compensator. The system stability and the high gain and phase margins are concerned in the selection of the values for $T_{1p}(t)$ and $\tau_{1_p}(t)$. The proper gain provides the phase lead necessary for system stability. The bode plot of the compensated system is shown in Fig.10, from which the gain margin= 15.6[dB] and the phase margin=35.25[deg]. In addition, the transient response is shown in Fig. 11, where the oscillatory behavior of output had disappeared, and the control effort is shown in Fig. 12. This figure shows how the control effort is smooth and settled fast within 1.2 [sec] to the steady state zero value.

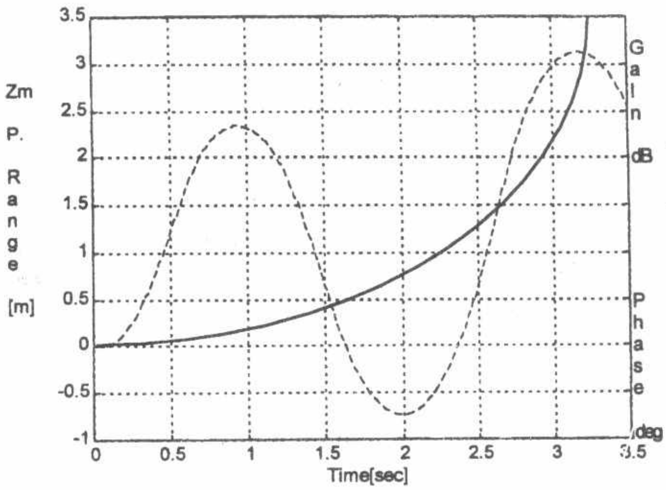

Fig. 9: ---- Closed loop step response
—— open loop step response

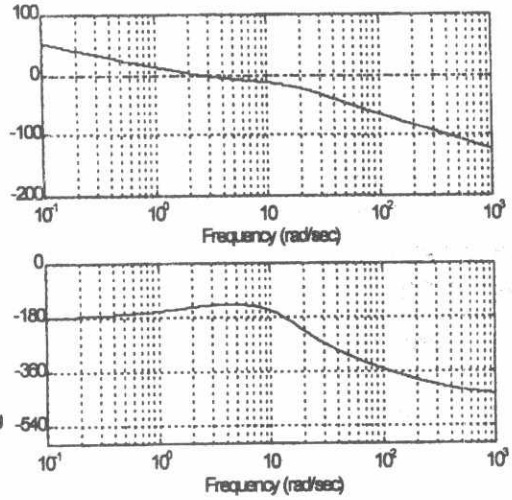

Fig.10: Compensated open loop bode plot

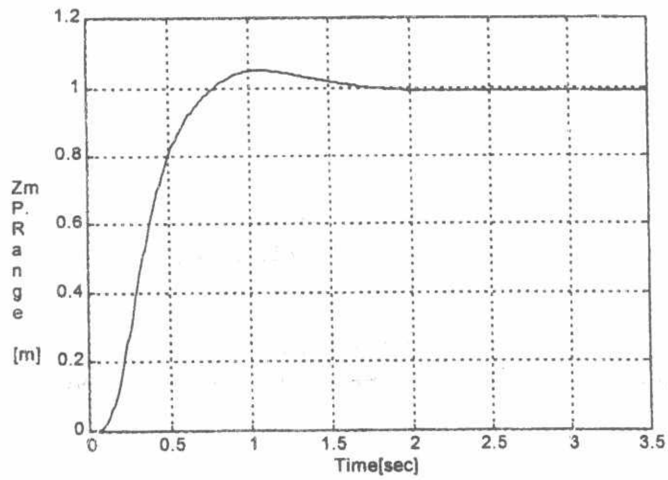

Fig.11: Closed loop step response

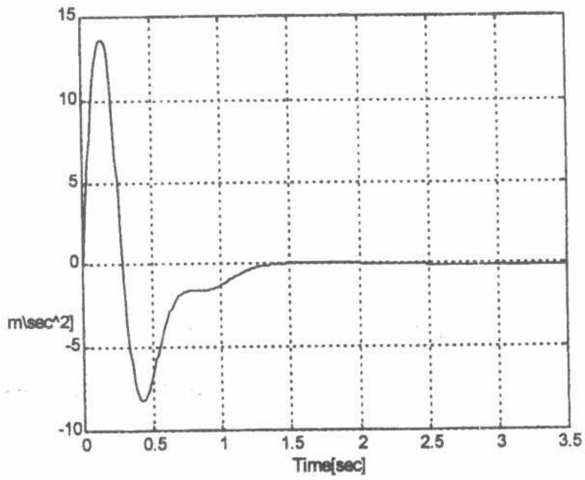

Fig.12: Missile acceleration

5.2 Yaw channel compensation

The missile guidance unit (MGU) supplies steering commands to the aerodynamic control surfaces for the missile maneuver toward its target. As known, the tank is maneuvering in the yaw plane and consequently the unity compensator may not be enough to insure a good stability, gain and phase margins for the yaw channel. Therefore, the analysis of the yaw channel is carried out using additional inner feedback loop through a gyro.The different parameters characterizing the dynamics of the yaw channel are selected as follows: gain of yaw channel (K_{oy}=59.15), time constant of flare (T_f=0.01), time constant of detector (τ_e=0.031), time constant of missile dynamic in yaw channel (τ_{1_y} =8.88) and aerodynamic turning rate time constant (τ_s=8.8). Therefore, the value of the yaw loop gain K_{oy} is equal approximately equal to double of K_{op} (i.e. K_{oy} =59.15) because the target maneuvers in azimuth plane only. Thus, to investigate the performance of the yaw channel, it is considered without the gyro and with the gyro in the next subsections.

5.2.1 Without gyro

Considering the yaw channel without gyro, the closed loop transfer function has the following form:

$$\frac{Y_m(s)}{Y_o(s)} = \frac{k_{oy}(1 - T_f^2 s^2)(\tau_{3y}s + 1)}{k_{oy}(1 - T_f^2 s^2)(\tau_{3y}s + 1) + s^2(\tau_e s + 1)(\tau_f s + 1)\left[\left(\frac{s}{w_y}\right)^2 + \left(\frac{2\zeta_y}{w_y}\right)s + 1\right]} \quad (7)$$

Substituting the different variables into Eqn (7) yields :

$$\frac{Y_m(s)}{Y_o(s)} = \frac{29.1(1-(0.01)^2 s^2)(0.1s+1)}{29.1(1-(0.01)^2 s^2)(0.1s+1) + s^2(0.031s+1)(0.005s+1)\left[\left(\frac{s}{15}\right)^2 + \left(\frac{2*0.6}{15}\right)s + 1\right]} \quad (8)$$

To stabilize the yaw channel, a lead-lag compensation network G_{cy} is considered whose transfer function has the following form:

$$G_{cy}(s) = \frac{\varepsilon_{cy}(s)}{\varepsilon_{uncy}(s)} = \frac{C_{1y}(T_{1y}s + 1)}{\tau_{1y}s + 1} \quad (9)$$

where, $\varepsilon_{cy}, \varepsilon_{uncy}$ are the electrical compensated and uncompensated missangle signal in yaw plane, C_{1y} = 3.4 is the gain of yaw compensator network and T_{1y}, τ_{1_y} are time constants of Lead-Lag network and selected to be (8.45, 8.835), respectively. The lead-lag filter given by T_{1y} and τ_{1_y} provides the phase lead necessary for system stability.

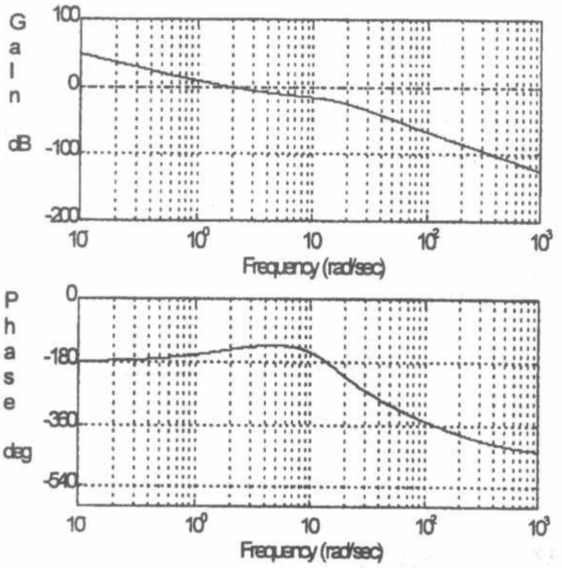

Fig. 14: Compensated open loop bode diagram

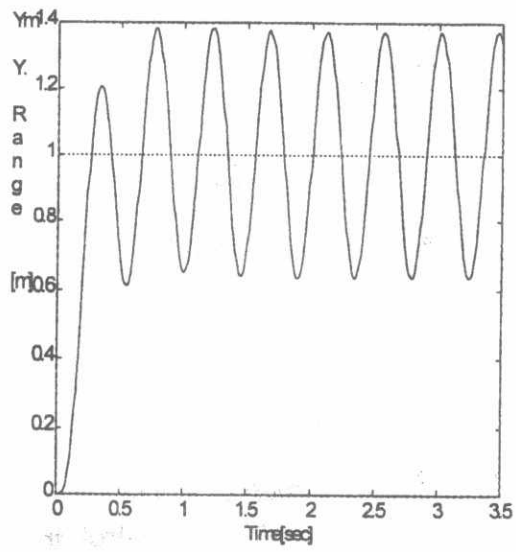

Fig. 13: Closed loop step response

The transient response of the system is shown in Fig. 13, where the response is fast but oscillating around an average level. In addition, the frequency response of the system is shown in Fig. 14, where the gain margin equals 19.4 [dB] and the phase margin is 38.8 [deg].

5.2.2 With gyro

To overcome the oscillation appeared in the system response, a gyroscope is used to sense the missile tilt angle of the yaw attitude. The gyro output information is summed with steering signals to provide additional feedback into the missile servos to modify the missile motion. The gyro transfer can be considered as first order or second order element. The first order gyro considered with unity gain and time lag equals to 0.1 [sec] . The transient response shown in Fig. 15 indicates how this type had damped the output oscillations. In addition, the frequency response is shown in Fig. 16 where the gain margin is 88[dB] and the phase margin is 43[deg]. To reduce the settling time (3.5 [sec]), the second order gyro is considered with natural frequency of 150[rad/sec] and damping coefficient equals 0.6. The transient response and frequency response are shown, respectively, in Fig. 15 and Fig. 16 from which it is clear that the settling time had decreased from 3.5[sec] to 0.8 [sec] while the gain margin is still 88[dB] and the phase margin decreased little to 38[deg]. To stay on the robustness of these compensators and their ability to withstand against disturbances, the measurements are corrupted with noise and the system performance is evaluated, which is the subject of next section.

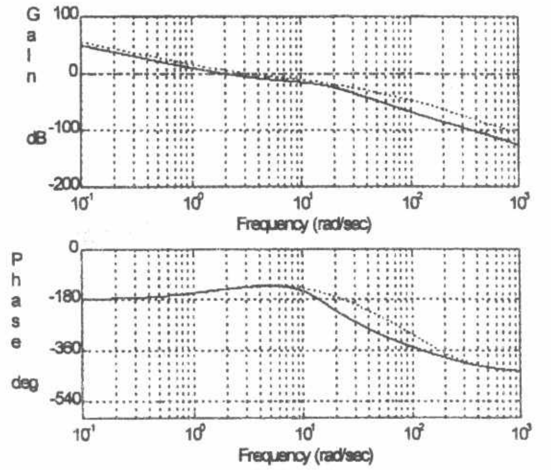

Fig. 16: Bode diagram of open loop

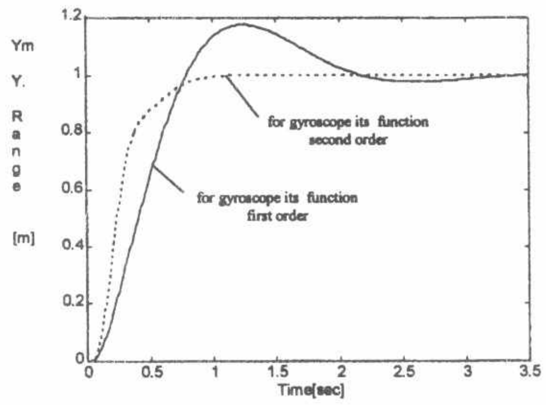

Fig. 15: Closed loop step response

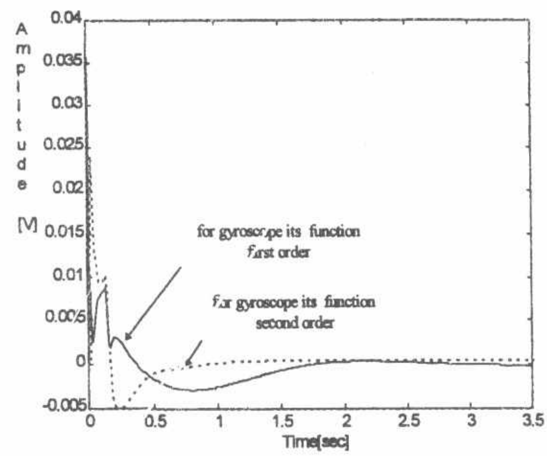

Fig. 17: Control effort signal

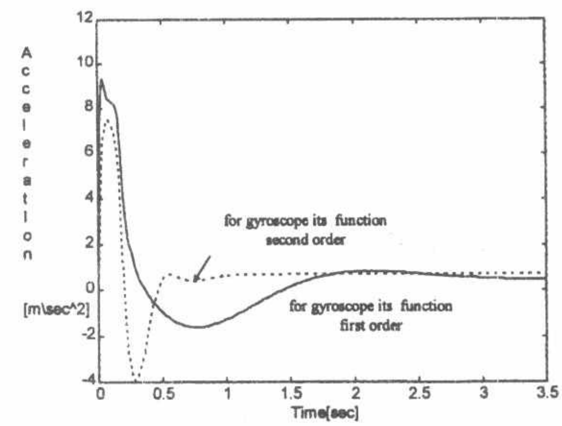

Fig. 18: Missile acceleration

5.3 Robustness of the designed autopilot

The development of control theory since about 1980 can be seen as a return to the ideas and principles established by Bode in 1930s, but one which has also led to considerable generalizations of these ideas [5]. Notions such as the *sensitivity function and stability margins*, which were rather eclipsed by the LQG theory [5] which dominated the 1960s and 1970s, have been re-established as central to the objectives of using feedback. Despite the effects of uncertainty on the system, the real problem in robust feedback control system design is to synthesize a control law which maintains system response and error signals within prespecified tolerances. The system uncertainties may be in the form of disturbance signals, measurement noise signals, unmodelled dynamics and/or unmodelled nonlinear distortion. Designing a highly accurate control system in the presence of plant uncertainty is a classical design problem, practically the plant parameters are never precisely known and may vary slowly over time. Therefore, it is necessary to design a control system that performs adequately over a range of plant parameters. This control system is said to be robust when it maintains a satisfactory level of stability and performance over a range of plant parameters and disturbances [2,3,5]. For the underlying system, the guidance commands are generated in accordance with signals representing the missile deviation from the target line of sight. These measured signals are usually contaminated by noises and therefore it is necessary to determine how such noise signals will alter the desired performance of the system.

5.3.1 Pitch channel with disturbance

For investigating the system performance with noise, a white noise signal with zero mean and 0.01 variance is injected with the useful signal to the system. The system response and control effort are shown in Fig. 19 and Fig. 20. From these results it is clear how the control effort is sensitive to such noise in spite of its low level and this will deteriorate the performance of the actuators and shorten their life time much. In addition, the transient response of demanded normal acceleration will be high.

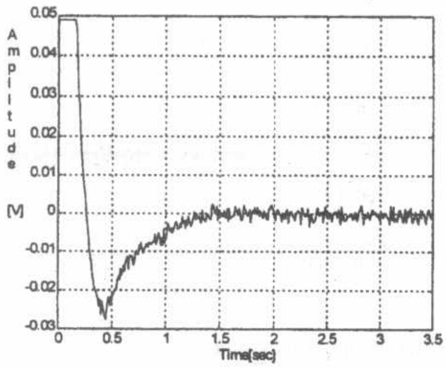

Fig. 20: Control effort signal with noise

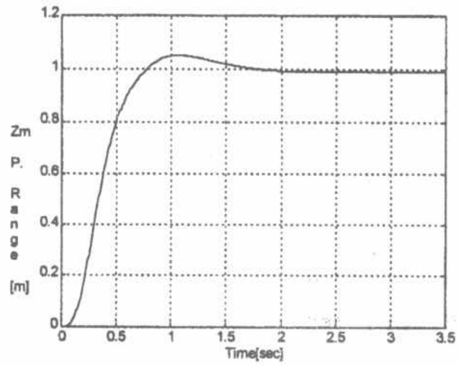

Fig. 19: Closed loop step response with noise

To improve the performance of the system under the noise, a second-order filter or an oscillating member is added to Gcp(s) for attenuation of high frequency sensor noise. That is, the transfer function of the compensator Gcp(s) becomes as follows:

$$G_{cp}(s) = \frac{\varepsilon_{cp}(s)}{\varepsilon_{uncp}(s)} = \frac{C_{1p}(T_{1p}s+1)}{\tau_{1p}s+1} * \frac{1}{[\frac{s}{w_p}]^2 + \frac{2\zeta_p}{w_p}s + 1} \tag{10}$$

where w_p, ζ_p are natural frequency and damped ratio of the oscillating member in pitch loop compensator and their values are (33 [rad/sec], 0.4), respectively. The response of this new system is shown in Fig. 21 where the overshoot had decreased by about 50% and also the settling time had decreased little. The control effort is shown in Fig. 22 from which it is clear how it become smoother than before and somehow noise free.

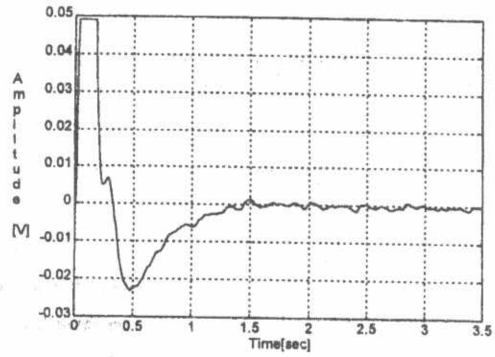

Fig. 22: Control effort signal

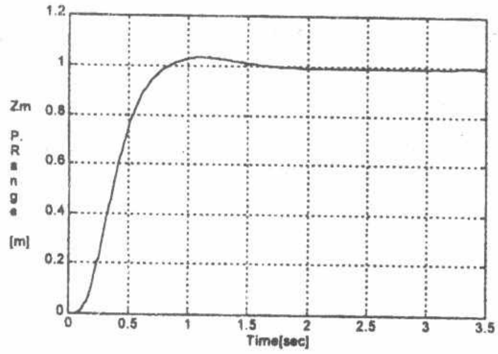

Fig. 21: Closed loop step response with noise

5.3.2 Yaw channel with disturbance

The yaw channel is investigated by applying a white noise with zero mean and 0.01 variance to the system in conjunction with useful signals. The system response and the control effort are shown in Fig. 23 and Fig. 24. These figures show that the control effort had gained the more contribution from the input noise.

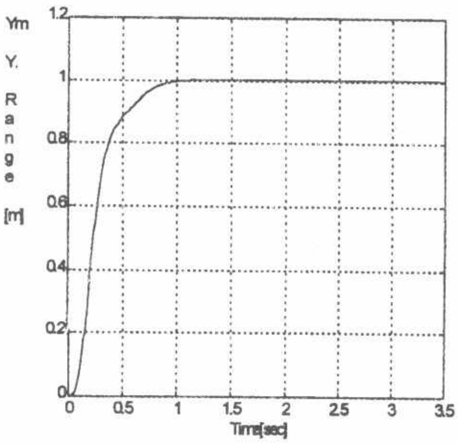

Fig. 23: Closed loop step response

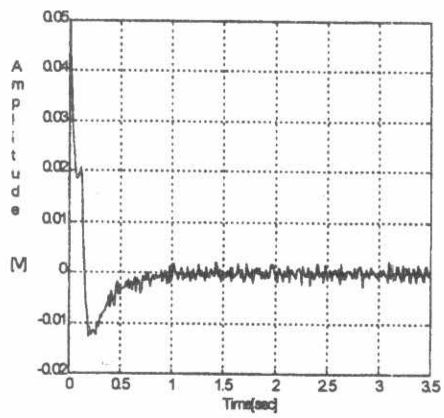

Fig. 24: Control effort signal

As a first trial to eliminate the effect of the noise, an oscillating member is added to the compensator as follows:

$$G_{cy}(s) = \frac{C_{1y}(T_{1y}s+1)}{\tau_{1y}s+1} * \frac{1}{[\frac{s}{w_y}]^2 + \frac{2\zeta_y}{w_y}s + 1} \qquad (11)$$

where w_y, ζ_y are natural frequency and damped ratio of filter in the yaw loop compensator and their values are (33 [rad/sec], 0.6). The system response and the control effort are shown in Figures (25, 26) from which it is clear that the control effort becomes smoother while the system response become sluggish.

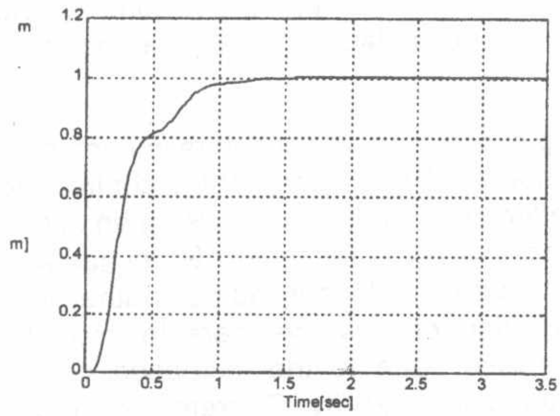

Fig. 25: Closed loop step response

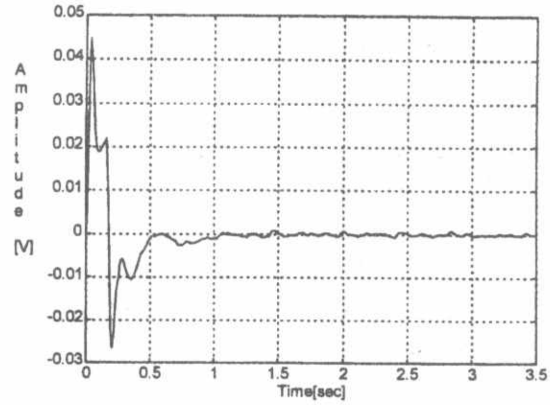

Fig. 26: Control effort signal

One approach to correct this side effect upon the system response is to utilize another lead-lag in cascade with compensator. That is, the transfer function of the compensator becomes as follows:

$$G_{cy}(s) = \frac{C_{1y}(T_{1y}s+1)}{\tau_{1y}s+1} * \frac{1}{[\frac{s}{w_y}]^2 + \frac{2\zeta_y}{w_y}s+1} * \frac{T_{2y}s+1}{\tau_{2y}s+1} \qquad (12)$$

where T_{2y} and τ_{2_y} are time constant of lag-lead network and selected to be (0.9, 1.05), respectively. The system response is shown in Fig. 27, where it become faster with very little overshoot. The control effort is shown in Fig. 28 and it is clear how it is still smooth but it became slower to pay for increasing the response speed.

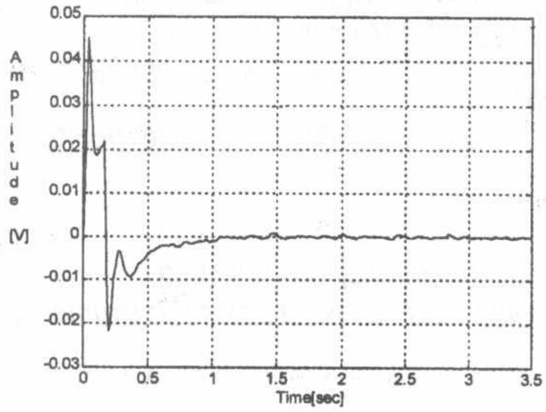

Fig. 28: Control effort signal

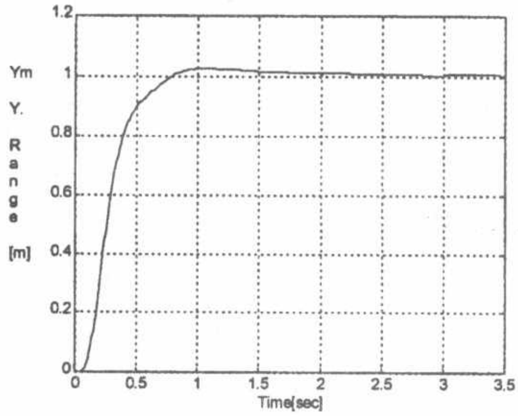

Fig. 27: Closed loop step response

Conclusions

The increasing importance of the antitank missile systems attracts the system engineering researchers all over the world to deal with as a purposeful aggregation of subsystems which are functionally interdependent. The variety of new missiles with higher performance requirements impulse new problems in structure, effectiveness of control, cost, reliability...etc. one of the most interesting and challenging problem areas for antitank missile is that of the guidance and control. The unity compensators were not adequate for stabilizing the guidance loops, nor suitable for achieving the performance requirements. Therefore, a compensation network is added to insure the stability and achieve the performance requirements. However, the yaw loop has important special state that the target maneuvers in this plane and consequently to achieve good results in this direction, a gyroscope is placed in the inner loop to meet target maneuver at different circumstances.

The autopilot design had carried out using cascaded compensators in each channel and investigated without and with external noises. It was clear that the control effort is the more sensitive to such noises. This effect was eliminated by using an oscillating member in cascade with the compensator. However, the yaw channel had another effect of making the response slower which overcome by cascading another lead-lag member with the compensator. The addition of new members to improve the robustness of the autopilot is not preferred due to the increased order and consequently complexity with cost and reduced reliability. Therefore, this system necessitates another approaches for tuning the classic controller leading to improve its robustness or locking for the advanced control techniques such as LQG and H . These techniques are the subject of future work.

References

[1]Andrew Grace, Alan J.Laub, John N.Little, and Clay Thompson, *Control System Toolbox*, The Mathworks,1990.

[2]Blakelock, J.B., *Automatic Control of Aircraft and Missiles*, Second Edition, John Wiley & Sons 1991.

[3]Dorf, R.C., *Modern Control Systems*, Sixth Edition, Addison Wiesley, 1990.

[4]EL-Sheikh, G.A., *Guidance and Control: Theory and Applications*, to be Published.

[5]EL-Sheikh, G.A., M.J.Grimble, and M.A.Johanson, *on the performance of GH self-Tuning for Aero Engine Control*, control-97, warwick University, March 01-07,1997, pp1306-1310.

[6]Garnell P. and D.J.East, *Guided Weapon Control System*,pergamon press 1977.

[7]Grace, Jason Kinchen , and Rob Mauceri , *Simulink*, The Mathworks, 1990.

[8]Hashad, A.I., *An Enhancement System For Guidance and Control of IR Command Guided Missiles*, M.Sc.thesis, Military Technical College, 1988.

[9]Lawrence, A., *Modern Inertial Technology: Navigation, Guidance and Control*, Springer Verlag, 1993.

[10]Locke, A.S., *Guidance*, D.Van Nostrand Company, 1955.

[11]Maintenance and Repair Documents of Tow.

[12]Puckett, A.E., and S.Ramo, *Guided Missile Engineering*, McGraw Hill,1959.

[13]Savet, P.H., *Gyroscopes: Theory and Design; with Applications to Instrumentation, Guidance and Control*, McGraw Hill, 1961.

[14]Zarchan, P., *Tactical and Strategic Missile Guidance*, Second Edition ,AIAA,1997.