COMPUTER SIMULATED DEVELOPMENT OF A COMMAND TO LINE-OF-SIGHT MISSILE USING ON-OFF CONTROL (U)
NAVAL POSTGRADUATE SCHOOL MONTEREY CA J Y YEUN DEC 83
UNCLASSIFIED
ELECTROLETHESIS

COMPUTER SIMULATED DEVELOPMENT
OF
A COMMAND TO LINE-OF-SIGHT MISSILE
USING ON-OFF CONTROL

by

Je Young, Yeun
December 1983

Thesis Advisor:

H. A. Titus

Co-advisor:

Alex Gerba, Jr.

Approved for public release; distribution unlimited
An on-off control provides a minimum time response for missile control. For application in missile control systems, it is wasteful of control effort (due to chatter) to use a ideal relay. Hence it is necessary to modify the ideal relay into a saturating linear control. The result was almost the same to that of using the ideal relay.
Computer Simulated Development
of a Command to Line-of-Sight Missile
Using ON-OFF Control

by

Je Young, Yeun
Lieutenant Colonel, Korean Air Force
B.S., Korean Air Force Academy, 1972

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1983

Author:

Approved by:

Thesis Advisor

Second Reader

Chairman, Department of Electrical Engineering

Dean of Science and Engineering
ABSTRACT

An on-off control provides a minimum time response for missile control. For application in missile control systems, it is wasteful of control effort (due to chatter) to use an ideal relay. Hence it is necessary to modify the ideal relay into a saturating linear control. The result was almost the same to that of using the ideal relay.
TABLE OF CONTENTS

I. INTRODUCTION ................................................. 9
II. OVERVIEW OF LINE-OF-SIGHT GUIDANCE CONTROL ........ 11
III. TYPICAL ENGAGEMENT SEQUENCE .......................... 15
IV. ON-OFF (BANG-BANG) CONTROL ............................ 19
V. BASIC COMMAND TO LINE-OF-SIGHT SIMULATION .......... 25
   A. SCENARIO .............................................. 25
   B. PROGRAMMED GUIDANCE PHASE ......................... 27
   C. ON-OFF, THRUST VECTOR, MISSILE CONTROL .......... 28
   D. SIMULATION RESULTS .................................. 28
VI. PSEUDO-LOS COMMAND SIMULATION ........................ 38
VII. SIMULATIONS WITH TWO-LEVEL RELAY AND
     SATURATION CONTROL .................................... 44
     A. TWO-LEVEL RELAY .................................... 44
     B. SATURATING LINEAR CONTROL ......................... 46
VIII. CONCLUSION .................................................. 59
APPENDIX A: VARIABLES LIST ................................... 61
APPENDIX B: PROGRAM OF THE SWITCHING FUNCTION .......... 62
APPENDIX C: PROGRAM OF THE BASIC COMMAND TO LOS ....... 63
APPENDIX D: PROGRAM OF THE MANEUVERING TARGET ......... 65
APPENDIX E: PROGRAM OF THE COMMAND TO PSEUDO-LOS .... 67
APPENDIX F: PROGRAM OF THE BASIC COMMAND TO LOS WITH
             TWO-LEVEL RELAY ................................... 69
APPENDIX G: PROGRAM OF THE MANEUVERING TARGET WITH
TWO-LEVEL RELAY ........................................ 71

APPENDIX H: PROGRAM OF THE COMMAND TO PSEUDO-LOS
WITH TWO-LEVEL RELAY .................................. 73

APPENDIX I: PROGRAM OF THE BASIC COMMAND TO LOS WITH
SATURATION CONTROL .................................... 75

APPENDIX J: PROGRAM OF THE MANEUVERING TARGET WITH
SATURATION CONTROL .................................... 77

APPENDIX K: PROGRAM OF THE COMMAND TO PSEUDO-LOS
WITH SATURATION CONTROL ................................ 79

LIST OF REFERENCES ........................................... 81

INITIAL DISTRIBUTION LIST .................................. 82
LIST OF TABLES

I. The Basic LOS Command Simulation Result ........ 37
II. The Pseudo LOS Command Simulation Result ........ 39
III. Two-Level Relay Control Result ............... 45
IV. Saturating Linear Control Result (N=1) ........ 49
V. Comparison of the Basic LOS Command Results .... 59
VI. Comparison of the Maneuvering Target Results .... 60
VII. Comparison of the Pseudo-LOS Command Results .... 60
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Missile Target Encounter with LOS Guidance</td>
<td>12</td>
</tr>
<tr>
<td>2.2</td>
<td>Basic Geometry</td>
<td>13</td>
</tr>
<tr>
<td>2.3</td>
<td>Simplified Guidance Loop of LOS Guidance</td>
<td>13</td>
</tr>
<tr>
<td>3.1</td>
<td>Roland Missile System Operational Schematic</td>
<td>18</td>
</tr>
<tr>
<td>4.1</td>
<td>Parabolic Switching Function</td>
<td>21</td>
</tr>
<tr>
<td>4.2</td>
<td>Block Diagram of ON-OFF Controller</td>
<td>21</td>
</tr>
<tr>
<td>4.3</td>
<td>CRE versus Time</td>
<td>22</td>
</tr>
<tr>
<td>4.4</td>
<td>CPE versus Time</td>
<td>22</td>
</tr>
<tr>
<td>4.5</td>
<td>F versus Time</td>
<td>23</td>
</tr>
<tr>
<td>4.6</td>
<td>CPE versus CRE</td>
<td>23</td>
</tr>
<tr>
<td>4.7</td>
<td>U versus Time</td>
<td>24</td>
</tr>
<tr>
<td>5.1</td>
<td>Simplified Flow Chart of Basic LOS Command</td>
<td>26</td>
</tr>
<tr>
<td>5.2</td>
<td>Geometry of Basic LOS Guidance</td>
<td>27</td>
</tr>
<tr>
<td>5.3</td>
<td>Block Diagram of the Basic LOS Command</td>
<td>28</td>
</tr>
<tr>
<td>5.4</td>
<td>The Basic LOS Command</td>
<td>29</td>
</tr>
<tr>
<td>5.5</td>
<td>The Basic LOS Command</td>
<td>31</td>
</tr>
<tr>
<td>5.6</td>
<td>The Basic LOS Command</td>
<td>32</td>
</tr>
<tr>
<td>5.7</td>
<td>The Basic LOS Command</td>
<td>33</td>
</tr>
<tr>
<td>5.8</td>
<td>The Maneuvering Target</td>
<td>34</td>
</tr>
<tr>
<td>5.9</td>
<td>The Maneuvering Target</td>
<td>35</td>
</tr>
<tr>
<td>5.10</td>
<td>The Maneuvering Target</td>
<td>36</td>
</tr>
<tr>
<td>5.11</td>
<td>U versus Time for a Maneuvering Target</td>
<td>37</td>
</tr>
<tr>
<td>6.1</td>
<td>Block Diagram of the Pseudo LOS Command System</td>
<td>38</td>
</tr>
<tr>
<td>6.2</td>
<td>The Pseudo-LOS Command</td>
<td>40</td>
</tr>
<tr>
<td>6.3</td>
<td>The Pseudo-LOS Command</td>
<td>41</td>
</tr>
<tr>
<td>6.4</td>
<td>The Pseudo-LOS Command</td>
<td>42</td>
</tr>
<tr>
<td>6.5</td>
<td>U versus Time for the Pseudo-LOS Command</td>
<td>43</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>7.1</td>
<td>Two-Level Relay</td>
<td>45</td>
</tr>
<tr>
<td>7.2</td>
<td>U versus Time for the Basic LOS Guidance</td>
<td>46</td>
</tr>
<tr>
<td>7.3</td>
<td>U verse Time against the MVR Target with Two-Level Relay</td>
<td>47</td>
</tr>
<tr>
<td>7.4</td>
<td>U verse Time of the Pseudo-LOS with Two-Level Relay</td>
<td>47</td>
</tr>
<tr>
<td>7.5</td>
<td>Linear Switching Relay</td>
<td>48</td>
</tr>
<tr>
<td>7.6</td>
<td>The Basic LOS Command (Saturation)</td>
<td>50</td>
</tr>
<tr>
<td>7.7</td>
<td>The Basic LOS Command (Saturation)</td>
<td>51</td>
</tr>
<tr>
<td>7.8</td>
<td>The Basic LOS Command (Saturation)</td>
<td>52</td>
</tr>
<tr>
<td>7.9</td>
<td>Maneuvering Target (Saturation)</td>
<td>53</td>
</tr>
<tr>
<td>7.10</td>
<td>Maneuvering Target (Saturation)</td>
<td>54</td>
</tr>
<tr>
<td>7.11</td>
<td>Maneuvering Target (Saturation)</td>
<td>55</td>
</tr>
<tr>
<td>7.12</td>
<td>Pseudo-LOS Command (Saturation)</td>
<td>56</td>
</tr>
<tr>
<td>7.13</td>
<td>Pseudo-LOS Command (Saturation)</td>
<td>57</td>
</tr>
<tr>
<td>7.14</td>
<td>Pseudo-LOS Command (Saturation)</td>
<td>58</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

Guided missiles are classified into four broad categories, depending on launch and target position characteristics. These categories are (1) air -to -air (2) air -to -ground (3) surface -to -air and (4) surface -to -surface. Each category of the above will employ one or more of the following guidance schemes; programmed command, line-of-sight, lead-angle, proportional navigation homing and inertial. The beam rider guidance is included in the line-of-sight guidance. A number of missiles also use a combination of these methods. For example, the initial part of the missile trajectory may use programmed guidance while the terminal phase may use beam-rider.

This thesis discusses the surface-to-air missile controlled by on-off, thrust vector, control. Consideration was given to determine the effects of the two-level relay and the saturation linear control. In order to verify the results, it was tested by using the type of control for three different types of missile-target scenarios:

(1) LOS command against non-maneuvering target
(2) LOS command against maneuvering target
(3) Pseudo-LOS command against non-maneuvering target.

In chapter 2, a discussion of a line-of-sight guidance was presented and a practical example of it was shown in chapter 3. The general concept of on-off control was described in chapter 4. The simulation results of the basic command to line-of-sight against both a non-maneuvering and a maneuvering target were shown in chapters 5 and that of pseudo-LOS case was in chapter 6. Finally, a discussion of two-level relay and saturating linear control was presented in chapter 7. A table of variables which were used in this
thesis is shown in the Appendix A. Computer simulation was accomplished using Digital Simulation Language, DSL.
II. OVERVIEW OF LINE-OF-SIGHT GUIDANCE CONTROL

A LOS system can be called a "3-point" guidance system since there is one point which defines the tracker, another the target and a third which defines the position of the missile. The object of the guidance system is to constrain the missile to lie as nearly as possible on the line joining the tracker and the target called the Line Of Sight (LOS). The concept is simple and can be implemented in many ways; perhaps it is this apparent simplicity which explains why many of the guided weapon systems as yet designed are LOS system.

Consider a target flying straight and at constant speed, and a missile flying at a different angle but constant speed, having been launched when the target occupies a position TO (see Figure 2.1).

After intervals of time of 1, 2, 3 etc seconds the LOS is shown as OT1, OT2, OT3 etc. Since the missile ideally always lies on these lines the flight path will be a curved one, for an approaching target, the curvature becomes increasingly severe towards the end of the engagement. We note that the tangent to the flight path at any one point defines the instantaneous direction of the missile velocity. It is seen that the missile velocity vector will, in general, not be directed along the LOS; towards the end of the engagement it may be at a considerable angle to it [Ref. 1].

In an actual situation the guidance signals transmitted to the missile are the demanded lateral accelerations (LATAX) in two axes at the right angles to the beam. These demands are resolved into missile axes within the missile. An error compensation term endeavouring to keep the error off the beam (\( \sigma_{mt} \)) equal to zero.
Figure 2.1  Missile Target Encounter with LOS Guide

A basic geometry and a simplified guidance loc shown in Figure 2.2 and Figure 2.3.

Suppose that the cross range error (CRE) of Fig 1 can be measured either directly or by means of the difference between OT and OM, together with some knowledge of missile range (Rm), then

\[ \text{CRE} = Rm(\sigma_t - \sigma_m) \]  \hspace{1cm} (2.1)

If this error off the beam is used as an acceleration \( U \), it needs some damping so that good response characteristics are obtained. A dynamic equation of the form

\[ \text{CRE} = G1(\text{CRE}) + G2(\text{CRE}) \]  \hspace{1cm} (2.2)

needs to be satisfied, where \( G1 \) and \( G2 \) are constants.

Necessity leads immediately to the consideration filtered error. In the presence of noise on the sight.
Figure 2.2  Basic Geometry

Figure 2.3  Simplified Guidance Loop of LOS Guidance
and hence on the cross range error, CRE, such a filter design is not simple and becomes a compromise between requirements for smoothing the noise and giving an adequate response to a demand. Modern techniques allow filters to be designed statistically if some knowledge of the noise characteristics is available or can be assumed. Figure 2.3 shows the position of such a filter $F(s)$ in the guidance loop. It includes a gain $G$, and the acceleration demand is

$$U = F(s) R_m \left( \alpha_t - \alpha_m \right)$$  \hspace{1cm} (2.3)

The missile transfer function is represented by $A(s)$ and when the achieved acceleration is doubly integrated and divided by $R_m$ it represents a new measure of the missile beam angle $(\alpha_m)$, thus closing the loop when differenced with the target beam angle $(\alpha_t)$.

While this concept is simply a LOS or beam riding guidance situation it is by no means as clear in homing how a guidance law can be devised in the absence of information on missile and target positions [Ref. 2].
III. TYPICAL ENGAGEMENT SEQUENCE

In order to provide a "vehicle" through which to better understand the basic aspects of command to line-of-sight guidance methodology, the engagement sequence of a short-range, air-defense, missile system is described. The Roland system was selected because the general operational aspects of the system are available at the unclassified level [Ref. 4].

The entry of one or more aerial targets into the range of the search radar is indicated to the Roland vehicle commander by an audible tone. At the same time, a synthetic display of the targets appears on a screen to give the commander all the information needed to select the most threatening target. The screen images are different for friendly and enemy targets. Also, the entry of the target into the missile envelope, utilizing target advanced-range computations, is indicated by a change in the display. With the search antenna raised and the search radar activated, target acquisition is possible even when the vehicle is in motion.

There are three modes of identification, friend or foe (IFF) interrogation: automatic, manual, and automatic within a given range.

When the commander has recognized a target as hostile and decided to engage it, he places a cursor over the screen image. This automatically brings the turret to bear and tracking can commence in either the "radar" or "optical" modes. In the "radar" mode, the tracking radar automatically accepts target designation from the search radar, searches for, locks onto, and tracks the target.
In the "optical" mode, the aimer searches for the target in elevation with an optical sight. To aid him an electronic instrument displays the maximum theoretical elevation for the search. When the aimer has acquired the target in his cross-hairs, he keeps the target in his sight by manipulating a control stick. This control keeps the target properly positioned by moving the turret in azimuth and swivelling a mirror in elevation.

As soon as the commander confirms that the target is within missile range, he initiates the firing sequence in the "radar" mode, or authorizes "optical" mode firing through a command displayed in the aimer's sight. The aimer, then, can initiate the firing sequence.

The missile is guided by a command to line-of-sight technique. This means that the target is tracked optically or by radar and the deviation of the missile from this line of sight is determined and corrected by a guidance command. The commander may switch from "radar" to "optical" and back again, as desired, even after the missile has been launched.

Target tracking and determination of the missile's deviation from the line of sight are different for each mode. In the "radar" mode, the guidance radar has two receiving channels. One is used for target tracking and the other is used to locate the missile in the radar lobe through reception of the missile's radio frequency beacons. By comparing these angles, an error between the missile and the target line of sight can be determined. In the "optical" mode, a biaxially-stabilized mirror is manually controlled to keep the target vertically in the aimer's sight and the turret is rotated to the azimuth of the target line of sight. An infrared goniometer is mounted to provide missile angle from the tracker by following flares mounted on the rear of the missile. Then, a deviation of the missile angle from the target line of sight can be determined.
Two groups of signals are introduced into the command computer: the velocity of the line of sight in azimuth and elevation, and the deviation of the missile from the line of sight in azimuth and elevation. Based upon data from the line-of-sight movement and the angular deviations of the missile, the necessary guidance signals are calculated.

The guidance signals are relayed to the missile by a transmitter with highly directional characteristics. The command-transmitting antenna is slaved to the missile angle in both azimuth and elevation. It, therefore, is trained on the missile continuously.

The side forces required for missile course corrections are produced through deflection of the exhaust jet of the sustainer motor by spoilers at the rear of the missile (thrust-vector control).

When the missile reaches the point of impact with the target, the warhead is detonated by either percussion, contact fuse or the radio-frequency, proximity fuse. The warhead consists of a radial-effect, multiple-fragmentation charge.

Figure 3.1 presents an operational schematic of the basic Roland missile system operation.

The computer simulations contained herein are generic in nature within the command to line-of-sight guided-missile type and have only reasonable estimates of missile capabilities introduced. This ensures unclassified results. At the same time, the simulations are of sufficient complexity to properly weigh the relative merits of the guidance variations discussed [Ref. 3].
From target & missile

SEARCH RADAR

TRACK RADAR

OPTICAL TRACK

MISSILE TARGET DEVIATION

COMMAND COMPUTER

FIRING AUTHORIZATION

AIMER

FIRE

FIRE*

MISSILE LAUNCH SEQUENCER

To missile

OPTICAL SIGHT

COMMAND TRANSMITTER

GUIDANCE & CONTROL COMMANDS

*Clear weather mode only

Figure 3.1 Roland Missile System Operational Schematic
IV. ON-OFF (BANG-BANG) CONTROL

As discussed before, LOS guidance maintains a missile position on the LOS. Usually missile position has a cross range error (CRE) and we want to reduce this error to zero in the minimum time. This kind of problem can be solved by using the on-off control. The basic concept of this is that:

Given a system for which the drive is limited (has a maximum or saturation value), the fastest response is obtained if maximum forward drive is applied at \( t = 0 \), and is reversed at a proper instant \( t = t_1 \) so that deceleration under maximum reverse drive reduces the velocity to zero at precisely the command value of the output. The drive is then set to zero.

The ideal relay permits only two conditions; full acceleration and full deceleration [Ref. 5].

From the Bang-Bang control law, we can derive the switching function which makes the error go to zero by using the proper switching time. From Newton's second law:

\[
P = m \dot{C}_{RE}\]

\[
\dot{C}_{RE} = \frac{d}{dt} (C_{RE}) = \frac{P}{m} = U
\]

\[
C_{RE} = C_{RE} \, dt = U \, t + k_1
\]

But at \( t = 0 \), \( C_{RE} = 0 \) and \( k_1 = 0 \). Therefore

\[
\dot{C}_{RE} = \frac{d}{dt} (C_{RE}) = U \, t \quad (4.1)
\]

\[
C_{RE} = C_{RE} \, dt = U \, t^2 + k_2 \quad (4.2)
\]
From the equation 4.1
\[ t = \frac{C\hat{E}}{U} \]
\[ t^2 = \left(\frac{C\hat{E}}{U}\right)^2 \] (4.3)
Substitute equation 4.3 into equation 4.2
\[ C\hat{E} = \frac{U}{2} \left(\frac{C\hat{E}}{U}\right)^2 + k2 \]
\[ = \frac{(C\hat{E})^2}{2U} + k2 \] (4.4)
where \( k2 \) is integration constant. But if we apply a full deceleration at the halfway point, the equation 4.4 becomes
\[ F = \frac{(C\hat{E} + |C\hat{E}|)}{2U} + C\hat{E} \] (4.5)
and is called the ERROR FUNCTION. \( U \) will be
\[ U = \pm G \]
or
\[ U = -(G) \text{SIGN}(F) \] (4.6)
Equations 4.5 and 4.6 represent the SWITCHING FUNCTION which makes the error go to zero in the minimum time. The switching function and the block diagram of the on-off controller are depicted on the Figures 4.1 and 4.2. And we can obtain the cross range error, \( C\hat{E} \), by doubly integrating \( U \) with the initial condition of \( C\hat{E} \). We have
\[ C\hat{E} = U \, dt + C\hat{E}(0) \]
\[ C\hat{E} = \int C\hat{E} \, dt + C\hat{E}(0) \] (4.7)
The simulation results of these equations are given on Figures 4.3 through 4.7 and the computer program is attached (see Appendix B).
Figure 4.1 Parabolic Switching Function

Figure 4.2 Block Diagram of ON-OFF Controller
Figure 4.3  CRE versus Time

Figure 4.4  CRE versus Time
Figure 4.5  F versus Time

Figure 4.6  CRE versus CRE
Figure 4.7  U versus Time
V. BASIC COMMAND TO LINE-OF-SIGHT SIMULATION

A. SCENARIO

The engagement was designed with the ground tracker and missile launching unit located at the origin.

The target was flown across the first quadrant from a position 4000 meters on the x-axis and 1000 meters on the y-axis (4000,1000). The velocity vector of the target was parallel to the x-axis and magnitude was 250 meters per second.

Since most missiles need a few seconds of boost, the missile is not controlled during this time. We assumed that the missile was controlled after one second from the firing time and controlled by PROGRAMMED GUIDANCE up to this time. After the time of missile "capture", the missile was controlled by the on-off, TVC method with the LOS guidance law. The simplified flow chart is shown in the Figure 5.1.

In order to simplify the problem, we assumed that:

1) the velocity vector of missile, \( V_m \), was parallel to the LOS between the target and origin and the magnitude of \( V_m \) was constant, 500 meters per second;
2) the LATAX was applied to the missile at right angles to the LOS. This was a reasonable assumption for this kind of missile. So the angle \( \phi + \alpha_m \), in the Figure 2.2 is almost same to angle \( \alpha_t \);
3) the measurement noise was zero so we omitted the filter, \( F(s) \);
4) the magnitude of LATAX was 150 meters/second\(^2\) which was about 15 Gs.

The geometry depicted in Figure 5.2 summarizes the geometric situation.
Figure 5.1  Simplified Flow Chart of Basic LOS COMM
For mathematical convenience of simulation, we need to define the sign of the CRE and the LATAX as follow:

+|CRE| : When the missile position is upper-side of LOS
-|CRE| : when the missile position is lower-side of LOS
+ |U| : when the LATAX is upward direction
- |U| : when the LATAX is downward direction

This sign was based on the positive $\sigma_M$ which is defined when $\sigma_M$ is greater than $\sigma_t$.

B. PROGRAMMED GUIDANCE PHASE

Since the major emphasis of this paper was on-off control, we assumed that the missile flew along the LOS during the programmed guidance phase. But, in a practical situation, there is some cross range error which is occurred by disturbances such as wind, propulsion system and
autopilot time delay, etc. Hence we made initialization errors, and the on-off control started with these errors.

C. ON-OFF, THRUST VECTOR, MISSILE CONTROL

The detail of the on-off control was discussed before, hence we applied this to the LOS guidance scheme. The block diagram of this system is depicted in the Figure 5.3 [Ref. 3].

In order to determine the CRE, the tracker estimates the missile's range \( R_m \), by the elapsed time of flight and the missile's velocity profile. The program of this simulation is attached in Appendix C.

![Block Diagram of the Basic LOS Command](image)

Figure 5.3 Block Diagram of the Basic LOS Command

D. SIMULATION RESULTS

Figure 5.4 shows the missile and target geometry in X-Y plane. The missile intercepted the target at the point \( A(2605,1000) \) with the almost zero miss distance.
Figure 5.5(a) shows the distance between target and missile versus time. The distance decreased linearly and neared zero at the time at 5.58 seconds.

Figure 5.4 The Basic LOS Command

Figure 5.5(b) shows the CRE versus time. The initial cross range error at the missile capture time one second after firing was about 50 meters. Since the CRE at the "missile capture time" was positive, the CRE increased initially. So the maximum CRE was about 58.2 meters at the time 1.330 seconds. Then it decreased to almost zero meter at 2.55 seconds. To get a faster response, we should increase the magnitude of the LATAX. We should note here
that the CRE does not maintain zero value because we did not consider the target motion terms in this phase of the simulation [Ref. 2]. So the missile had some small cross range error and the BANG-BANG controller had tried to reduce this error in a chatter-mode.

Figure 5.6(a) shows the CRE versus time. Figure 5.6(b) shows the CRE versus CRE. As we expected this curve followed the SWITCHING FUNCTION as shown in figure 4.4. Figures 5.7(a) and 5.7(b) show the F versus time and the U versus time.

This program was tested using maneuvering targets and the results were almost same except the impact position. The results of this simulation were shown on the Figures 5.8 through 5.11 and the program is attached in Appendix D. The comparison of these simulations is summarized in Table I.
Figure 5.5 The Basic LOS Command
Figure 5.6  The Basic LOS Command
Figure 5.7  The Basic LOS Command
Figure 5.8 The Maneuvering Target
Figure 5.9 The Maneuvering Target
Figure 5.10 The Maneuvering Target

(a) CRE versus CRE
(b) F versus Time

ERROR F vs. TIME WITH MANEUVERING TARGET

TIME

CRE

CRE
Figure 5.11  U versus Time for a Maneuvering Target

<table>
<thead>
<tr>
<th>TABLE I</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Basic LOS Command Simulation Result</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>NON-MANEUVRING TARGET</th>
<th>MANEUVERING TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{time(control)} = 1.0 \text{ sec} )</td>
<td>( \text{time} = 1.0 \text{ sec} )</td>
</tr>
<tr>
<td>( \text{CRE(0)} = 49.910(\text{m}) )</td>
<td>( \text{CRE} = 49.907(\text{m}) )</td>
</tr>
<tr>
<td>( \text{CRED(0)} = 49.832(\text{m/sec}) )</td>
<td>( \text{CRED} = 49.891(\text{m/sec}) )</td>
</tr>
<tr>
<td>( \text{time(max.CRE)} = 1.33 \text{ sec} )</td>
<td>( \text{time} = 1.33(\text{sec}) )</td>
</tr>
<tr>
<td>( \text{CRE(max)} = 58.184(\text{m}) )</td>
<td>( \text{CRE} = 58.201(\text{m}) )</td>
</tr>
<tr>
<td>( \text{time(intercept)} = 5.58 \text{ sec} )</td>
<td>( \text{time} = 5.61 \text{ sec} )</td>
</tr>
<tr>
<td>( (X_m,Y_m) = (2604.7, 999.88) )</td>
<td>( (2597.9, 1057.7) )</td>
</tr>
<tr>
<td>( \text{CRE} = 4.3344 \times 10^{-5} )</td>
<td>( -6.5448 \times 10^{-6} )</td>
</tr>
<tr>
<td>( \text{distance} = 0.34894(\text{m}) )</td>
<td>( 0.47889(\text{m}) )</td>
</tr>
</tbody>
</table>

37
VI. PSEUDO-LOS COMMAND SIMULATION

The guidance scheme of the lead angle command is almost the same as that of the basic LOS command. Instead of the tracker-to-target line-of-sight this guidance scheme uses the tracker-to-estimated impact point and is called "synthetic line-of-sight" (SLOS), or "pseudo line-of-sight". The missile is controlled to fly along this pseudo line-of-sight. The block diagram of this system is easily modified from that of the basic LOS and is shown in Figure 6.1.

The estimated impact point at the instantaneous time is calculated by using the "time to go" (Tg) and the "closing velocity" (Vc) between the target and the missile.

![Figure 6.1 Block Diagram of the Pseudo LOS Command System](image)

38
The "closing velocity" and "time to go" are calculated as follow:

\[ V_c = \left( (V_{tx} - V_{mx})^2 + (V_{ty} - V_{my})^2 \right)^{1/2} \]

\[ T_g = \frac{\text{distance between target and missile}}{V_c} \]

\[ = \frac{((X_t - X_m)^2 + (Y_t - Y_m)^2)^{1/2}}{V_c} \]

The missile goes to the impact point directly. The simulation result is almost same as in the basic LOS case. On other hand, this guidance scheme is poor in an ECM situation. In order to compare the results we used the same data as that of the basic LOS command. These are shown in Figures 6.2 through 6.5 and the summarized results are shown in Table II. The computer program is attached in Appendix E.

| TABLE II |
| The Pseudo LOS Command Simulation Result |

| .time (control) | 1.0 sec |
| .CRE (0) | 43.912 (m) |
| .CRE (0) | 43.823 (m/sec) |
| .time (MAX.CRE) | 1.33 sec |
| .CRE (max) | 58.184 (m) |
| .time (intercept) | 5.58 sec |
| (X_m,Y_m) | (2604.7, 999.92) |
| (X_t,Y_t) | (2605.0, 1000.0) |
| .CRE | 2.9572 |10^{-5}(m) |
| .miss-distance | 0.35137 (m) |
Figure 6.4 The Pseudo-LOS Command
Figure 6.5  U versus Time for the Pseudo-LOS Command
VII. SIMULATIONS WITH TWO-LEVEL RELAY AND SATURATION CONTROL

The LOS guidance with an "ideal" relay has been discussed. In this chapter, the effect of the different types of lateral acceleration demand are discussed. In order to compare the results with the previous simulations, the same parameters were used.

A. TWO-LEVEL RELAY

The large magnitude of the LATAX makes a fast response. But in the case of small CRE, a smaller magnitude of LATAX is needed. This idea was developed in a "two-level" relay as shown on the Figures 7.1(a;b). The shaded area on Figure 7.2(b) shows the region of a lower level of LATAX in the "CRE versus CRE" phase plain. It provided the minimum over-correction. The computer programs were easily modified by adding one statement,

\[
\text{IF } (|\text{CRE}|+|\text{CRE}|) \lt M \text{ THEN } G = 3/(N1/N2).
\]

We used the values 150 m/sec² for N1 and 15 m/sec² for N2 and 1.0 for M in the simulations of the basic LOS command and the pseudo LOS command. The results were almost the same as the previous, except in the figure for "U versus time". Table III summarized these simulation results and Figures 7.2, 7.3 and 7.4 show the "U versus time" of each case. The programs were attached in Appendix F, G and H.
Figure 7.1 Two-Level Relay

TABLE III
Two-Level Relay Control Result

<table>
<thead>
<tr>
<th>UNIT</th>
<th>NON-MVR</th>
<th>MVR-TGT</th>
<th>PSEUDO-LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>.time(control)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>CRE(0)</td>
<td>49.910</td>
<td>49.907</td>
<td>49.910</td>
</tr>
<tr>
<td>CRE(0)</td>
<td>49.832</td>
<td>49.891</td>
<td>49.828</td>
</tr>
<tr>
<td>.time(MAX.CRE)</td>
<td>1.33</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td>CRE(max)</td>
<td>58.184</td>
<td>58.201</td>
<td>58.184</td>
</tr>
<tr>
<td>.time(intercept)</td>
<td>5.58</td>
<td>5.61</td>
<td>5.58</td>
</tr>
<tr>
<td>Xa</td>
<td>2604.7</td>
<td>2597.9</td>
<td>2604.7</td>
</tr>
<tr>
<td>Ym</td>
<td>999.98</td>
<td>1057.7</td>
<td>999.92</td>
</tr>
<tr>
<td>It</td>
<td>2605.0</td>
<td>2597.5</td>
<td>2605.0</td>
</tr>
<tr>
<td>Et</td>
<td>1000.0</td>
<td>1057.5</td>
<td>1000.0</td>
</tr>
<tr>
<td>CRE</td>
<td>-2.63E-6</td>
<td>-3.63E-6</td>
<td>5.03E-8</td>
</tr>
<tr>
<td>miss-distance</td>
<td>0.34894</td>
<td>3.47889</td>
<td>0.35137</td>
</tr>
</tbody>
</table>
Figure 7.2  \( U \) versus Time for the Basic LOS Guidance

B. SATURATING LINEAR CONTROL

In the previous section the two-level relay was discussed. The "saturating linear control" as depicted in the Figure 7.5(a) and 7.5(b) was also studied. The shaded area on the Figure 7.5(b) shows the region of linear control in the "CRE versus CRE" phase plane. The computer programs were easily modified by adding one statement,

\[
\text{IF (ABS}(F).\text{LE.} M) \quad U = -3 * F / M.
\]

The value of "\( M \)" determines the linear region for \( F \). The Figures 7.6 through 7.8 show the simulation results of the basic LOS command against the non-maneuvering target case for "\( M \)" equal 1.5 and 10. When choosing the value "\( M \)" equal to "one", the intercept time and miss distance are almost the same as the counterpart of the ideal relay case. Hence the saturating linear control can be used in practice
Figure 7.3  U versus Time against the MVR Target with Two-Level Relay

Figure 7.4  U versus Time of the Pseudo-LOS with Two-Level Relay
instead of the ideal relay by choosing a proper value of "M". The summarized results are in the Table IV. Figures 7.9 through 7.11 show the results of the maneuvering target case and Figures 7.12 through 7.14 show the results of the pseudo-LOS case. These programs are given in Appendix I, J and K.

Figure 7.5 Linear Switching Relay
<table>
<thead>
<tr>
<th>UNIT</th>
<th>NON-MVR</th>
<th>MVR-TGT</th>
<th>PSEUDO-LOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>time (control)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>CRE (0)</td>
<td>49.910</td>
<td>49.907</td>
<td>49.912</td>
</tr>
<tr>
<td>CRE (0)</td>
<td>49.832</td>
<td>49.891</td>
<td>49.828</td>
</tr>
<tr>
<td>time (MAX. CRE)</td>
<td>1.33</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td>CRE (max)</td>
<td>58.184</td>
<td>58.201</td>
<td>58.184</td>
</tr>
<tr>
<td>time (intercept)</td>
<td>5.58</td>
<td>5.61</td>
<td>5.58</td>
</tr>
<tr>
<td>Xm</td>
<td>2604.7</td>
<td>2598.0</td>
<td>2604.7</td>
</tr>
<tr>
<td>Ym</td>
<td>999.84</td>
<td>1057.6</td>
<td>999.88</td>
</tr>
<tr>
<td>Xt</td>
<td>2605.0</td>
<td>2597.5</td>
<td>2605.0</td>
</tr>
<tr>
<td>Yt</td>
<td>1000.0</td>
<td>1057.5</td>
<td>1000.0</td>
</tr>
<tr>
<td>CRE</td>
<td>-0.349</td>
<td>-0.0702</td>
<td>-0.349</td>
</tr>
<tr>
<td>miss-distance</td>
<td>0.3507</td>
<td>0.4841</td>
<td>0.3492</td>
</tr>
</tbody>
</table>
Figure 7.6 The Basic LOS Command (Saturation)
Figure 7.7 The Basic LOS Command (Saturation)
Figure 7.8  The Basic LOS Command (Saturation)
Figure 7.9 Maneuvering Target (Saturation)
Figure 7.11 Maneuvering Target (Saturation)
Figure 7.12  Pseudo-LOS Command (Saturation)
Figure 7.13  Pseudo-LOS Command (Saturation)
VIII. CONCLUSION

The comparison of results for the ideal relay, two-level relay and saturating linear control against the basic LOS command and pseudo-LOS command against a non-maneuvering target and maneuvering target are provided in the Tables V, VI and VII. These simulation results clearly demonstrate that "on-off" control of a missile is highly desirable and that "saturating linear control" of a missile has little adverse effects compared to an "ideal relay" control.

| TABLE V |
| Comparison of the Basic LOS Command Results |

<table>
<thead>
<tr>
<th>UNIT</th>
<th>IDEAL RELAY</th>
<th>TWO-LEVEL RELAY</th>
<th>SATURATION CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>time(control)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>CRE(0)</td>
<td>49.910</td>
<td>49.910</td>
<td>49.910</td>
</tr>
<tr>
<td>CRED(0)</td>
<td>49.832</td>
<td>49.832</td>
<td>49.832</td>
</tr>
<tr>
<td>time(MAX.CRE)</td>
<td>1.33</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td>CRE(max)</td>
<td>58.184</td>
<td>58.184</td>
<td>58.184</td>
</tr>
<tr>
<td>time(intercept)</td>
<td>5.58</td>
<td>5.58</td>
<td>5.58</td>
</tr>
<tr>
<td>Xm</td>
<td>2604.7</td>
<td>2604.7</td>
<td>2604.7</td>
</tr>
<tr>
<td>Ym</td>
<td>999.88</td>
<td>999.88</td>
<td>999.88</td>
</tr>
<tr>
<td>CRE</td>
<td>4.338-5</td>
<td>4.338-5</td>
<td>4.338-5</td>
</tr>
<tr>
<td>miss-distance</td>
<td>0.34894</td>
<td>0.34894</td>
<td>0.34894</td>
</tr>
</tbody>
</table>
### TABLE VI
Comparison of the Maneuvering Target Results

<table>
<thead>
<tr>
<th>UNIT</th>
<th>IDEAL RELAY</th>
<th>TWO-LEVEL RELAY</th>
<th>SATURATION CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>time(control)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>CRE(0)</td>
<td>49.907</td>
<td>49.907</td>
<td>49.907</td>
</tr>
<tr>
<td>CRE(0)</td>
<td>49.891</td>
<td>49.891</td>
<td>49.891</td>
</tr>
<tr>
<td>time(MAX.CRE)</td>
<td>1.33</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td>CRE(max)</td>
<td>58.201</td>
<td>58.201</td>
<td>58.201</td>
</tr>
<tr>
<td>time(intercept)</td>
<td>5.61</td>
<td>5.61</td>
<td>5.61</td>
</tr>
<tr>
<td>Xm</td>
<td>2597.5</td>
<td>2597.5</td>
<td>2597.5</td>
</tr>
<tr>
<td>Ym</td>
<td>1057.5</td>
<td>1057.5</td>
<td>1057.5</td>
</tr>
<tr>
<td>CRE</td>
<td>-6.548E-6</td>
<td>3.638E-6</td>
<td>-0.0702</td>
</tr>
<tr>
<td>miss-distance</td>
<td>0.47889</td>
<td>0.47889</td>
<td>0.4841</td>
</tr>
</tbody>
</table>

### TABLE VII
Comparison of the Pseudo-LOS Command Results

<table>
<thead>
<tr>
<th>UNIT</th>
<th>IDEAL RELAY</th>
<th>TWO-LEVEL RELAY</th>
<th>SATURATION CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>time(control)</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>CRE(0)</td>
<td>49.912</td>
<td>49.910</td>
<td>49.912</td>
</tr>
<tr>
<td>CRE(0)</td>
<td>49.828</td>
<td>49.828</td>
<td>49.828</td>
</tr>
<tr>
<td>time(MAX.CRE)</td>
<td>1.33</td>
<td>1.33</td>
<td>1.33</td>
</tr>
<tr>
<td>CRE(max)</td>
<td>58.184</td>
<td>58.184</td>
<td>58.184</td>
</tr>
<tr>
<td>time(intercept)</td>
<td>5.58</td>
<td>5.58</td>
<td>5.58</td>
</tr>
<tr>
<td>Xm</td>
<td>2604.7</td>
<td>2604.7</td>
<td>2604.7</td>
</tr>
<tr>
<td>Ym</td>
<td>999.92</td>
<td>999.92</td>
<td>999.92</td>
</tr>
<tr>
<td>CRE</td>
<td>2.968E-5</td>
<td>2.968E-5</td>
<td>2.968E-5</td>
</tr>
<tr>
<td>miss-distance</td>
<td>0.35137</td>
<td>0.35137</td>
<td>0.35137</td>
</tr>
</tbody>
</table>
## Variables List

<table>
<thead>
<tr>
<th>Diagram Variables</th>
<th>Computer Variables</th>
<th>Noun Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRE</td>
<td>CRE</td>
<td>cross-range-error</td>
</tr>
<tr>
<td>( \dot{CRE} )</td>
<td>( \dot{CRE} )</td>
<td>rate of cross-range-error change</td>
</tr>
<tr>
<td>( F )</td>
<td>( F )</td>
<td>error function</td>
</tr>
<tr>
<td>( G )</td>
<td>( G )</td>
<td>magnitude of lateral acceleration</td>
</tr>
<tr>
<td>( U )</td>
<td>( U )</td>
<td>missile's lateral acceleration</td>
</tr>
<tr>
<td>( \dot{\theta} )</td>
<td>( \dot{\theta} )</td>
<td>angle between the LOS to target and X-axis</td>
</tr>
<tr>
<td>( \theta_m )</td>
<td>( \theta_m )</td>
<td>angle between the beam to missile and X-axis</td>
</tr>
<tr>
<td>( \dot{\theta}_m )</td>
<td>( \dot{\theta}_m )</td>
<td>angle difference between ( m ) and ( t )</td>
</tr>
<tr>
<td>( v_c )</td>
<td>( v_c )</td>
<td>crossing velocity</td>
</tr>
<tr>
<td>( t_g )</td>
<td>( t_g )</td>
<td>time to go</td>
</tr>
<tr>
<td>( t(\text{control}) )</td>
<td>( t(\text{control}) )</td>
<td>beginning time of on-off control</td>
</tr>
<tr>
<td>SLOS</td>
<td>SLOS</td>
<td>synthetic line-of-sight</td>
</tr>
<tr>
<td>( X_m )</td>
<td>( X_m )</td>
<td>X-coordinate of missile position</td>
</tr>
<tr>
<td>( Y_m )</td>
<td>( Y_m )</td>
<td>Y-coordinate of missile position</td>
</tr>
<tr>
<td>( X_t )</td>
<td>( X_t )</td>
<td>X-coordinate of target position</td>
</tr>
<tr>
<td>( Y_t )</td>
<td>( Y_t )</td>
<td>Y-coordinate of target position</td>
</tr>
<tr>
<td>( v_m )</td>
<td>( v_m )</td>
<td>velocity of the missile</td>
</tr>
<tr>
<td>( v_t )</td>
<td>( v_t )</td>
<td>velocity of the target</td>
</tr>
<tr>
<td>( v_{mx} )</td>
<td>( v_{mx} )</td>
<td>X-component of missile's velocity</td>
</tr>
<tr>
<td>( v_{my} )</td>
<td>( v_{my} )</td>
<td>Y-component of missile's velocity</td>
</tr>
<tr>
<td>( v_{tx} )</td>
<td>( v_{tx} )</td>
<td>X-component of target's velocity</td>
</tr>
<tr>
<td>( v_{ty} )</td>
<td>( v_{ty} )</td>
<td>Y-component of target's velocity</td>
</tr>
</tbody>
</table>
APPENDIX B

PROGRAM OF THE SWITCHING FUNCTION

TITLE BANG-BANG CONTROL
TITLE SWITCHING FUNCTION
TITLE * YEUN, J.I. *
INTGER NPLLOT
CONST NPLLOT=1
INITIAL CRE = 1.0
CRD = 0.
ACRED = 0.
*******
DERIVATIVE
*******
NOSORT *
G = 1.0
F = CRE + (CRD*ACRED)/(2*G)
U = G * SIGN(1.*F)
CRD = INTGEL(0.,U)
CRE = INTGEL(CRE,CRD)
ACRED = ABS(CRE)
IF(CRE.LE. 0.0) CALL ENDJOB
SAMPLE CALL DRWG(1,1,TIME,CRE)
CALL DRWG(2,1,CRE,CRD)
CALL DRWG(3,1,TIME,F)
CALL DRWG(4,1,TIME,CRED)
CALL DRWG(5,1,TIME,U)
TERMINAL CALL ENDRW(NPLLOT)
CONTROL PINTIM=2.1,DELT=0.01,DELS=0.01
PRINT 0.1,G,F,U,CRE,CRD
END
STOP

62
APPENDIX C

PROGRAM OF THE BASIC COMMAND TO LOS

** Title **

BASIC COMMAND TO L.O.S
WITH IDEAL RELAY
HIGH PERFORMANCE

* Title *

***** YEUN, J.Y. *****

INTEGER NL10 KILL
CONST NPL01=1, TCON=1.0
CONST VM=500., VT=250., PI=3.141593, KILL=0

INITIAL

XT0 = 4000,
YTO = 1000;
GAMT = PI
F = 0.

* 

***************************************************************************************************************************************************************************

DERIVATIVE
***************************************************************************************************************************************************************************

NOSORT
***************************************************************************************************************************************************************************

*** TARGET PARAMETERS ***

***************************************************************************************************************************************************************************

VTX = VT*COS (GAMT)
VTY = VT*SIN (GAMT)
XT = VTX*TIME + XT0
YT = VTY*TIME + YTO
SIRT = ATAN2(YT, XT)
IF (TIME .GE. TCON) GO TO 50

***************************************************************************************************************************************************************************

*** MISSILE PARAMETERS ***

***************************************************************************************************************************************************************************

* PROGRAMMED GUIDANCE ***************************************************************************************************************************************************************************

* 

SIGN = SIRT + 0.1
VXM = VM * COS (SIGN)
VYM = VM * SIN (SIGN)
XM = INTEGRAL(0., VXM)
YM = INTEGRAL(0., VYM)
RM = SQRT(XM*2 + YM*2)
SIRT = SIGN - SIRT
CRE = RM * SIN (SIGN)
CRED = DERIV (0., CRE)
GO TO 200

***************************************************************************************************************************************************************************

* ON-OFF GUIDANCE (BANG-BANG CONTROL) ***************************************************************************************************************************************************************************

***************************************************************************************************************************************************************************

* 

50 CONTINUE

* 

G = 150.
ACRED = ABS (CRED)
F = CRE + (CRED*ACRED)/(2*G)
U = -G * SIGN (1., F)
CRED = INTEGRAL(0., U)
CRE = INTEGRAL (CRE, CRED)

* 

RM = VM*TIME
A3 = CRE/RM
SIRT = ASIN(A3)
SIGN = SIRT + SIRT
XM = RM * COS(SIGM)
YM = RM * SIN(SIGM)

MISSION RESULT
KILL = 0 : TGT MISSED
KILL = 1 : TGT DESTROYED

XDIST = XT-XM
YDIST = YT-YM
DIST = SQRT(XDIST**2 + YDIST**2)
IF (DIST .LE. 5) KILL = 1
IF (DIST .GT. 5) KILL = 0
IF (XM .GT. (XT + 30)) CALL ENDOB

SORT

OUTPUT AND PLOT CONTROL CARD

SAMPLE
CALL DRWG (1,1, XM, YM)
CALL DRWG (1,2, XT, YT)
CALL DRWG (2,1, TIME, DIST)
CALL DRWG (3,1, TIME, CRE)
CALL DRWG (4,1, TIME, CRE)
CALL DRWG (5,1, CRE, CRE)
CALL DRWG (6,1, TIME, F)
CALL DRWG (7,1, TIME, 0)

TERMINAL
CALL ENDRW (NPL0T)

PRINT 0.005, XM, YM, XT, YT, CRE, CRE, DIST, KILL
END
STOP
**APPENDIX D**

**PROGRAM OF THE MANEUVERING TARGET**

**TITLE** BASIC COMMAND TO LOS
**TITLE** WITH MANEUVERING TGT
**TITLE** *** YEUN, J.Y. ***
**INTEG** RKSFX
**INTEGR** NPlot, KILL
**CONST** NPlot = 1, TCON = 1.0
**CONST** VM = 500.0, VT = 250.0, PI = 3.141593, KILL = 0

**INITIAL**
XTO = 4000.0  
YTO = 1000.0  
GAMT = PI  
P = 0.0  

*  

**NOSORT**  
**TARGET PARAMETERS** ***
**PARAMETERS**
VXT = VT*COS(GAMT)  
VYT = VT*SIN(GAMT)  
XT = VTX*TIME + XTO  
YT = 100*SIN(0.5*PI*TIME) + YTO  
SIGT = ATAN2(YT, XT)  
IP = (TIME - GET_TCOM) * GO TO 50  

**MISSILE PARAMETERS** ***
**PARAMETERS**

* **PROGRAMMED GUIDANCE** ******************

*  

SIGM = SIGT + 0.1  
VXM = VM * COS(SIGM)  
VYM = VM * SIN(SIGM)  
XM = INTEGR(0.0, VXM)  
YM = INTEGR(0.0, VYM)  
RM = SQRT(XM**2 + YM**2)  
SIGMT = SIGM - SIGT  
CRE = RM * SIN(SIGMT)  
CRED = DERIV(0.0, CRE)  
GO TO 200  

**ON-OFF GUIDANCE (BANG-BANG CONTROL)** ******************

**CONTINUE**

*  

G = 150.0  
ACRED = ABS(CRED)  
P = CRE * (CRED*ACRED)/(2*3)  
U = -G * SIGN(1.0, P)  
CRED = INTGRL(0.0, U)  
CRE = INTGRL(CRE, CRED)  
ACRE = ABS(CAB)  

*  

RM = VM*TIME  
A3 = CRE/RM  
SIGT = ABSIN(A3)  
SIGM = SIGT + SIGMT

65
XM = RM * COS(SIGM)
YM = RM * SIN(SIGM)

MISSION RESULT
KILL = 0 ; TGT MISSED
KILL = 1 ; TGT DESTROYED

XDIST = XT - XM
YDIST = YT - YM
DIST = SQRT(XDIST**2 + YDIST**2)

IF (DIST .LE. 5.0) KILL = 1
IF (DIST .GT. 5.0) KILL = 0
IF (XM .GT. (XT+30)) CALL ENDF

SORT
OUTPUT AND PLOT CONTROL CARD

SAMPLE
CALL DRWG (1,1,XM,YM)
CALL DRWG (2,1,XT YT)
CALL DRWG (3,1,TIME,CRE)
CALL DRWG (4,1,TIME,CRED)
CALL DRWG (5,1,CRED)
CALL DRWG (6,1,TIME F)
CALL DRWG (7,1,TIME U)

TERMINAL
CALL ENDRW(NPLOT)

CONTDRV TIM=5.9,DELT=0.001,DELS=0.003
PRINT 0.005,XM,YM,XT YT,CRE,CRED,DIST,KILL
END
STOP
APPENDIX E
PROGRAM OF THE COMMAND TO PSEUDO-LOS

TITLE PSEUDO - LOS COMMAND
TITLE WITH IDEAL RELAY
** YEUN, J.Y. ***
INTEGER N PLOT, KILL
CONST N PLOT = 1, T CON = 1.0
CONST VM = 500., VT = 250., PI = 3.141593, KILL = 0
INITIAL
XTO = 4000.
YTO = 1000.
TG = 0.
f = 0.
GAM T = PI

*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
DERIVATIVE
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
NOSORT
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
** TARGET PARAMETERS ****
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
VTX = VT*COS (GAM T)
VTY = VT*SIN (GAM T)
XT = VTX*TIME + XTO
YT = VTY*TIME + YTO
SIGT = ATAN2 (XT, XT)
XLOS = XT + VTX*TG
YLOS = YT + VTY*TG
SLOS = ATAN2 (YLOS, XLOS)
IF (TIME .GE. TCON) GO TO 50

*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
*** MISSILE PARAMETERS ***
*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
* PROGRAMMED GUIDANCE *+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
* S I G M = SLOS + 0.1
VMX = VM * COS (SIG M)
VN Y = VM * SIN (SIG M)
XM = INTEGRAL (0., VMX)
YM = INTEGRAL (0., VM Y)
RM = SQRT (XM**2 + YM**2)
SIGMS = SIG M - SLOS
CRE = RM * SIN (SIGMS)
CRED = DERIV (0., CRE)
GO TO 200

*+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
* ON-OFF GUIDANCE (BANG-BANG CONTROL) *+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++*
* 50 CONTINUE
* G = 150.
ACRED = ABS (CRED)
P = CRE + (CRED*ACRED)/(2*G)
U = -G * SIG M (1. , P)
CRED = INTEGRAL (0. , U)
CRE = INTEGRAL (CRE, CRED)
* RM = VM*TIME

67
A3 = CRE/RM
SIGNS = ARSIN(A3)
SIGM = SLOS + SIGNS
VMX = VM * COS(SLOS)
VMY = VM * SIN(SLOS)
XM = RM * SIN(SIGM)
YM = RM * SIN(SIGM)

230 CONTINUE
*

*** MISSION RESULT ***
KILL = 0 ; TGT MISSED
KILL = 1 ; TGT DESTROYED

XDIST = XT-XM
YDIST = YT-YM
DIST = SQRT(XDIST**2 + YDIST**2)
VC = SQRT((VTX-VMX)**2 + (VTY-VMY)**2)
TG = DIST/VC
IF (DIST .LE. 0.5) KILL = 1
IF (DIST .GT. 0.5) KILL = 0
IF (XM .GT. (XT+0.3)) CALL ENDDO

SORT

****** OUTPUT AND PLOT CONTROL CARD ******

SAMPLE
CALL DRG(1,1,XM,YM)
CALL DRG(1,2,XT,YT)
CALL DRG(2,1,TIME,DIST)
CALL DRG(3,1,TIME,CRE)
CALL DRG(4,1,TIME,CRE)
CALL DRG(5,1,CRE,CRE)
CALL DRG(6,1,TIME,F)
CALL DRG(7,1,TIME,U)

TERMINAL
CALL ENDRW(NPLOT)

CONTPL PNTIM=5.9,DELT=0.01,DELS=0.001
PRINT 0.1,TG,XM,YM,XT,YT,CRE,CRE,DIST,KILL
END
STOP
APPENDIX F
PROGRAM OF THE BASIC COMMAND TO LCS WITH TWO-LEVEL RELAY

`TITLE BASIC COMMAND TO LCS
TITLE WITH TWO LEVEL RELAY
TITLE YEUN, J.Y. ****
INTGERS NPLN, KILL
CONST NPLN=1, TCON=1.0
CONST VM=500.0, VT=250.0, PI=3.141593, KILL=0
INITIAL
   XTO = 4000.
   YTO = 1000.
   GAMT = PI
   F = 0.
*
************************************************************
DERIVATIVE
************************************************************
NOSORT
************************************************************
*** TARGET PARAMETERS ***
************************************************************
VTX = VT*COS(GAMT)
VTY = VT*SIN(GAMT)
XT = VTX*TIME + XTO
YT = VTY*TIME + YTO
SIGT = ATAN2(YT,XT)
IF(TIME.GE.TCON) GO TO 50
************************************************************
*** MISSILE PARAMETERS ***
************************************************************
* PROGRAMMED GUIDANCE ***************************************
*
   SIGM = SIGT+0.1
   VXN = VM*COS(SIGM)
   VYN = VM*SIN(SIGM)
   XM = INTEGRAL(0.0, VXN)
   YM = INTEGRAL(0.0, VYN)
   RM = SORT(XM**2 + YM**2)
   SIGMT = SIGM - SIGT
   CRE = RM*SIN(SIGMT)
   CRED = DERIV(0.0,CRE)
   GO TO 200
************************************************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) ****************************
************************************************************
* 50 CONTINUE
*
   G = 150.
   ACRE = ABS(CRE)
   ACRED = ABS(CRED)
   IF((ACRE+ACRED).LT.1.) G = 15
   F = CRE + (CRED*ACRED)/(2*3)
   U = -G * SIGN(1.*F)
   CRED = INTEGRAL(0.0,F)
   CRE = INTEGRAL(CRE,CRED)
*
   RM = VM*TIME
   A3 = CRE/RM

69`
SIGMT = ARSIN(A3)
SIGM = SIGT + SIGMT
XM = RM * COS(SIGM)
YM = RM * SIN(SIGM)

200 CONTINUE

MISSION RESULT
KILL = 0; TGT MISSED
KILL = 1; TGT DESTROYED

XDIST = XT-XM
YDIST = YT-YM
DIST = SQRT(XDIST**2 + YDIST**2)
IF (DIST .LE. 5) KILL = 1
IF (DIST .GT. 5) KILL = 0
IF (XM .GT. (XT+30)) CALL ENDJOB

MISSION RESULT
KILL = 0; TGT MISSED
KILL = 1; TGT DESTROYED

SAMPLE
CALL DRW1(1,1,XM,YM)
CALL DRW2(2,1,TIME,DIST)
CALL DRW3(3,1,TIME,CRE)
CALL DRW4(4,1,TIME,CRED)
CALL DRW5(5,1,CRE,CRED)
CALL DRW6(6,1,TIME,F)
CALL DRW7(7,1,TIME,U)

TERMINAL
CALL ENDRW(NPLOT)
CONTROL PNTIM=0.9, DELT=0.001, DELS=0.003
PRINT 0.005, XM, YM, XT, YT, CRE, CRED, DIST, KILL
END
STOP
APPENDIX G
PROGRAM OF THE MANEUVERING TARGET WITH TWO-LEVEL RELAY

TITLE BASIC COMMAND TO LOS
TITLE WITH MANEUVERING TGT
TITLE *** YEUN, J.Y. ***

INTEGER NPLQ,T,CON=1.0
CONST VM=500.,VT=250.,PI=3.141593,KILL=0

INITIAL
X0 = 4000.
Y0 = 1000.
GAMT = PI
P = 0.

* ***************************************************************
DERIVATIVE
*************************************************************************
NO SORT
*************************************************************************
*** TARGET PARAMETERS ***
*************************************************************************
VTX = VT*COS(GAMT)
VTY = VT*SIN(GAMT)
XT = VT*TIME + X0
YT = 100*SIN(0.5*PI*TIME) + Y0
S1GT = ATAN2(YT,XT)
IF (TIME.GE.CON) GO TO 50
*************************************************************************
*** MISSLE PARAMETERS ***
*************************************************************************
* PROGRAMMED GUIDANCE *********************************************************
* 
SIGM = SIGT+0.1
VMX = VM * COS(SIGM)
VMY = VM * SIN(SIGM)
XM = INTEGRAL(0.,VMM)
YM = INTEGRAL(0.,VMX)
RM = SQRT(XM**2 + YM**2)
SIGM = SIGM - SIGT
CRE = RM * SIN(SIGM)
CRED = DERIV(0.,CRE)
GO TO 200
*************************************************************************
* ON-OFF GUIDANCE (BANG-BANG CONTROL) ***************************************
*************************************************************************
* 50 CONTINUE
* 
G = 150.
ACRE = ABS(CRE)
ACRED = ABS(CRED)
IF ((ACRE+ACRED).LT.1.) G = 15.
F = CRE + (CRED+ACRED)/(2*G)
U = -G * SIGN(1.-F)
CRED = INTEGRAL(0.5,U)
CRE = INTEGRAL(CRE,CRED)
ACRE = ABS(CRE)
* 
RM = VM*TIME
A3 = CRE/RM
SIGH = ARSIN(A3)
SIGM = SIGT + SIGMT
XM = RM * COS(SIGM)
YM = RM * SIN(SIGM)

******************************************************************************

200 CONTINUE
*

******************************************************************************

*** MISSION RESULT *** KILL = 0 : TGT MISSED
KILL = 1 : TGT DESTROYED

XDIST = XT-XM
YDIST = YT-YM
DIST = SQRT(XDIST**2 + YDIST**2)
IF (DIST .LE. 5) KILL = 1
IF (DIST .GT. 5) KILL = 0
IF (XM .GT. (XT+30)) CALL ENDJOB

*

SORT

************* OUTPUT AND PLOT CONTROL CARD **************

SAMPLE

CALL DRWG (1,1,XM,YM)
CALL DRWG (1,2,XT,YT)
CALL DRWG (2,1,TIME,DIST)
CALL DRWG (3,1,TIME,CRE)
CALL DRWG (4,1,TIME,CRED)
CALL DRWG (5,1,CRE,CRED)
CALL DRWG (6,1,TIME,F)
CALL DRWG (7,1,TIME,U)

TERMINAL

CALL ENDBW (NPLOT)

CONTROL PRINT=5.9,DELT=0.001,DELS=0.003
PRINT 0.005, XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
STOP
**APPENDIX B**

**PROGRAM OF THE COMMAND TO PSEUDO-LOS WITH TWO-LEVEL RELAY**

**TITLE**

PSEUDO - LOS COMMAND

**TITLE**

WITH TWO-LEVEL RELAY

**TITLE**

**** YEUN, J.Y. ****

**INTEGER**

HKSFX

**CONST**

NPL =1, TCON = 1.0

**CONST**

VM = 500., VT = 250., PI = 3.141593, KILL = 0

**INITIAL**

YTO = 4000.

YTO = 1000.

TG = 0.

GAMT = PI

F = 0.

* 

***************************************************************************************

**DERIVATIVE**

***************************************************************************************

**NOSORT**

***************************************************************************************

**TARGET PARAMETERS**

***************************************************************************************

**MISSILE PARAMETERS**

***************************************************************************************

* PROGRAMMED GUIDANCE  ***************************************************************************************

* 

SIGM = SLOS + 0.1

VMX = VM * COS(SIGM)

VHY = VM * SIN(SIGM)

XM = INTGRL(0. , VMX)

YM = INTGRL(0. , VHY)

RM = SQRT(XM**2 + YM**2)

SIGNS = SIGM - SLOS

CRE = RM * SIN(SIGNS)

CRED = DERIV(0., CRE)

GO TO 200

***************************************************************************************

* ON-OFF GUIDANCE (BANG-BANG CONTROL)  ***************************************************************************************

***************************************************************************************

* 50  

CONTINUE

* 

G = 150.

ACRE = ABS(CRE)

ACRED = ABS(CRED)

IF (ACRE + ACRED .LT. 1.) G = 15.

F = CRE + (CRED + ACRE) / (2*G)

U = -G * SIGN(1., F)

CRED = INTGRL(0., U)

CRE = INTGRL(CRE, CRED)
\*  
\* \textbf{RM} = VM*TIME 
\textbf{A3} = CRE/RM 
\textbf{SIGNS} = ARSIN(A3) 
\textbf{SIGM} = SLOS + SIGNS 
\textbf{VMX} = VM * COS(SLOS) 
\textbf{VYM} = VM * SIN(SLOS) 
\textbf{XM} = RM * COS(SIGM) 
\textbf{YM} = RM * SIN(SIGM) 
\*  
200 \hspace{1cm} \texttt{CONTINUE} 
\*  
\* \textbf{MISSION RESULT} ** \textbf{KILL} = 0 ; TGT MISSED 
*** \textbf{MISSION RESULT} *** \textbf{KILL} = 1 ; TGT DESTROYED 
\*  
\textbf{XDIST} = XT-XM 
\textbf{YDIST} = YT-YM 
\textbf{DIST} = SQRT(XDIST**2 + YDIST**2) 
\textbf{VC} = SQRT((VTX-VMX)**2+(VTY-VMY)**2) 
\textbf{TG} = DIST/VC 
\textbf{IF} (DIST .LE. 5) \textbf{KILL} = 1 
\textbf{IF} (DIST .GT. 5) \textbf{KILL} = 0 
\textbf{IF} (X M .GT. (XT+30)) \texttt{CALL ENDJOB} 
\*  
\* \textbf{SORT} 
\* \textbf{OUTPUT AND PLOT CONTROL CARD} \textbf{ENDJOB} 
\*  
\* \textbf{SAMPLE} 
\texttt{CALL DRWG (1,1,XM,YM)} 
\texttt{CALL DRWG (1,2,XT,YT)} 
\texttt{CALL DRWG (2,1,TIME,DIST)} 
\texttt{CALL DRWG (3,1,TIME,CRE)} 
\texttt{CALL DRWG (4,1,TIME,CRE)} 
\texttt{CALL DRWG (5,1,TIME,F)} 
\texttt{CALL DRWG (6,1,TIME,U)} 
\*  
\textbf{TERMINAL} \texttt{CALL ENDRW (NPLT)} 
\texttt{PRINT 0.1,TG,XM,YM,XT,YT,CRE,CRE,DST,KILL} 
\texttt{END} 
\texttt{STOP}
APPENDIX I

PROGRAM OF THE BASIC COMMAND TO LOS WITH SATURATION CONTROL

TITLE BASIC COMMAND TO L.O.S
TITLE MISSILE CONTROL
TITLE WITH SATURATION CONTROL
INTEG RKSPX
CONST NPLOT=1,TCON=1.0, CUR=1
CONST VM=500., VT=250., PI=3.141593, KILL=0
PARAM M = 10.
INITIAL XTO = 4000.
    YTO = 1000.
    GANT = PI
    F = 0.

* ******************************************************
DERIVATIVE
* ******************************************************
NOSORT
*** TARGET PARAMETERS ***
**************************************************************
VTX = VT*COS(GANT)
VTY = VT*SIN(GANT)
XT = VTX*TIME + XTO
YT = VTY*TIME + YTO
SIGT = ATAN2(YT,XT)
IF (TIME.GE.TCON) GO TO 50

*** MISSILE PARAMETERS ***
**************************************************************
* PROGRAMMED GUIDANCE ******************************************************
*
SIGM = SIGT*0.1
VXM = VM * COS(SIGM)
VYM = VM * SIN(SIGM)
XM = INTGRL(0., VXH)
YM = INTGRL(0., VYM)
RM = SQRT(XM**2 + YM**2)
SIGT = SIGM - SIGT
CRE = RM * SIN(SIGMT)
CRED = DERIV(0., CRE)
GO TO 200

* ON-OFF GUIDANCE (BANG-BANG CONTROL) ******************************************************
*
50 CONTINUE
*
G = 150.
ACRED = ABS(CRED)
P = CRE + (CRE*ACRED)/(2*G)
U = -G * SIGN(1., F)
IF (ABS(P).LT. M) U = -G*F/M
CRE = INTGRL(0.,0., U)
CRED = INTGRL(0., CRE, CRED)
*
RM = VM*TIME
A3 = CRE/CM
SIGT = ABSIN(A3)

75
SIGM = SIGT + SIGMT
XM = RM * COS(SIGM)
YM = RM * SIN(SIGM)

*********** MISSION RESULT ***********
KILL = 0 : TGT MISSED
KILL = 1 : TGT DESTROYED

XDIST = XT-XM
YDIST = YT-YM
DIST = SQRT(XDIST**2 + YDIST**2)
IF (DIST .LE. 5) KILL = 1
IF (DIST .GT. 5) KILL = 0

********** OUTPUT AND PLOT CONTROL CARD **********

SAMPLE
CALL DRWG(1,CUR,XM,YM)
CALL DRWG(2,CUR,TIME,DIST)
CALL DRWG(3,CUR,TIME,CRE)
CALL DRWG(4,CUR,CRE,CRE)
CALL DRWG(5,CUR,TIME,F)
CALL DRWG(6,CUR,TIME,EU)

TERMINAL
IF (CUR .EQ. 3) CALL ENDRW(NPLOT)
CUR = CUR + 1

PRINT 0.005,XM,YM,AT,IT,CRE,CRE,DIST,KILL
END
PARAM M = 5.
END
PARAM M = 1.
END
STOP
APPENDIX J

PROGRAM OF THE MANEUVERING TARGET WITH SATURATION CONTROL

TITLE BASIC COMMAND TO LOS
TITLE (MANEUVERING TGT)
TITLE WITH SATURATION CONTROL

INTEGER NINPUT, KILL, CUR

CONST NINPUT = 1, TCON = 1.0, CUR = 1

CONST VM = 500., VT = 250., PI = 3.141593., KILL = 0

PARAM M = 10.

INITIAL X0 = 4.000.
Y0 = 1.000.
GAMT = PI
P = 0.

*

******************************************************************************************

DERIVATIVE
******************************************************************************************

NO SORT

******************************************************************************************

*** TARGET PARAMETERS ***

******************************************************************************************

VTX = VT*COS(GAMT)
VTY = VT*SIN(GAMT)
XT = VTX*TIME + X0
YT = 100*SIN(0.5*PI*TIME) + Y0
SIGT = ATAN2(YT, XT)
IF (TIME.GE.TCON) GO TO 50

******************************************************************************************

*** MISSILE PARAMETERS ***

******************************************************************************************

* PROGRAMMED GUIDANCE ****************************

*

SIGN = SIGT + 0.1
VXM = VM * COS(SIGM)
VYM = VM * SIN(SIGM)
XM = INTGRL(0, VM)
YM = INTGRL(0, VYM)
RM = SQRT(XM**2 + YM**2)
SIGHT = SIGM - SIGT
CRE = RM * SIN(SIGT)
CRED = DERIV(0, CRE)
GO TO 200

******************************************************************************************

* ON-OFF GUIDANCE (BANG-BANG CONTROL) ****************************

******************************************************************************************

*

50 CONTINUE

*

G = 150.
ACRED = ABS(CRED)
P = CRE + (CRED*ACRED)/(2*G)
U = -G * SIGN(1, P)
IF (ABS(P) .LT. M), U = -G*P/M
CRED = INTGRL(0.0, U)
CRE = INTGRL(CRE, CRED)
ACRE = ABS(ACRE)

*

RM = VM*TIME
A3 = CRE/RM
SIGMT = ARSIN(A3)
SIGM = SIGT * SIGMT
XM = RM * COS(SIGM)
YM = RM * SIN(SIGM)

------------------------------------------------------------------------
200 CONTINUE
*
------------------------------------------------------------------------
*** MISSION RESULT *** KILL = 0 ; TGT MISSED
*** KILL = 1 ; TGT DESTROYED
------------------------------------------------------------------------
XDIST = XT-XM
YDIST = YT-YM
DIST = SQRT(XDIST**2 + YDIST**2)
IF (DIST .LE. 5) KILL = 1
IF (DIST .GT. 5) KILL = 0
*
SORT
------------------------------------------------------------------------
******** OUTPUT AND PLOT CONTROL CARD ********
------------------------------------------------------------------------
SAMPLE
CALL DRWG (1,CUR,XM,YM)
CALL DRWG (2,CUR,TIME,DIST)
CALL DRWG (3,CUR,TIME,CRE)
CALL DRWG (4,CUR,CRE,CRED)
CALL DRWG (5,CUR,TIME, U)
CALL DRWG (6,CUR,TIME, U)
TERMINAL
IF (CUR .EQ. 3) CALL ENDRW (NPLOT)
CUR = CUR + 1
CONTROL PINTIM=5.65,DELT=0.001,DELS=0.003
PRINT 0.005,XM,YM,XT,YT,CRE,CRED,DIST,KILL
END
PARAM M = 5.
END
PARAM M = 1.
END
STOP
APPENDIX K

PROGRAM OF THE COMMAND TO PSEUDO-LOS WITH SATURATION CONTROL

TITLE PSEUDO - LOS COMMAND
TITLE WITH SATURATION CONTROL
TITLE ***** YEUN, J.Y. *****
INTEG RKSFX
INTEGER NPLOT,KILL,CUR
CONST VM=500.,VT=250.,PI=3.141593,KILL=0
PARAM N = 10.
INITIAL
XTO = 4000.
YTO = 1000.
TG = 0.
GAMT = PI
F = 0.

******************************************************************************

DERIVATIVE
******************************************************************************

NOSORT
******************************************************************************

*** TARGET PARAMETERS ***
******************************************************************************

VTX = VT*COS(GAMT)
VTY = VT*SIN(GAMT)
XT = VTX*TIME + XTO
YT = VTY*TIME + YTO
SIGT = ATAN2(YT,XT)
XLOS = XT + VTX*TG
YLOS = YT + VTY*TG
SLOS = ATAN2(YLOS,XLOS)
TIME = TIME + TIME

IF (TIME.GE.TCON) GO TO 50

******************************************************************************

*** MISSILE PARAMETERS ***
******************************************************************************

** PROGRAMMED GUIDANCE **
******************************************************************************

SIGM = SLOS + 0.1
VMX = VM * COS(SIGM)
VMY = VM * SIN(SIGM)
XM = INTEGRAL(0.,VMX)
YM = INTEGRAL(0.,VMY)
RM = SQRT(XM**2 + YM**2)
SIGNS = SIGM - SLOS
CRE = RM * SIN(SIGNS)
CRD = DERIV(0.,CRE)
GO TO 200

******************************************************************************

* ON-OFF GUIDANCE (BANG-BANG CONTROL) ****************************************
******************************************************************************

* 50

CONTINUE

G = 150.
ACRED = ABS(CRED)
P = CRE + (CRE*ACRED)/(2*G)
U = -G * SIGM1 - P
IF (ABS(P).LT.31) U = -G * P / M
CRED = INTEGRAL(0.,U)
CRE = INTEGRAL(CRE,CRED)
RN = VM*TIME
A3 = CRE/RM
SIGMS = ARSIN(A3)
SIGM = SLOS + SIGMS
VMX = VM * COS(SLOS)
VMY = VM * SIN(SLOS)
XM = RM * COS(SIGM)
YM = RM * SIN(SIGM)

**************************************************************
200 CONTINUE
**************************************************************

*** MISSION RESULT *** KILL = 0 ; TGT MISSED

XDIST = XT-XM
YDIST = YT-YM
DIST = SQRT(XDIST**2 + YDIST**2)
VC = SQRT((VTX-VMX)**2 + (VTY-VMY)**2)
TG = DIST/VC
IF (DIST < 5) KILL = 1
IF (DIST > 5) KILL = 0

SORT

******* OUTPUT AND PLOT CONTROL CARD ***************

CALL DRWG (1,CURXM,YN)
CALL DRWG (2,CURTIME,DIST)
CALL DRWG (3,CURTIME,CRE)
CALL DRWG (4,CURTIME,CRE)
CALL DRWG (5,CURTIME,CRE)
CALL DRWG (6,CURTIME,CRE)

TERMINAL

IF (CUR .EQ. 3) CALL ENDRW(NPLOT)
CUR = CUR + 1

PRINT 0.005,TG,XM,YM,XT,YT,CRE,CRE,DIST,KILL
END
PARAM M = 5.
END
PARAM M = 1.
END
STOP
LIST OF REFERENCES


<table>
<thead>
<tr>
<th>No.</th>
<th>Distribution List</th>
</tr>
</thead>
</table>
| 1.  | Defense Technical Information Center  
      Cameron Station  
      Alexandria, Virginia 22314 |
| 2.  | Library, Code 0142  
      Naval Postgraduate School  
      Monterey, California 93943 |
| 3.  | Department Chairman, Code 62  
      Department of Electrical Engineering  
      Naval Postgraduate School  
      Monterey, California 93943 |
| 4.  | Division of Foreign Education  
      Department of Personnel Administration  
      Headquarters of Korean Air Force  
      Daebang-dong, Youngdungpo-gu  
      Seoul, Korea |
| 5.  | Professor H. A. Titus, Code 62Ts  
      Department of Electrical Engineering  
      Naval Postgraduate School  
      Monterey, California 93943 |
| 6.  | Professor Alex Gerba, Jr., Code 62Gs  
      Department of Electrical Engineering  
      Naval Postgraduate School  
      Monterey, California 93943 |
| 7.  | Academic Dean  
      Air Force Academy  
      Daebang-dong, Youngdungpo-gu  
      Seoul, Korea |
| 8.  | LTC. Je Young, Yeo  
      Jamsil 221-4, Gangdong-gu  
      Seoul, Korea |