

NASA Contractor Report 181696

# Simulated Final Approach Path Captures Using the Microwave Landing System

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J. B. Feather

McDonnell Douglas Corporation  
Long Beach, California 90846

Contract NAS1-18028  
December 1988



National Aeronautics and  
Space Administration

Langley Research Center  
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## LIST OF SYMBOLS

$D_{TG}$	Distance to go to glide point intercept, feet
$G_S$	Glidepath angle, degree
$h_D$	Desired altitude used in vertical guidance law, feet
$h_M$	Altitude derived from MLS angle and range data, feet
$h_S$	Altitude used to start glidepath capture, feet
$K_1, K_2$	Gains used in enhanced ILS look-alike lateral capture algorithm
$K_3, K_4$	Gains used in enhanced ILS look-alike vertical capture algorithm
$R_{DME}$	Range from DME/P, feet
$V_g$	Ground speed, feet/second
$X_M, Y_M, Z_M$	Position Coordinates derived from MLS angle and range data, feet
$X_D$	Distance from origin to azimuth and DME/P transmitters, feet
$Y_E$	Offset of elevation antenna from runway centerline, feet
$Z_D$	Height of azimuth & DME/P transmitters, feet
$Z_E$	Height of elevation transmitter, feet
$\Delta h, \dot{\Delta h}$	Altitude and altitude rate deviations used in vertical capture algorithm, feet & feet/second

## SUMMARY AND INTRODUCTION

This report presents results of studies in which path capture concepts were simulated and evaluated using the Microwave Landing System (MLS). The work was performed as a part of the Advanced Transport Aircraft Operating System (ATOPS) contract, jointly sponsored by NASA and the FAA. Previous MLS guidance studies (References 1 and 2) have provided simulated path tracking data on landing using complex approach paths, and on precision departures and missed approaches. The present study considers the aircraft at the end of vectoring and provides methods of capturing MLS final approach paths. These capture concepts are based on certain interception techniques similar to those described in References 3 and 4. Simulation of these concepts were made using the MD-80 aircraft as the study model.

Consideration was given to a basic system consisting of the MLS receiver with some computational capability, but not requiring a waypoint database or a full-up path computer. Such a system could be used to implement an enhanced ILS look-alike capture of the extended runway centerline. Better capture and tracking (both laterally and vertically) are realized over existing ILS procedures. It may be possible that such a system could be retrofitted into existing aircraft without the need of a flight management system.

To remove the restriction of centerline captures only, more complete systems were considered that use a path computer. This computer allowed "smart" captures with lateral and vertical path control over the entire MLS coverage volume. These "smart" capture concepts were integrated into the guidance laws previously developed (Reference 1). The basic idea was to use the aircraft present position at the time of capture engage as an initial waypoint, which resulted in a smooth capture of the desired lateral and vertical paths.

This report describes each of the capture concepts studied, then discusses simulation results for several lateral and vertical captures. Path deviations are presented with MLS noise, steady winds, turbulence, and in some situations when a speed reduction and configuration change take place during the capture.



## RECOMMENDATIONS FOR FOLLOW-ON ACTIVITY

Simulator experiments with a pilot in the loop are recommended as follow-on activities to the present study. Tasks in the proposed study would include:

- Preparing a real-time program for the simulator that include lateral and vertical guidance laws and capture algorithms.
- Providing several different equipment complements, ranging from a minimum system to a full-up system with flight management system and CRT displays.
- Performing experiments on the simulator that involve complex lateral and vertical approaches, and path captures. Emphasis would be placed on evaluating the guidance laws based on pilot ability to perform given tasks.

## FORMULATION OF ENHANCED ILS LOOK-ALIKE CAPTURES

This concept does not require a full-up path computer for its operation. However, this enhanced ILS look-alike capture concept provides an improvement over existing ILS localizer and glideslope captures.

Equations for this concept may be derived by first considering the complete geometry of Figure 1. Position coordinates from this figure are found to be:

$$y_M = -R_{DME} \sin \theta_{AZ}$$

$$x_M = b - \left[ b^2 - c \right]^{1/2}$$

$$\text{where: } b = x_D \cos^2 \theta_{EL}$$

$$c = \cos^2 \theta_{EL} \left[ x_D^2 - R_{DME}^2 + y_M^2 \right]$$

$$+ \sin^2 \theta_{EL} \left[ -y_M + y_E \right]^2$$

$$z_M = z_E - \left[ x_M^2 + \left( -y_M + y_E \right)^2 \right]^{1/2} \tan \theta_{EL}$$

A lateral steering signal,  $\phi_{STR}$ , is computed from the above y-position variable and a rate term,  $\Delta \dot{y}$ , derived using a complementary filter (See Reference 1). Thus,

$$\Delta y = y_M$$

$$\Delta \dot{y} = \text{complementary filter}$$

At MLS engage,

$$\phi_{STR} = 0.0$$

Capture starts when

$$K_1 \Delta y + K_2 \Delta \dot{y} \text{ changes sign}$$

$$\text{where: } K_1 = 0.045$$

$$K_2 = 0.5$$

During capture and track, the steering signal is computed from

$$\phi_{STR} = -(K_1 \Delta y + K_2 \Delta \dot{y})$$

$$|\phi_{STR}| \leq 25 \text{ deg}$$

} (1)

A vertical steering signal,  $\theta_{STR}$ , is computed in a similar manner.

A 3 degree glideslope angle was assumed for the present study, but this angle could be selectable. Between MLS engage and lateral capture, the roll steering signal is zero. During capture and track, the steering signal is limited to an arbitrary 25 degrees. Only a single pitchover to the desired glideslope is made and no segmented glideslope approaches are possible. Also, the aircraft course must intersect the extended runway centerline at MLS engage (an example is shown in Figure 4), and the aircraft must be below the desired glideslope (captures from above are not possible). Under these assumptions, the enhanced ILS look-alike concept provides improved path tracking over the conventional ILS approaches.

#### FORMULATION OF LATERAL PATH CONTROL

Three types of lateral path captures were studied. The first was an extended runway centerline capture, the second a path capture, and the third a waypoint capture. An example of a lateral path as defined by a set of waypoints is shown in Figure 5. The numbered points shown define the turn points where the turn begins, and the roll out points where the turn is completed. The radii for these turns are computed based on a nominal (no wind) bank angle and the aircraft ground speed. The actual bank angle will differ from the nominal angle when winds are present. The nominal bank angle has been chosen so the actual angle required for the turn does not exceed 15 degrees in extreme wind conditions.

The turn and roll out points have been used in previous MLS studies (Reference 1 and 2) for landings, takeoffs, and missed approaches. The present study uses these points as references to establish a capture path so an intercept may be made from an arbitrary starting point.

Captures cannot occur when the aircraft is too close to an existing waypoint (Figure 8(B)). The aircraft could not complete the capture turn before beginning the next turn at turn point 5. As in the first case, a message identifying the situation would be issued and no capture would be attempted.

## 2. Specified Course Capture

Capture of a path is desired from a specified course angle that is different than the aircraft present course. Figure 9(A) shows this situation. Waypoints WP4 and WP5 are not unique, since they could be located at many different points along the present course path. Waypoint 5 is chosen such that turn anticipation for the first turn would start at WP6 (the point of capture engage). Previous studies have indicated a 4 second lead gives satisfactory anticipation for the turn. Once WP4 and WP5 are fixed, the turn and roll out points are computed. Capture then begins, which consists of two turns separated by a straight leg.

In some instances, the initial position of the aircraft would not permit a path capture at the specified intercept angle. In Figure 9(B), WP5 is selected so roll out point 5 and turn point 6 are coincident. In this way, a smooth transition to the desired path is accomplished by an S turn.

There are cases when the aircraft is too close to the path for a turn to be completed before beginning the next turn. Figure 10 illustrates this situation, where turn point 7 would occur before roll out point 8. The algorithm does not allow executing a capture in such cases.

### Waypoint Capture

A waypoint capture differs from a path capture in that the intercept is between the present aircraft position and a designated point from an established waypoint database. This point-to-point type of capture can be made between almost any two points in space. The capture is accomplished by constructing a turn circle at the present position and tangent to the course line, and a

In Figure 13(B), the aircraft pitches up to intercept the glidepath just before point 5. The algorithm computes all parameters necessary for the capture, and issues a message if the initial glidepath angle would be too large.

localizer and glideslope beams of ILS. This fact allows the enhanced ILS look alike algorithm to work with position and rate signals for a longer time than conventional ILS. Second, the range from the precision DME is more accurate than the range estimator used by the ILS. And finally, a different set of gains on  $\Delta y$  and  $\Delta \dot{y}$  were used as compared to ILS. These gains remained constant in the simulation of the enhanced system.

A time history of the bank angle is shown in Figure 18. An arbitrary bank command limit of 25 degrees was applied to the steering signal, Equation (1). This limit is necessary since at MLS engage the steering signal would be very large. During this limit period, lateral guidance is heading hold. The peak bank angle attained for this case is seen to be less than 20 degrees. The pitch time history is given in Figure 19. Here, the pitchover to a -3 degree glidepath begins at 10 seconds. At 50 seconds, a pitchup occurs to compensate for the turn to the centerline.

Figures 20 and 21 show the lateral and vertical path deviations for this case. Lateral guidance is heading hold until 38 seconds, then capture takes place. Vertical guidance is altitude hold for the first 10 seconds, then pitchover occurs. After the initial transient, the vertical deviation is less than  $\pm 15$  feet. In Figures 22 and 23 are these path deviations represented in dots (see Figures 15 & 16) as a function of distance to go. Lateral capture occurs at a distance to go of 42,300 feet and vertical capture occurs at 48,500 feet.

The effects of crosswinds on tracking is illustrated in Figures 24(A) and 24(B). The tic marks on the paths indicate the start of capture. Before this time, both systems show deviations in course due to the winds. After capture starts, the enhanced ILS look-alike system shows superior tracking performance with an order of magnitude improvement in overshoot with crosswinds.

#### EXTENDED RUNWAY CENTERLINE CAPTURES

Three extended runway centerline captures were simulated. The first one uses the same initial conditions as the enhanced ILS look-alike capture but employs

70 degrees relative to the centerline. At roll out point 2, the altitude is 515 feet and the aircraft is about 1.6 nmi from the glidepoint intercept (GPI). An ILS localizer capture would not be possible in this situation due to the narrow beam width. Figure 34 shows the bank angle history (roll out was completed past the 70 second time shown on the graph). Lateral path deviation is presented in Figure 35. Path tracking was maintained within  $\pm 1/4$  dot. The vertical path deviation was within  $\pm 0.2$  dot (about 12 feet) during vertical capture.

#### Specified-Course Capture (Case 5)

A centerline capture of a different type is shown in Figure 36, where a 90 degree angle is to be used for intercept. The aircraft's initial course is almost parallel to the runway, but the course line does intersect the centerline. This particular capture results in essentially a 180 degree turn to the final leg. There is a very short straight segment between the two turns, which results in the bank angle time history is shown in Figure 37. The ground track for this particular capture was selected to match one used in the MLS crew procedure study (Reference 5). A speed reduction is programmed during this capture, and the aircraft configuration is changed at the same time. Initially, the speed is 160 knots, the flaps are 15 degrees, and the gear is up. At a distance to go of 11 nmi these parameters are changed to 140 knots, 40 degree flaps, and gear down. The velocity time history is shown in Figure 38, and the path deviations are given in Figures 39 and 40. Distances at which the turns occur, the time of pitchover, and the configuration change are noted on these two figures. Tracking is within  $\pm 1/2$  dot, except for the vertical deviation at start of pitchover.

#### PATH CAPTURES

Several cases were simulated to illustrate the performance of the capture algorithms when an established MLS approach path was intercepted. Effects of external disturbances on these capture paths were investigated. Steady winds were considered in establishing a nominal bank angle for defining the curved portion of the capture. Cases were studied where the nominal bank angle had to be increased to allow the path capture to be made.



Case 8 is the same as Case 7, except the speed is 140 knots for the entire capture. Figure 48 shows the 15 degree angle for Case 8. Lateral path deviation for both cases were within  $\pm 0.2$  dot. Vertical path deviation for Case 7 was within  $\pm 0.75$  dot, and was  $\pm 0.5$  dot for Case 8.

## WAYPOINT CAPTURES

Three point-to-point captures were evaluated. These captures use waypoint databases that were defined in previous cases. Instead of capturing a specific path, the waypoint captures are constructed to pass through a designated waypoint in the database.

### Capture with a 15 Degree Nominal Bank Angle (Case 9)

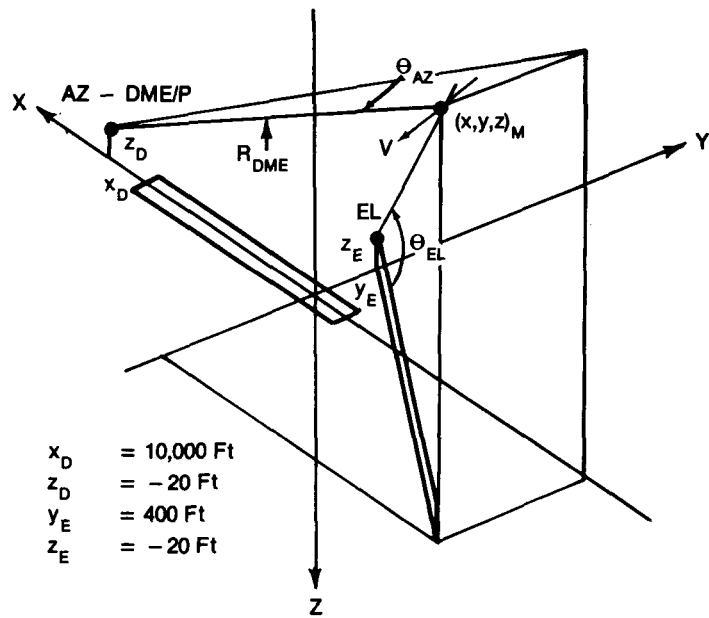
Three waypoints from Case 7 are used here as the database for this waypoint capture. Figure 49 shows the capture path. Two turns are made, separated by a straight segment. The initial position and speed of the aircraft require a 15 degree nominal bank angle for the turns. The actual bank time history is shown in Figure 50. The speed (Figure 51) changes during the first turn, so that by 70 seconds the bank has been reduced to about 12 degrees. The second short turn is also at 12 degrees. Both lateral and vertical path deviations for Case 9 are about the same as the deviations for the path capture of Case 7.

### Capture with a 10 Degree Nominal Bank Angle (Case 10)

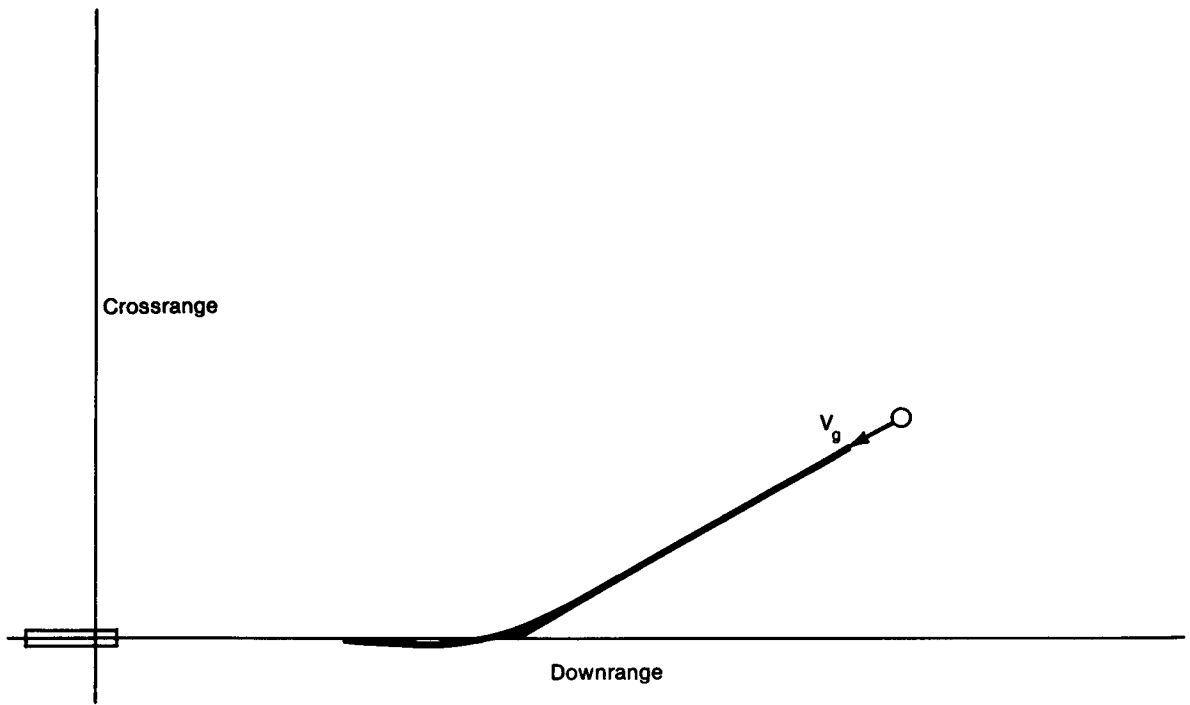
This capture uses the Case 6 waypoint database, where it is desired to intercept WP5. The aircraft is at the same initial position as in Case 6. This waypoint capture is another way to make the intercept instead of a path capture prior to WP5. The bank angle time history of Figure 53 shows the two 10 degree turns, and the third turn (not part of the capture path) that is made near WP4. The radius for this turn is 6500 feet, which results in a 15 degree bank angle.

## REFERENCES

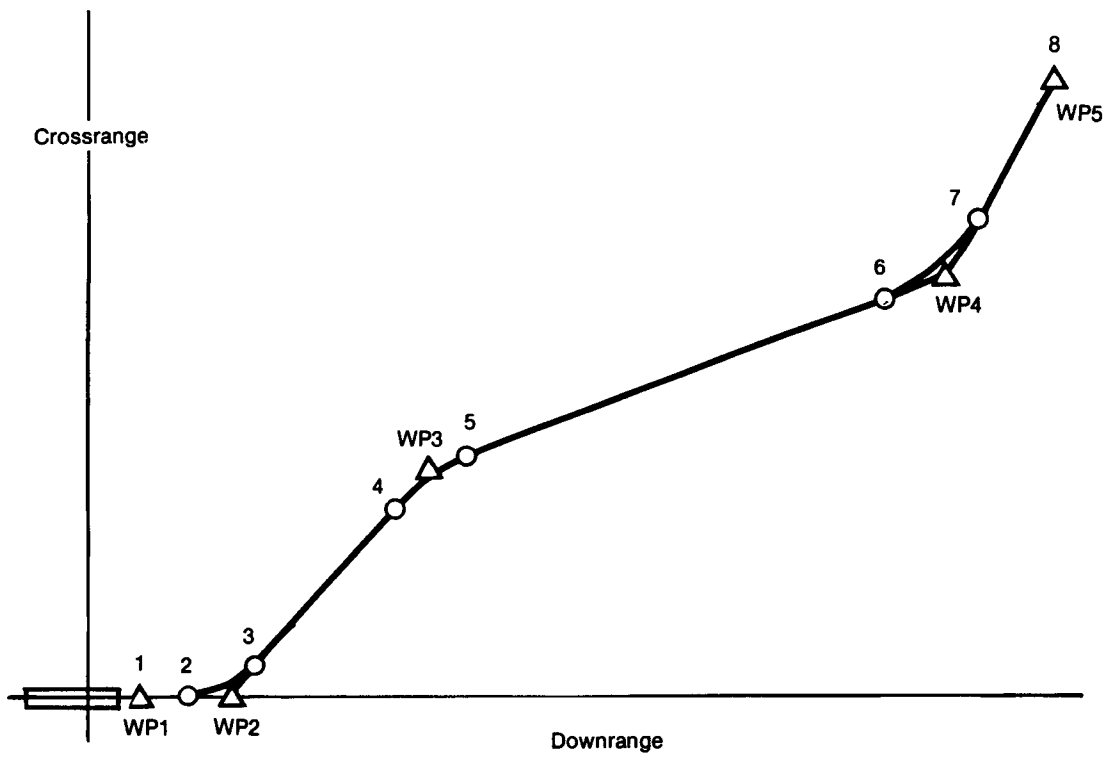
1. J. B. Feather: Guidance Law Simulation Studies for Complex Approaches Using the Microwave Landing System (MLS), NASA CR-178182, November 1986.
2. J. B. Feather: Simulation of Automatic Precision Departures and Missed Approaches Using the Microwave Landing System, NASA CR-178312, July 1987.
3. L. J. J. Erkelens and W. Aardoom: Considerations on MLS Approach Path Interception Techniques, National Aerospace Laboratory NLR (The Netherlands), Report NLR TR 83142L, November 1983.
4. L. J. J. Erkelens and P. J. van der Geest: Flight Simulation of MLS Interception Procedures Applicable to Laterally Segmented Approach Paths, paper prepared for the AIAA Atmospheric Flight Mechanics Conference, August 1986.
5. L. G. Summers and J. E. Jonsson: Crew Procedures and Workload of Retrofit Concepts for Microwave Landing Systems. NASA CR-181700, 1988.



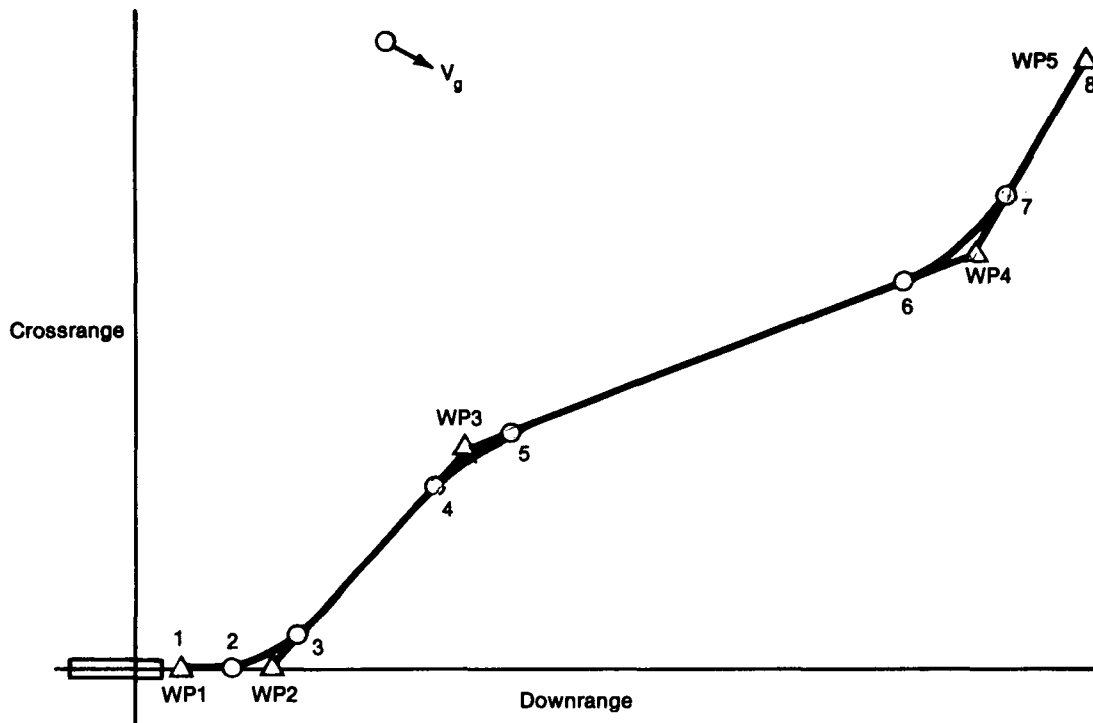
**FIGURE 1. MLS SITE GEOMETRY**



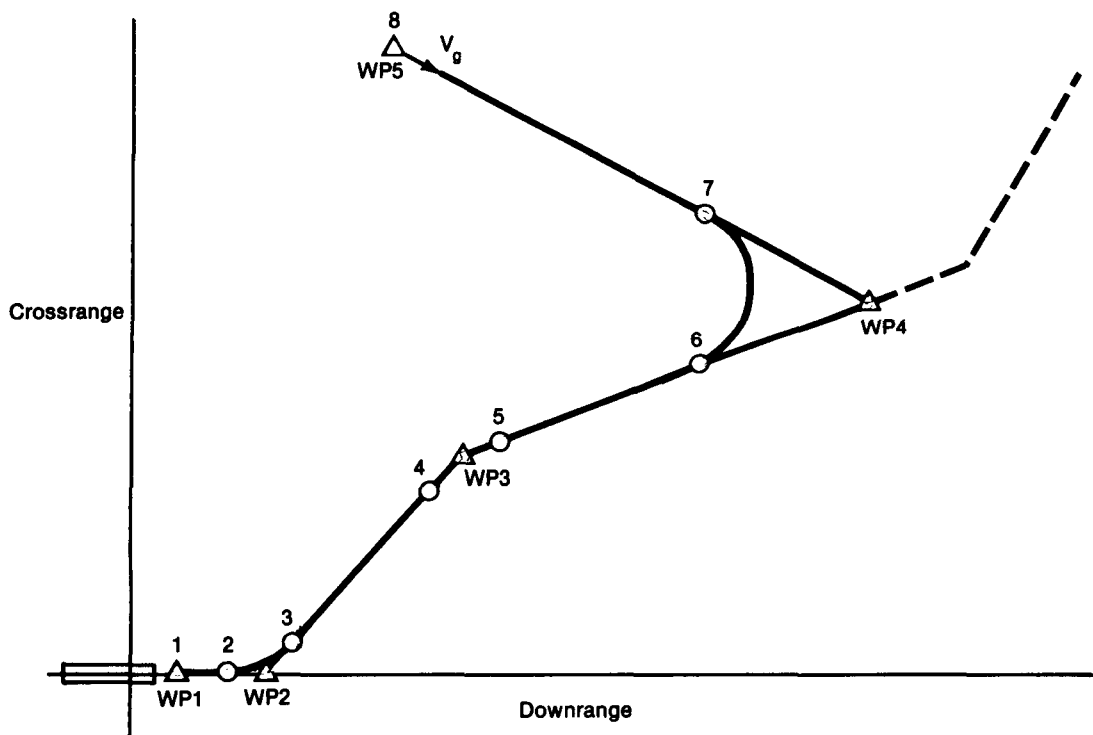
**FIGURE 4. ENHANCED ILS LOOK-ALIKE CAPTURE**



**FIGURE 5. EXAMPLE OF MLS LATERAL APPROACH PATH DEFINED BY WAYPOINTS**

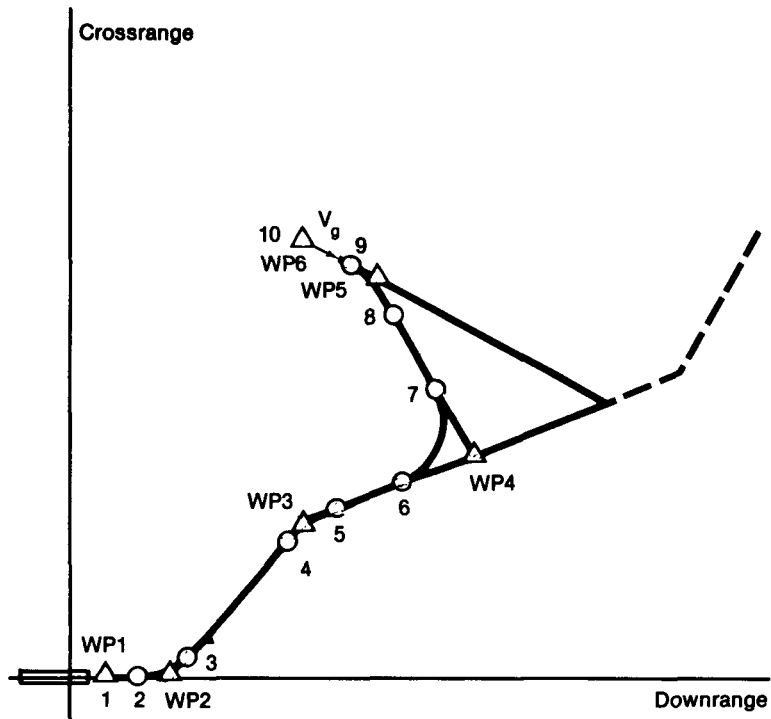


A. Lateral Path Geometry

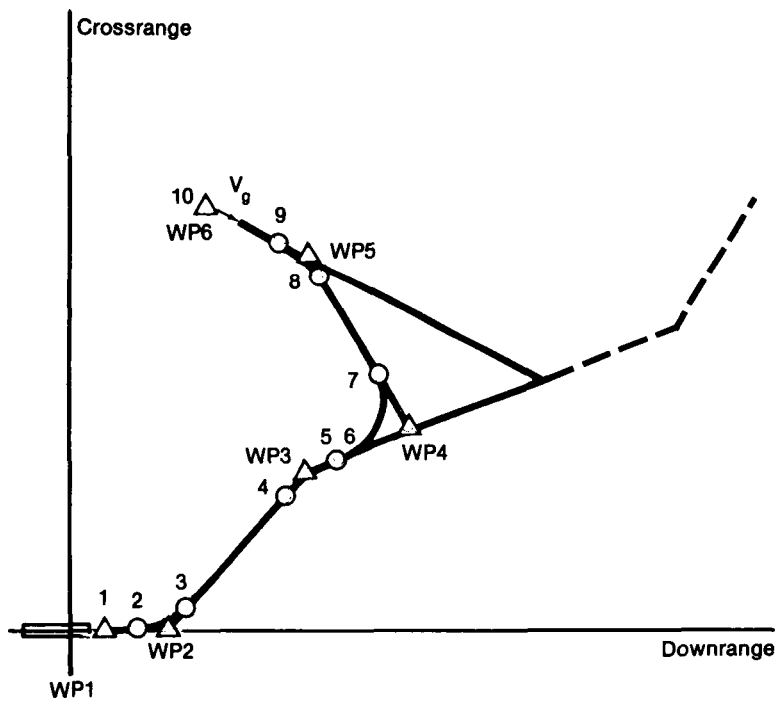


B. Waypoints and Turn Points Defined for Capture

FIGURE 7. PATH CAPTURE FROM PRESENT COURSE ANGLE

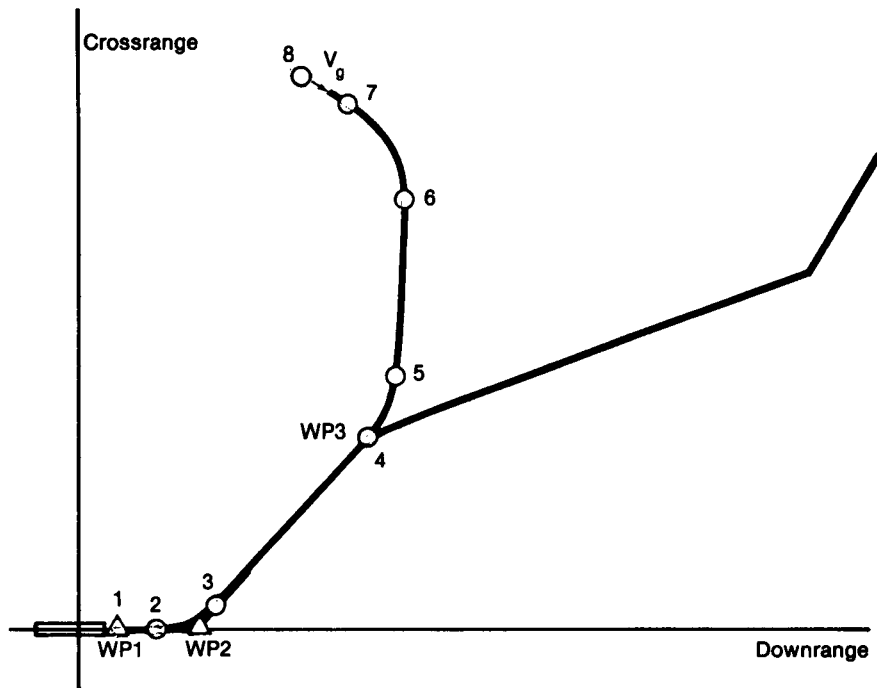


A. First Turn Start at MLS Capture Engage

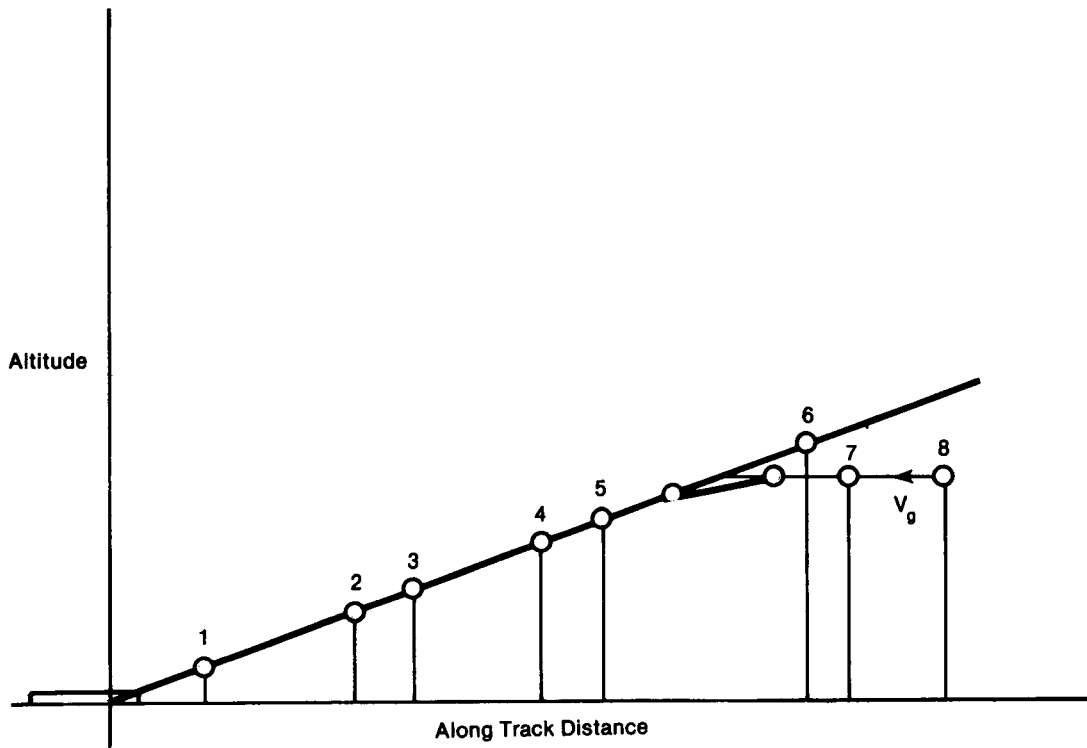


B. First Turn Delayed

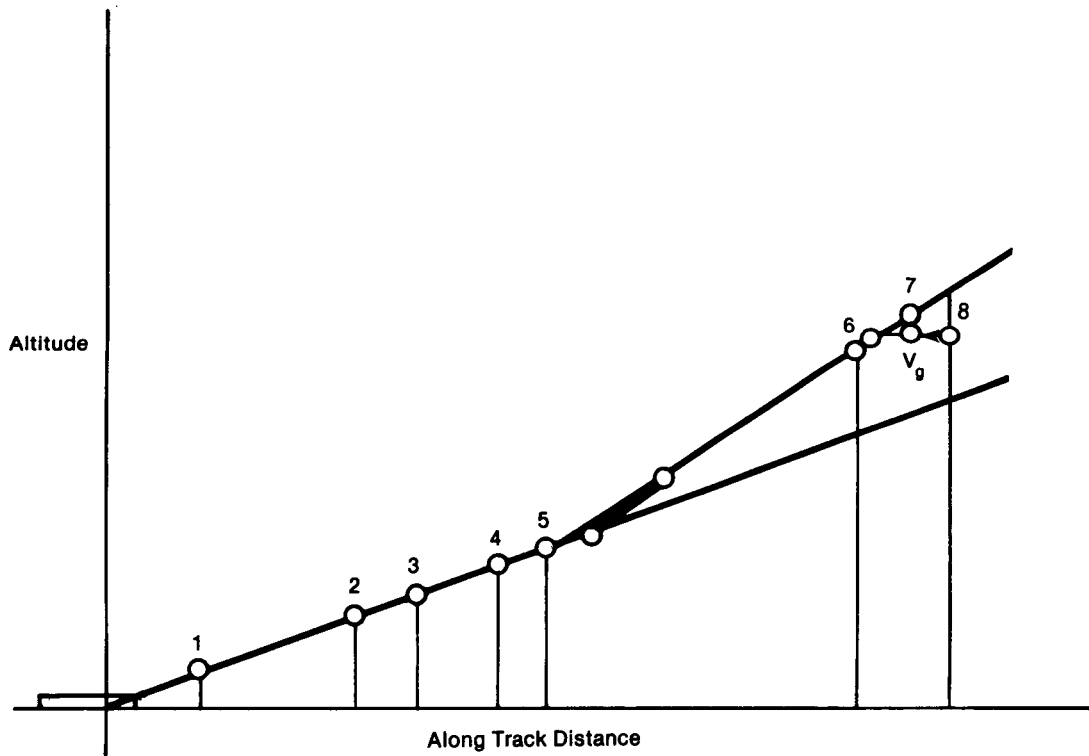
FIGURE 9. PATH CAPTURE FROM SPECIFIED COURSE ANGLE



**FIGURE 11. WAYPOINT CAPTURE**



A. Capture from Below Glidepath



B. Capture from Above Glidepath

FIGURE 13. VERTICAL PATH CAPTURES



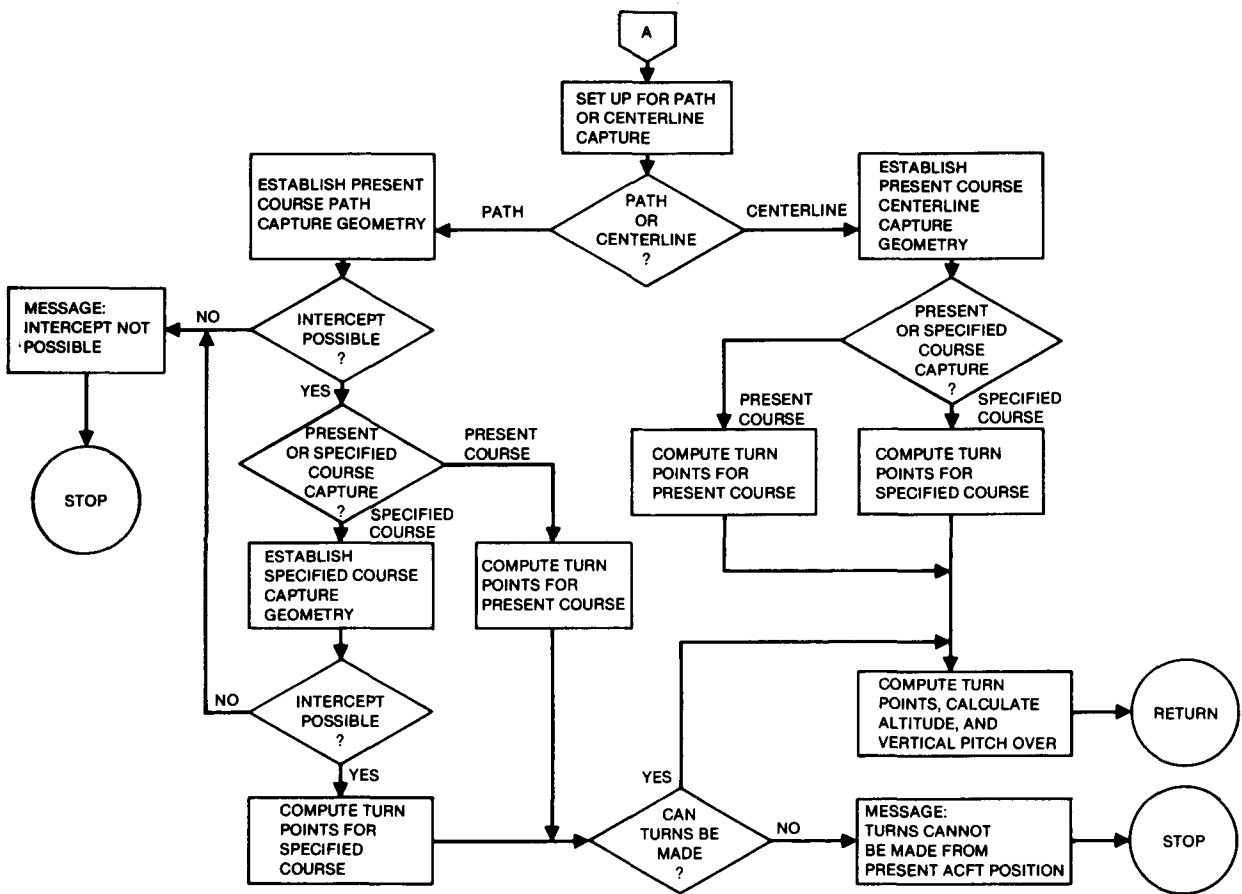


FIGURE 14. FLOW CHART OF PATH CAPTURE ALGORITHM (SHEET 2 OF 3)

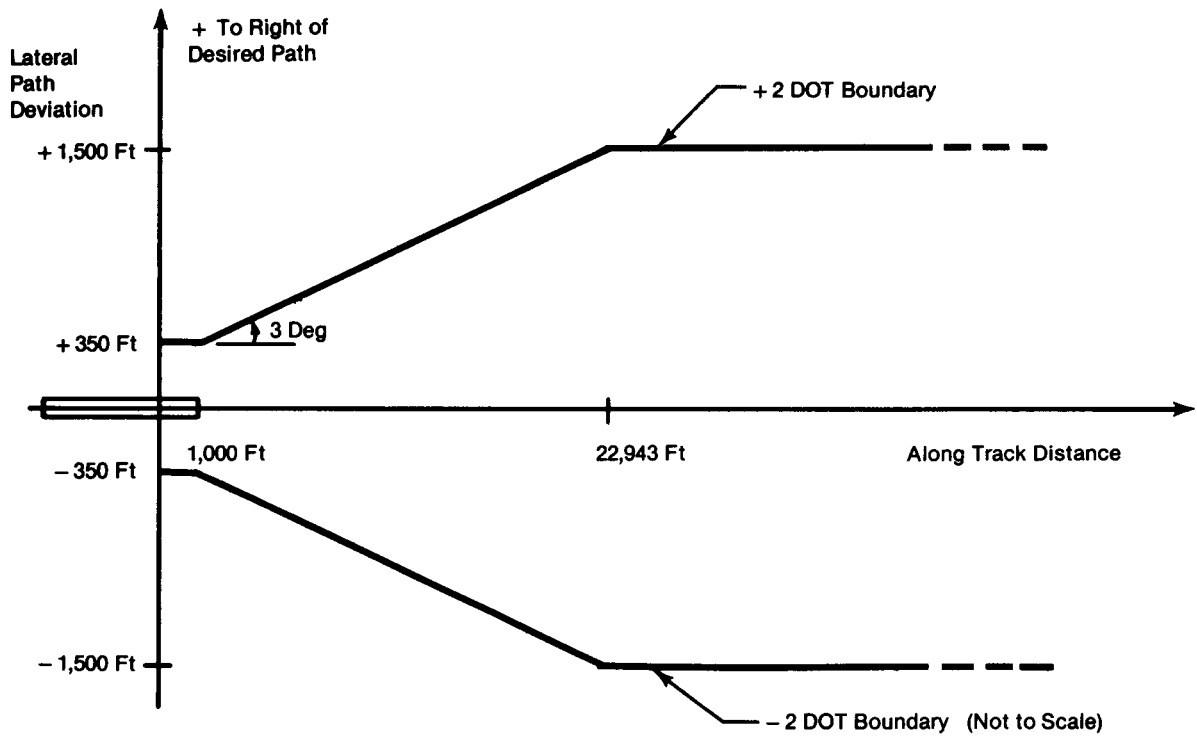


FIGURE 15. DEFINITION OF LATERAL PATH DEVIATION

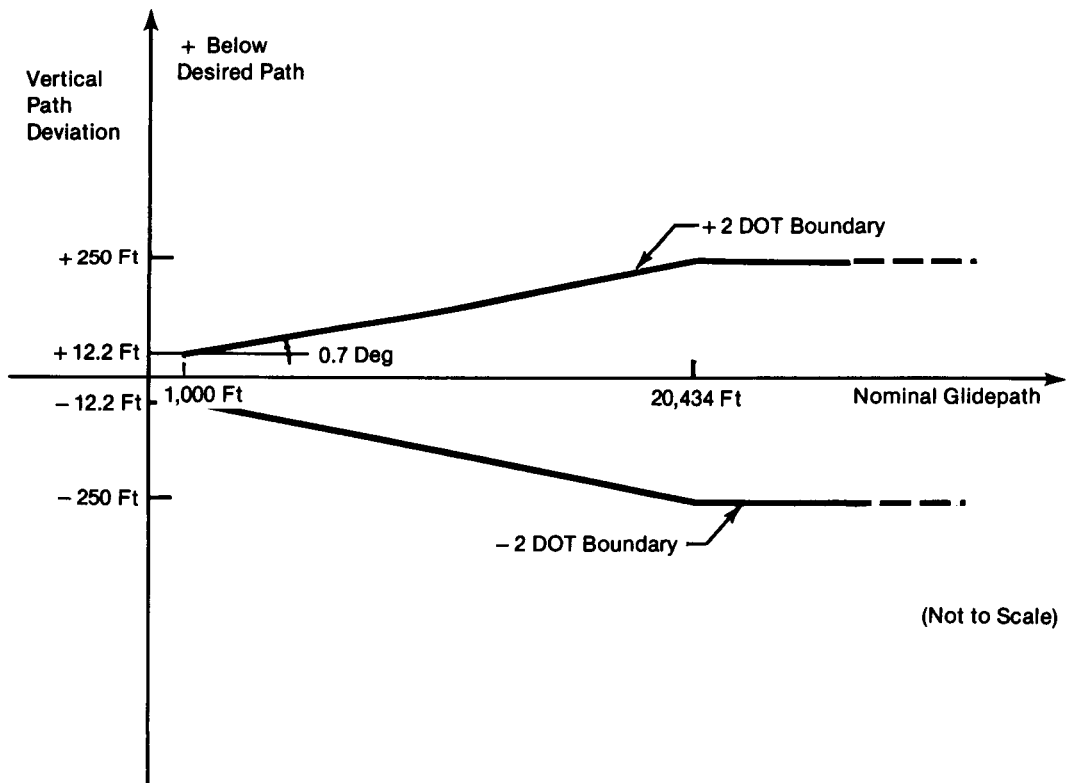
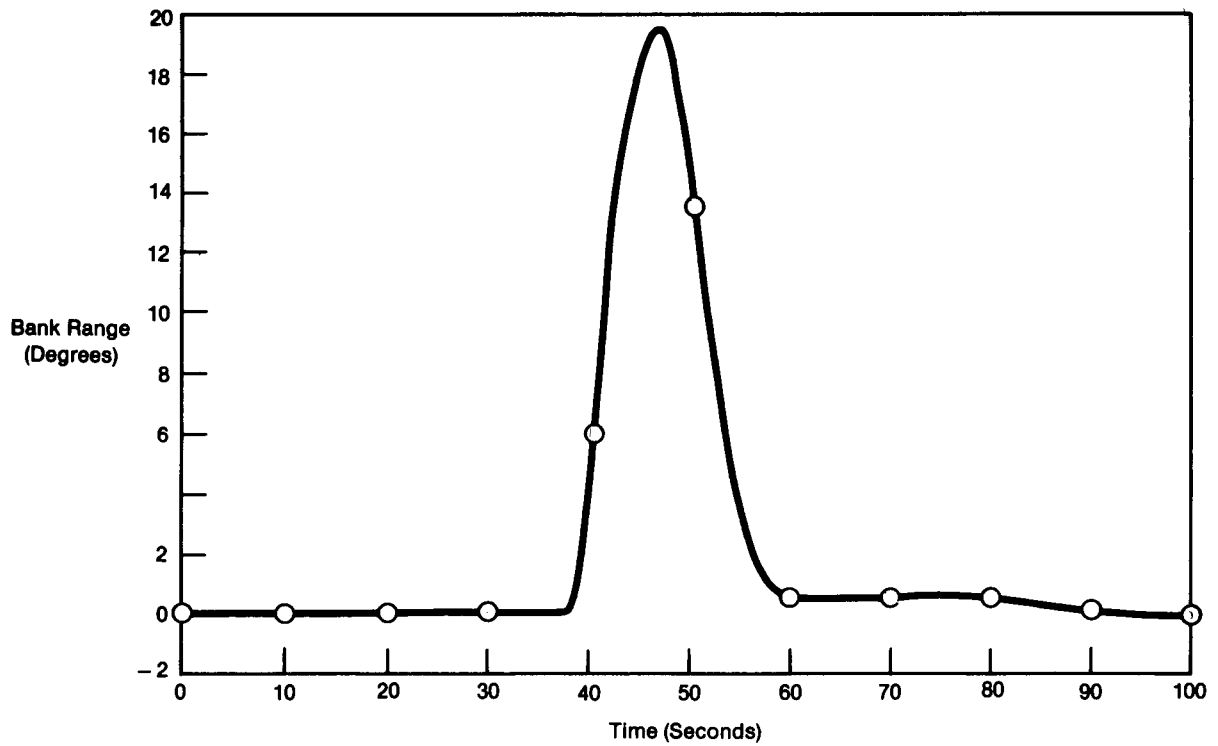
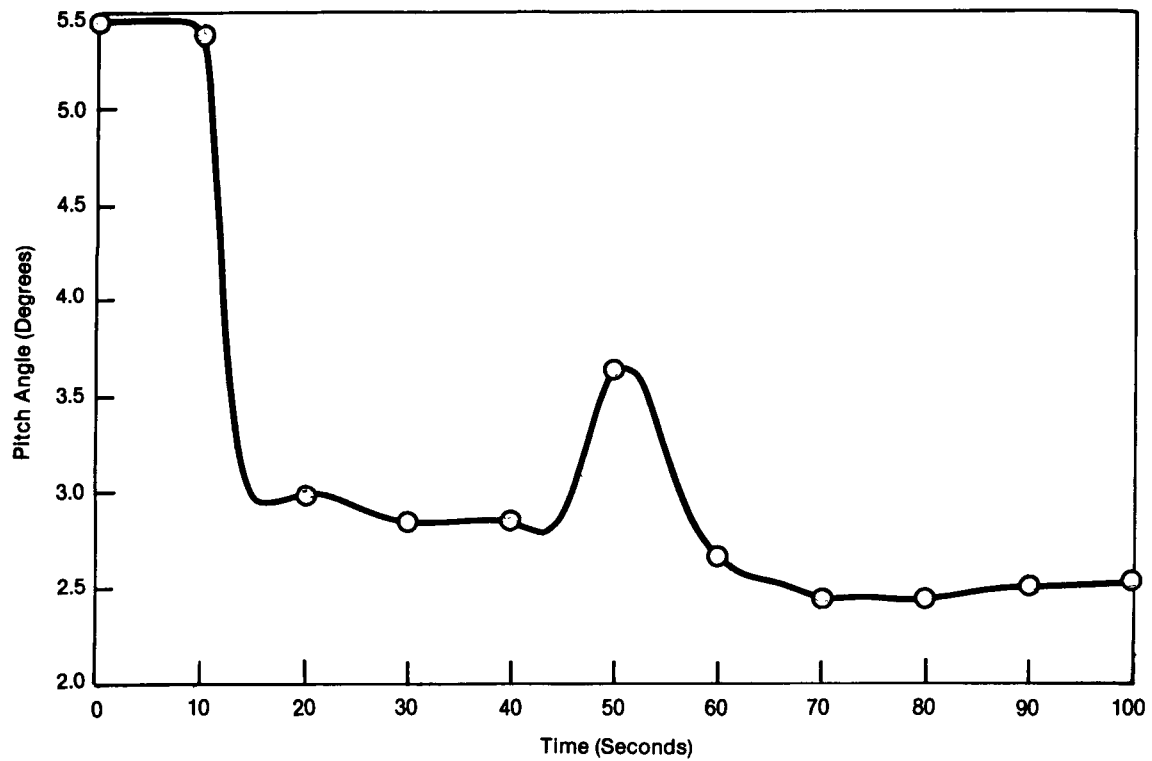


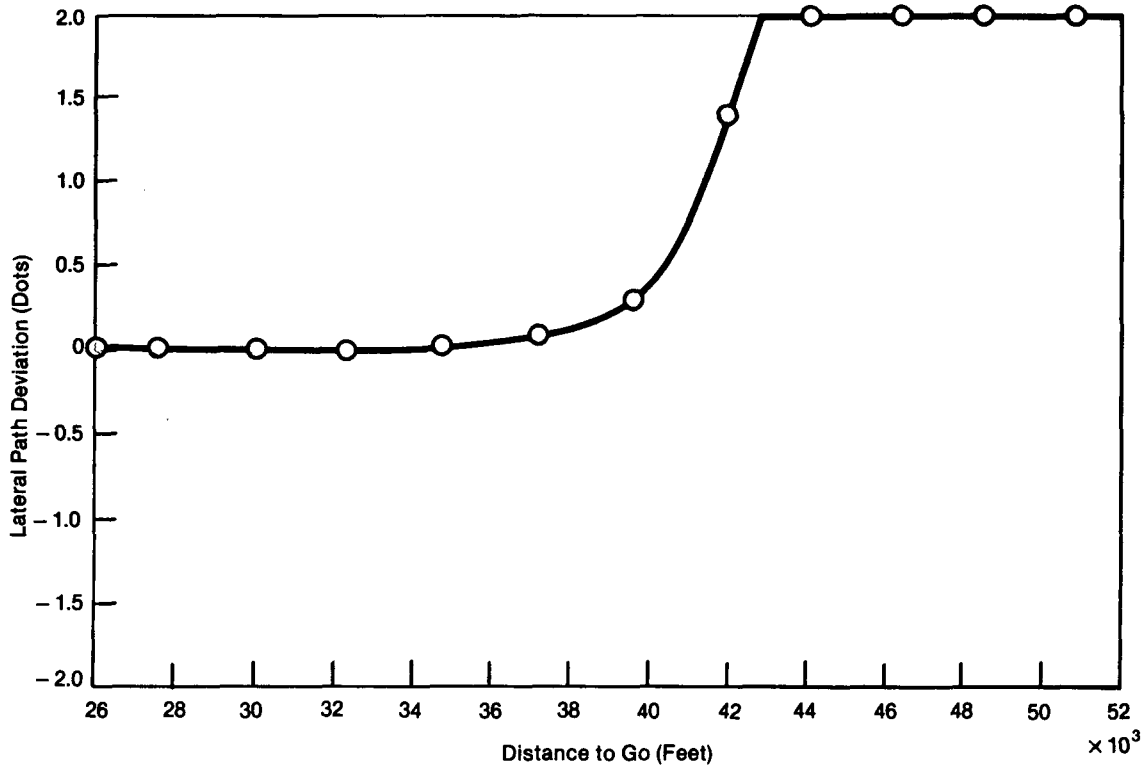
FIGURE 16. DEFINITION OF VERTICAL PATH DEVIATION



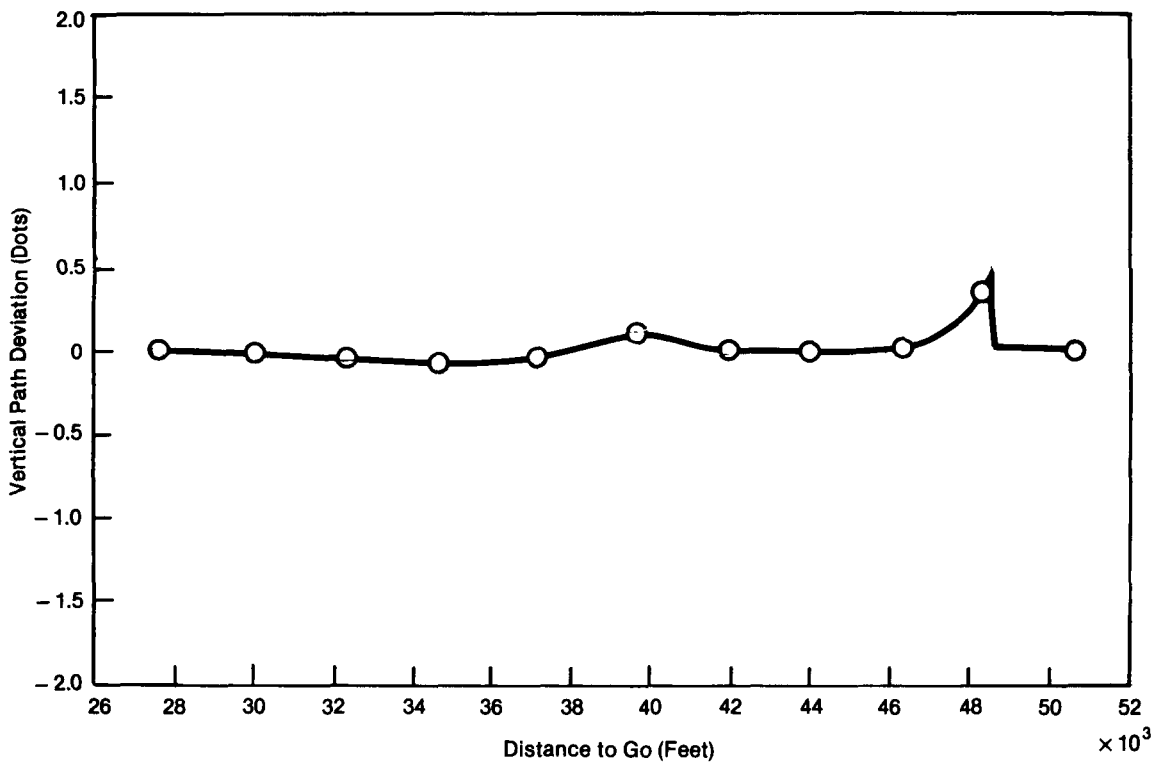
**FIGURE 18. BANK ANGLE TIME HISTORY FOR ENHANCED ILS LOOK-ALIKE (CASE 1)**



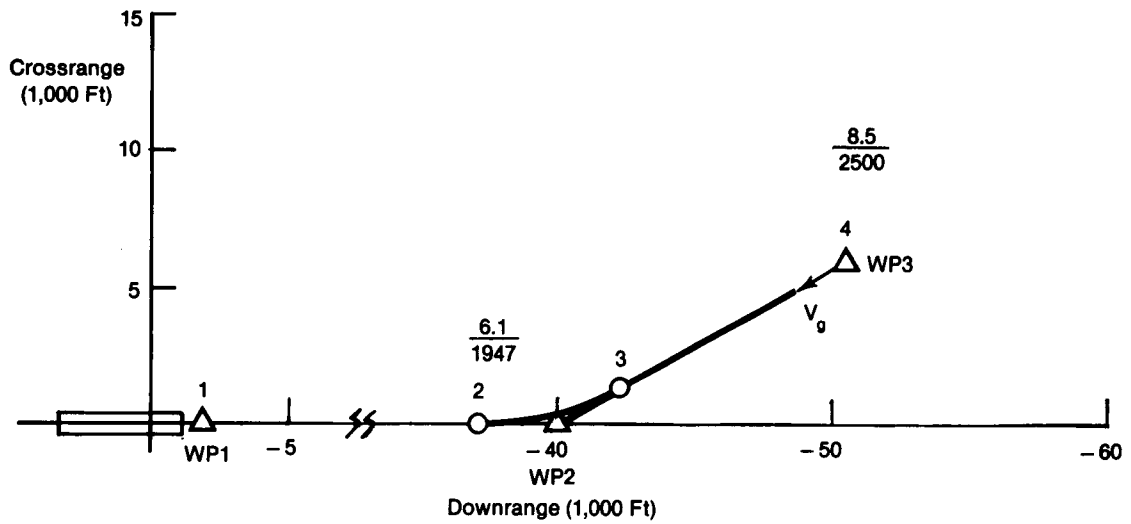
**FIGURE 19. PITCH ANGLE TIME HISTORY FOR ENHANCED ILS LOOK-ALIKE (CASE 1)**



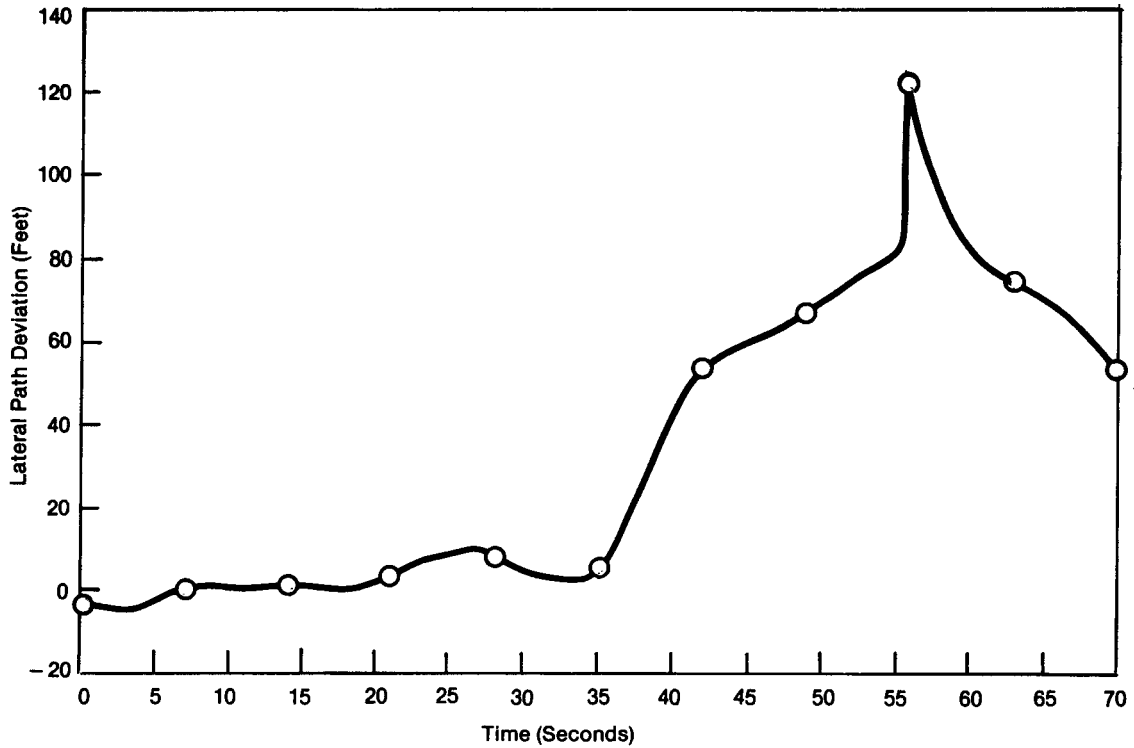
**FIGURE 22. LATERAL PATH DEVIATION (DOTS) FOR ENHANCED ILS LOOK-ALIKE (CASE 1)**



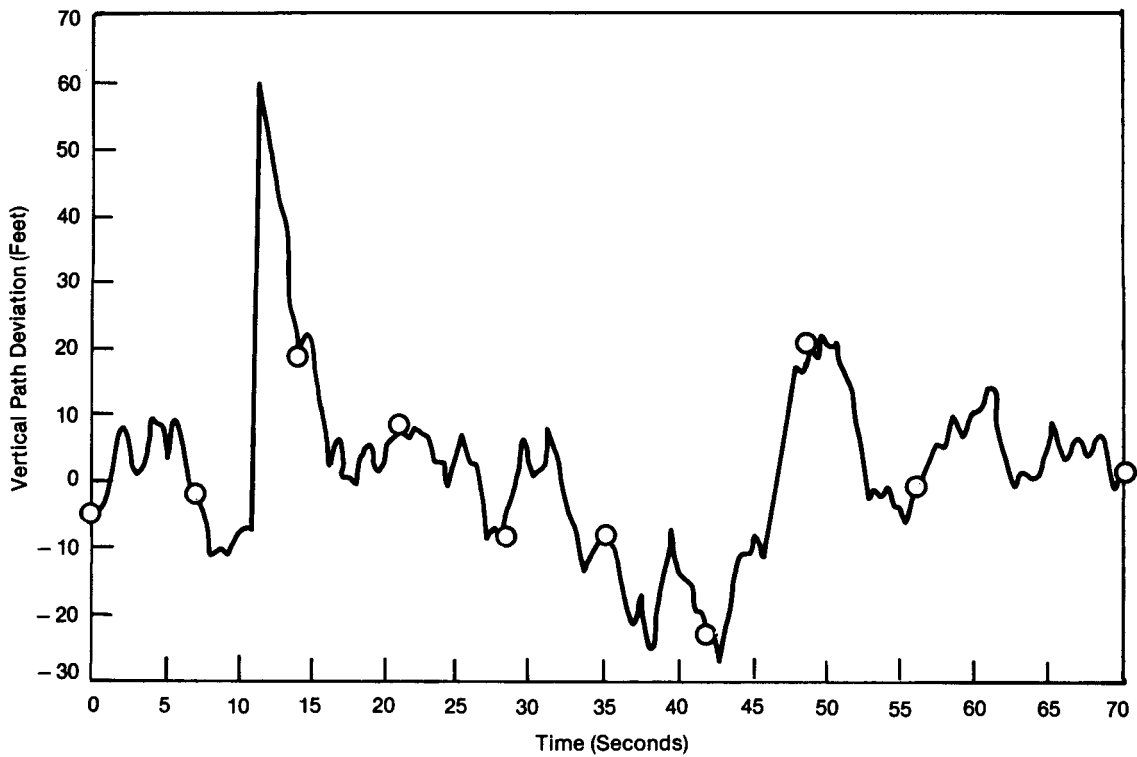
**FIGURE 23. VERTICAL PATH DEVIATION (DOTS) FOR ENHANCED ILS LOOK-ALIKE (CASE 1)**



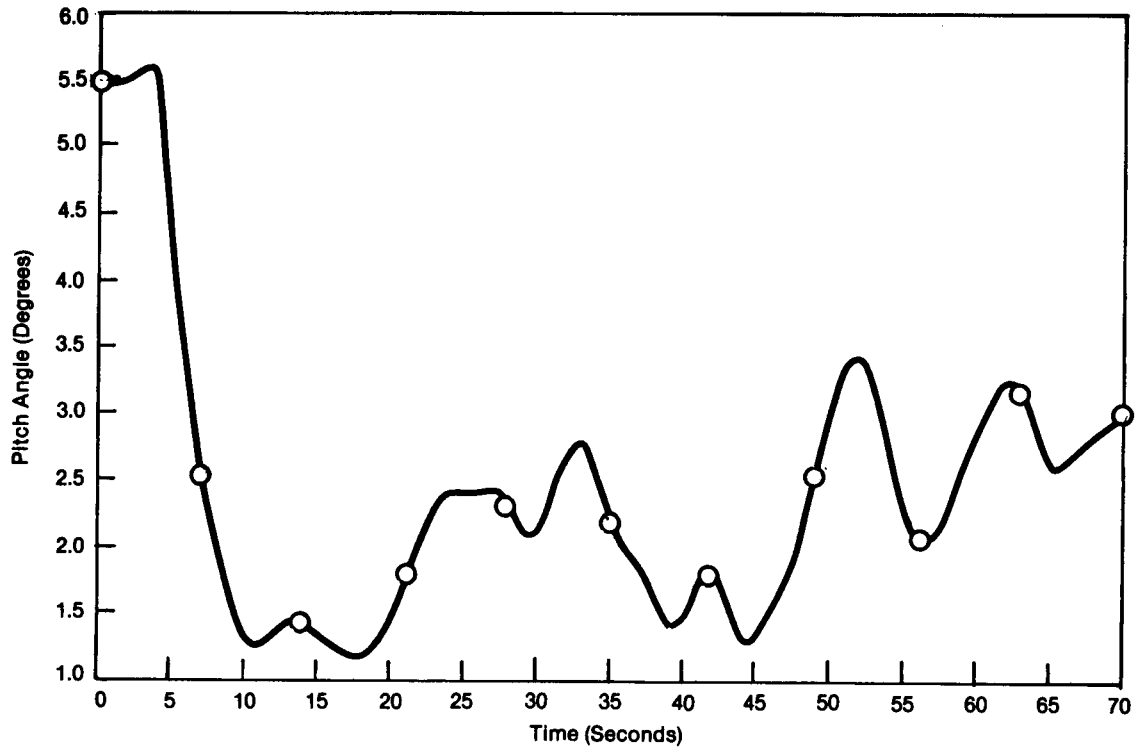
**FIGURE 25. EXTENDED RUNWAY CENTERLINE CAPTURE FROM PRESENT COURSE, LONG FINAL (CASE 2)**



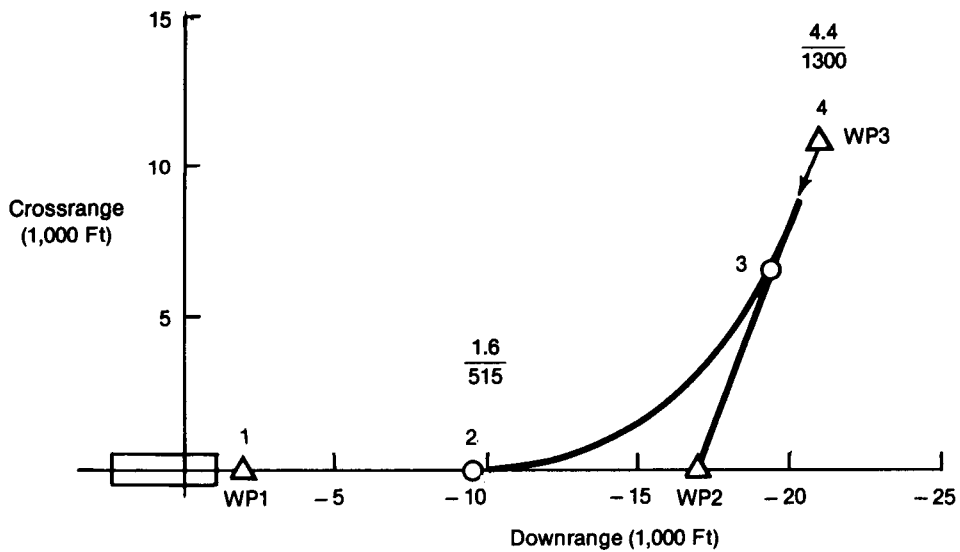
**FIGURE 28. LATERAL PATH DEVIATION FOR CENTERLINE CAPTURE, LONG FINAL (CASE 2)**



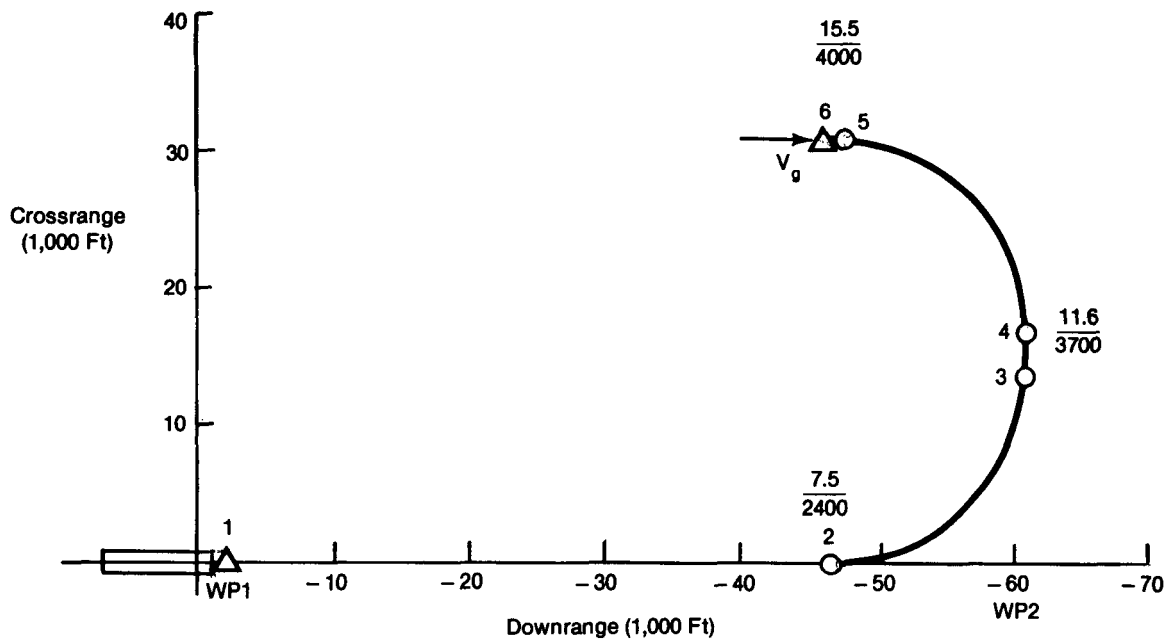
**FIGURE 29. VERTICAL PATH DEVIATION FOR CENTERLINE CAPTURE, LONG FINAL (CASE 2)**



**FIGURE 32. PITCH ANGLE TIME HISTORY FOR CAPTURE FROM ABOVE GLIDEPATH (CASE 3)**

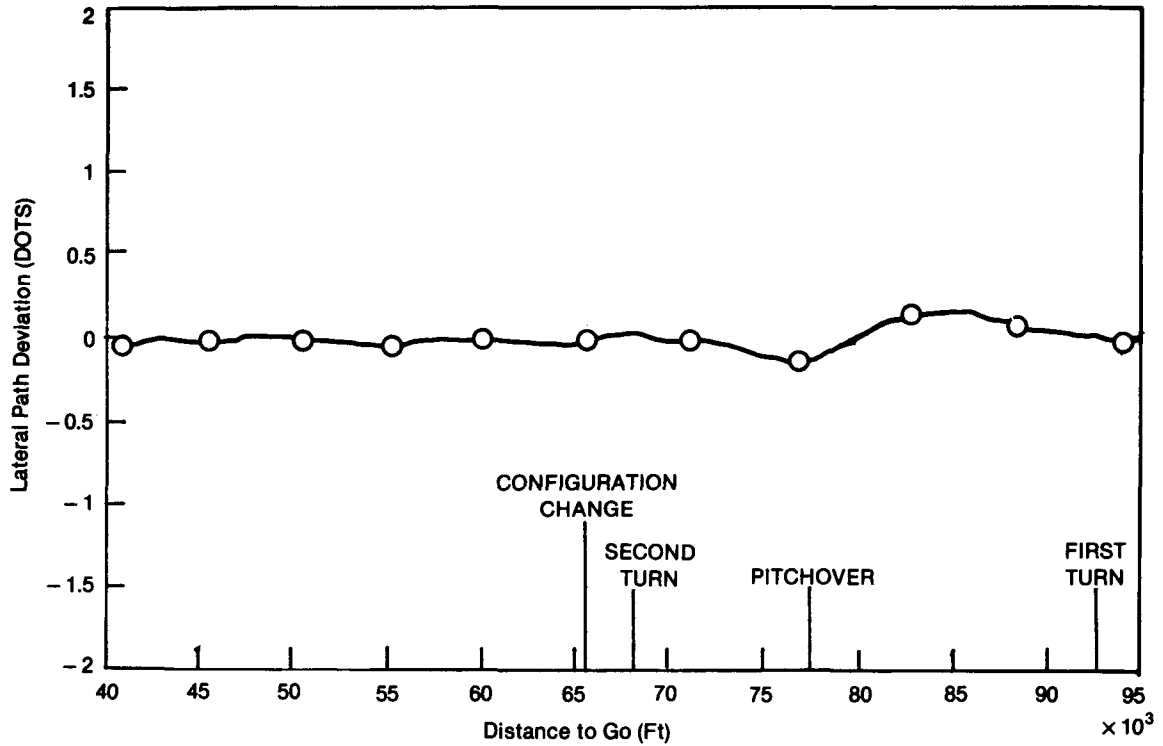


**FIGURE 33. EXTENDED RUNWAY CENTERLINE CAPTURE FROM PRESENT COURSE, SHORT FINAL (CASE 4)**

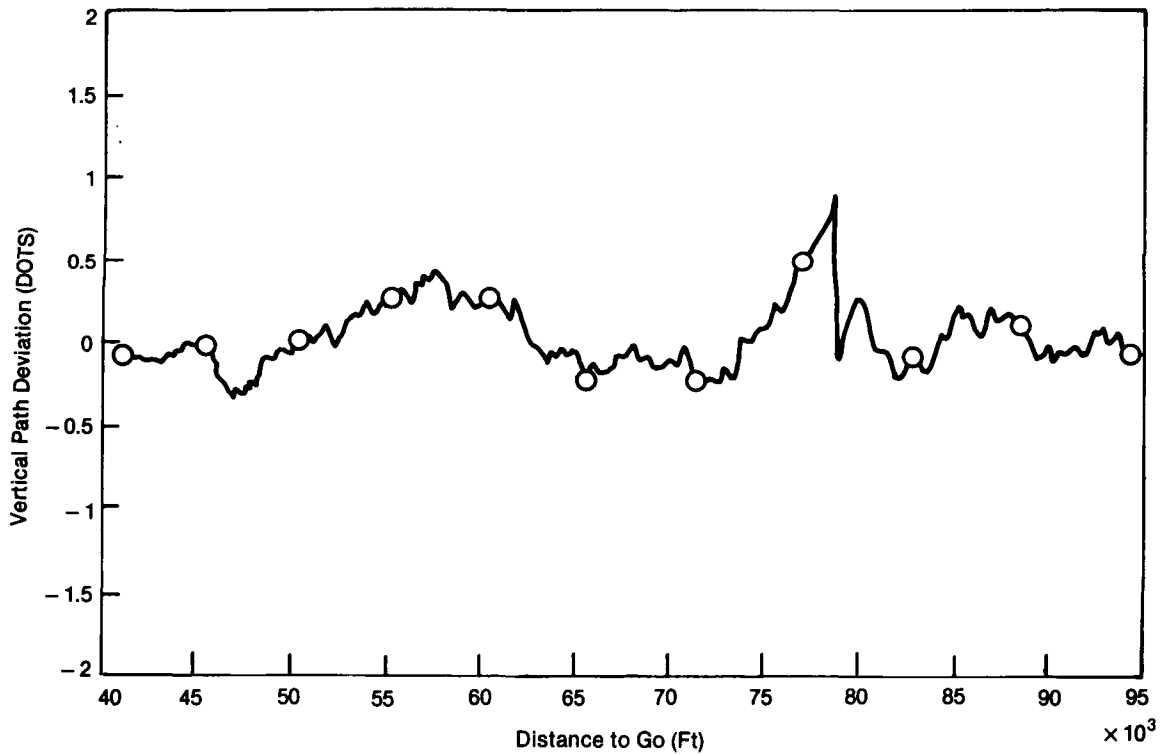


**FIGURE 36. EXTENDED RUNWAY CENTERLINE CAPTURE FOR SPECIFIED COURSE ANGLE (CASE 5)**

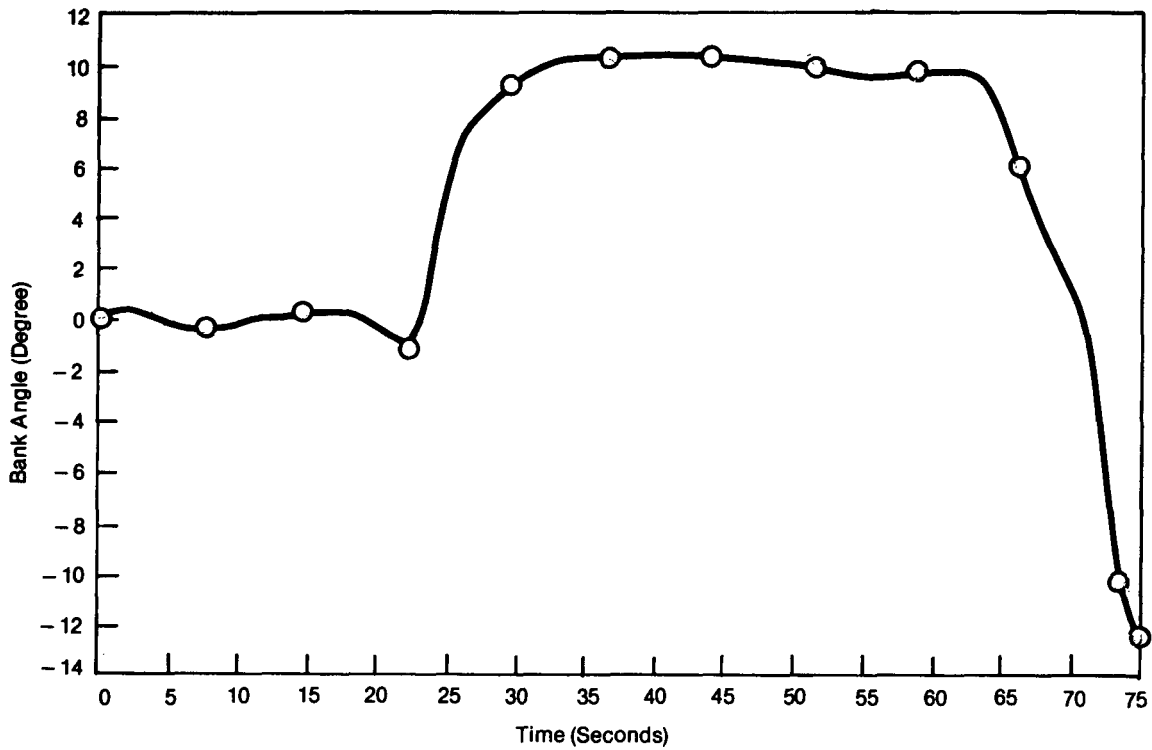




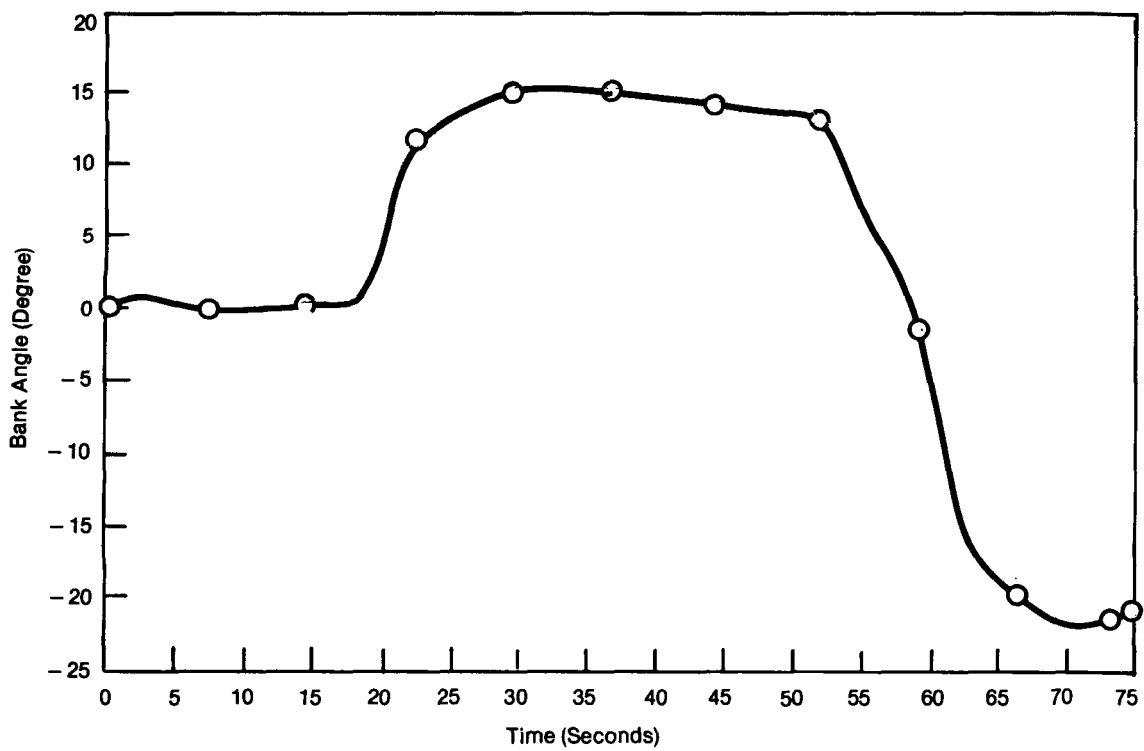
**FIGURE 39. LATERAL PATH DEVIATION (DOTS) FOR CENTERLINE CAPTURE FROM SPECIFIED COURSE ANGLE (CASE 5)**



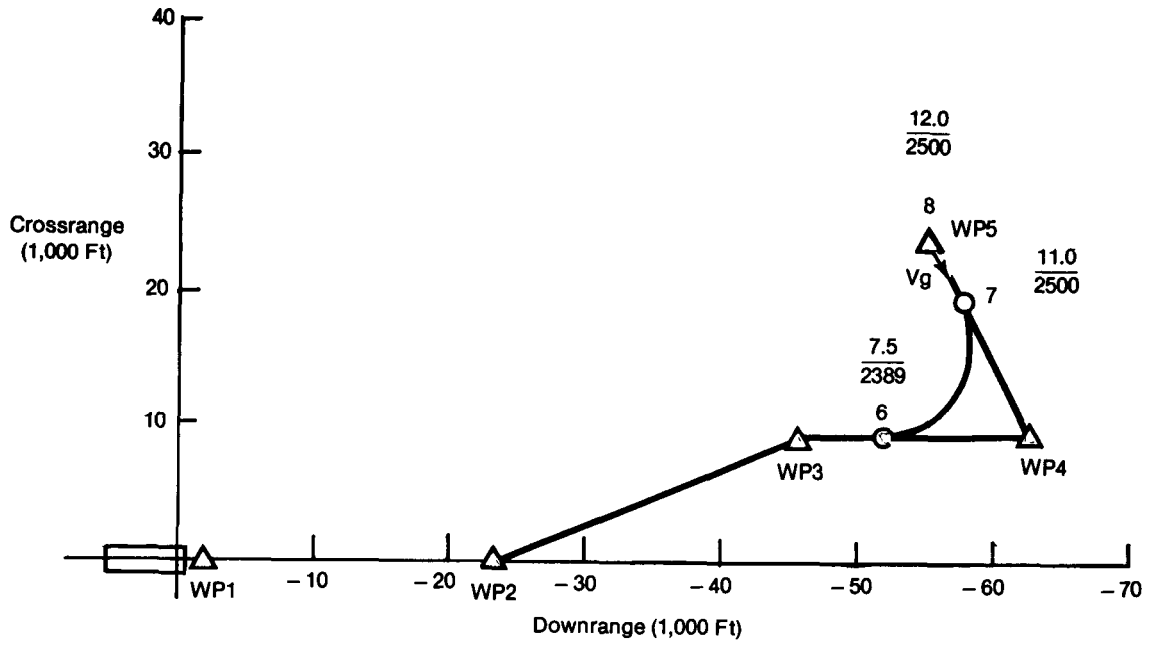
**FIGURE 40. VERTICAL PATH DEVIATION (DOTS) FOR CENTERLINE CAPTURE FROM SPECIFIED COURSE ANGLE (CASE 5)**



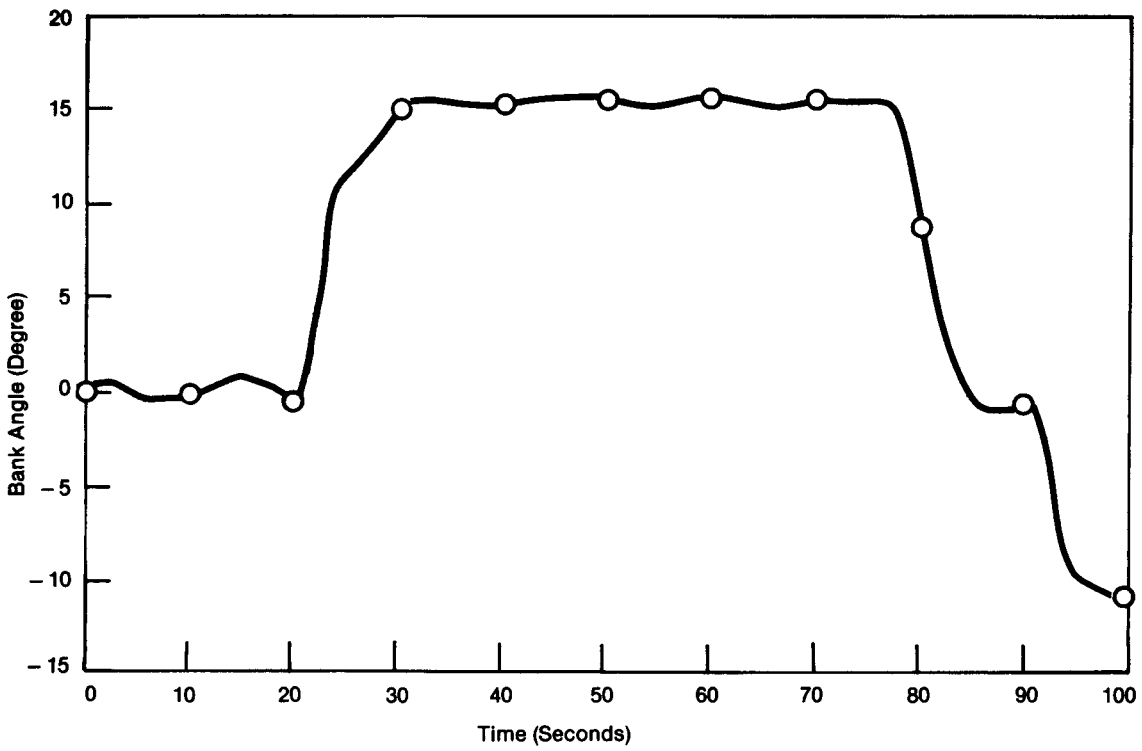
**FIGURE 42. BANK ANGLE TIME HISTORY FOR PATH CAPTURE FROM PRESENT COURSE, NO WIND (CASE 6)**



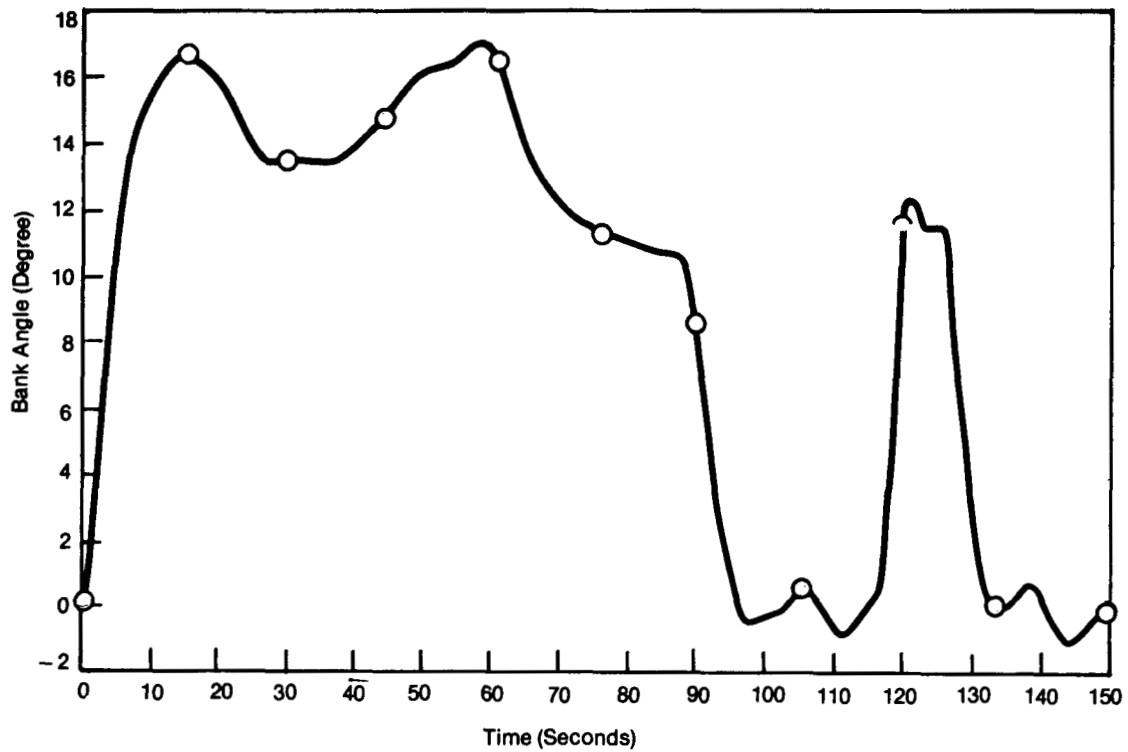
**FIGURE 43. BANK ANGLE TIME HISTORY FOR PATH CAPTURE FROM PRESENT COURSE, WITH WIND (CASE 6)**



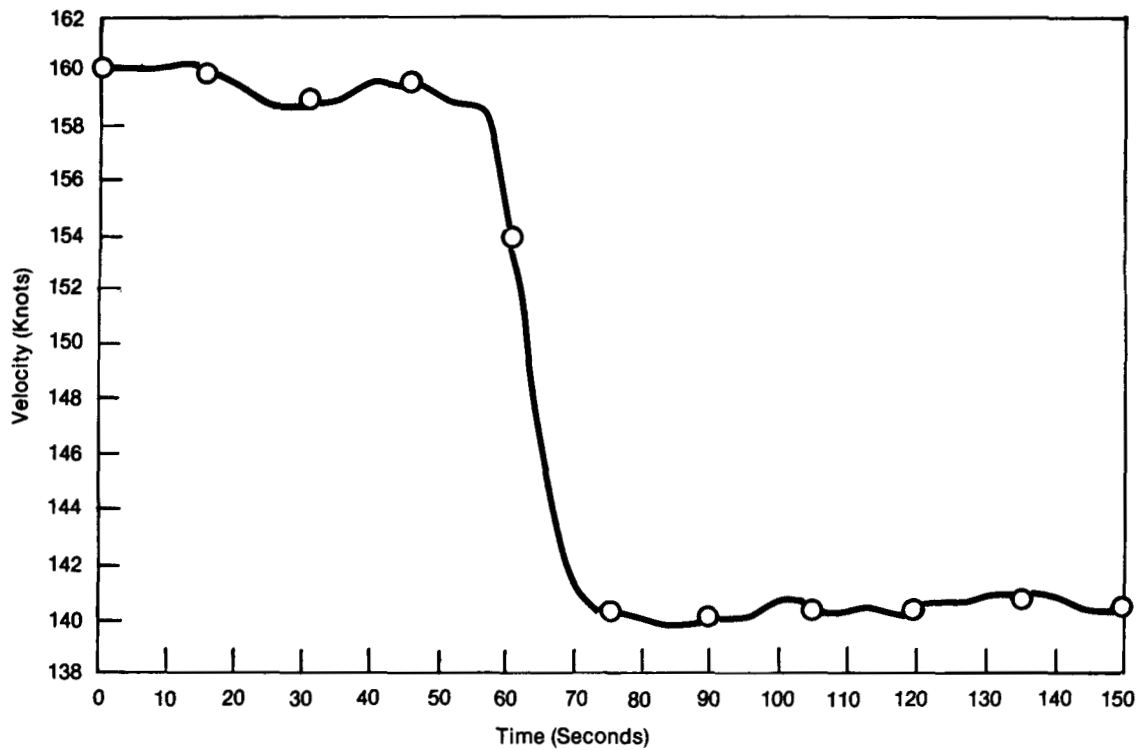
**FIGURE 45. PATH CAPTURE FROM PRESENT COURSE WITH INCREASED BANK ANGLE LIMIT (CASE 7)**



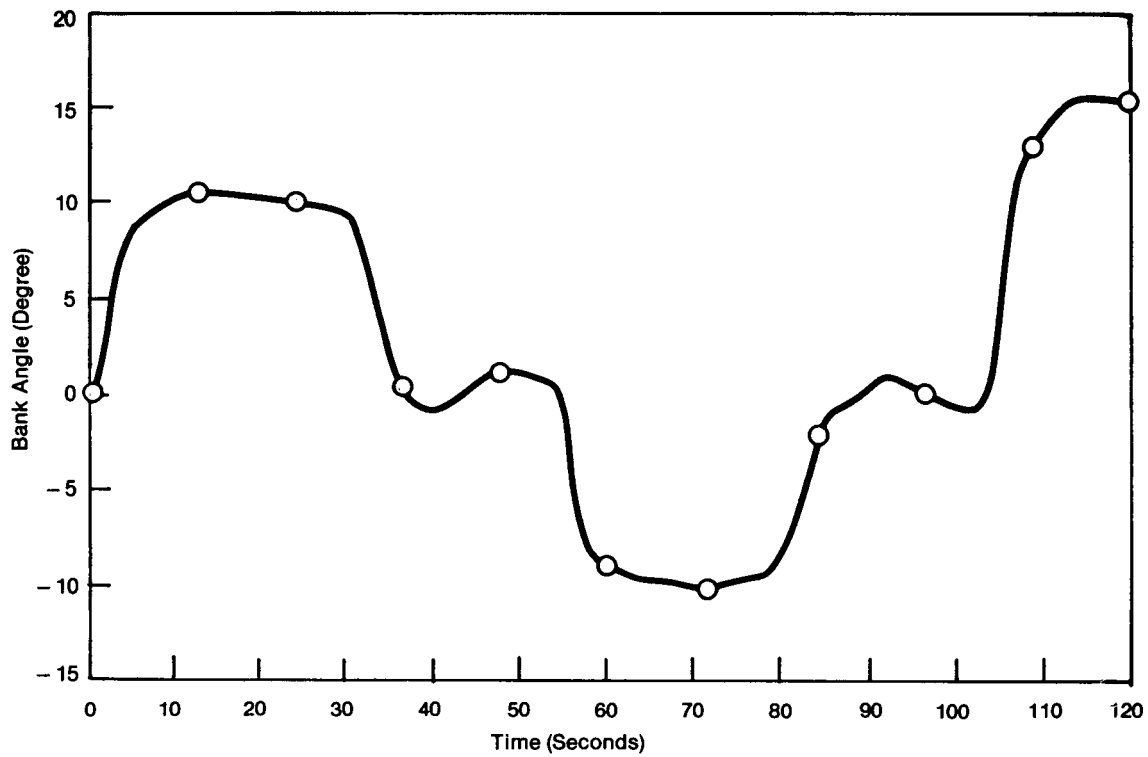
**FIGURE 48. BANK ANGLE TIME HISTORY WITH INCREASED BANK LIMIT, CONSTANT SPEED (CASE 8)**



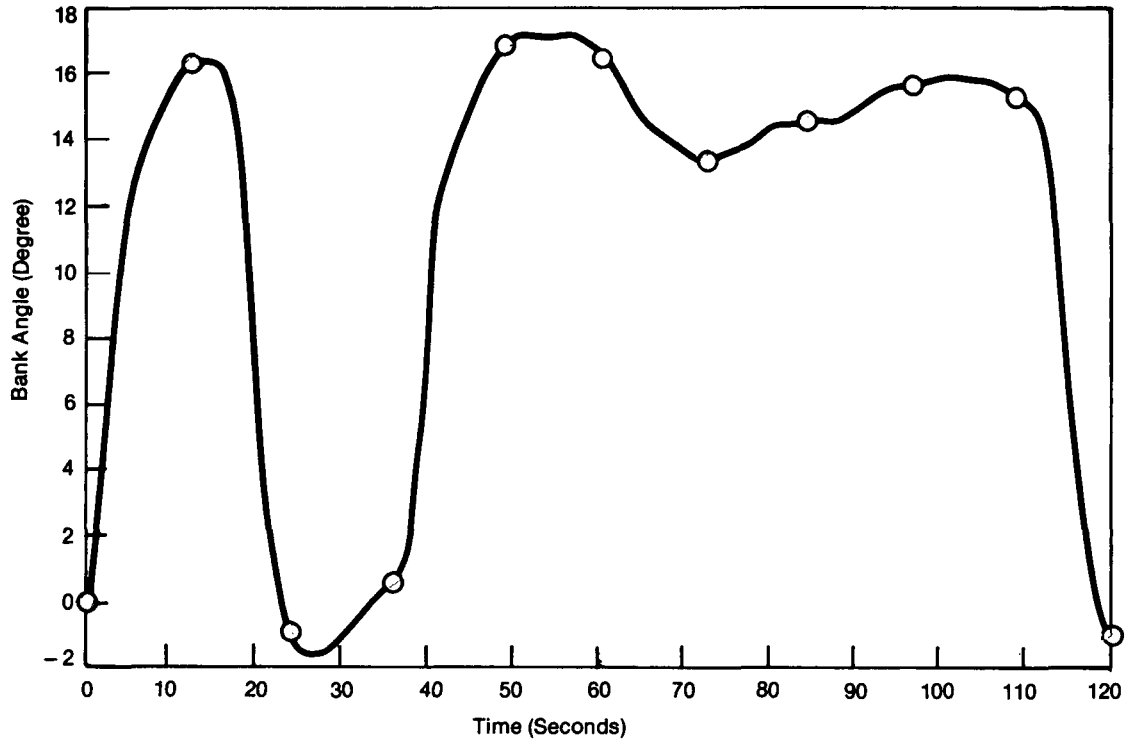
**FIGURE 50. BANK ANGLE TIME HISTORY WITH 15-DEGREE BANK COMMAND LIMIT (CASE 9)**



**FIGURE 51. VELOCITY TIME HISTORY WITH 15-DEGREE BANK COMMAND LIMIT (CASE 9)**



**FIGURE 53. BANK ANGLE TIME HISTORY WITH 10-DEGREE BANK COMMAND LIMIT (CASE 10)**



**FIGURE 55. BANK ANGLE TIME HISTORY WITH 15-DEGREE BANK COMMAND LIMIT (CASE 11)**

TABLE A-1. MLS NOISE PARAMETERS ( $2\sigma$  or 95% PROBABILITY)

AZIMUTH	ELEVATION	DME
PFE = 0.0312 DEG ( <u>+6</u> FT)	PFE = 0.018 DEG ( <u>+0.30</u> FT)	PFE = 100 FT
CMN = 0.0208 DEG ( <u>+4</u> FT)	CMN = 0.012 DEG ( <u>+0.20</u> FT)	CMN = 60 FT

PFE = PATH FOLLOWING ERROR

CMN = CONTROL MOTION NOISE

RUNWAY LENGTH = 10,000 FT.





# Report Documentation Page

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16. Abstract <p>Computer simulation results are presented in this report for intercepting final approach paths using various Microwave Landing System (MLS) path capture concepts. This study, conducted under the Advanced Transport Operating System (ATOPS) program, simulated these captures using the MD-80 aircraft as the study model.</p> <p>Several different capture concepts were investigated. Systems that could be retrofitted into existing aircraft with minimum hardware and software changes were considered. An enhanced ILS look-alike capture provided improved tracking performance over conventional ILS without using a full-up path computer. The other concepts used waypoint databases and path computers to provide "smart" captures. These captures included lateral path intercepts as well as vertical path control. Winds, turbulence, and MLS noise were included in the simulation. In all cases, acceptable tracking errors were obtained during transition to the final approach path.</p>					
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