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THE EFFECT OF LANDING SYSTEM COVERAGE AND PATH GEOMETRY ON LATERAL POSITION ERRORS AT THE RUNWAY THRESHOLD

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SUMMARY

This report presents the results of an analytical study performed to determine the effect of the azimuth coverage of a Microwave Landing System (MLS) on the ability of an airplane, with an initial navigation position estimate error, to navigate to the runway threshold. The test path chosen for this study consists of an initial straight segment leading into a 130° turn with a 2286 m radius and ending in a straight-in final approach segment. The test-path configuration was varied by changing the MLS azimuth coverage angle and the final approach length. The aircraft was positioned with an initial offset to the left or right of the desired path along the line of intersection with the MLS azimuth coverage. A fast time computer simulation program, using a simplistic point mass model of the airplane, was used for this study. The data from this study indicates that the lateral position errors at the runway are primarily a function of the final approach length. The effect of the azimuth coverage on the lateral position errors was restricted by the turn characteristics of the horizontal steering control laws.

INTRODUCTION

The introduction of the Microwave Landing System (MLS) at airports in the nation can provide the capability for substantial improvements in capacity and reductions in the noise around these airports. The mechanism for these improvements involves the aircraft following an approach path other than the traditional 3° Instrument Landing System (ILS) straight-in, constant speed approach. Steeper approaches (ref. 1), approaches at other than constant speed (ref. 2), and curved approaches have been suggested as possible alternatives, each of which have both the potential for increased capacity, as well as reduced noise and reduced fuel consumption.

The expanded coverage of the MLS signals allows an airplane to receive highly accurate position information with the potential for improved path accuracy on close-in automatic final approaches and reduced landing dispersion capability. For those airplanes equipped with only area navigation systems, this updated position information may increase their capability to approach the runway under low visibility conditions.

Prior to entering a terminal area, an aircraft can navigate using VOR, DME, or inertial navigation systems, to determine a best estimate of position. These navigation systems can accumulate varying magnitude of position error depending on the types of radio inputs and system used. Upon entering the coverage of the MLS signals, an aircraft could receive more accurate position information which would result in a rapid shift of the position estimate and a corresponding guidance error.

The purpose of this report is to present the results of an analytical study to access the effect of MLS coverage on the ability of an aircraft with an initial navigation position estimate error to navigate to the runway threshold.

This report will present the horizontal-path capture capabilities of the navigation and guidance system presently incorporated on the NASA TCV airplane using MLS updated position information. The test conditions included various MLS azimuth coverage angles and final approach lengths.

SYMBOLS

Values are presented in both SI units and the units used in calculations.

CAS	calibrated airspeed, kns
KY	cross-track error steering command gain, deg/m, (deg/ft)
$K\dot{Y}$	track-angle error steering command gain, s/m, (s/ft)
TKE	track-angle error, the difference between the airplane heading and the desired heading, deg
VGS	ground speed, kns
X	course cut heading values, deg
XTK	cross-track error, the perpendicular distance between the airplane and its desired path, m, (ft)
ψ_I	course cut heading, deg

TEST CONDITIONS AND PROCEDURES

A plan view of the test flight path chosen for this study is shown in figure 1. The path consists of an initial straight segment leading into a 130° turn with a 2286 m (7500 ft) radius and ending in a final approach segment. The path is defined through a series of four waypoints. The first waypoint is simply a starting point for the path; the second defines the turn.

The third waypoint represents the threshold from which the path capture capabilities were referenced and marks the beginning of the runway. The MLS azimuth signal originated from a point on the path 2743.2 m (9000 ft) past waypoint 3 or 304.8 m (1000 ft) beyond the end of the runway. Waypoint 4 represents the end of the path.

The test-path configuration was varied by changing the MLS azimuth coverage and the final approach length. The azimuth coverage angles used were 60°, 40°, 20°, 10°, and 2.5°. The final approach length was varied from 3704 m (2.0 nmi) to 926 m (0.5 nmi) in 926 m increments.

For all test conditions the airplane was initially positioned so that its track and bank angle were those which the airplane would have had if it was directly on course at the point of intersection with the MLS azimuth coverage. The aircraft was positioned to the left or right of the desired path along the line of intersection with the MLS. The range of offset distances were from 0.0 to 9.4.4 m (3000 ft) in 304.8 m (1000 ft) increments. A sign convention was employed to represent offsets to the left of course as negative and to the right as positive. Initial positioning in this manner represented the lateral path errors that might exist after navigating for an extended period to time (ref. 3). Upon entering the coverage of the MLS azimuth signal, the accurate cross-track position information and track-angle error information is used for flight guidance and control computation. Some offset conditions were omitted for those test-path configurations which showed minimal change in path recovery characteristics as a function of the initial offset.

The bank-angle, track-angle error and cross-track error at the point at which the airplane crossed the runway threshold were recorded for each test condition. These data were then analyzed to determine which test conditions met a selected landing criterion. The test conditions which met the criterion were used to define the flight-path capture limits of the navigation and guidance system as a function of MLS azimuth coverage and final approach length.

COMPUTER SIMULATION MODEL

A fast-time computer simulation program was used for this study. The program models the path definition, navigation position estimate, and guidance functions of the NASA Terminal Configured Vehicle B-737 airplane. A simplistic point mass model of the airplane is used in the fast-time program. The point mass model responds to the bank-angle command with a maximum roll rate of up to 4^{o} per second. A comparison of the path tracking response of a six-degree-of-freedom simulated B-737 airplane and the point mass model flown over identical paths is shown in figure 2. In general, the two models show similar response characteristics. The resultant cross-track error is somewhat larger during portions of the turn using the fast time model, so the limits of the path capture capabilities determined by this study should be well within the limits of the actual system.

Figure 3 is a block diagram showing the horizontal steering control laws used in this study. Cross-track error, track-angle error, and ground speed are combined to give a bank-angle command proportional to the horizontal guidance errors. During curved path segments, the nominal bank angle required to track the curved path in a no wind environment and with no lateral path error at the airplane's present ground speed is added to the bank angle command.

RESULTS AND DISCUSSION

The lateral flight-path recovery capabilities of the MLS updated navigation and guidance system were evaluated based upon the cross track (XTK), track-angle error (TKE), bank-angle data at the runway threshold, and the initial offset conditions. Successful landing criteria were selected as $\pm$ 1.524 m ($\pm$ 5 ft) of cross track and $\pm$ 0.5° of bank-angle and track-angle error at the threshold.

Figures 4(a) through (e) are plots of the cross-track error at the runway threshold as a function of the initial offset condition and the final approach length for each angle of MLS azimuth coverage. These data illustrate the effect of the final approach length on the systems path recovery capabilities.

Figures 4(a) and (b) show that for azimuth coverage greater than $\pm$ 40°, variation of intial offset had no effect on the runway threshold cross-track error. The cross track changed only with the final approach length. The 60° and 40° azimuth angles (figs. 4(a) and (b)) show very little change in the cross-track error as the final approach length decreases. In these cases, it was noted that the airplane had nearly or completely captured the path before entering the turn and the final cross-track errors were brought about by the steering control laws turn initiations and roll-out characteristics. Figure 4(c) shows that with the azimuth coverage reduced to $\pm 20^{\circ}$, the initial offset can affect the cross track. The cross track changed with initial offsets to the right of the path (inside the turn), for final approach lengths of 926 m and 1852 m. Figure 4(d) shows that with a $\pm 10^{\circ}$ azimuth coverage, cross-track errors are increased, and all final approach lengths show variation. Figure 4(e) also shows an increase in cross-track error for each final approach length with a $\pm 2.5^{\circ}$ azimuth coverage. However, for initial offsets to the extreme right of the path, the cross track begins to converge toward the path centerline rather than diverge as with the $\pm 10^{\circ}$ azimuth coverage (fig. 4(d)). It should be noted, however, that these data exhibited excessive bank angles and track-angle errors at the threshold. This is due primarily to the initial position of the airplane causing the guidance system to overshoot the path centerline quickly and be correcting back toward the centerline upon crossing the runway threshold.

Figures 5(a) through (d) are plots of the same data showing the cross-track error as a function of angle of MLS azimuth coverage and initial offset for each final approach length. The effect of azimuth angle on the path capture capabilities is illustrated.

Figure 5(a) shows that with a 3704 m final, very little change in cross-track error results as the azimuth angle is decreased. Figures 5(b), (c), and (d), 2778 m, 1852 m and 926 m final approach, respectively, show the increasing divergence in cross-track error with initial offset variation for azimuth angles of 20^{0} or less. As discussed before, the 60^{0} and 40^{0} azimuth angles show very little change in cross-track error as the initial offsets vary, but show a total increase in cross-track error as the final approach length decreases. These data indicate that the final cross-track error is a function of the aircraft's cross-track error upon exiting the turn and the final approach length.

The data in figure 6 indicate that having the airplane in a position and attitude for a successful landing is primarily a function of the length of the final approach path. All runs with an initial cross-track error in which the final approach path was 2778 m (1.5 nmi), or greater, resulted in recoveries which met the selected landing condition limits. As the azimuth was decreased to a degree in which the aircraft was already into the turn at the point of intersection with the MLS (that is, 20^{0} or less) the path capture capabilities were increased. This increased capability was only in cases where the initial offset was to the right of the path. This is due to the offset positioning of the aircraft to the inside of the turn. With this position and the same heading as if it were on course, the airplane is already positioned to intercept the desired path, and therefore, decreases the recovery time needed. This is true only to the point at which the aircraft begins to overshoot the runway. Since the recovery capabilities in this area are erratic and strictly a function of initial positioning, their reliability to meet landing criteria should be questioned.

CONCLUDING REMARKS

Within the assumptions of this study (that is, no winds, limited path variations, and limited offset conditions), the results indicate that after an initial lateral offset condition the resulting lateral position error at the runway threshold is primarily a function of the straight-in final approach length. The MLS angular azimuth coverage had a smaller effect, possibly due to the horizontal steering control law turn characteristics and the initial offset conditions chosen. With a final approach length of 2778 m (1.5 nmi), or greater, the navigation and guidance system delivered the aircraft model to within 1.5 m (± 5 ft) of the runway centerline with track-angle error and bank angle within 0.5°.

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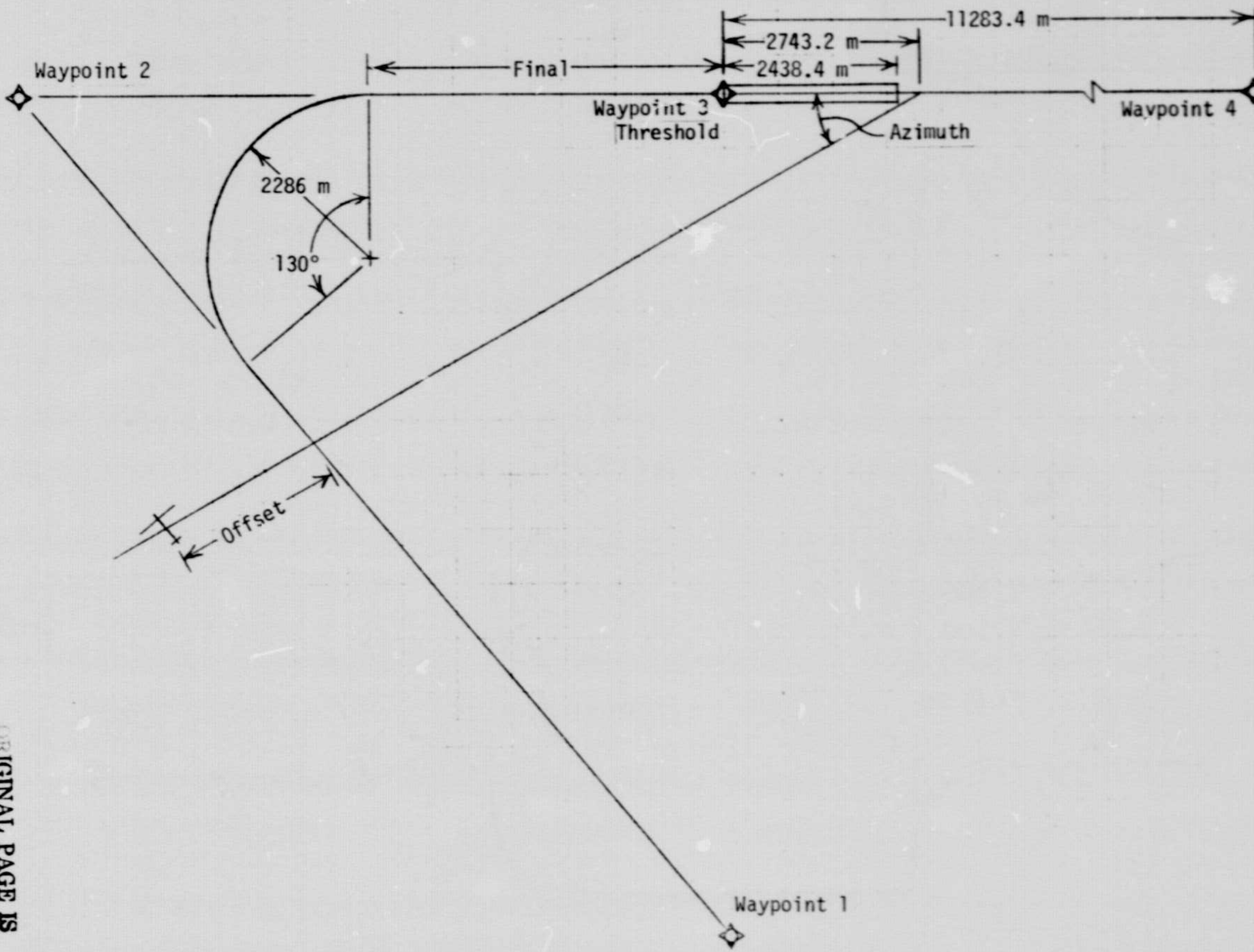


Figure 1. - Plan view of test path

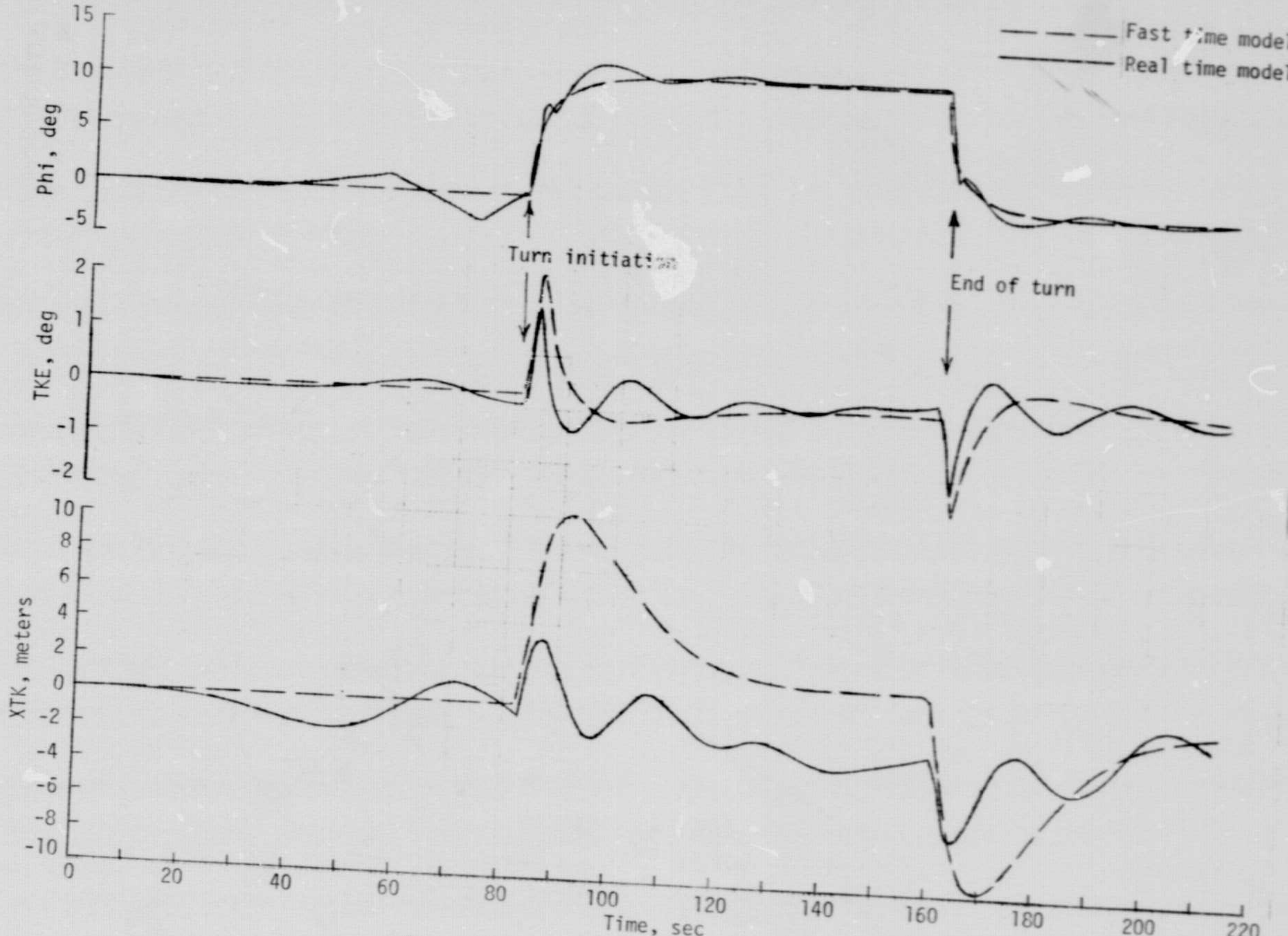
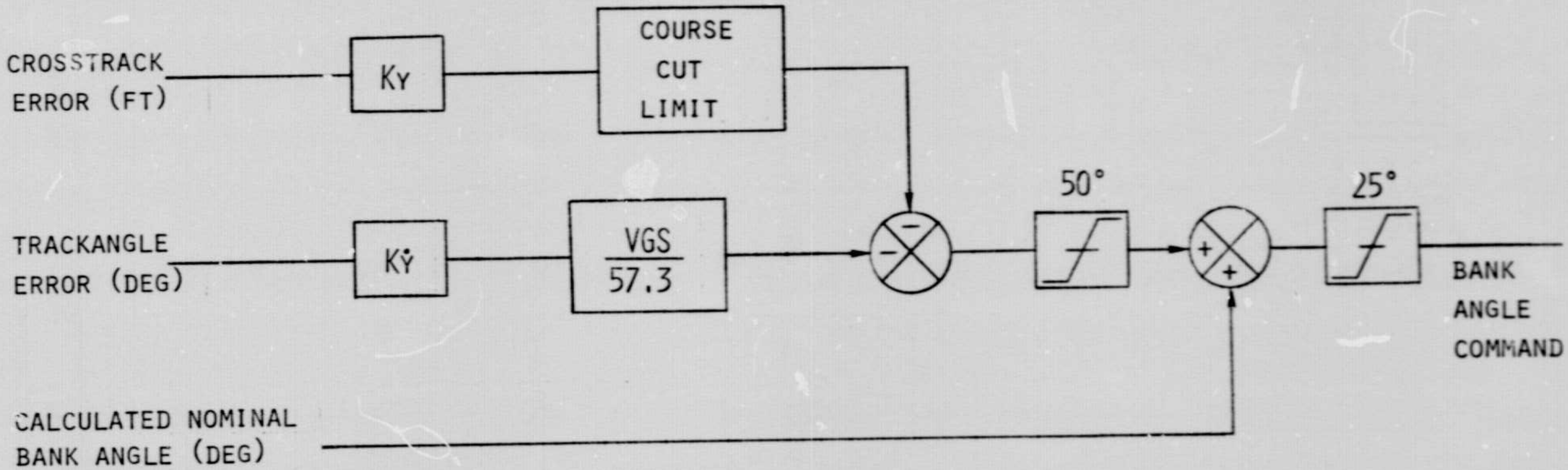


Figure 2. - Computer model response comparison



$$\text{COURSE CUT LIMIT} = \frac{\pm \, VGS \, K_{\dot{Y}}}{57.3} \psi_I \quad \text{IN WHICH}$$

$$\text{COURSE CUT HEADING } (\psi_I) = \begin{cases} 30° \text{ FOR } X < 30° \\ 90° \text{ FOR } X > 90° \\ X \text{ OTHERWISE} \end{cases}$$

$$X = \frac{470 \, |XTK|}{(VGS)^2} - 30°$$

$$K_{\dot{Y}} = \begin{cases} .5 \text{ FOR CAS} \leq 100 \\ .68 - (.0018 \text{ CAS}) \text{ FOR } 100 < \text{CAS} < 300 \text{ KTS} \\ .14 \text{ FOR CAS} \geq 300 \text{ KTS} \end{cases}$$

$$K_Y = K_{\dot{Y}}^{\,2} / 7.12$$

Figure 3 - Horizontal steering control laws

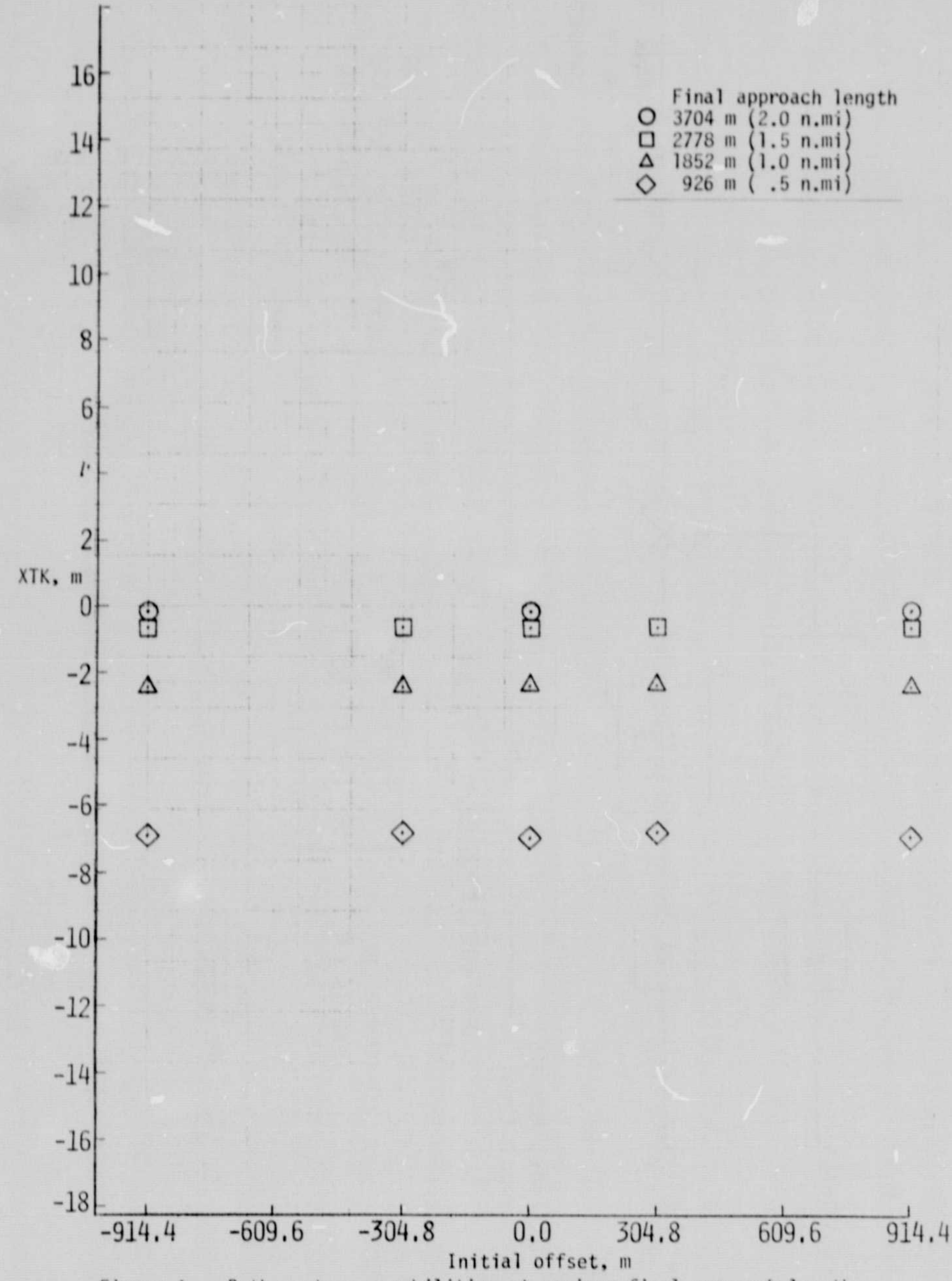
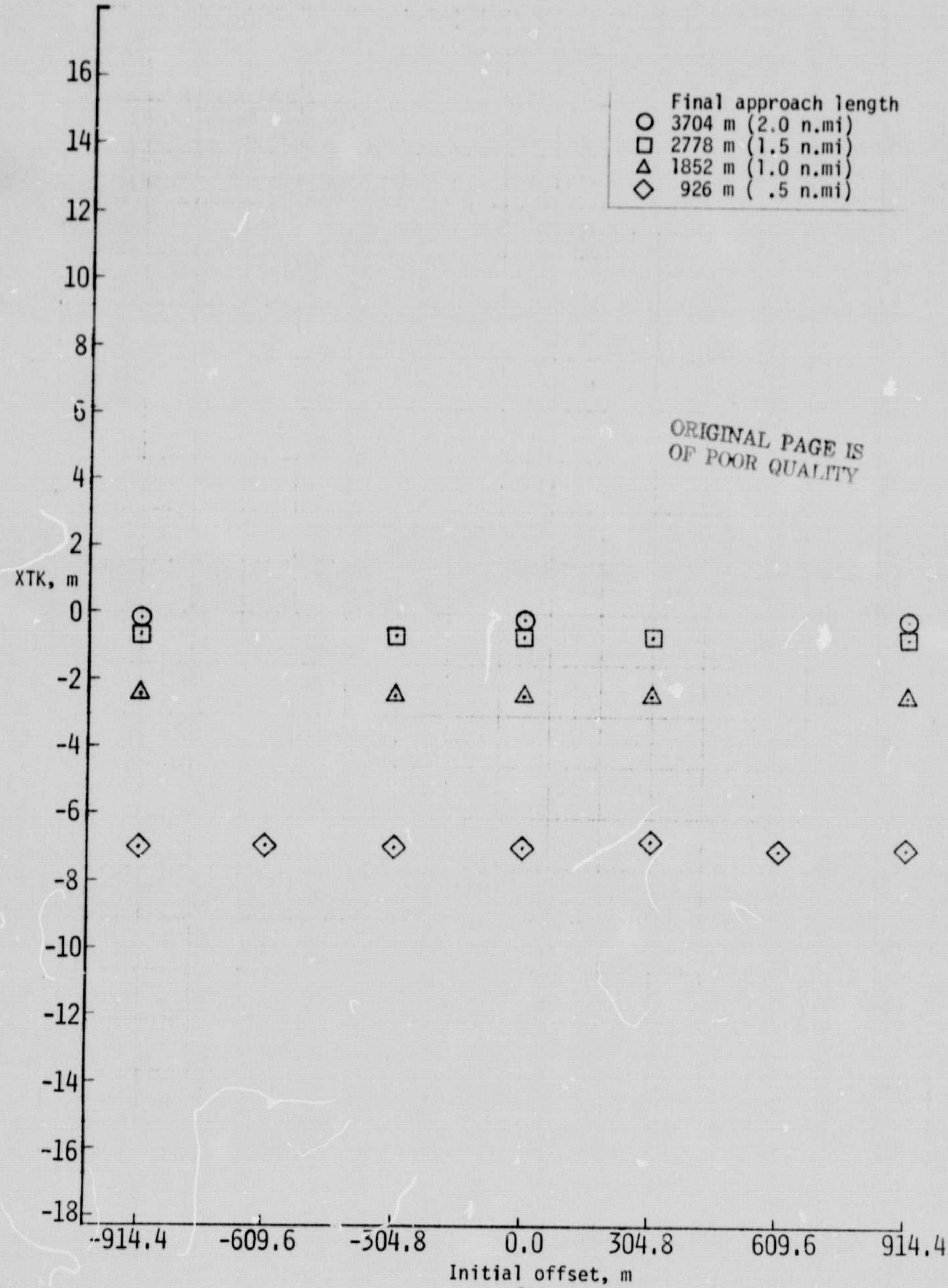


Figure 4. - Path capture capabilities at various final approach lengths.
(a) 60^{o} Azimuth



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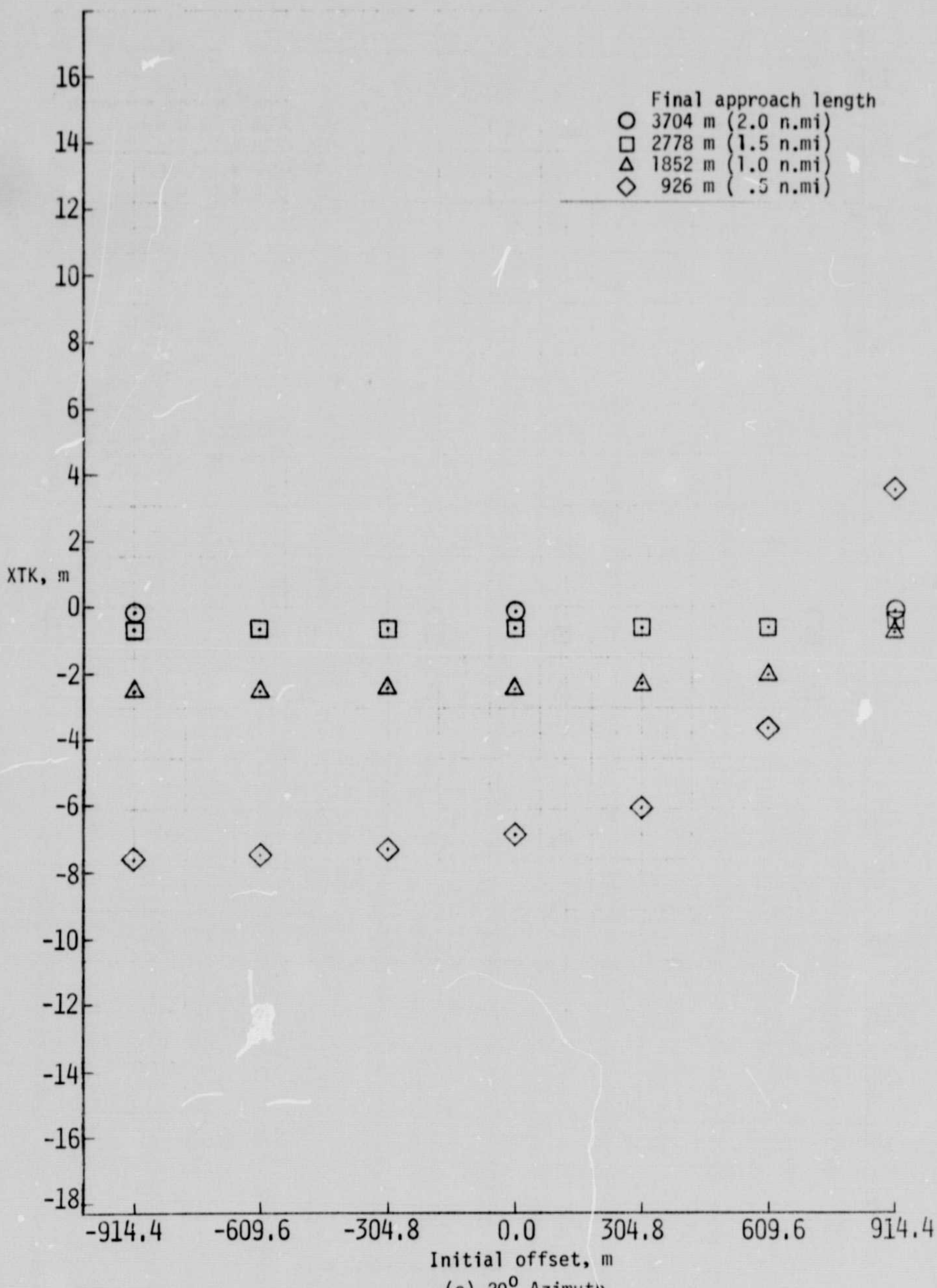
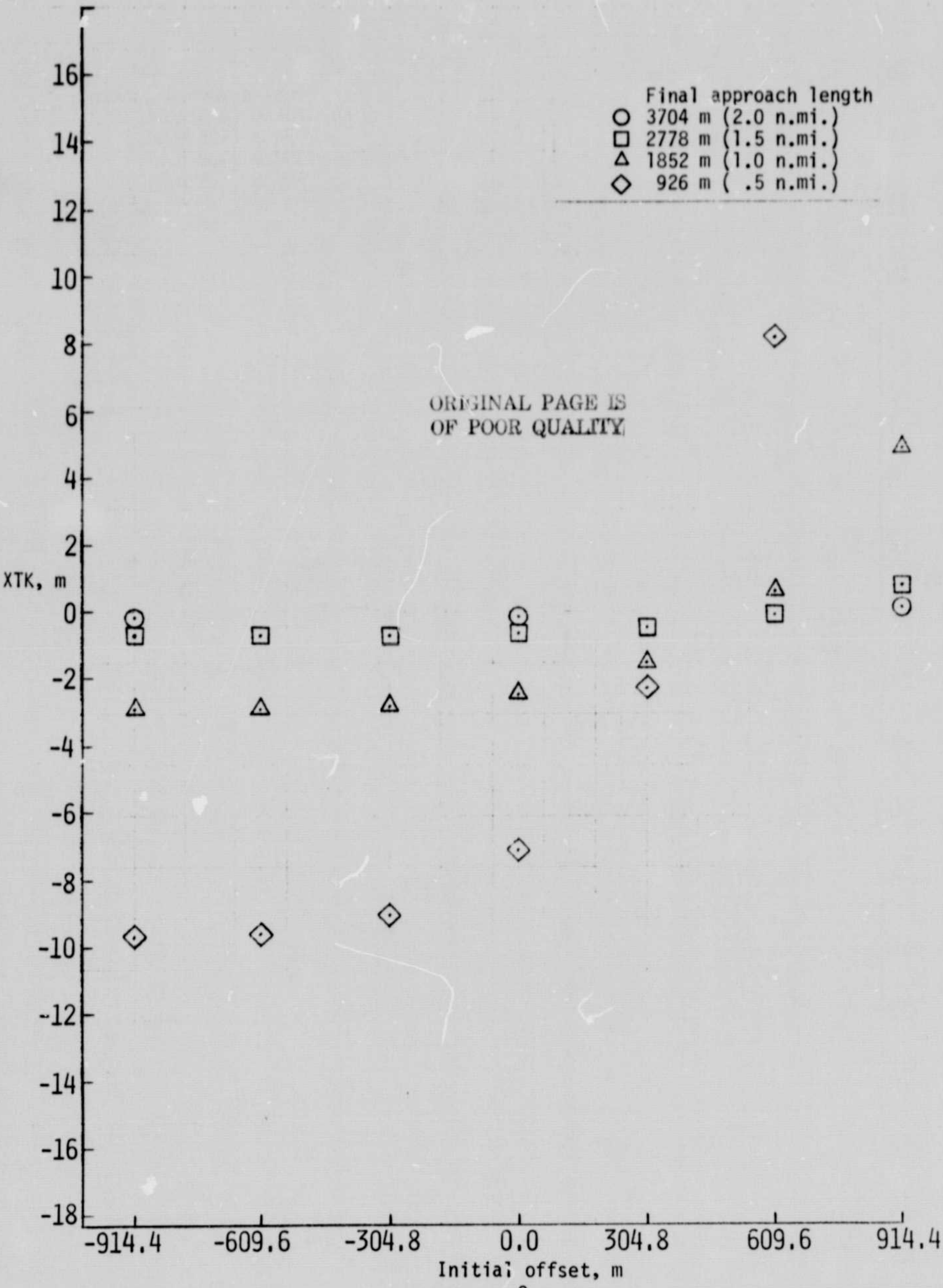
(b) 40° Azimuth

Figure 4. - Continued



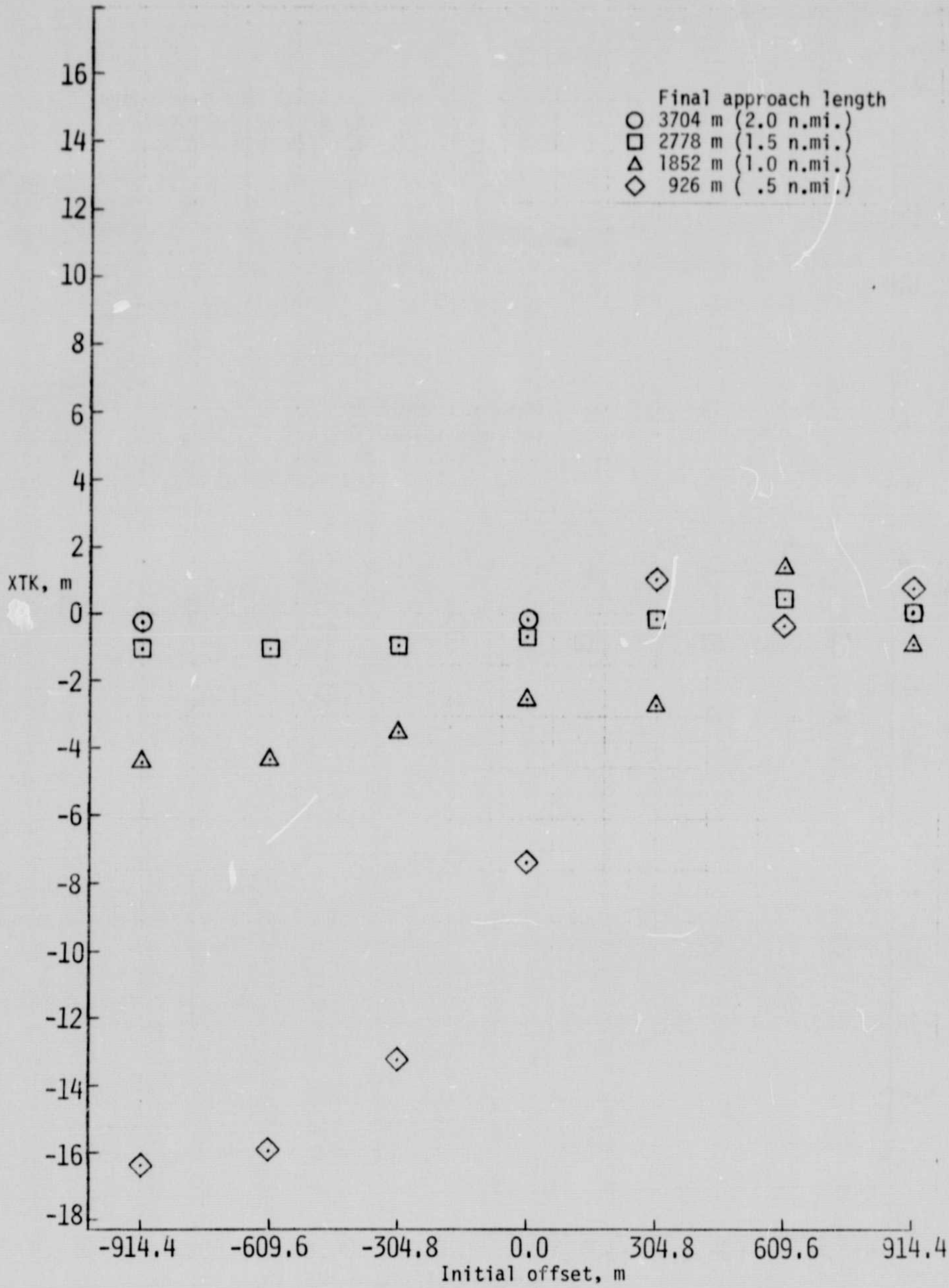
(c) 20° Azimuth

Figure 4. - Continued



(d) 10° Azimuth

Figure 4. - Continued



(e) 2.5° Azimuth

Figure 4. - Concluded

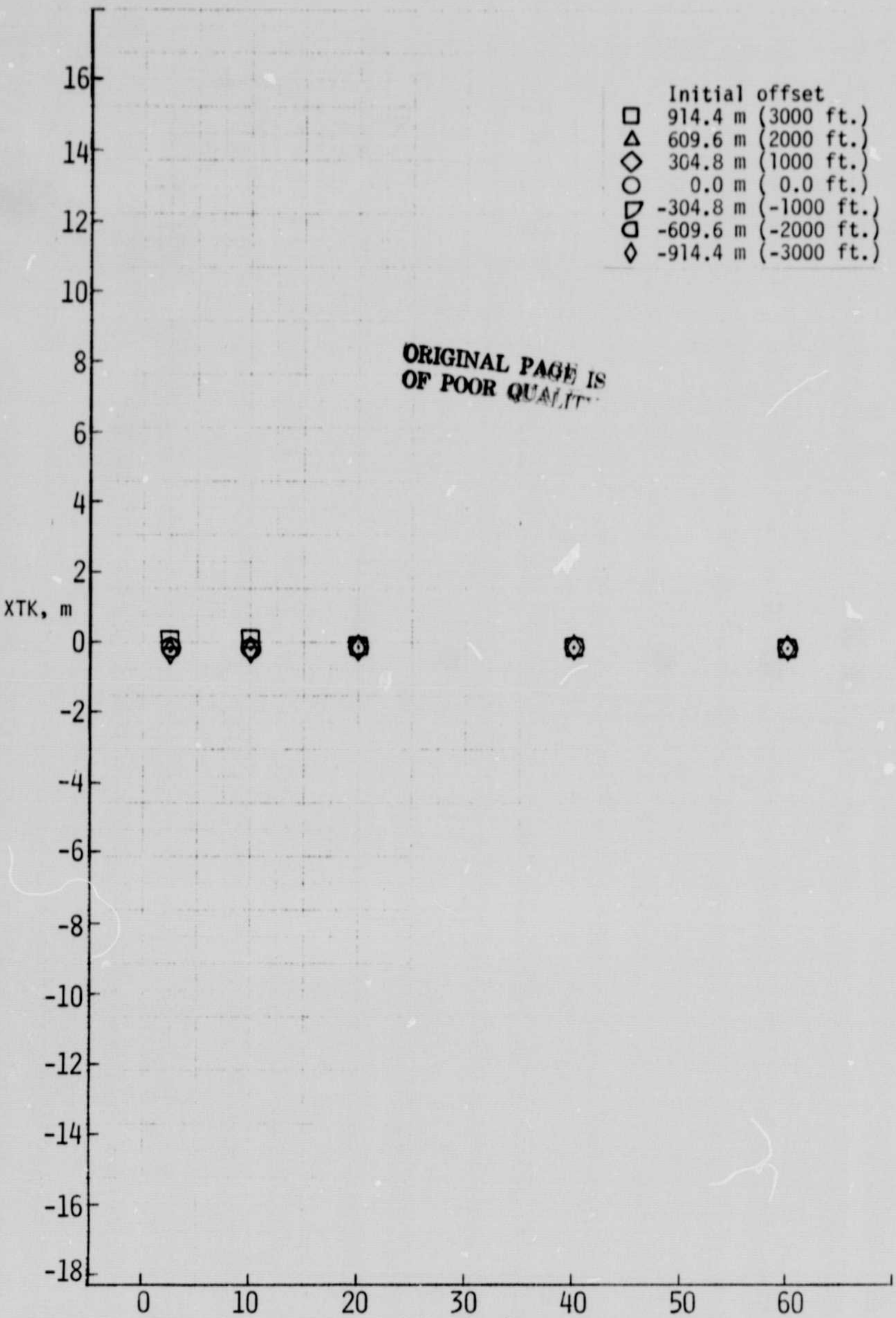
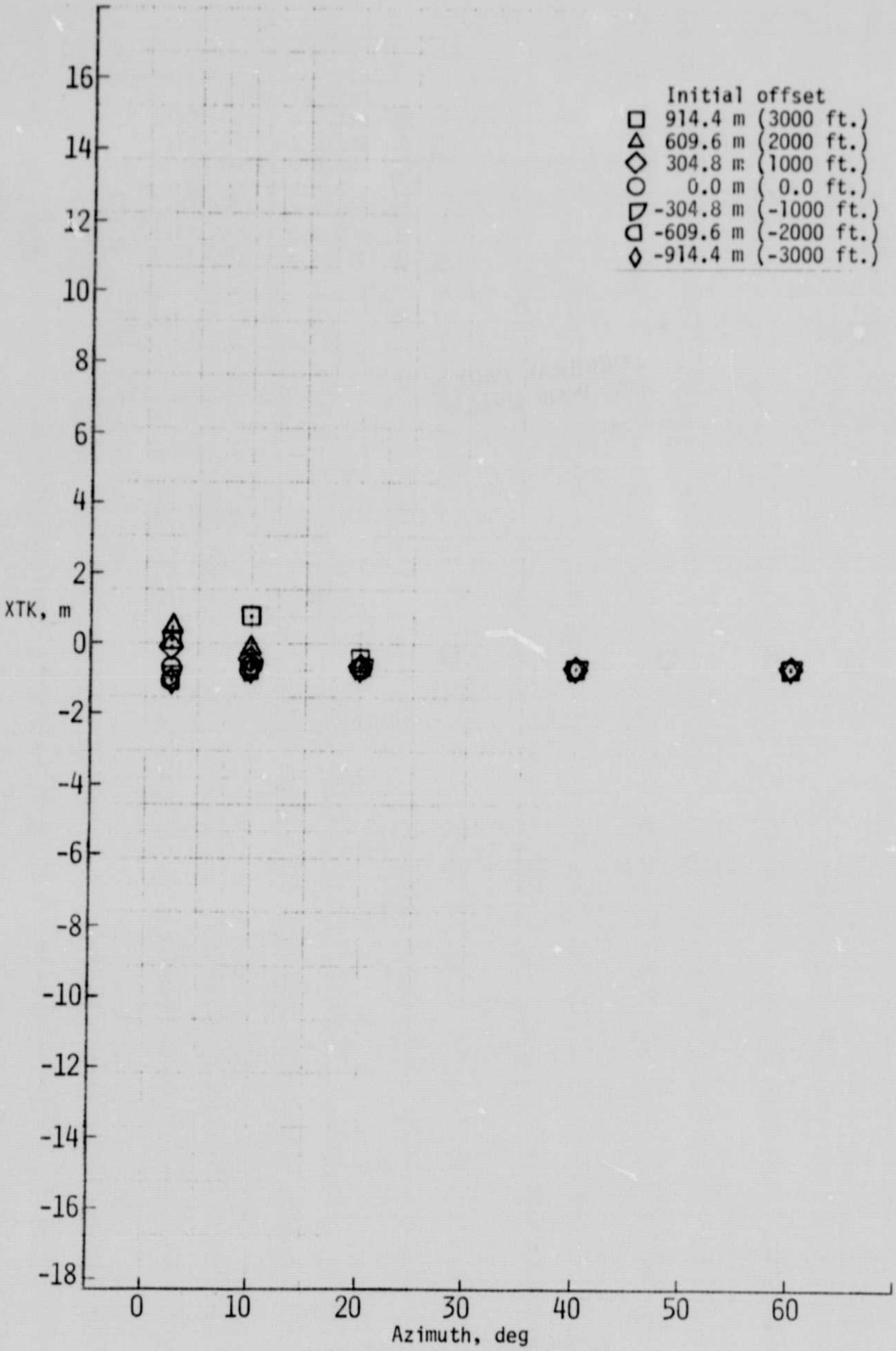
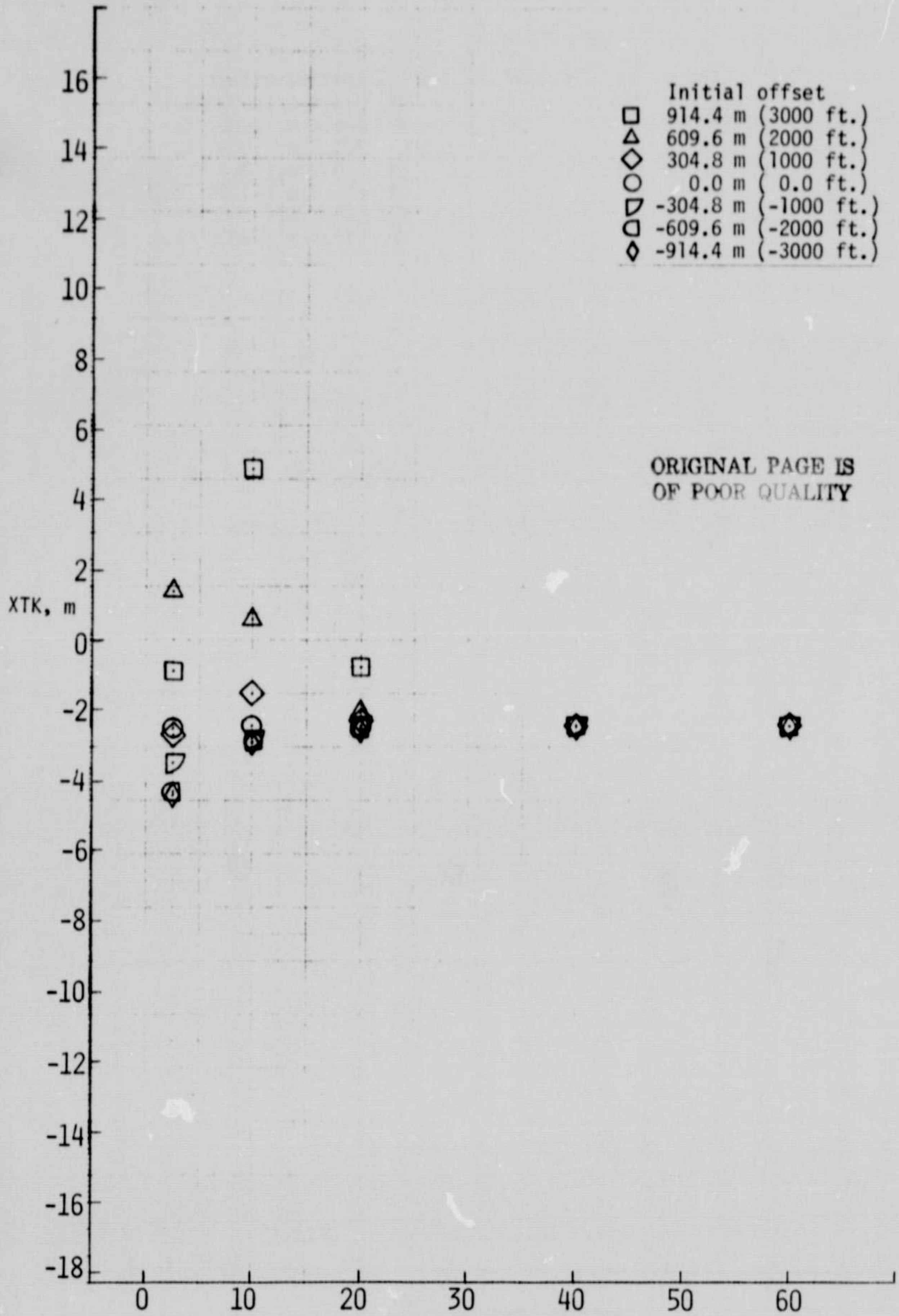


Figure 5. - Effect of azimuth coverage on path capture capabilities.
(a) 3704 m (2.0 n.mi.) Final



(b) 2778 m (1.5 n.mi.) Final

Figure 5. - Continued



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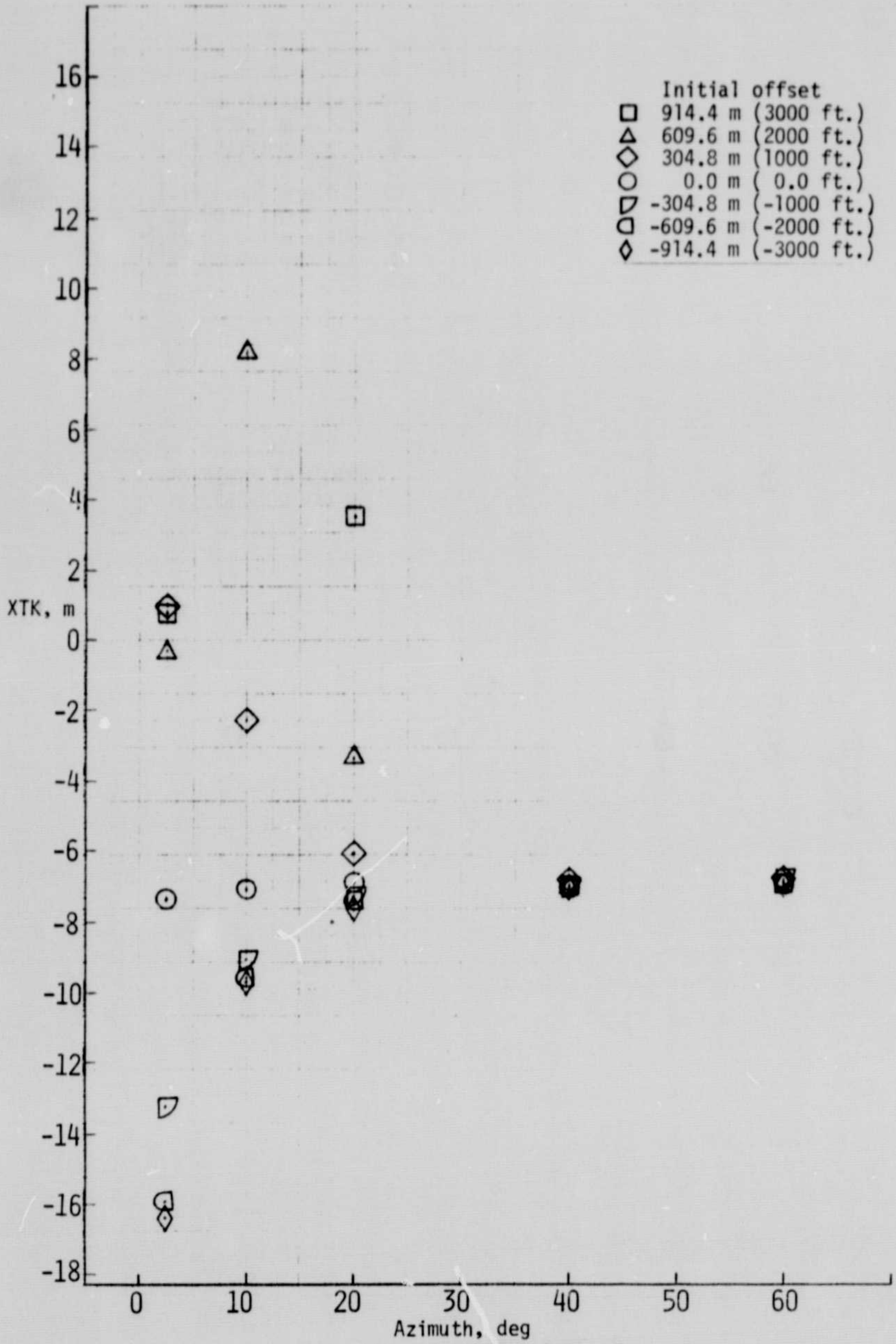
(c) 1852 m (1.0 n.mi.) Final

Figure 5. - Continued.



(d) 926 m (.5 n.mi.) Final

Figure 5. - Concluded

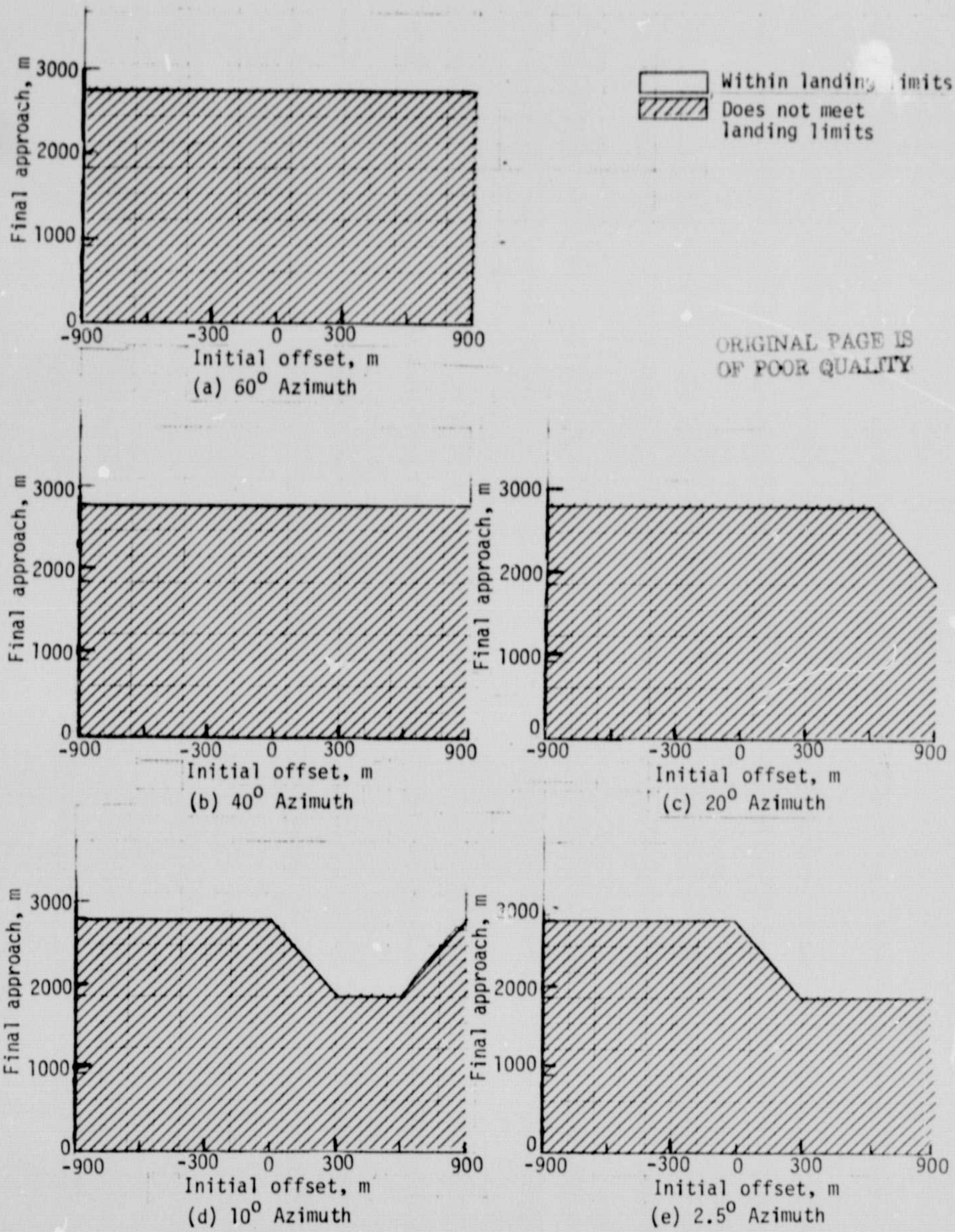


Figure 6. - Path capture recovery limits

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16. Abstract

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