NASA TECHNICAL NOTE

N73-31949
NASA TN D-7298

NASA TN D-7298

A FIXED-BASE SIMULATION STUDY OF TWO STOL AIRCRAFT FLYING CURVED, DESCENDING INSTRUMENT APPROACH PATHS

by Margaret S. Benner, Richard H. Sawyer, and Milton D. McLaughlin

Langley Research Center
Hampton, Va. 23665

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1973

1. Report No.
NASA TN D-7298

2. Government Accession No

3. Recipient's Catalog No

4. Title and Subtitle
A FIXED-BASE SIMULATION STUDY OF TWO STOL AIRCRAFT FLYING CURVED, DESCENDING INSTRUMENT APPROACH PATHS

5. Report Date
October 1973

6. Performing Organization Code

7. Author(s)
Margaret S. Benner, Richard H. Sawyer, and Milton D. McLaughlin

8. Performing Organization Report No
L-8868

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, Va. 23665

10. Work Unit No
501-38-18-00

11. Contract or Grant No

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Note

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A real-time, fixed-base simulation study has been conducted to determine the curved, descending approach paths (within passenger-comfort limits) that would be acceptable to pilots, the flight-director-system logic requirements for curved-flight-path guidance, and the paths which can be flown within proposed microwave landing system (MLS) coverage angles. Two STOL aircraft configurations were used in the study.

Generally, no differences in the results between the two STOL configurations were found. The investigation showed that paths with a 1828.8-m (6000-ft) turn radius and a 1828.8-m (6000-ft) final-approach distance were acceptable without winds and with winds up to at least 15 knots for airspeeds from 75 to 100 knots. The altitude at roll-out from the final turn determined which final-approach distances were acceptable. Pilots preferred to have an initial straight leg of about 1 n. mi. after MLS guidance acquisition before turn intercept. The size of the azimuth coverage angle necessary to meet passenger and pilot criteria depends on the size of the turn angle; ±60° was adequate to cover all paths except ones with a 180° turn.

17. Key Words (Suggested by Author(s))
STOL
Microwave landing system
Curved instrument approach path

18. Distribution Statement
Unclassified – Unlimited

19. Security Classif (of this report)	20. Security Classif (of this page)	21. No of Pages	22. Price*
Unclassified	Unclassified	34	Domestic, $3.00 Foreign, $5.50

*For sale by the National Technical Information Service, Springfield, Virginia 22151

A FIXED-BASE SIMULATION STUDY OF TWO STOL AIRCRAFT FLYING CURVED, DESCENDING INSTRUMENT APPROACH PATHS

By Margaret S. Benner, Richard H. Sawyer, and
Milton D. McLaughlin
Langley Research Center

SUMMARY

The feasibility of curved, descending approach paths for commercial STOL aircraft in a microwave landing system (MLS) using a programed flight-director system has been studied in real time. Two STOL aircraft configurations were used in the study. The test program consisted of flying various curved, descending approach paths on a 6° glide slope and determining (1) which paths, within passenger-comfort limits, were acceptable to the pilots, (2) the flight-director-system logic requirements for curved-flight-path guidance, and (3) the paths which can be flown within the proposed MLS coverage angles.

Generally, no differences in the results between the two STOL configurations were found. The investigation showed that paths with a 1828.8-m (6000-ft) final-approach distance and a 1828.8-m (6000-ft) turn radius were acceptable without winds and with winds up to at least 15 knots for airspeeds from 75 to 100 knots. The altitude at roll-out from the turn determined which final-approach distances were acceptable. Pilots preferred to have an initial straight leg of about 1 n. mi. after MLS guidance acquisition before turn intercept. The pilots agreed that an annunciator light on the panel was necessary to indicate when the commanded bank angle included the bank angle for the programed curved flight path in addition to any bank angle for correction of a deviation from the flight path. The MLS azimuth coverage angle necessary to meet pilot and passenger criteria depends on the size of the turn angle; $\pm 60^{\circ}$ was adequate to cover the 90° and 135° turn paths. However, the $\pm 60^{\circ}$ was not large enough for most of the 180° turn paths. The distance-to-go information presented to the pilots was considered to be useful by them to remain oriented on the flight path and to anticipate turns and roll-out times.

INTRODUCTION

In congested terminal areas where airspace is severely limited, short take-off and landing (STOL) airplanes appear to offer a means of providing increased commercial transport service without interfering with the present conventional operations. Noninterfering STOL arrival paths appear possible because of the steep descent and slow-speed capabilities of these airplanes. In some situations curved, descending flight paths are required for providing the noninterference ability necessary in allocated airspace, separation from obstacles, and noise-abatement routings. Guidance along curved, descending approach paths is expected to be available from the proposed microwave landing system (MLS).

In order to study the feasibility of several curved, descending approach paths for commercial STOL aircraft and the relationship of these paths to MLS azimuth coverage requirements, NASA has conducted a simulation program at the Langley Research Center. The objectives of the program were to determine (1) what curved, descending approach paths, within passenger-comfort limits, are acceptable to pilots, (2) the flight-director-system logic requirements for curved-flight-path guidance, and (3) the paths which can be flown within proposed MLS coverage angles.

Both lightweight and mediumweight STOL aircraft (high lift, twin turboprop) were represented by a digital computer. Commercial airline pilots were used to "fly" the fixed-base simulator.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

b	wing span, m (ft)
$\bar{c}$	mean aerodynamic chord, m (ft)
C_L	lift coefficient, $L/\bar{q}S$
C_l	rolling-moment coefficient, $M_X/\bar{q}bS$
C_m	pitching-moment coefficient, $M_Y/\bar{q}bS$
C_n	yawing-moment coefficient, $M_Z/\bar{q}bS$
C_Y	side-force coefficient, $F_Y/\bar{q}S$
d	final-approach distance, m (ft)
F_Y	side force, N (lb)

L	aircraft lift, N (lb)
M_X	rolling moment, m-N (ft-lb)
M_Y	pitching moment, m-N (ft-lb)
M_Z	yawing moment, m-N (ft-lb)
p	angular velocity about body X-axis, rad/s
q	angular velocity about body Y-axis, rad/s
$\bar{q}$	dynamic pressure, N/m^2 (psi)
r	angular velocity about body Z-axis, rad/s
R	radius of turn, m (ft)
S	wing area, m^2 (ft^2)
V	aircraft velocity, m/s (ft/sec)
Y	localizer deviation, m (ft)
α	angle of attack, rad
β	angle of slideslip
δ_a	aileron deflection, rad
δ_e	elevator deflection, rad
δ_R	rudder deflection, rad
δ_{wh}	wheel deflection, rad
ΔZ	glide-slope deviation, m (ft)

A dot over a symbol indicates differentiation with respect to time.

EQUIPMENT AND METHOD

A fixed-base simulator linked to a digital computer facility was used to represent the lightweight and mediumweight STOL configurations used in the investigation. The configurations were representative of the Twin Otter and Buffalo aircraft, respectively.

The aerodynamic characteristics of the STOL aircraft used in the study are given in table 1. The lightweight STOL representation had a fixed landing gear, a high wing, twin turboprop engines, and a maximum weight of 55 602.8 N (12 500 lbf); the mediumweight STOL representation had a retractable landing gear, a high wing, twin turboprop engines, and a maximum weight of 177 928.8 N (40 000 lbf). Equations for the six degrees of freedom were used in the representation of the airplane's motion. To "fly" the simulator, pilots used pitch control for glide-slope correction and thrust for speed control. The characteristics of the engines and other pertinent airplane systems were simulated.

The basic flight instrumentation (see fig. 1) included a modern flight-director system which included an attitude direction indicator (ADI), a conventional horizontal situation indicator (HSI) with distance measuring equipment (DME) and course-heading windows, and, located on the copilot side of the instrument panel, an HSI which had a servo course pointer. The commanded course for this HSI was continually updated during the turns to be tangent to the curved flight path.

The flight-director-guidance logic was modified to provide the capability of following a steep and curved flight path (see the appendix). The flight-director commands were displayed on an ADI on a vertical bar for roll command and on a horizontal bar for pitch command. The commanded bank angle was limited to 25° and the localizer intercept angle was limited to 45°. The flight director was also programed to provide an unlagged correction for cross winds. Glide-slope and localizer deviation indicators on the ADI were activated at the intercept of the simulated MLS guidance area.

The guidance capability of the MLS was simulated by programing the approach paths to be flown. Deviations from the programed glide slope and localizer were used as inputs to the flight-director system.

The instrumentation also included an optical projector type of moving pictorial navigation display (PND). The PND map had a scale of 2 n. mi. per inch. Lead information for the turn entrance was presented to the pilot two ways. A small annunciator light mounted on the panel was activated during the period from 5 sec before the entrance to the turn until 5 sec before the exit from the programed turn. This 5-sec time corresponded to 192.9 m (633 ft) at 75 knots. Also, a 2-sec lead before entering and exiting a programed turn was indicated by a command-bar jump programed into the flight-director roll-command bar.

The simulator also included accessory equipment for navigation requirements. The radio-aids equipment provided simulation of one VHF omnirange radio navigation station and provided the capability for one-station area navigation used to acquire MLS guidance.

TEST PROGRAM

Figure 2 shows the general shapes of the approach paths. The ground projections of these curved paths were formed by connecting circular and straight segments of various sizes. All portions of these segments continually descend in the vertical plane at a 6° angle to intercept the runway at the desired touchdown point. Final-approach distances (the distance from the end of the turn to touchdown) of 1828.8 and 914.4 m (6000 and 3000 ft) and radii of the turn onto the final approach of 1828.8, 914.4, 731.5, and 457.2 m (6000, 3000, 2400, and 1500 ft) were used. The paths investigated had a turn angle of either 90°, 135°, or 180°. The MLS beam was assumed to originate on the center line at the far end of the 609.6-m (2000-ft) runway and have one-half azimuth coverage angles of 20°, 40°, or 60°. The MLS azimuth coverage angle chosen for each flight path tested had to include, as a minimum, a straight segment before the turn, the turn onto the final approach, and the entire final-approach segment. The azimuth coverage also had to include, in the initial requirements, a minimum of 2 n. mi. of approach path projected on the ground so that the glide slope would be intercepted from below at an altitude of at least 304.8 m (1000 ft). This altitude is assumed to be the minimum for flight prior to final-descent guidance acquisition. The straight segment gave the pilots time to stabilize after localizer acquisition and before glide-slope intercept.

Table 2 lists the geometry of the paths tested, the height of the glide slope at the MLS coverage intercept point, the distance-to-go from this point (the ground distance along the path to touchdown), the MLS angle chosen for each of the configurations, and the length of the straight segment in the MLS coverage before the turn.

Figure 3 shows the glide slopes and localizer beams used in the simulation. The approaches were flown on a 6° glide slope having a beam width of ± 15.2 m (± 50 ft). The localizer beam width was a constant ± 60.9 m (± 200 ft) for the first 1219.2 m (4000 ft), and then fanned out at $\pm 2.5^{\circ}$. The glide-slope and localizer beams were curved to fit the flight path being investigated.

The tests were initiated by setting the aircraft on a straight leg about 4 n. mi. from the programed turn. Using area navigation, the pilot flew level at cruise speed, 225 knots calibrated airspeed (KCAS) for the mediumweight STOL and 155 KCAS for the lightweight STOL, toward the MLS intercept point on the heading for the paths being tested. Approach flaps and gear were lowered before MLS acquisition to aid in slowing the airplane to approach speed. The simulated MLS guidance was manually activated by selection of the flight-director approach mode when the distance-to-go, continuously displayed in the

DME window, was equal to the predetermined distance-to-go at MLS intercept. The localizer was acquired before glide-slope intercept in the MLS guidance area by entering the MLS coverage area below the glide-slope altitude at the intercept point. A flare for landing was not programed into the problem, and the approaches were terminated at a breakout altitude of 30.48 m (100 ft).

Most of the landing approaches were flown with an approach speed of 75 knots for both STOL configurations. Several were flown at an approach speed of 100 knots to determine the effect of higher approach speeds. Most approaches were flown with no wind present, but several had a constant cross wind or tail wind of 10, 15, or 20 knots in relation to the final-approach course.

The simulator was operated by seven teams of pilots from four airlines, each team consisting of a captain and a first officer. The captain of each crew had airline-pilot supervisory and/or flight-instruction experience. The first officer was either an airline qualified captain or first officer. At least one member of each crew was type-rated in the Twin Otter airplane, which is a lightweight STOL aircraft.

RESULTS AND DISCUSSION

The results of the curved-approach-path simulation program are presented in figures 4 to 11. Pilots' comments and opinions on the various paths are included in this discussion. The passenger-comfort limit criteria were assumed to be a bank angle of 30°, a pitch angle of -12°, and a descent rate of 365.8 m/min (1200 ft/min). These values, stated by the pilots to be reasonable for commercial operation of an unpressurized STOL, are used to help rate the acceptability of each path. Generally, no differences in the results between the two STOL aircraft were found.

Time Histories

Typical time histories of the pertinent quantities recorded are shown in figure 4 for a lightweight STOL in a no-wind condition. Typical mediumweight STOL data were similar to that shown in figure 4.

Bank Angle

Figure 5 presents maximum bank angle (held for at least 5 sec) for speeds of 75 and 100 knots in a no-wind condition for the turn radii tested. Figure 5(a), lightweight STOL data, indicates that although the maximum experimental bank angle exceeded the calculated steady-state value by up to 14°, the values are still within the passenger-comfort bank-angle limit of 30° for the turn radii tested. The maximum experimental bank angle for mediumweight STOL (see fig. 5(b)) exceeded the calculated value by up to 9° but remained below the 30° limit.

Figure 6 presents maximum bank-angle data with winds present. Comparison of figures 5 and 6 indicates that winds do not significantly affect the maximum bank angles and the bank angles remain within the passenger-comfort limit for the wind conditions tested.

The range of maximum bank angle above the calculated curves is due to the combined effects of wind, off-speed operations, and bank-angle inputs required to correct for deviations from the flight path.

Pitch Angles

Pitch-angle variations during two approaches for each of two approach configurations of the lightweight STOL are shown in figure 7. In the results shown, the large pitch-down occurrences result from the pitch-over maneuver at glide-slope intercept and from full flap deflection. The cyclic variations during the last 1 to 2 n. mi. are associated with glide-slope flight-path control. The pitch-up occurrences at around 2 n. mi. (configuration A) and 4 n. mi. (configuration B) result from angle-of-attack increases in slowing to final approach speed (75 knots) from about 120 knots (configuration A) and 155 knots (configuration B). The pitch-angle variations in the approach for the mediumweight STOL were similar.

For a number of approaches with each STOL airplane, the peak value of maximum pitch angle θ_{max} (held for at least 5 sec) and the percentage of approaches in which θ_{max} exceeded -12° (passenger-comfort level) are given in the following table. The results are limited to approaches with no-wind or cross-wind conditions and full flap deflection throughout the final approach phase.

STOL	No. of approaches	Peak θ_{max}	% approaches with θ_{max} > -12°
Lightweight	35	-17.9°	74.3
Mediumweight	39	-19.6°	53.8

These results show that STOL-type approaches made with these non-powered-lift airplanes involve pitch-down angles which generally exceed the assumed passenger-comfort limit. This limit was based on pilot opinion. Investigation of passenger reaction to these high pitch-down angles appears to be important.

Glide Slope

Figure 8 shows the descent rates for the no-wind condition on a 6° glide slope. Figure 8(a) shows lightweight STOL data and figure 8(b) shows mediumweight STOL data. For both configurations, the descent rates are below 365.8 m/min (1200 ft/min) for up to 110 knots. Figure 9 shows descent-rate data in a wind condition for both STOL configurations. The descent rates are below 365.8 m/min (1200 ft/min). These figures indicate that pilots are able to fly a 6° glide slope without exceeding the descent-rate passenger-comfort level in both wind and no-wind conditions.

Flight-Path Deviations at Turn Entrance and Exit

Figures 10 and 11 show flight-path deviations from the localizer and glide-slope center lines at the turn entrance and exit points for turn radii of 1828.8 and 914.4 m (6000 and 3000 ft), respectively. The unflagged symbols are entrance values and the corresponding flagged symbols are exit values. Because of the large number of different conditions on these figures, tables 3 and 4 should be used with the figures. Tables 3 and 4 list the speed of each run and the maximum bank angles used by the pilots to correct deviations in the flight path in the turn for the 1828.8- and 914.4-m (6000- and 3000-ft) turn radii, respectively.

For turns of 1828.8-m (6000-ft) radius, the results in figure 10(a) indicate that for the lightweight STOL with values of initial deviation as large as -303.3 m (-995 ft) (localizer) or 70 m (213 ft) (glide slope), the exits were nearly on the center lines. For the mediumweight STOL (see fig. 10(b)), with initial deviations as large as 426.7 m (1400 ft) (localizer) or -109.7 m (-360 ft) (glide slope), the exits again were nearly on the center lines.

For turns of 914.4-m (3000-ft) radius, the results in figure 11(a) indicate that with a combined localizer deviation of 76 m (250 ft) and a glide-slope deviation of -38 m (-125 ft), the lightweight STOL was maneuvered nearly to the center lines at the turn exit. For the mediumweight STOL, figure 11(b), deviations as large as 280 m (920 ft) (localizer) or -70 m (213 ft) (glide slope) were corrected to small values by the end of the turns.

The results in tables 3 and 4 indicate that for both airplanes and both turn radii the maximum bank angles used were well within the passenger-comfort limit of 25° for all the turns.

To regain the center lines from larger localizer or glide-slope deviations may be possible for either turn radius; however, no larger deviations were found in the data of this study.

Pilots' Comments

Acceptable paths.- Most pilots agreed that one of the main factors in deciding which final-approach distances were acceptable was the turn roll-out altitude (the altitude at the end of the turn onto the final-approach course). Of the two final-approach distances tested, only the 1828.8-m (6000-ft) one was acceptable to them. The turn roll-out altitude for this final approach was 192.0 m (630 ft). The 914.4-m (3000-ft) final approach was not acceptable because the 96.0-m (315-ft) turn roll-out altitude was considered too low by all the pilots. They objected to maneuvering the aircraft this near to the ground. In addition, they preferred more time after the turn to get the aircraft stabilized on the flight path than was available with the shorter distance.

The pilots agreed that the flight path with a 1828.8-m (6000-ft) turn radius and a 1828.8-m (6000-ft) final-approach distance was acceptable both with and without winds from both safety and passenger-comfort aspects. Turn radii of 731.5 and 457.2 m (2400 and 1500 ft) were unacceptable to them because these turns were difficult to fly and several times the pilots were unable to maintain the curved flight path. The path with a 914.4-m (3000-ft) final-approach distance was usually acceptable when no winds were present, but its acceptability with winds from 10 to 20 knots was questionable. Some pilots liked it and others did not. The area of disagreement for this path was whether or not the pilot could get the aircraft stabilized on course if it was off course at the end of the turn. Most pilots preferred to get the airplane into a landing configuration before the final approach.

The pilots felt that the 6° glide slope was acceptable and that it allowed sufficient maneuvering margin for wind shears and a sufficient margin for correcting for inadvertent displacements from the glide path.

MLS azimuth coverage angle.- The pilots preferred MLS coverage angles which were large enough to include an initial straight-leg segment of about 1 n. mi. after entering the MLS coverage area and before entering the programed turn. This segment gave them time (48 sec at 75 knots and 36 sec at 100 knots) to acquire the localizer and stabilize on the path before the turn began.

Instrumentation.- Pilots preferred the servo HSI to the conventional HSI for orientation during the programed turns. However, this was the only time it was preferred since it had no course heading or distance-to-go digital readouts as did the conventional HSI. They especially liked the distance-to-go information because it oriented them on the flight path and gave them an indicator by which to anticipate turns and roll-out times.

The pilots agreed that an annunciator light on the panel was necessary to indicate when the commanded bank angle included the bank angle for the programed curved flight path in addition to any bank angle for correction of a deviation from the flight path.

MLS Azimuth Coverage Angles

Based on the geometry of the curved flight path and the approximately 1 n. mi. necessary before the programed turn acquisition, the MLS azimuth coverage angle for each path was determined. The $\pm 40^{\circ}$ and $\pm 60^{\circ}$ angles were adequate for the 90° and 135° turn configurations. The 180° turn configurations were not adequately covered by the $\pm 60^{\circ}$ angle except for the last path in table 2. In order to obtain the 1-n. mi. straight leg, angles up to 80° would be necessary.

CONCLUSIONS

A simulator study was conducted on two STOL aircraft to determine the acceptability of curved flight paths having a 6° glide slope with various turn radii and final-approach distances and to determine what angles of microwave landing system (MLS) coverage would be required. Turns of 90°, 135°, or 180° were used. Pilots qualified to fly the Twin Otter airplane evaluated lightweight and mediumweight STOL configurations in a Langley Research Center fixed-base STOL simulator equipped with a flight director programed for curved flight-path guidance. Generally, no differences in the results between the two STOL configurations were found.

The results of the study have indicated that:

(1) The paths with a 1828.8-m (6000-ft) turn radius and a 1828.8-m (6000-ft) final-approach distance are acceptable with constant winds up to at least 15 knots for airspeeds from 75 to 100 knots for both the lightweight and mediumweight STOL. Paths with a 1828.8-m (6000-ft) final approach and 914.4-m (3000-ft) turn radius are acceptable for airspeeds of about 75 knots with winds up to at least 10 knots. Smaller turn radii or final approach distances were found unacceptable even without winds.

(2) The altitude at roll-out from the turn was one of the main factors in determining which final-approach distances were acceptable. With the 6° glide slope used, the 1828.8-m (6000-ft) final approach had a roll-out altitude of 192.0 m (630 ft), the lowest altitude tested which the pilots considered safe for maneuvering flight.

(3) Pilots preferred to have an initial straight leg of about 1 n. mi. after MLS guidance acquisition before turn intercept. This gave the pilot time to stabilize the aircraft on the localizer before the turn.

(4) The pilots agreed that an annunciator light on the panel was necessary to indicate when the commanded bank angle included the bank angle for the programed curved flight path in addition to any bank angle for correction of a deviation from the flight path.

(5) MLS coverage angles of $\pm 40^{\circ}$ and $\pm 60^{\circ}$ are adequate to meet all the criteria to cover the 90° and 135° turn paths tested, but angles greater than $\pm 60^{\circ}$ are generally needed for the 180° turn configurations.

(6) The distance-to-go information presented to the pilots was considered to be useful by them to remain oriented on the flight path and to anticipate turns and roll-out times.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 11, 1973.

APPENDIX

FLIGHT-DIRECTOR-SYSTEM LOGIC

Figure 12 shows block diagrams for the flight-director logic. Figure 12(a) is the logic for the lateral direction and figure 12(b) for the longitudinal direction.

The following additional symbols are for figure 12:

g	gravitational constant, m/s^2 (ft/sec^2)
h	airplane altitude, m (ft)
h_c	altitude commanded by flight director, m (ft)
s	Laplace operator
ϵ	localizer deviation, Y/Range, rad
θ	pitch angle, deg
ϕ	bank angle, deg

ϕ (turn) bias = $\frac{V^2}{gR}$, deg

ψ	airplane heading, deg
$\Delta\psi$	airplane heading error, deg

Two items are unique to the flight director programed for the STOL curved-approach-path program. The turn bias bank-angle signal in the lateral-direction logic enters the problem only during the curved segment of the programed flight path. Also in the lateral-direction logic, a commanded heading is generated and is used to obtain the $\Delta\psi$.

TABLE 1 - AIRCRAFT AERODYNAMIC CHARACTERISTICS

	Lightweight STOL	Mediumweight STOL
Weight, N (lbf)	55 602 8 (12 500)	177 928 8 (40 000)
Aircraft velocity, m/s (ft/sec)	38 6 (126 6)	38 6 (126 6)
Flap deflection, deg	37 5	40
Wing area, m^2 (ft^2)	39 0 (419 8)	87 8 (945 1)
Wing span, m (ft)	19 8 (65 0)	29 3 (96 0)
Mean aerodynamic chord, m (ft)	1 98 (6 5)	3 14 (10 3)
Mass moments of inertia		
About body X-axis, kg-m^2 (slug-ft^2)	4 9 × 10^6 (3 6 × 10^6)	81 1 × 10^6 (59 8 × 10^6)
About body Y-axis, kg-m^2 (slug-ft^2)	8 0 × 10^6 (5 9 × 10^6)	65 1 × 10^6 (48 0 × 10^6)
About body Z-axis, kg-m^2 (slug-ft^2)	11 8 × 10^6 (8 7 × 10^6)	133 1 × 10^6 (98 2 × 10^6)
Inclination of principal axis with respect to body axis, rad (deg)	-0 059 (-3 38)	-0 160 (-9 2)
Angle of attack, rad (deg)	-0 061 (-3 5)	0 0 (0 0)
Thrust coefficient	0 0	0 1
Drag coefficient	0 17	0 39
$C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha}$	5 51	5 45
$C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha}$	-1 82	-1 91
$C_{L_q} = \frac{\partial C_L}{\partial (q\bar{c}/2V)}$	5 50	7 97
$C_{m_q} = \frac{\partial C_m}{\partial (q\bar{c}/2V)}$	-23 9	-39 25
$C_{L_{\dot{\alpha}}} = \frac{\partial C_L}{\partial (\dot{\alpha}\bar{c}/2V)}$	1 64	2 57
$C_{m_{\dot{\alpha}}} = \frac{\partial C_m}{\partial (\dot{\alpha}\bar{c}/2V)}$	-6 50	-11 49
$C_{L_{\delta_e}} = \frac{\partial C_L}{\partial \delta_e}$	0 45	0 54
$C_{m_{\delta_e}} = \frac{\partial C_m}{\partial \delta_e}$	-1 77	-2 37
$C_{Y_\beta} = \frac{\partial C_Y}{\partial \beta}$	-1 0	-1 29
$C_{Y_r} = \frac{\partial C_Y}{\partial (rb/2V)}$	0 50	0 50
$C_{Y_p} = \frac{\partial C_Y}{\partial (pb/2V)}$	-0 1	-0 20
$C_{Y_{\delta_{wh}}} = \frac{\partial C_Y}{\partial \delta_{wh}}$	-----	0 02
$C_{Y_{\delta_a}} = \frac{\partial C_Y}{\partial \delta_a}$	0 0	-----
$C_{Y_{\delta_R}} = \frac{\partial C_Y}{\partial \delta_R}$	0 39	0 41
$C_{l_\beta} = \frac{\partial C_l}{\partial \beta}$	-0 08	-0 12
$C_{l_p} = \frac{\partial C_l}{\partial (pb/2V)}$	-0 55	-0 50
$C_{l_r} = \frac{\partial C_l}{\partial (rb/2V)}$	0 43	0 58
$C_{l_{\delta_{wh}}} = \frac{\partial C_l}{\partial \delta_{wh}}$	-----	0 09
$C_{l_{\delta_a}} = \frac{\partial C_l}{\partial \delta_a}$	0 2	-----
$C_{l_{\delta_R}} = \frac{\partial C_l}{\partial \delta_R}$	0 04	0 05
$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$	0 14	0 16
$C_{n_p} = \frac{\partial C_n}{\partial (pb/2V)}$	0 0	-0 16
$C_{n_r} = \frac{\partial C_n}{\partial (rb/2V)}$	-0 21	-0 24
$C_{n_{\delta_{wh}}} = \frac{\partial C_n}{\partial \delta_{wh}}$	-----	0 0
$C_{n_{\delta_a}} = \frac{\partial C_n}{\partial \delta_a}$	-0 04	-----
$C_{n_{\delta_R}} = \frac{\partial C_n}{\partial \delta_R}$	-0 15	-0 18

TABLE 2.- CURVED APPROACH PATHS

R, m (ft)	d, m (ft)	Turn angle, deg	Glide-slope height at MLS intercept, m (ft)	Distance-to-go from MLS intercept, n. mi.	MLS azimuth coverage half-angle, deg	Straight segment in MLS area before turn, n. mi.
1828.8 (6000)	1828.8 (6000)	90	679.7 (2230)	3.5	40	1.0
1828.8 (6000)	1828.8 (6000)	135	826.0 (2710)	4.2	60	.9
1828.8 (6000)	1828.8 (6000)	180	829.1 (2720)	4.3	60	.3
1828.8 (6000)	914.4 (3000)	90	952.8 (3126)	4.9	60	2.9
1828.8 (6000)	914.4 (3000)	135	643.1 (2110)	3.3	60	.5
1828.8 (6000)	914.4 (3000)	180	641.6 (2105)	3.3	60	-.3
914.4 (3000)	1828.8 (6000)	90	541.0 (1775)	2.8	40	1.0
914.4 (3000)	1828.8 (6000)	135	624.8 (2050)	3.2	60	1.1
914.4 (3000)	1828.8 (6000)	180	632.5 (2075)	3.3	60	.7
914.4 (3000)	914.4 (3000)	90	594.4 (1950)	3.1	60	1.8
914.4 (3000)	914.4 (3000)	135	440.4 (1445)	2.3	60	.6
914.4 (3000)	914.4 (3000)	180	446.5 (1465)	2.3	60	.2
731.5 (2400)	1828.8 (6000)	90	516.6 (1695)	2.6	40	1.0
731.5 (2400)	1828.8 (6000)	135	583.4 (1914)	3.0	60	1.0
731.5 (2400)	1828.8 (6000)	180	591.3 (1940)	3.1	60	.9
731.5 (2400)	914.4 (3000)	90	548.6 (1800)	2.8	60	1.7
731.5 (2400)	914.4 (3000)	135	408.4 (1340)	2.1	60	.6
731.5 (2400)	914.4 (3000)	180	403.9 (1325)	2.1	60	.4
457.2 (1500)	1828.8 (6000)	90	472.4 (1550)	2.4	40	1.1
457.2 (1500)	1828.8 (6000)	135	523.9 (1719)	2.7	60	1.1
457.2 (1500)	1828.8 (6000)	180	537.6 (1764)	2.8	60	1.0
457.2 (1500)	914.4 (3000)	90	480.1 (1575)	2.5	60	1.5
457.2 (1500)	914.4 (3000)	135	350.0 (1148)	1.8	60	.6
457.2 (1500)	914.4 (3000)	180	350.0 (1148)	1.8	60	.7

TABLE 3.- TURN ANGLE, SPEED, AND MAXIMUM BANK ANGLE DATA FOR RESULTS IN FIGURE 10

Figure	Symbol	Turn angle, deg	Speed, knots	Maximum bank angle, deg
10(a)	⌂	90	89	6
	◊	90	82	5
	⬠	135	91	10
	◠	135	88	10
	◹	135	82	6
	◺	135	80	6
	◇	90	78	5
	□	135	75	8
	☗	135	78	6
	♦	135	78	4
	⬟	135	99	9
	◗	135	99	8
10(b)	⬠	135	100	9
	□	135	93	8
	◠	135	77	6
	◿	135	78	8
	△	135	81	6

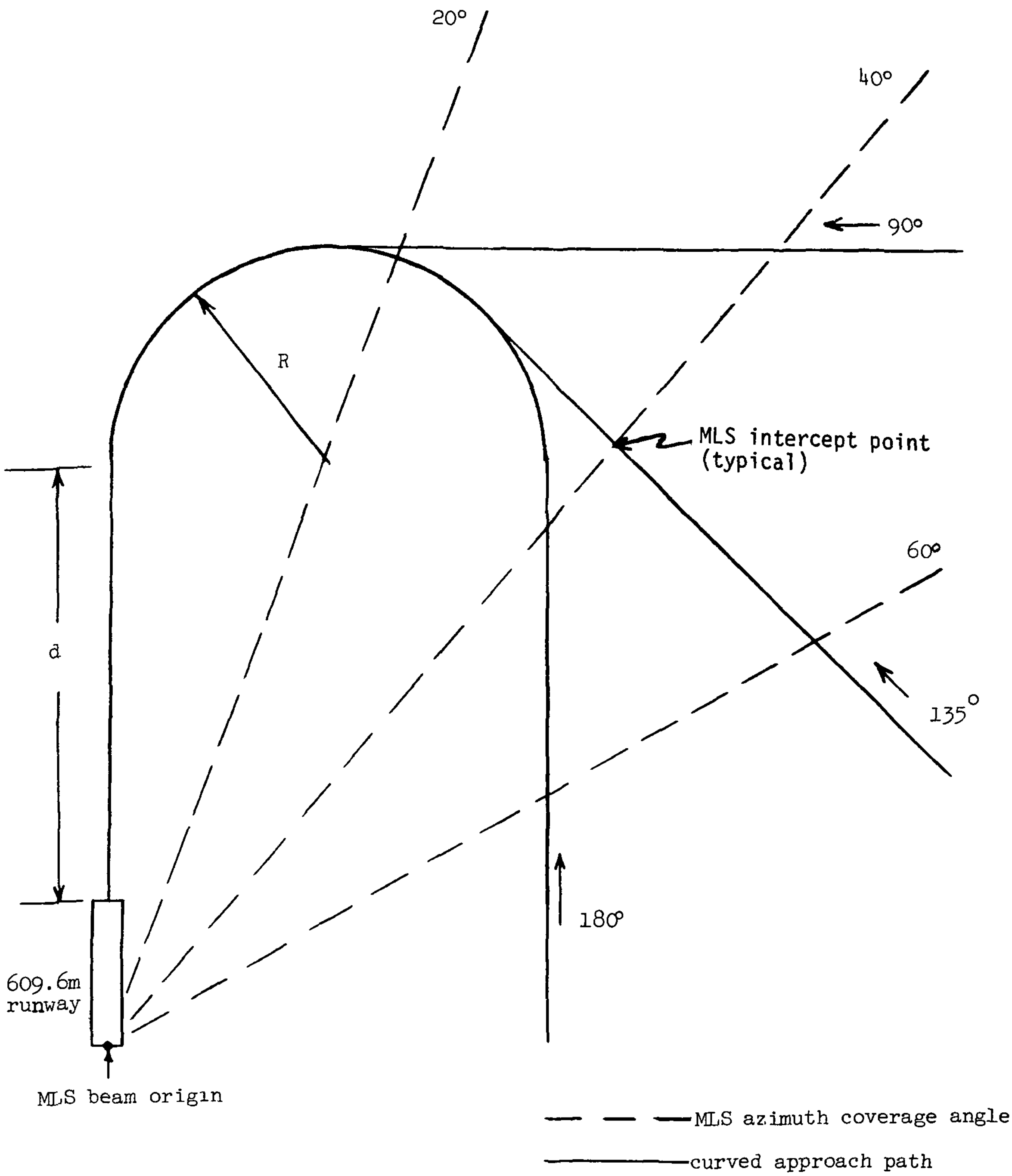
TABLE 4.- TURN ANGLE, SPEED, AND MAXIMUM BANK ANGLE DATA

FOR RESULTS IN FIGURE 11

Figure	Symbol	Turn angle, deg	Speed, knots	Maximum bank angle, deg
11(a)	⌂	90	72	7
	◊	90	85	10
	◇	135	75	10
	◠	135	97	12
	◺	135	94	13
11(b)	⌂	135	94	12
	□	135	90	12
	◊	90	96	11
	○	135	86	11

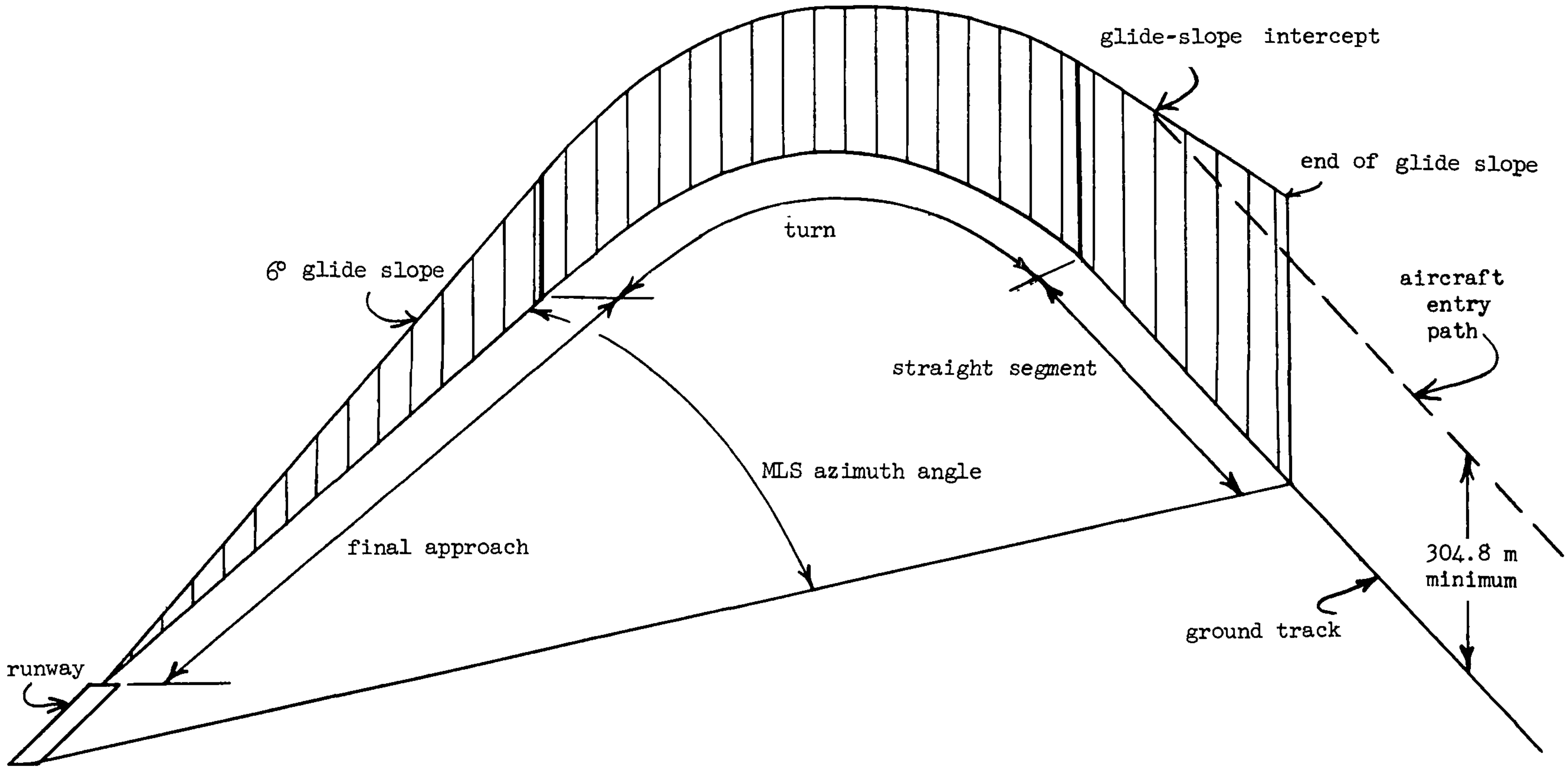
L-72-3813.1

Figure 1.- Simulator cockpit.



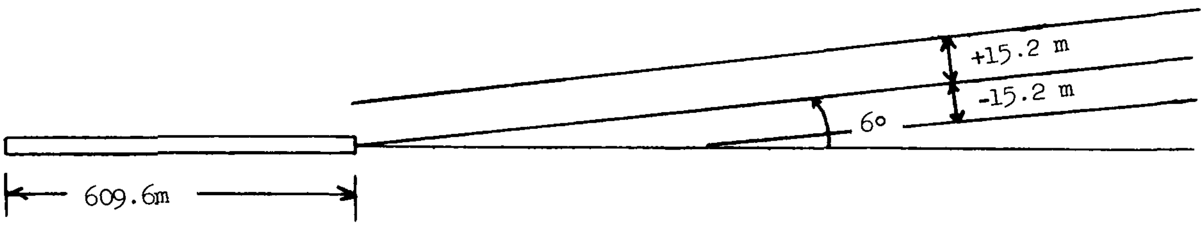
(a) Plan view.

Figure 2.- General shapes of the curved approach paths.

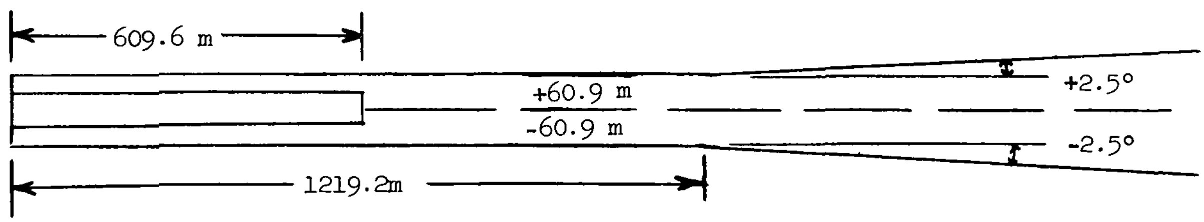


(b) Profile view.

Figure 2.- Concluded.



(a) Glide slope.



(b) Localizer.

Figure 3.- Localizer and glide-slope beams.

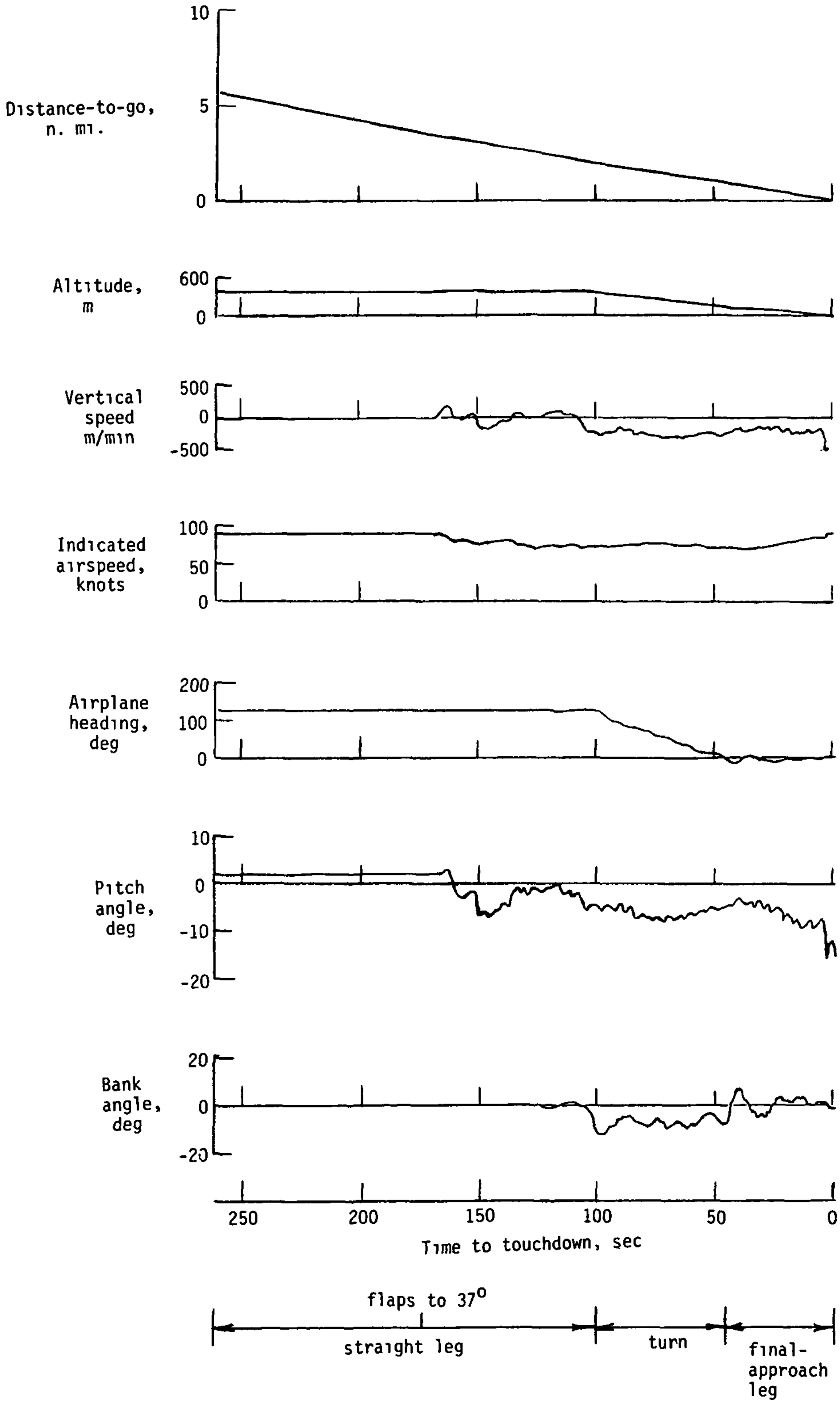
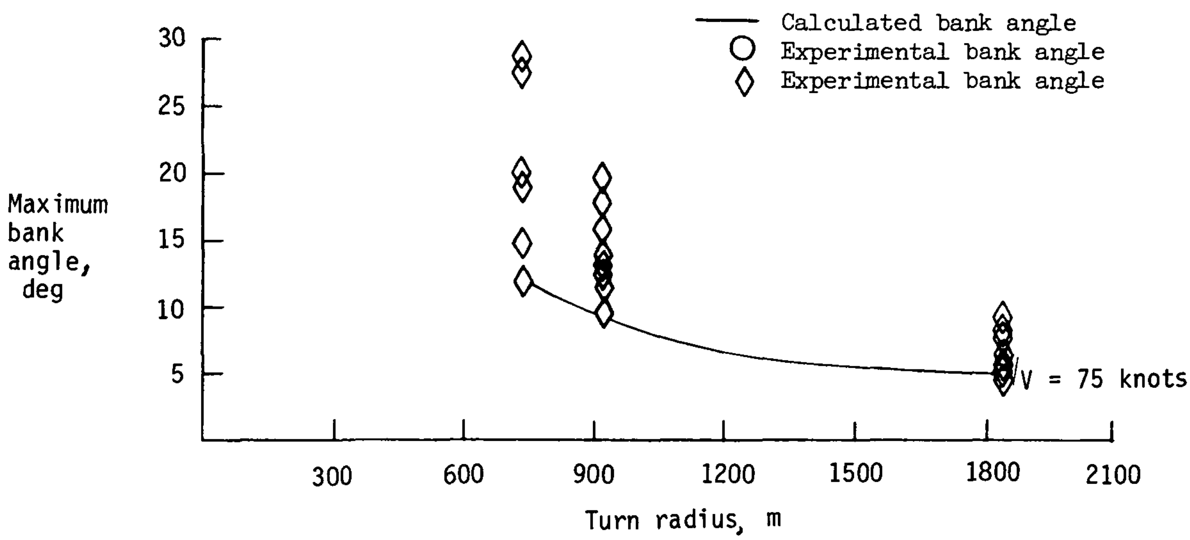
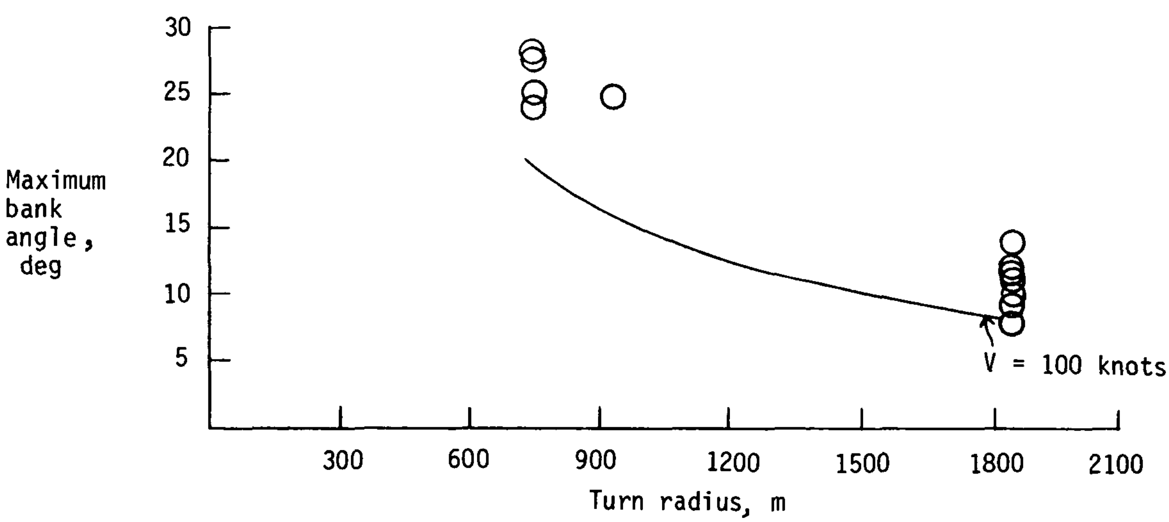


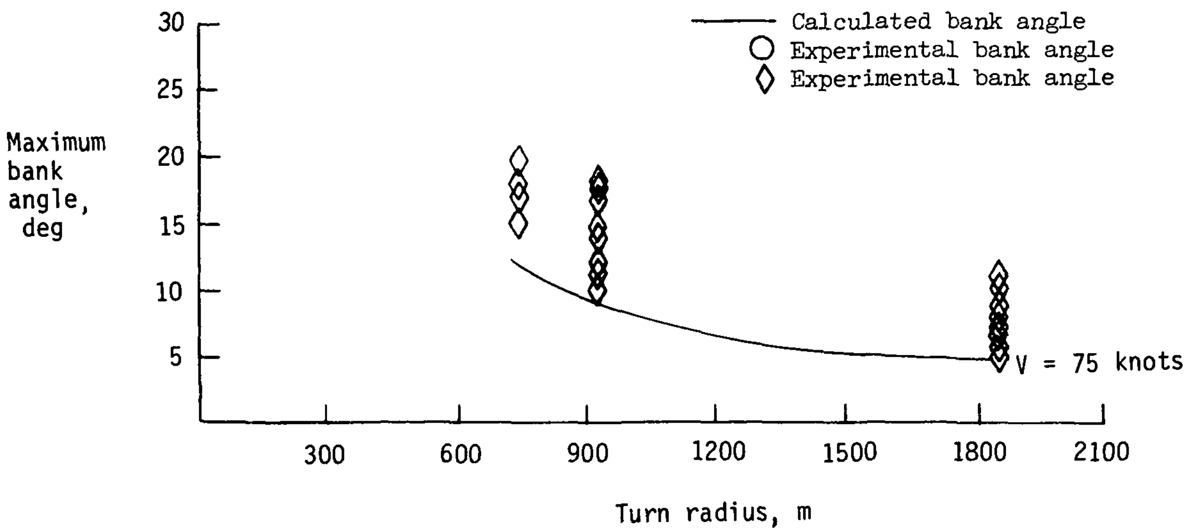
Figure 4.- Typical lightweight STOL data; R = 914.4 m (3000 ft); d = 1828.8 m (6000 ft); Turn = 180°.

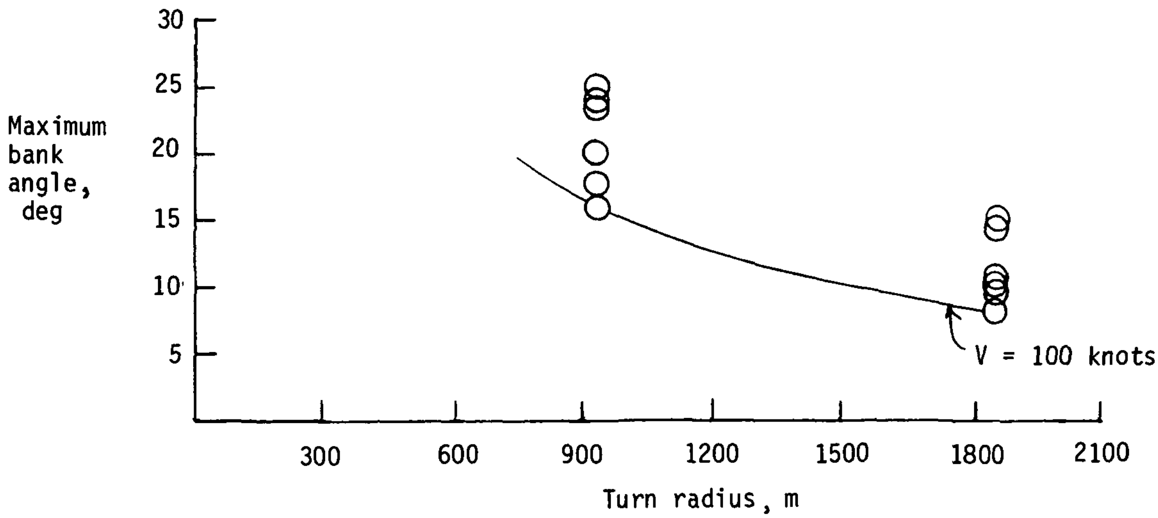




(a) Lightweight STOL.

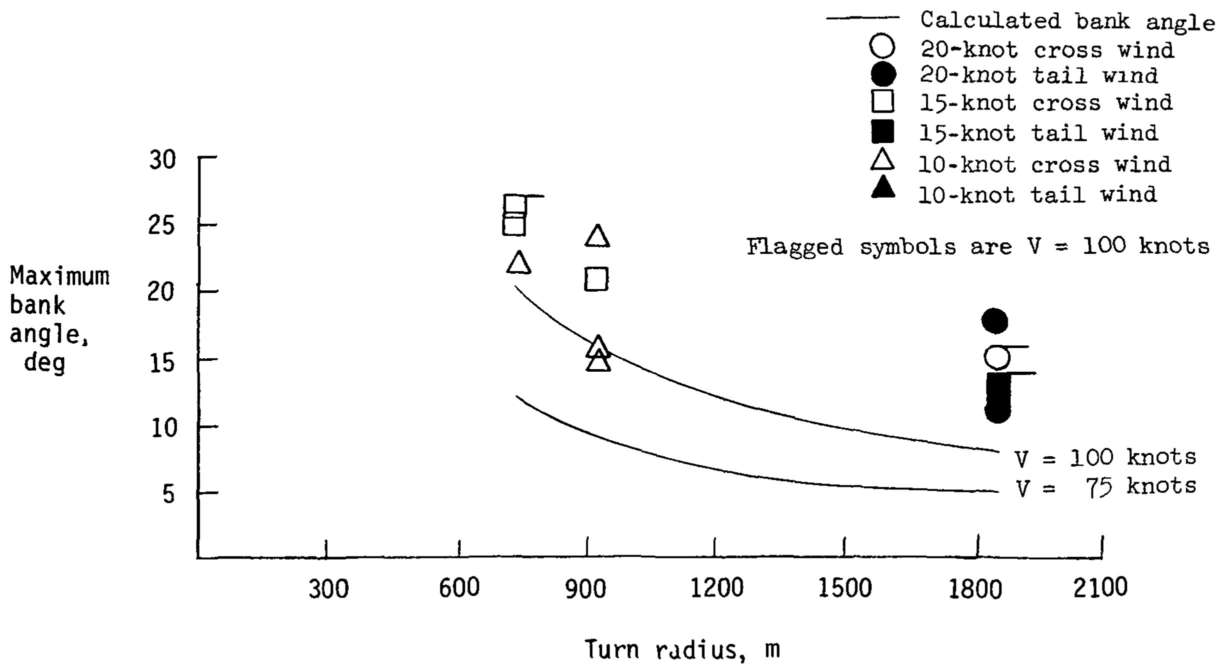
Figure 5.- Maximum bank angle in turn for no-wind condition.



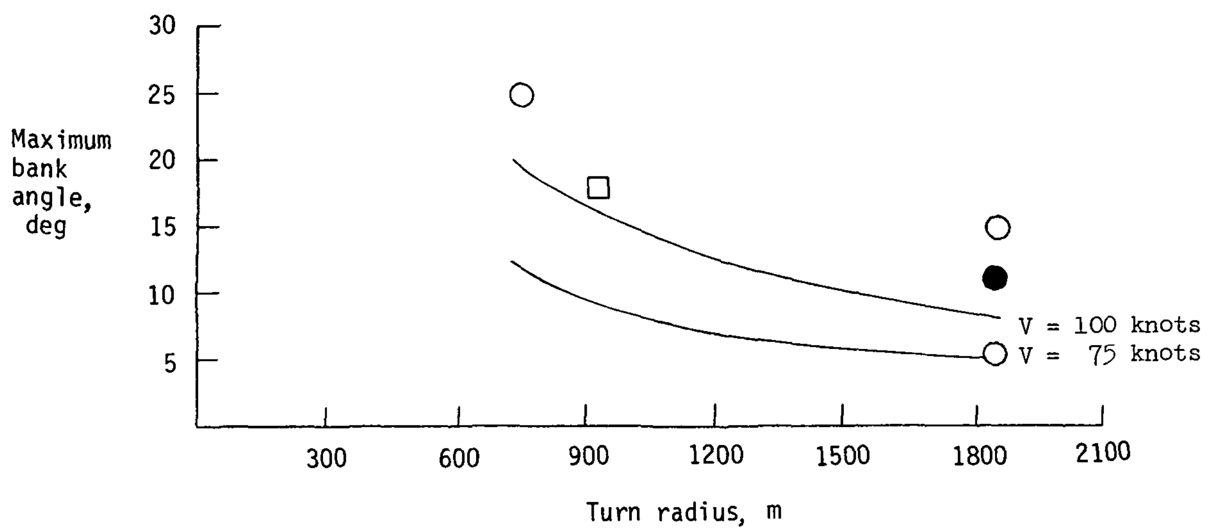


(b) Mediumweight STOL.

Figure 5.- Concluded.

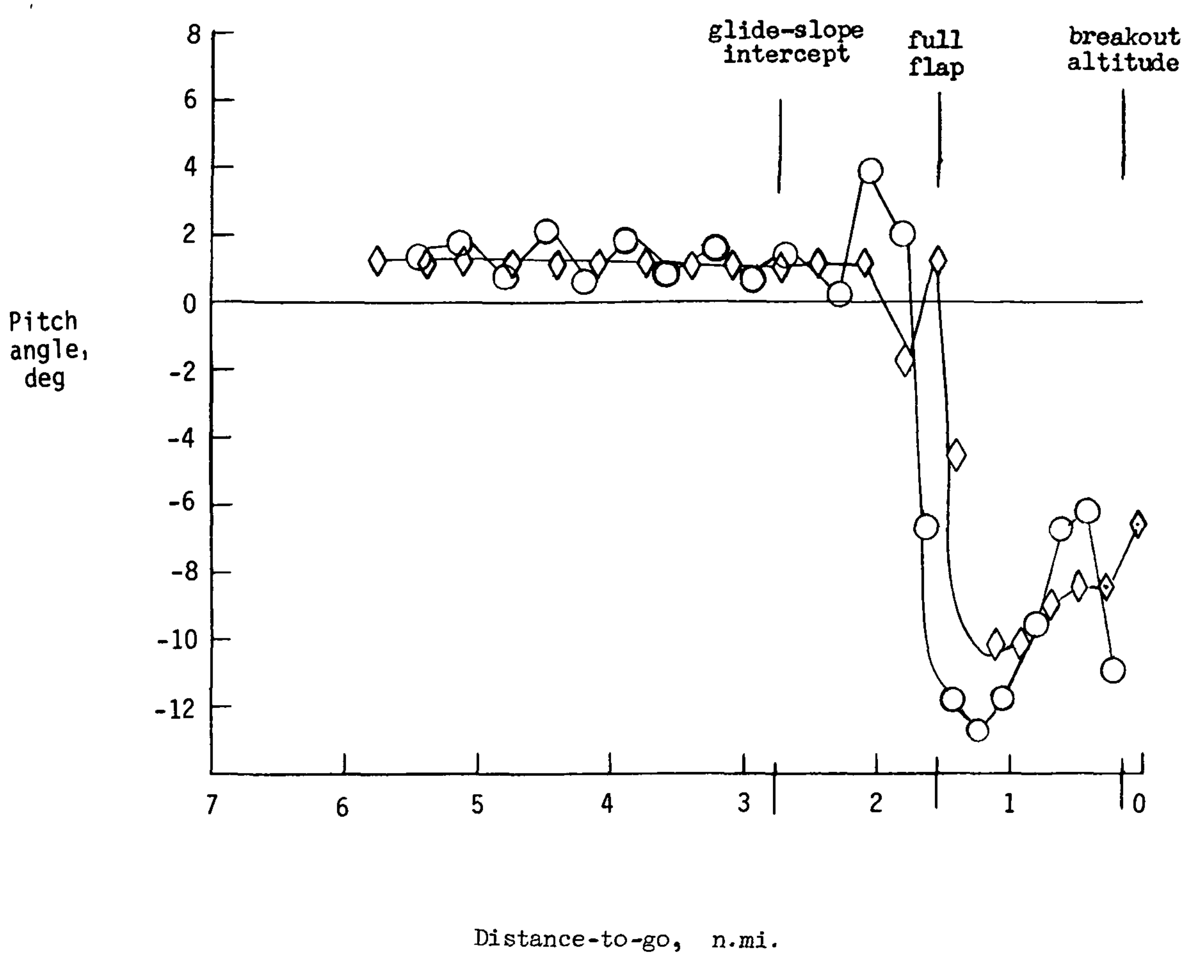


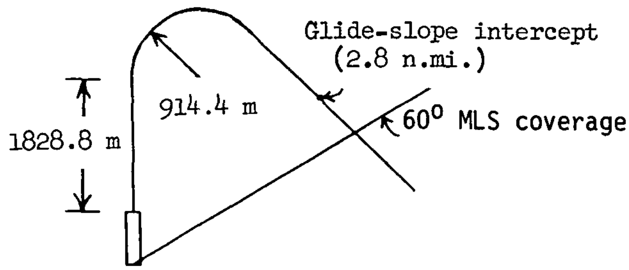
(a) Lightweight STOL.



(b) Mediumweight STOL.

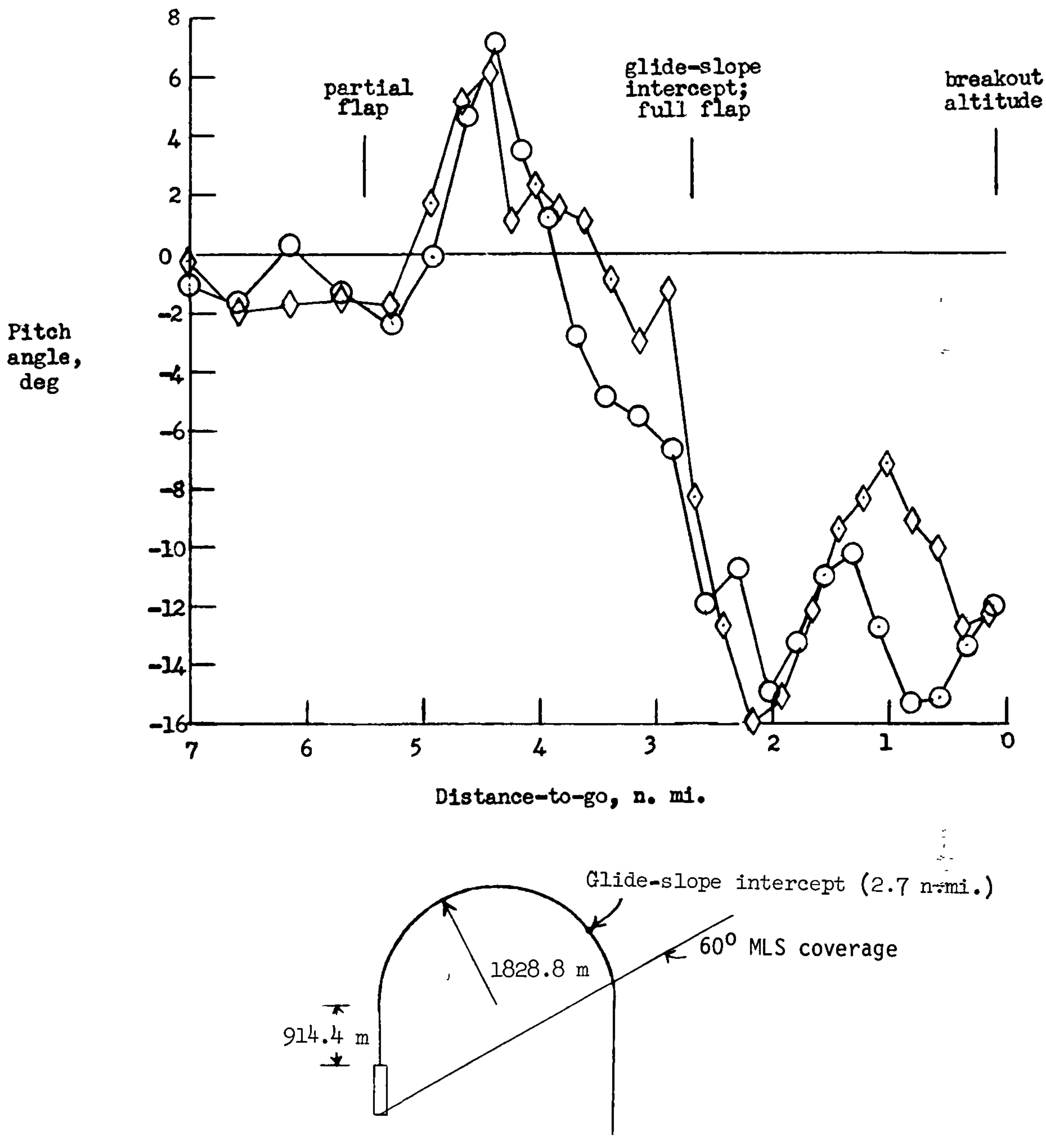
Figure 6.- Maximum bank angles in turn with wind present.





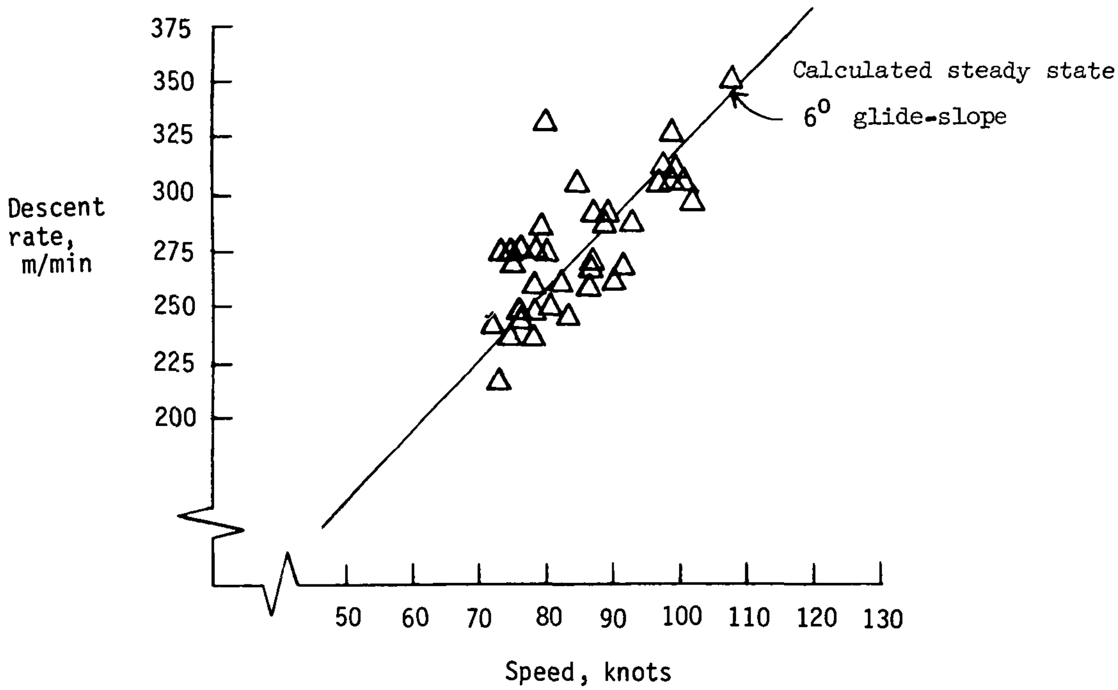
(a) Approach configuration A.

Figure 7.- Sample pitch-angle variations during approach for a lightweight STOL airplane.

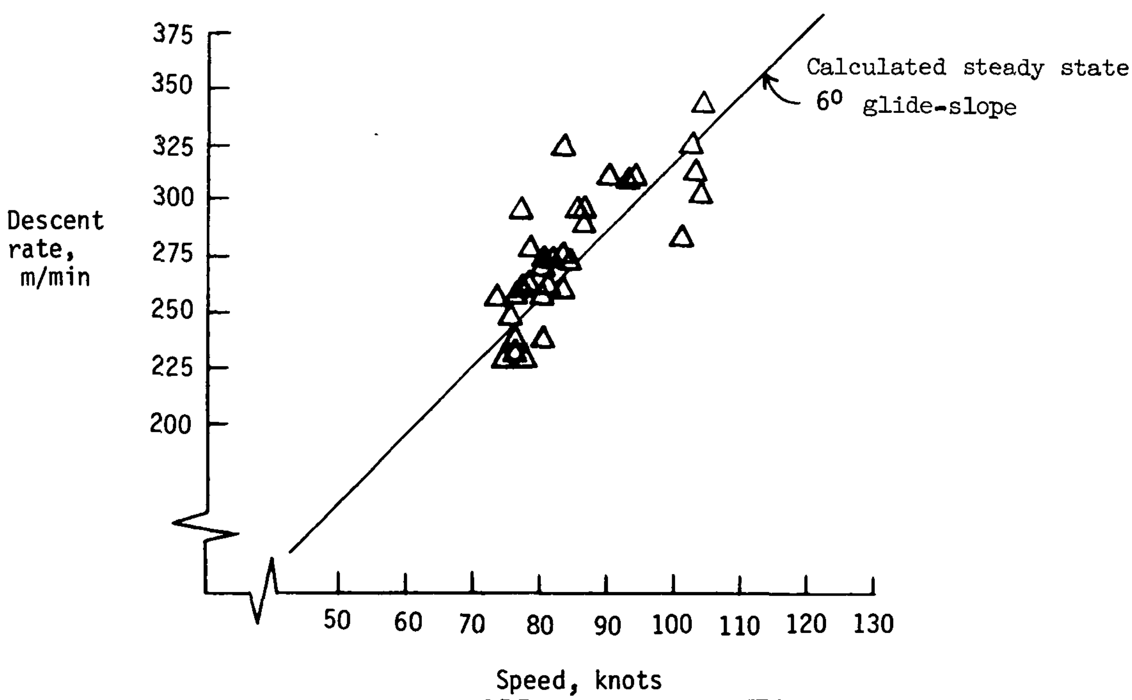


(b) Approach configuration B.

Figure 7.- Concluded.

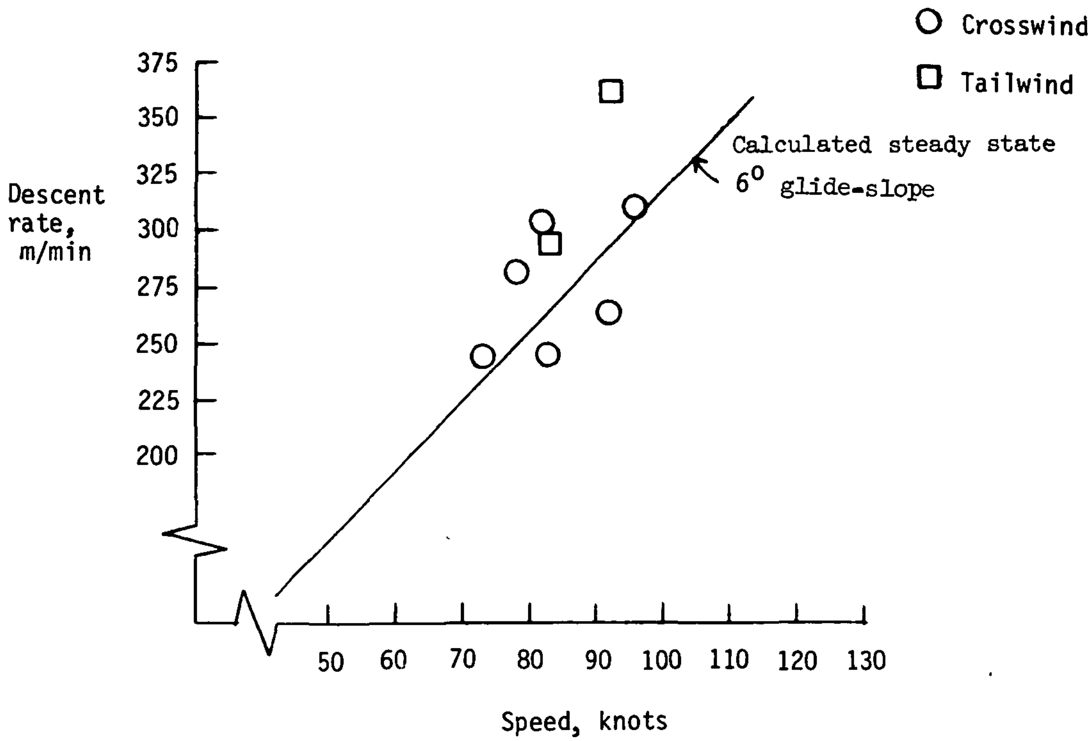


(a) Lightweight STOL.

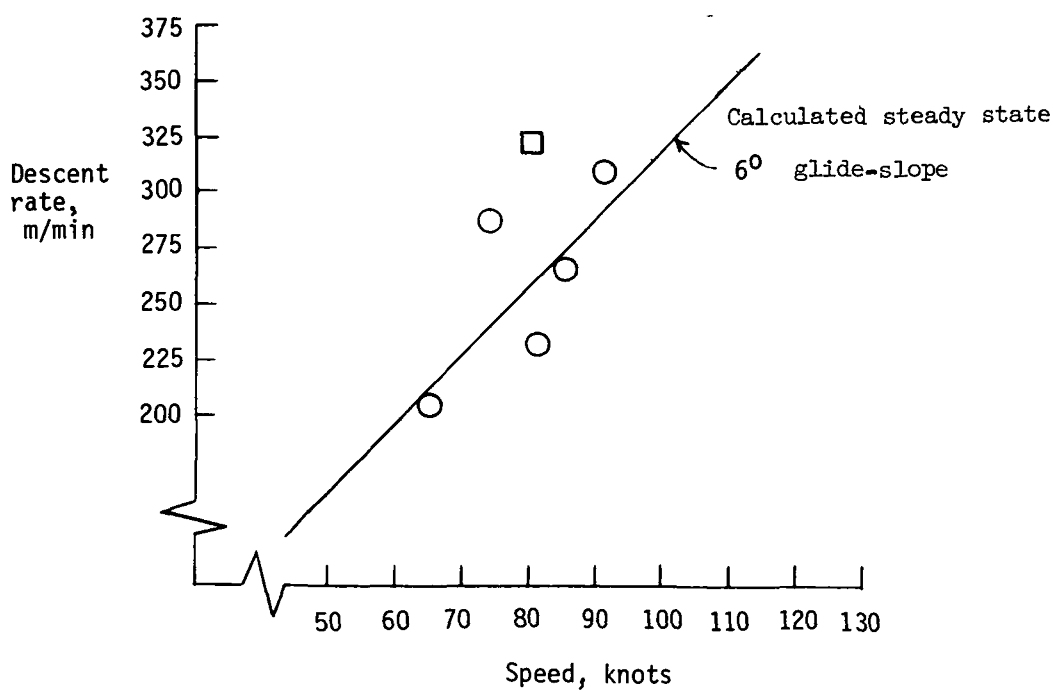


(b) Mediumweight STOL.

Figure 8.- Descent rates with no wind present.

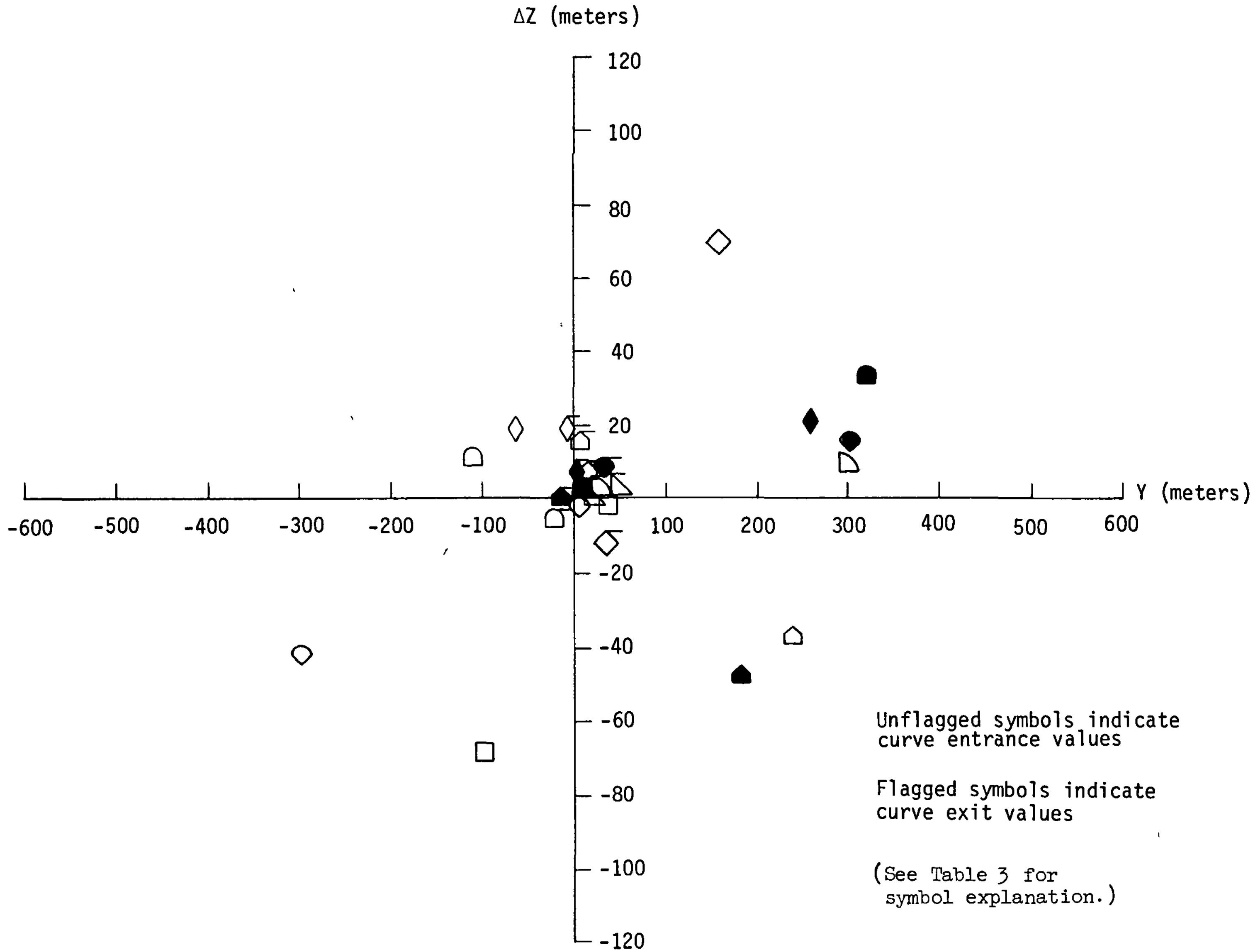


(a) Lightweight STOL.



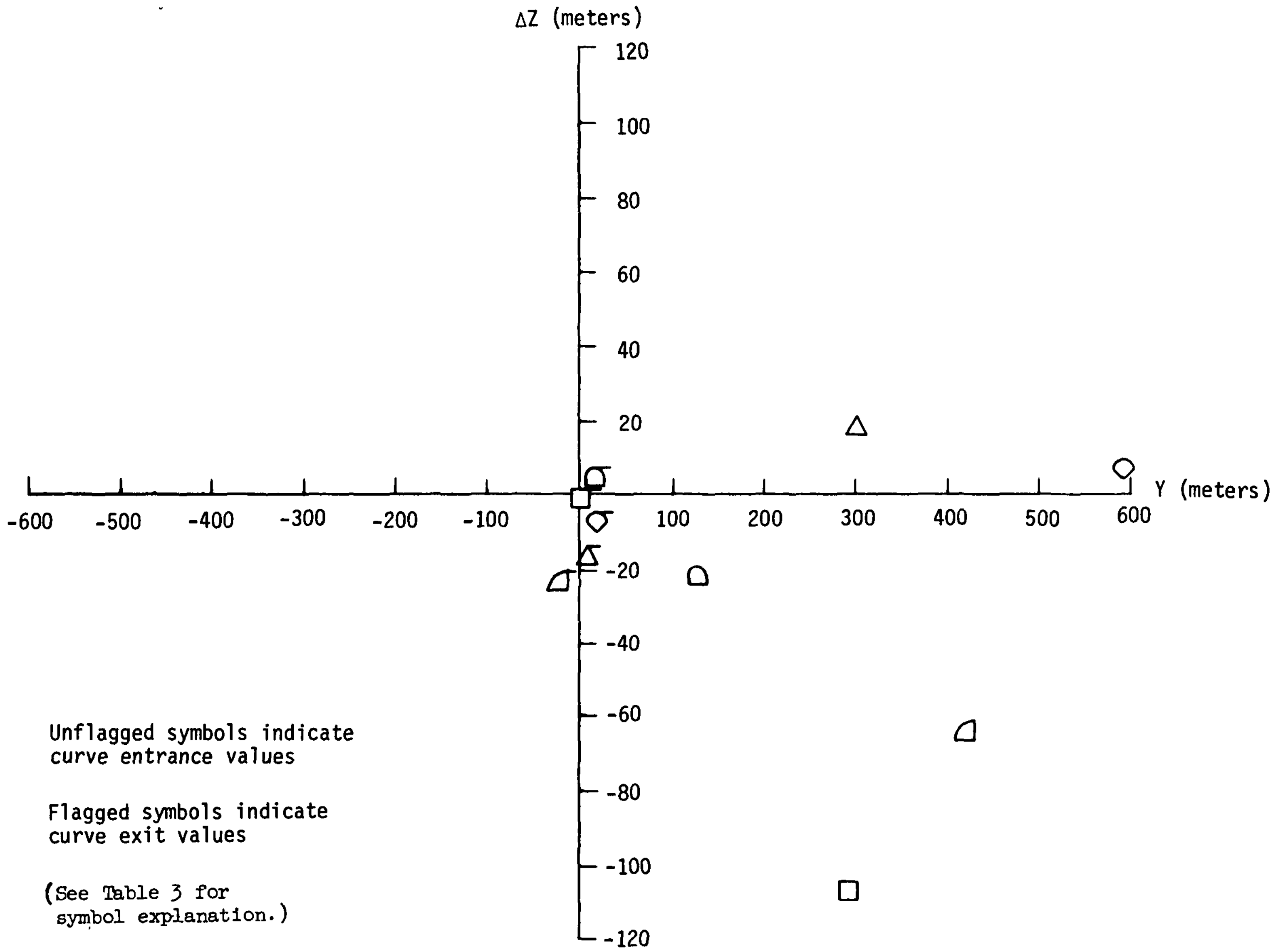
(b) Mediumweight STOL.

Figure 9.- Descent rates with winds present.



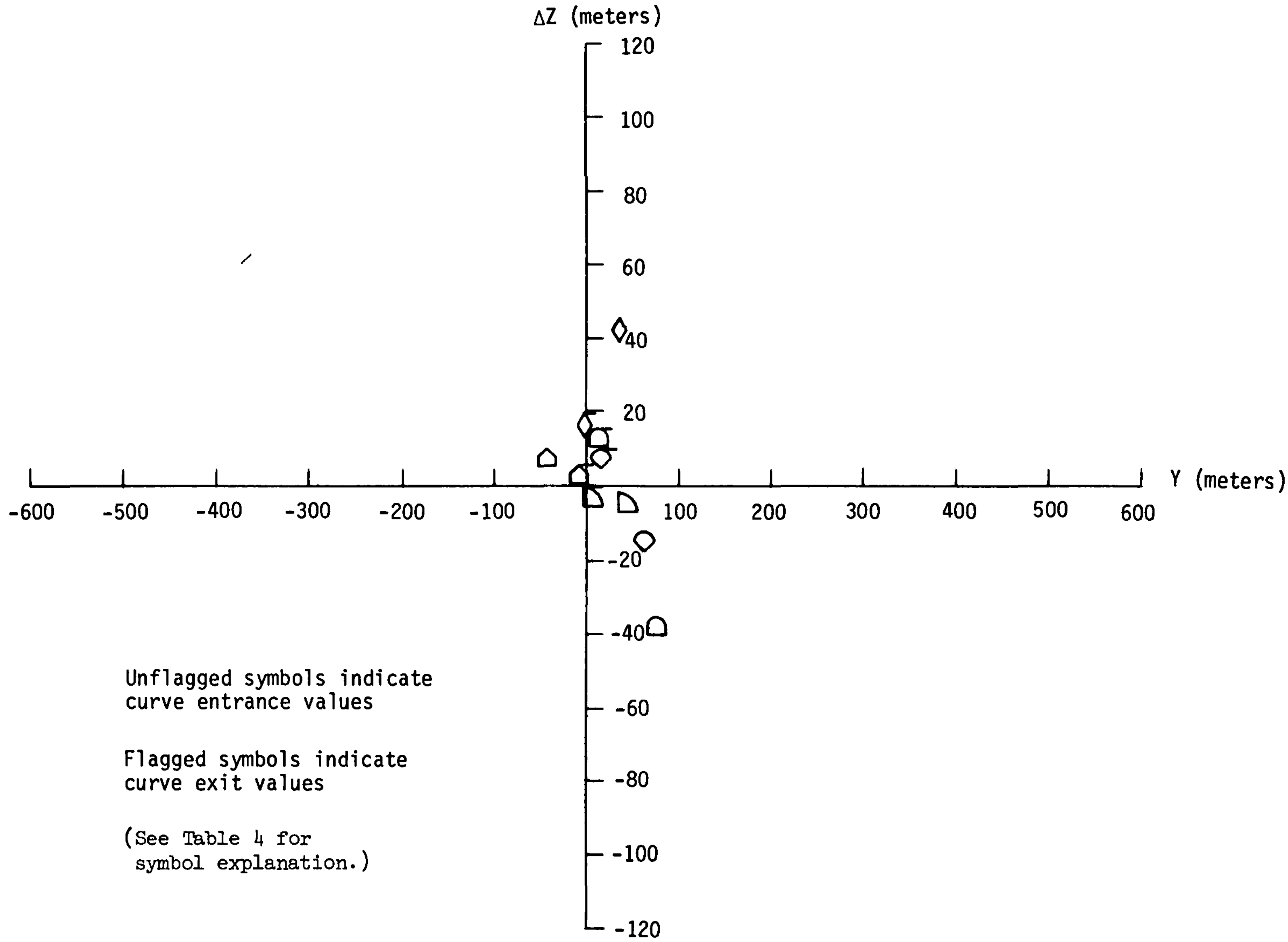
(a) Lightweight STOL.

Figure 10.- Flight-path deviations at turn entrance and exit for a 1828.8-m (6000-ft) radius turn.



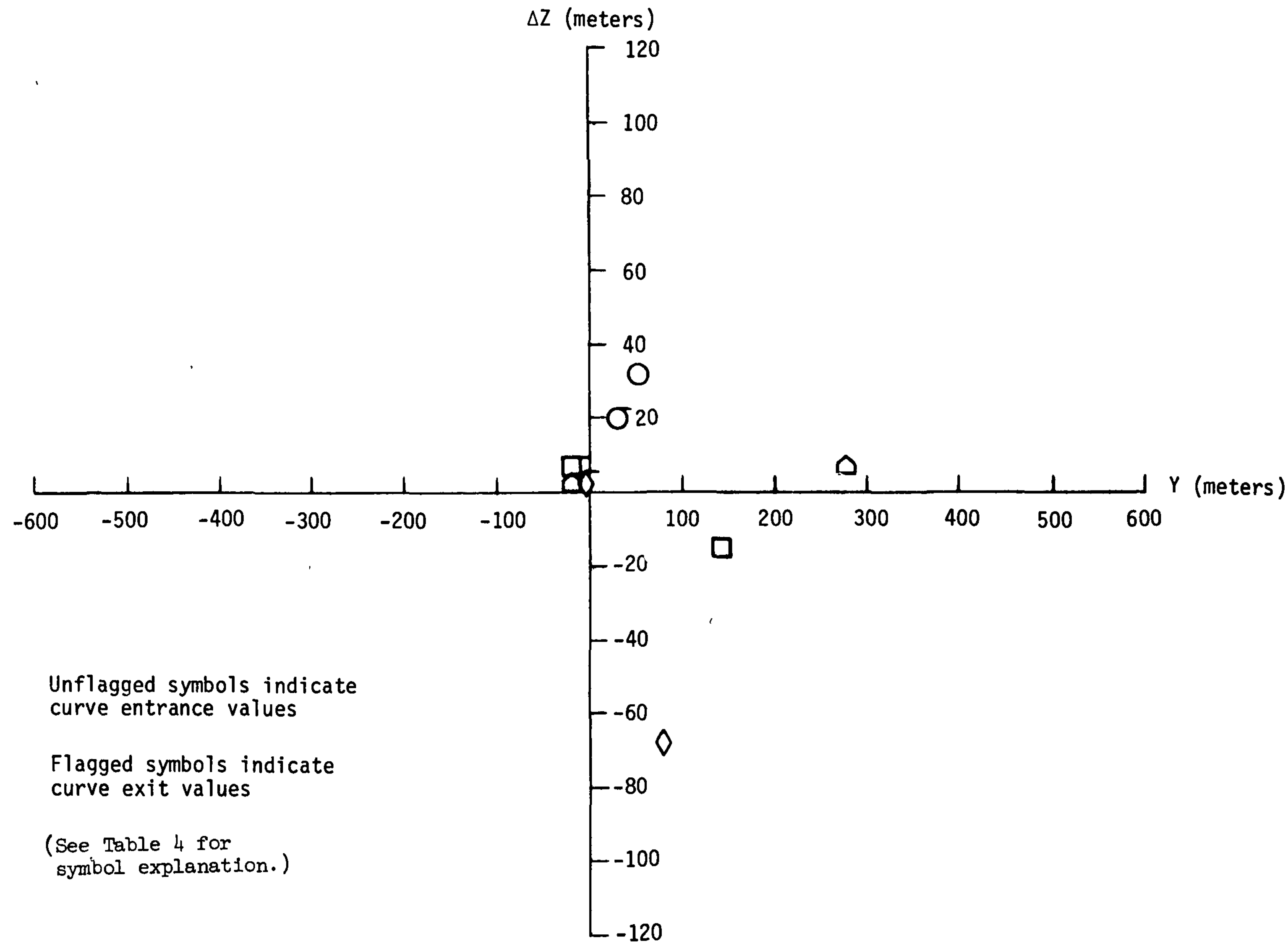
(b) Mediumweight STOL.

Figure 10.- Concluded.



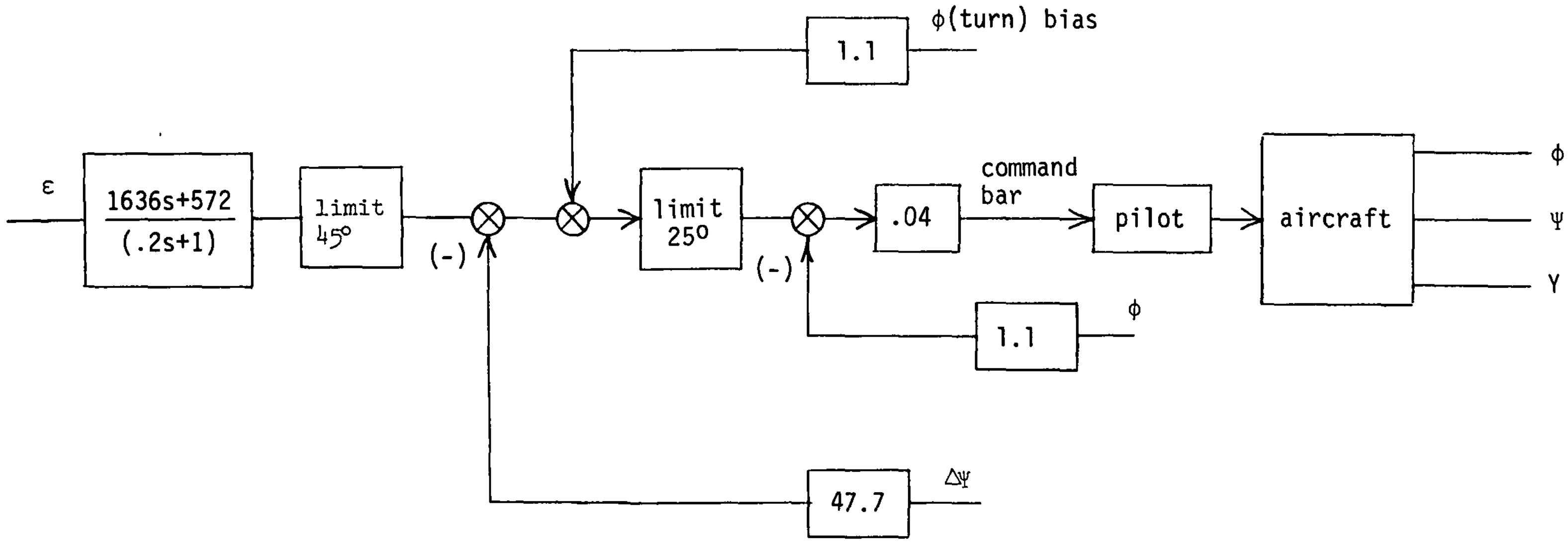
(a) Lightweight STOL.

Figure 11.- Flight-path deviations at turn entrance and exit for a 914.4-m (3000-ft) radius turn.



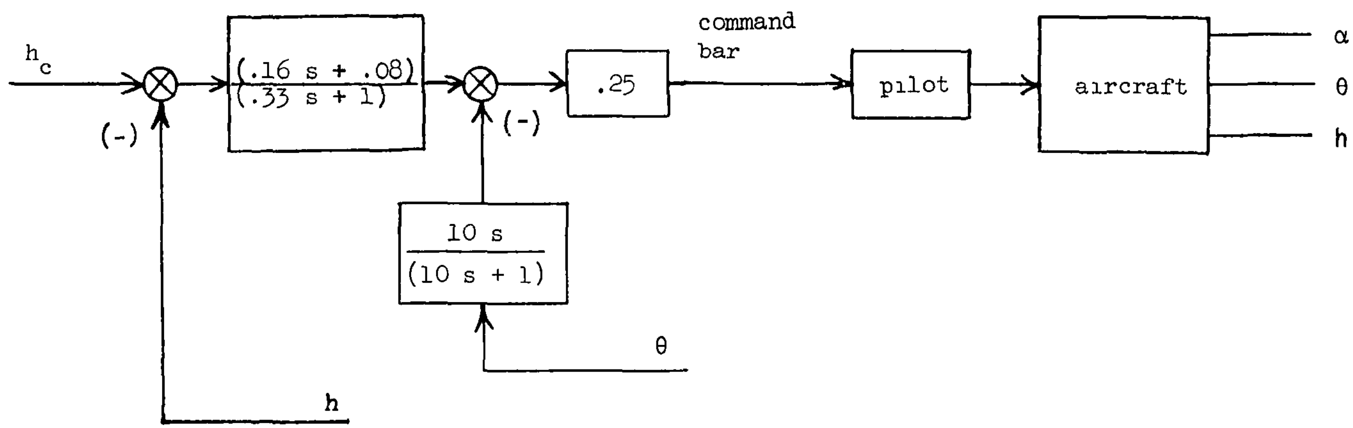
(b) Mediumweight STOL.

Figure 11.- Concluded.



(a) Lateral direction.

Figure 12.- Flight-director logic.



(b) Longitudinal direction.

Figure 12.- Concluded.

NASA-Langley, 1973 —— 2 L-8868

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof"

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge

TECHNICAL NOTES Information less broad in scope but nevertheless of importance as a contribution to existing knowledge

TECHNICAL MEMORANDUMS· Information receiving limited distribution because of preliminary data, security classification, or other reasons Also includes conference proceedings with either limited or unlimited distribution.

CONTRACTOR REPORTS Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge

TECHNICAL TRANSLATIONS Information published in a foreign language considered to merit NASA distribution in English

SPECIAL PUBLICATIONS Information derived from or of value to NASA activities Publications include final reports of major projects, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546