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FLIGHT INVESTIGATION OF THE VFR AND IFR LANDING APPROACH CHARACTERISTICS AND TERMINAL AREA AIRSPACE REQUIREMENTS FOR A LIGHT STOL AIRPLANE

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SUMMARY

A flight research program was conducted to determine the terminal area instrument flight capabilities of a light STOL airplane. Simulated (hooded) instrument landing approaches were made using a variety of steep single-segment and two-segment glide slopes. A brief investigation was also made of the visual flight terminal area capabilities of the aircraft. The results indicated that the airplane could be flown on a 7° glide-slope ILS-type approach in still air with an adequate 3° margin for downward correction. The light STOL aircraft could be flown on an approach pattern with a final leg less than one-third as long as that needed on the current ILS and with only two-thirds as much time required as that being used by current large CTOL transports.

INTRODUCTION

Within a few years, STOL aircraft may be operating into downtown STOL ports as well as into existing airports. The STOL ports are likely to be in tightly enclosed areas adjacent to such obstacles as tall buildings. It will be desirable to fly steep, curved approaches into the STOL ports day and night, in all weather, and with a wide range of crosswind and turbulence conditions. In order to exploit the use of STOL vehicles, the capabilities and limitations must first be defined. Some of the possibilities for terminal area instrument flight operations are discussed in reference 1.

The primary objective of the present investigation was to determine the terminal area instrument flight capabilities of a light STOL airplane on modified ILS patterns. The procedure used was to fly simulated (hooded) ILS landing approaches which had a variety of steeper glide slopes and shorter flight patterns than the standard 3° glide slope. The effects of reducing the glide slope at breakout were also evaluated using two-segment approaches. The flexibility in the selection of approach guidance patterns was provided by a radar guidance system which transmitted ILS deviations from a programed flight path. The guidance system is described in reference 2, which reports a similar type of investigation of the capabilities of CTOL jet transports for single-segment and two-segment instrument approaches. The current investigation also included a limited evaluation of the VFR approach characteristics of the light STOL airplane.

SYMBOLS AND ABBREVIATIONS

Except for airspeed which is given in knots, data are presented herein in the International System of Units (SI) with the equivalent values given parenthetically in the U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units. (Factors relating the two systems of units in this paper may be found in reference 3.)

a_n	normal acceleration, g units
a_X	longitudinal acceleration, g units
a_Y	lateral acceleration, g units
$\bar{c}$	mean aerodynamic chord, cm (in.)
C_L	lift coefficient, $\frac{W}{\frac{1}{2}\rho V^2 S}$
$\overline{C}_L$	mean (average) lift coefficient
CTOL	conventional take-off and landing
E_g	glide-slope error, positive for above center line, percent full-scale indicator deflection
E_L	localizer error, positive for right of center line, percent full-scale indicator deflection
F_c	column force, positive for pull, N (lb)
F_w	wheel force, positive for right input, N (lb)
g	acceleration due to gravity, m/sec^2 (ft/sec^2)
h_p	pressure altitude, m (ft)

IFR	instrument flight rules
ILS	instrument landing system
p	roll rate, positive for right roll, rad/sec
q	pitch rate, positive for nose up, rad/sec
r	yaw rate, positive for nose right, rad/sec
R/D	rate of descent, m/sec (fpm)
STOL	short take-off and landing
S	wing area, m^2 (ft^2)
V	true airspeed, knots
V_c	calibrated airspeed, knots
$\bar{V}_c$	mean (average) calibrated airspeed, knots
V_i	indicated airspeed, knots
VFR	visual flight rules
V/STOL	vertical or short take-off and landing
W	aircraft weight, N (lb)
X,Y,Z	body axes
x,y,z	orthogonal coordinates
α	angle of attack, deg
β	angle of sideslip, deg
γ	flight-path angle, deg

$\delta_{a,r}$ right aileron deflection, positive trailing edge down, deg

δ_f flap deflection, positive trailing edge down, deg

δ_r rudder deflection, positive trailing edge left, deg

δ_s stabilator deflection, positive trailing edge down, deg

δ_T throttle deflection, cm (in.)

θ pitch attitude angle, deg

ρ density, kg/m^3 ($slugs/ft^3$)

σ standard deviation

σ_{an} standard deviation of normal acceleration, g units

ϕ roll attitude angle, deg

TEST AIRPLANE

The test airplane was an early model of a single-engine high-wing STOL airplane with a 194 kW (260 hp) engine and a constant-speed propeller. The flight tests were made at weights of 13 300 to 14 200 N (3000 to 3200 lb). The wing loading ranged approximately from 620 to 670 N/m^2 (13 to 14 lb/ft^2). The normal center-of-gravity range is from 27 to 34 percent mean aerodynamic chord. For this program, aft center-of-gravity positions from 33 to 37 percent mean aerodynamic chord were used. These values were close to the aft center-of-gravity position used in the investigation of reference 4.

A photograph of the test airplane is shown in figure 1. Unusual features of the airplane are shown in the photograph and in a three-view drawing of figure 2. One particular feature to note is the size of the vertical tail. It is large and has a long moment arm with respect to the center of gravity which is intended to maintain both stability and control effectiveness at reduced STOL airspeeds. Other features which are beneficial to STOL performance include the 78 percent span Fowler flaps, the full-span aerodynamically actuated leading-edge slats, the stabilator, and the wide (40 percent) chord Frise ailerons which were mechanically linked to arc-shaped spoilers located at 15 percent chord. The crosswind landing gear was equipped with castoring main wheels and a steerable tail wheel.

The cockpit instrument panel is shown in figure 3. The panel was obsolete by modern standards in that it did not employ the basic T-arrangement of flight instruments with the attitude gyro in the center and in that the directional gyro was a horizontal card type. This instrument arrangement did not allow for an efficient scan pattern. Furthermore, it was necessary to locate the ILS indicator, which was installed for this program, off to the left in such a position as to further complicate the pilot scan pattern.

An evaluation of performance and flying qualities of the STOL-type airplane tested is reported in reference 4. In the present tests, flying qualities were evaluated primarily for the flap-down landing-approach condition, with an aft center-of-gravity position (37 percent $\bar{c}$). The static longitudinal stability was positive stick-fixed but became neutral stick-free, that is, in terms of $\partial F_c/\partial V_c$, below approximately 55 knots. The force per g for maneuvering at 60 knots was about 110 N (25 lb). The trim change, due to extending the flaps, required a push force of about 90 N (20 lb). Directional stability was positive and sideslip characteristics were linear and acceptable with noticeable, but reasonable, amounts of control force and deflection required to produce the sideslip and bank angles required for steady sideslip. At either 45 or 60 knots, full rudder was adequate to trim the airplane for about 20° left sideslip or 15° right sideslip. A lateral control force of 110 N (25 lb) produced a roll rate of about 25°/sec. A moderate amount of adverse sideslip (about 8°) resulted from such a full deflection roll maneuver. The Dutch roll damping ratio was 0.2 and the period was over 3 sec. In general, the flying qualities were acceptable for a VFR landing approach.

DATA RECORDING SYSTEM

Twenty-three parameters were recorded aboard the aircraft by a magnetic tape system. These parameters included the three linear accelerations, the three angular rates, the control surface deflections, the throttle position, the inboard slat positions, the flap position, the roll and pitch attitude angles, the angles of attack and sideslip, the airspeed, the altitude, the lateral and longitudinal control forces, and the glide-slope and localizer deviations. A record of elapsed time was recorded with these data. Several other channels of information were recorded at the radar site including the x-y and x-z plots of the approaches, and the deviations from the glide slope and localizer. The radar data were coordinated with the aircraft data by making two synchronizing marks, 1 min apart, on all the records during each approach.

FLIGHT CALIBRATIONS

Separate calibration flights were made for angle of attack and airspeed. The test method used for both calibrations was first to establish the aircraft at a desired indicated airspeed and flap condition with power for level flight. Data were then recorded when the aircraft was stabilized at the desired conditions. Data were taken throughout the permissible speed range at flap deflections of 0°, 20°, and 40°. The angle-of-attack calibration was obtained from the pitch attitude angle and indicated angle-of-attack measurements, assuming that the flight-path angle was zero.

During the airspeed calibration flights, the true airspeed was measured by a calibrated trailing anemometer which was deployed through a cabin window. The anemometer was suspended 1.5 wing spans behind and beneath the wing on a combination support-instrument cable. An electrical impulse proportional to the rotational speed of the anemometer propeller was transmitted to the tape recording system in the aircraft by the cable. The calibrated airspeed was obtained from the recorded values of true airspeed, pressure altitude, and temperature.

TEST CONDITIONS AND PROCEDURE

Approximately 10 approaches were made using each of 6°, $7\frac{1}{2}^{\circ}$, and 9° single-segment glide slopes and 6° to 3° and 9° to 3° two-segment glide slopes. The transition point for the two-segment approaches was about 1.6 km (1 statute mile) from the intended touchdown point at an altitude of about 84 m (277 ft). Only the rear portion of the center-of-gravity range was evaluated.

The simulated instrument approaches were flown with the evaluation pilot hooded. Approach guidance was provided by an ILS indicator which received signals from a modified AN/GSN-5 carrier landing radar system. A description of the radar system is given in the appendix of reference 2. Examples of the guidance patterns used in these tests, which show the deviation envelopes for full-scale ILS indicator deflection, are given in figures 4 to 6. In the vicinity of breakout, the localizer pattern was inadvertently made about one-half as wide as a typical operational ILS pattern. However, the depth of the glide-slope pattern was increased from that of the conventional ILS in proportion to the steepness of the approach, so that the time to fly level across the whole glide-slope signal was approximately the same for any glide slope.

The program was largely flown at 59 knots, calibrated, which was considered to be the minimum usable instrument approach speed, with full flap deflection ($\delta_f = 40^{\circ}$) by the primary NASA research pilot. However, a few approaches were made with a flap deflection of 20°, or at a slower approach speed. The data runs started when the ILS guidance was intercepted, usually at an altitude of 244 to 305 m (800 to 1000 ft). Most of the simulated ILS approaches started with a 90° turn to acquire the localizer. Depending on the turbulence level, the breakout altitude was about 61 m (200 ft) early in the program and was gradually reduced to about 30 m (100 ft).

EVALUATION OF VISUAL APPROACH CHARACTERISTICS

A brief flight evaluation was made of the VFR capabilities of the test airplane in the terminal area using the speed selected for the instrument approaches. The pilot concluded that the airplane could readily and safely operate in a rectangular take-off and landing pattern within a 805-m $\left(\frac{1}{2}\text{-mile}\right)$ square. At the selected calibrated approach speed of 59 knots (55 knots indicated) with full flap deflection, the steepest glide slope that could be maintained with engine idling and with no wind was approximately 10°. The resulting rate of descent of about 305 m/min (1000 fpm) was considered by the pilot to be undesirably high near the ground. According to reference 1, the maximum desirable rates of descent for instrument approaches to minimums are between 152 and 213 m/min (500 to 700 fpm).

Figure 7 is a time history of a visual approach at $\gamma = -10.5^{\circ}$ with $\delta_f = 40^{\circ}$. The headwind component during this run was 5 knots. It is evident that pitch control was not very active and the pitch-mode response, such as attitude and airspeed, was smooth. However there was a 6-knot crosswind at 30° with some turbulence. As a result, bank angle was unsteady and there was considerable lateral control activity. The project pilot assigned numerical ratings for each flight mode using the Cooper-Harper rating scale of reference 5. For a visual approach in calm air, the rating was 3, which corresponds to satisfactory characteristics. Because the test airplane has vigorous lateral-directional response to turbulence, the rating dropped to 5 in light turbulence $\left(\sigma_{an} = 0.1g\right)$ and $5\frac{1}{2}$ in moderate turbulence $\left(\sigma_{an} > 0.1g\right)$. The strong influence of the wind on steep approach capability is shown in the following table:

Airspeed, knots	Actual glide-path angle, deg	Equivalent no-wind glide-path angle, deg, for –			
		Headwind of –		Tailwind of –	
		10 knots	20 knots	10 knots	20 knots
50	6	4.8	3.6	7.2	8.4
	9	7.2	5.4	10.8	12.6
60	6	5.0	4.0	7.0	8.0
	9	7.5	6.0	10.5	12.0

The table shows that a headwind can increase the steep approach capability of a slow-flying airplane by an appreciable amount (16 to 40 percent). In figure 7, the headwind increased the glide-path angle by approximately 0.5° above an equivalent still-air angle of about 10°.

EVALUATION OF INSTRUMENT APPROACH CHARACTERISTICS

General

During an instrument approach in smooth air, the pilot can be expected to descend to the breakout altitude with the key flight parameters closely controlled or stabilized. These parameters include airspeed, rate of descent, attitude, heading, glide-slope deviation, and localizer deviation. Even with a steady crosswind, control of heading is complicated by the need of a crab angle in order to maintain a track on the localizer, that is, the extended runway center line. This task will also be made more difficult by the random inputs of turbulent air. It should be noted that the nominal wing loading of the test airplane was only 670 N/m^2 (14 lb/ft^2) which made the airplane very responsive to gust inputs.

The instrument panel layout, which was previously described, was also a handicap to the pilot. Therefore, it was necessary to attempt to make allowance for the shortcomings of the cockpit instrumentation in order to fairly evaluate the instrument flight capabilities of the test airplane.

Selection of Approach Speed (Hooded)

The airplane characteristics were evaluated in flight at low speeds to made a tentative selection of airspeeds for hooded ILS-type approaches with partial ($\delta_f = 20^\circ$) and full ($\delta_f = 40^\circ$) flap deflection. The pilot commented that below a calibrated airspeed of about 59 knots, the longitudinal and lateral control responses are noticeably more sluggish and, in spite of the large wing span and large tail volume, are degraded by what appears to be low damping. The pilot also noted that the speed-power stability for 40° flap deflection becomes neutral or changes from positive to negative at about 50 knots. The pilot reported, during an early hooded approach, that whenever the airspeed went a few knots below a target speed of 59 knots, the airplane was slow to accelerate in response to a nose-down correction and/or a power increase. The power increase required seemed large, and even with the corrective action the speed tended to decrease further to below 50 knots. Except under ideal smooth air conditions, the pilot workload for a hooded approach was excessive. Therefore, to keep the pilot workload more often within limits by providing better attitude control and simpler thrust-drag control, a calibrated ILS approach speed of 59 knots was selected for use with either 20° or 40° flap deflection.

Figure 8 shows the variation of manifold pressure required for level flight with airspeed for flap deflections of 0°, 20°, and 40°. Since more power is required with 40° flap deflection, a steeper descent is, of course, possible with 40° flap deflection. However, it would be necessary to reduce the approach speed from the 59 knots used for these tests to below 39 knots to increase the steep approach capability with full flaps. The speed-power stability would also be reduced and would become negative as the calibrated approach speed was reduced from 59 to 39 knots. In addition, the aerodynamic control power would be reduced by a factor of 2 at the lower speed.

The flight results showed that, on hooded approaches, the calibrated airspeed normally ranged from 55 to 60 knots with a typical 1σ value of less than 3 knots. Example data from typical hooded approaches, at or near the aft center-of-gravity limit with 40° flap deflection are as follows:

γ, deg	$\bar{V}_c$, knots	σ_{V_c}, knots	W		$\bar{C}_L$
			N	lb	
-6	57.2	2.3	14 200	3200	1.25
-7.5	56.4	2.6	13 300	3000	1.21
-9	57.1	2.4	13 600	3050	1.19

It should be noted that at the speeds or lift coefficients listed in this table, the airplane was operating with the slats retracted. The slats extend at about 45 knots for an angle of attack near 15° and C_L near 2.5. In fact, the lift coefficient of about 1.2 used for ILS approach was no higher than the value used for hooded ILS approaches with some large CTOL jet transports in references 2 and 6.

Selection of Maximum Descent Gradient (Hooded)

Hooded instrument approaches were flown on glide slopes of 6°, 7.5°, and 9°. In all approaches, there was some headwind. The pilot felt that the ability to correct down from an upward displacement to the glide slope while maintaining approach airspeed was very limited for an approach at $\gamma = -9^{\circ}$. There was a steady 10-knot headwind during the approaches at $\gamma = -7.5^{\circ}$. Therefore, the equivalent approach glide slope for still air would have been about 6.5°. Longitudinal control was considered to be acceptable for an instrument approach at a calibrated airspeed of 59 knots on a 7.5° glide slope with some headwind. The pilot concluded that he should have a fly-down capability of 3° in reserve. This level of correction capability has been recommended by other studies (for example, ref. 2). Table I presents approximate no-wind glide slopes, descent rates, and margins for the test airplane for an approach speed of 59 knots. At this airspeed, a margin of 3° corresponds to a rate of descent of about 90 m/min (300 fpm).

Evaluation of Steep Approaches (Hooded)

Figures 9 and 10 have been prepared to show how well the pilot was able to acquire and track the glide slope and localizer on approaches at $\gamma = -6^{\circ}$ and -7.5°. The localizer and glide-slope tracking are shown for five approaches at each glide slope. The figures consist of x-y and x-z plots, which are expanded by a factor of 10 across the path, that is, for the y and z ordinates. The straight-line boundaries shown represent full-scale deflection of the localizer and glide-slope indicators. Both sets of approaches were flown hooded in fairly smooth air. For approaches at $\gamma = -6^{\circ}$, there was light turbulence and a 60° crosswind of 10 knots from the left. For the approaches at $\gamma = -7.5^{\circ}$, there was a 10-knot headwind.

Localizer acquisition and tracking.- The test airplane had adequate lateral control for turning maneuvers. However, for some unexplained reason, turning to a heading and then accurately holding that heading was difficult. The lateral-directional characteristics were such that the airplane exhibited continual small-amplitude heading variations (2° to 3° in calm air, 3° to 5° in light turbulence) which increased the workload for the tracking task. A time history of one of the approaches at $\gamma = -6^{\circ}$ is shown in figure 11 and, with reference to heading wander, shows very active roll angle, roll rate, yaw rate, and aileron deflection. The roll angle (or bank angle) reached 10° several times after the final turn.

As previously stated, in this test program the localizer was usually acquired from a 90° intercept angle instead of the 45° intercept angle that would be used with a procedure turn. As shown in the x-y plot of figure 9(a), the localizer needle was coming off the full-scale stop at a range of about 4000 m (13 000 ft) and at a lateral deviation of about 213 m (700 ft). At this range, the time to fly halfway across the localizer at right angles was about 7 sec. In some approaches, the pilot overshot the center line by about 60 to 120 m (200 to 400 ft). The localizer could not be acquired with any precision, but it was acquired loosely in about 40 sec with a range decrement of up to 915 m (3000 ft). Even on flights when the localizer was acquired from a straight-in approach, the airplane tended to wander back and forth with a half-amplitude of about 30 m (100 ft). The convergence of localizer deviation with decreasing range (from touchdown) was better on the approaches at $\gamma = -7.5^{\circ}$ (fig. 10(a)), in which case the air was smoother with no crosswind.

Glide-slope acquisition and tracking.- The flight pattern was usually flown at 305 m (1000 ft) so that the airplane reached the glide-slope center line at a range of about 2440 m (8000 ft) for an approach at $\gamma = -7.5^{\circ}$ and 3050 m (10 000 ft) for an approach at $\gamma = -6^{\circ}$. At about that point, the flaps were manually cranked down from 20° to 40° and the localizer had just been "loosely" acquired. Increasing the flap deflection caused a nose-up trim change and, perhaps as a result, the airplane usually climbed 15 m (50 ft) or more. In spite of all the activity at and just before reaching the glide-slope center line, the pilot was able to establish the approximate desired descent flight path within a few seconds.

Glide-slope tracking was uniformly good during the $\gamma = -7.5^{\circ}$ approaches of figure 10, which were made in smooth air with a 10-knot headwind. The tracking was noticeably more erratic on the $\gamma = -6^{\circ}$ approaches of figure 9 in the presence of light turbulence and a 10-knot 60° crosswind. As has been stated, the pilot also frequently reported a problem with airspeed control in the approach with a tendency for the speed to decrease below 50 knots whenever the aircraft pitch attitude was allowed to become slightly nose high. Approach time histories in figures 11 and 12 show examples of hunting in pitch attitude of approximately $\pm 5^{\circ}$ and airspeed fluctuations of greater than ± 5 knots during hooded approaches. In contrast, the visual $\gamma = -10^{\circ}$ approach of figure 7 was made with far less hunting in pitch.

Pilot ratings of ILS operation.- The overall numerical pilot ratings for the landing approach were adversely affected by both instrument flight and rough air. The pilot did attempt to filter out the adverse effects of the instrument display in making these ratings. To correlate with the pilot definitions of turbulence level, the standard deviation of normal acceleration was determined for eight approaches in smooth air and four approaches in light to moderate turbulence. The ILS tests were terminated at greater levels of turbulence. The effect of turbulence acceleration levels on pilot ratings is shown in the following table:

	Turbulence level		
	VFR rating	IFR rating	σ_{an}, g units
Smooth air	3	5	≈ 0.05
Light turbulence	5	$5\frac{1}{2}$	≈ 0.1
Moderate turbulence	$5\frac{1}{2}$	6	> 0.1

Benefits from stability augmentation.- It is believed that the pilot ratings for IFR and ILS approach operations could be improved by at least 1 unit by means of simple stability augmentation devices. The handling in rough air would probably be improved by increasing the damping in yaw C_{n_r}. One approach would be to use a yaw damper which drives a segment of the rudder. It is expected that a yaw damper would reduce the heading wander. A second simple stability augmenter, a wing leveler such as the one discussed in reference 7, should help to reduce the excursions of bank angle in rough air and, therefore, also contribute to improved pilot ratings.

Approach Margins

Angle-of-attack margin.- The test airplane was equipped with self-deflecting full-span slats, which extend automatically at an angle of attack of about 15° corresponding to an airspeed of about 45 knots with full flap deflection. With slats extended, the airplane did not stall.

The angle-of-attack range used during the approaches with $\delta_f = 40^{\circ}$ ranged from 0° to 5°. The pilot had no direct knowledge of angle of attack or angle-of-attack margin. By using power to maintain level flight with flaps down, the angle of attack for maximum lift was 18° or more. According to reference 4, the angle of attack for maximum lift with engine idling and flaps down was at least 14°. Therefore, the angle-of-attack margin maintained during the ILS approaches was larger than necessary at 10° or more.

Lift margin.- It is estimated that with $\delta_f = 40^{\circ}$ and power for level flight, the maximum lift coefficient was greater than 3.0 and the power-off maximum lift coefficient was about 2.4. Therefore, the approach lift coefficients of 1.1 to 1.5 were only about one-half to two-thirds the power-off maximum lift coefficient.

It is interesting to note that with $\delta_f = 20^{\circ}$ the lift coefficient available was reduced by 0.5, but the pilot did not feel that it was necessary to increase the approach speed, that is, decrease the trim lift coefficient. Therefore, lift margin was not a controlling factor in the selection of ILS approach speed and a lower lift coefficient was used than would be suitable for VFR STOL operation.

Airspeed margin.- The calibrated approach airspeeds of 55 to 60 knots, used on the simulated (hooded) ILS approaches, were about 15 knots above the minimum suitable for VFR STOL approaches. As stated previously, the approach speed was selected so as to operate in a region of better pitch attitude and speed control, that is, on the front side of the power-required curve with the benefits of higher dynamic pressure over the control surfaces. On this particular type of airplane, these two factors were more important to the pilot during an ILS approach than knowing how much excess lift or maneuvering capability was in reserve at the approach speed.

Pattern Size in Terms of Space and Time

It is possible to get an idea of the relative size of current approach guidance patterns for CTOL transports and a smaller pattern suitable for the light STOL test airplane by comparing instrument approach patterns with those used during other test programs. Suitable data for comparison were presented in references 2 and 6. The references show that with several different types of jet transports, the localizer acquisition was started at a range of 12 to 16 km $\left(\text{about } 7\frac{1}{2} \text{ to } 10 \text{ statute miles}\right)$. The glide slope was intercepted at a range of about 8 km (5 statute miles). The pattern altitude and glide-slope intercept were about 457 m (1500 ft) above the runway for an approach at $\gamma = -3^{\circ}$ and proportionately higher for steeper approaches.

In contrast, to avoid excess use of time and airspace, the hooded approaches with the slower flying light STOL airplane were flown at lower pattern altitudes from about 244 to 305 m (800 to 1000 ft) above the runway and the localizer was usually intercepted at a range of only 3.2 to 4 km $\left(2 \text{ to } 2\frac{1}{2}\right.$ statute miles$\left.\right)$. Examination of time histories of these approaches indicated that on the average it took about 40 sec to get oriented with respect to the localizer from the time the airplane crossed the outer edge of the signals. The apparent time required to capture the glide slope was about 10 sec from the first crossing of the glide-slope center line. However, the pilot needed more time to be sure that he could stay on, or near, the glide-slope center line.

The instrument approach patterns flown in test programs by the light STOL and large CTOL transports are shown in figure 13. A standard 3° glide slope is shown for the large jet transport and a more suitable 7° glide slope is shown for the STOL. Even though the approach speed of the CTOL transport was more than twice that of the STOL, it took the CTOL almost 4 min to fly its approach pattern compared with under 3 min for the STOL. However, if the STOL were required to fly the larger pattern, its time on the instrument approach would approximately triple, even after allowing for the use of a much higher pattern speed to the vicinity of the glide slope. It is believed that these data illustrate the desirability of providing a steeper, shorter, instrument approach guidance pattern for aircraft capable of approach speeds slower than those of typical CTOL transports.

Breakout, Flare, and Touchdown

It might be assumed that a slow-flying STOL airplane would be suitable for operating to lower minimums than a heavy jet transport; a target breakout height of 15 m (50 ft) was selected as a reasonable goal. However, in the present tests, the pilot, who was breaking out from under a hood to perfect visibility, used 34 m (110 ft) as his lowest, frequently used, breakout altitude. The same breakout altitude was used for approach glide slopes ranging from 3° to $7\frac{1}{2}^{\circ}$, even though the corresponding rate of descent ranged from about 90 m/min (300 ft/min) to over 230 m/min (750 ft/min). At breakout, the airplane was then 9 to 20 sec from ground contact, if no flare was made. For an assumed flare height of 6 m (20 ft), the pilot would have at least 7 sec before start of flare compared with a 6-sec minimum suggested by reference 1 for a V/STOL approach at $\gamma = -6^{\circ}$ with no wind.

One factor that probably kept the breakout altitude higher than might be expected was the large pitch attitude change required for flare and landing. The large Fowler flaps caused the airplane to be nose-down with respect to the approach path. To make a three-point landing, the airplane attitude had to be quite nose-up. As a result, the pitch attitude change during the flare was 15° to 20°. The effect of glide slope and approach speed on pitch attitude and the change in pitch attitude from approach to touchdown can be determined from table II. Another factor which influenced the breakout altitude was the inability to steady out on a small localizer deviation. The piloting difficulty caused by the uncertain control of heading also led to a higher breakout altitude. The pitch attitude change required for flare and landing could be reduced by about 5°, if a reduced VFR approach speed of about 48 knots was used instead of the preferred ILS approach speed of 59 knots.

Since the flare of this airplane involves a large attitude change in a high drag configuration, a large decrease in airspeed usually occurs in the flare. A typical speed bleed-off during the flare was from 55 to 35 knots. Careful energy management during the flare is therefore required.

The numerical pilot ratings for the landing characteristics were not as good for hooded approaches with breakout at 34 m (100 ft) as for VFR approaches. The pilot ratings for VFR and hooded approaches are as follows:

Type of approach	Pilot rating for landing in –	
	Smooth air	Turbulent air
VFR	3	4 to 5
Hooded	5	6 to 7

It can be seen that the pilot rated the airplane as difficult to land except in smooth air following a visual approach.

Two-Segment Approaches

In conjunction with the selection of approach glide slopes and breakout altitudes, it was decided to evaluate some two-segment approaches to see whether a shallower final segment could be used to reduce either the minimum breakout altitude or the pilot workload at breakout, or both. A series of approaches for $\gamma = -6^{\circ}$ to -3° and one approach for $\gamma = -9^{\circ}$ to -3° were added to the test program. Figure 12 shows a time history of an approach at $\gamma = -6^{\circ}$ to -3°. To avoid enlarging the approach pattern excessively, the transition point was placed as close in as possible at altitudes from 61 to 91 m (200 to 300 ft), as shown in figure 6. The transition point was, therefore, as close as 0.8 km (0.5 mile) to the breakout point or twice that far from touchdown. The elapsed time from transition point to breakout was as little as 20 sec. Figure 14 presents x-y and x-z plots to show tracking of the localizer and glide slope for two 6° to 3° approaches.

The pilot commented that he tended to fly below the glide slope as he passed the transition point. Then, of course, the speed tended to decrease as he pitched up to regain the glide path even though he increased power. These developments made him uncomfortable because he was hooded and the airplane was only about 61 m (200 ft) above the ground at the time. As already stated, on the single-segment glide paths, the pilot tended to get into a pitch-hunting mode, because of the difficulty of coordinating stabilator and throttle inputs to obtain desired response of airspeed, pitch attitude, and glide path. It would, therefore, be expected that reaching the transition point without any lead information might cause hunting in pitch. The pilot did comment favorably, though, about the effects of breaking out from a 3° descent rather than a 6° or steeper descent. He noticed that for a given breakout altitude, there was noticeably more time to get set to flare and land from the shallower approach.

CONCLUSIONS

As a result of a research program with a single-engine light STOL airplane with a wing loading of 670 N/m^2 (14 lb/ft^2) on hooded instrument approaches, using an ILS deflection indicator, the following conclusions were reached with regard to terminal area and landing approach characteristics:

1. The test airplane could be flown on a 7° glide-slope ILS-type approach in still air with an adequate 3° margin in reserve for downward correction.

2. The pilot preferred a two-segment approach such as one with a 6° upper segment glide slope and a 3° lower segment glide slope with the transition elbow at least 1.6 km (1 mile) from touchdown. It was apparent that the shallow lower segment eased the pilot task at breakout and, therefore, should help to reduce the minimum breakout altitude.

3. Since better control response and stability and larger performance margins are required for an instrument approach, less of the STOL performance capability can be used on an ILS approach than on a VFR approach. Therefore, the selected minimum ILS approach speed of 59 knots was at least 10 knots above the STOL approach speed for visual flight.

4. The minimum breakout altitude of 34 m (110 ft) was higher than expected because of the inability to steady out on a small localizer deviation and also because a large pitch attitude change of over 15° was required from a 6° glide-slope approach to the three-point touchdown attitude.

5. With a steeper glide slope and lower pattern altitude for the instrument approach, the landing approach pattern of the light STOL can be reduced to the extent that the final leg is less than one-third as long as it would be with current ILS. The duration of the

STOL final approach would then be about two-thirds of the time required for a current large CTOL jet transport to make an ILS final approach.

6. The numerical pilot rating was 3 for a visual approach in smooth air but increased to 5 for an instrument approach in smooth air or for a visual approach in light turbulence.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., February 28, 1974.

REFERENCES

1. Reeder, John P.: The Impact of V/STOL Aircraft on Instrument Weather Operations. NASA TN D-2702, 1965.
2. Sawyer, Richard H.; and Schaefer, William T., Jr.: Operational Limitations in Flying Noise-Abatement Approaches. NASA TN D-5497, 1969.
3. Mechtly, E. A.: The International System of Units – Physical Constants and Conversion Factors (Second Revision). NASA SP-7012, 1973.
4. Craig, A. J.: Evaluation of the Performance, Stability and Control of the Helio Courier Airplane. Rep. No. 264 (Contract DA 44-177-TC-369), Dep. Eng. Res., Univ. of Wichita, Feb. 1957.
5. Cooper, George E.; and Harper, Robert P., Jr.: The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities. NASA TN D-5153, 1969.
6. Crane, Harold L.; Sommer, Robert W.; and Healy, Frederick M.: Effects of Reduced Airspeed for Landing Approach on Flying Qualities of a Large Jet Transport Equipped With Powered Lift. NASA TN D-4804, 1968.
7. Driscoll, Norman R.: Effects of a Simple Stability Augmentation System on the Performance of Non-Instrument-Qualified Light-Aircraft Pilots During Instrument Flight. NASA TN D-3970, 1967.

TABLE I.- ILS RATE OF DESCENT MARGINS FOR A CALIBRATED APPROACH SPEED OF 59 KNOTS WITH NO WIND

γ, deg	R/D		R/D margin		γ margin, deg	Minimum adequate γ margin, deg	Minimum adequate R/D margin	
	m/min	fpm	m/min	fpm			m/min	fpm
-3	95	312	222	728	7	≈3	≈90	≈300
-6	190	624	127	416	4	≈3	≈90	≈300
-7.5	238	780	79	260	2.5	≈3	≈90	≈300
-9	285	935	32	105	1	≈3	≈90	≈300
-10	317	1040	0	0	0	≈3	≈90	≈300

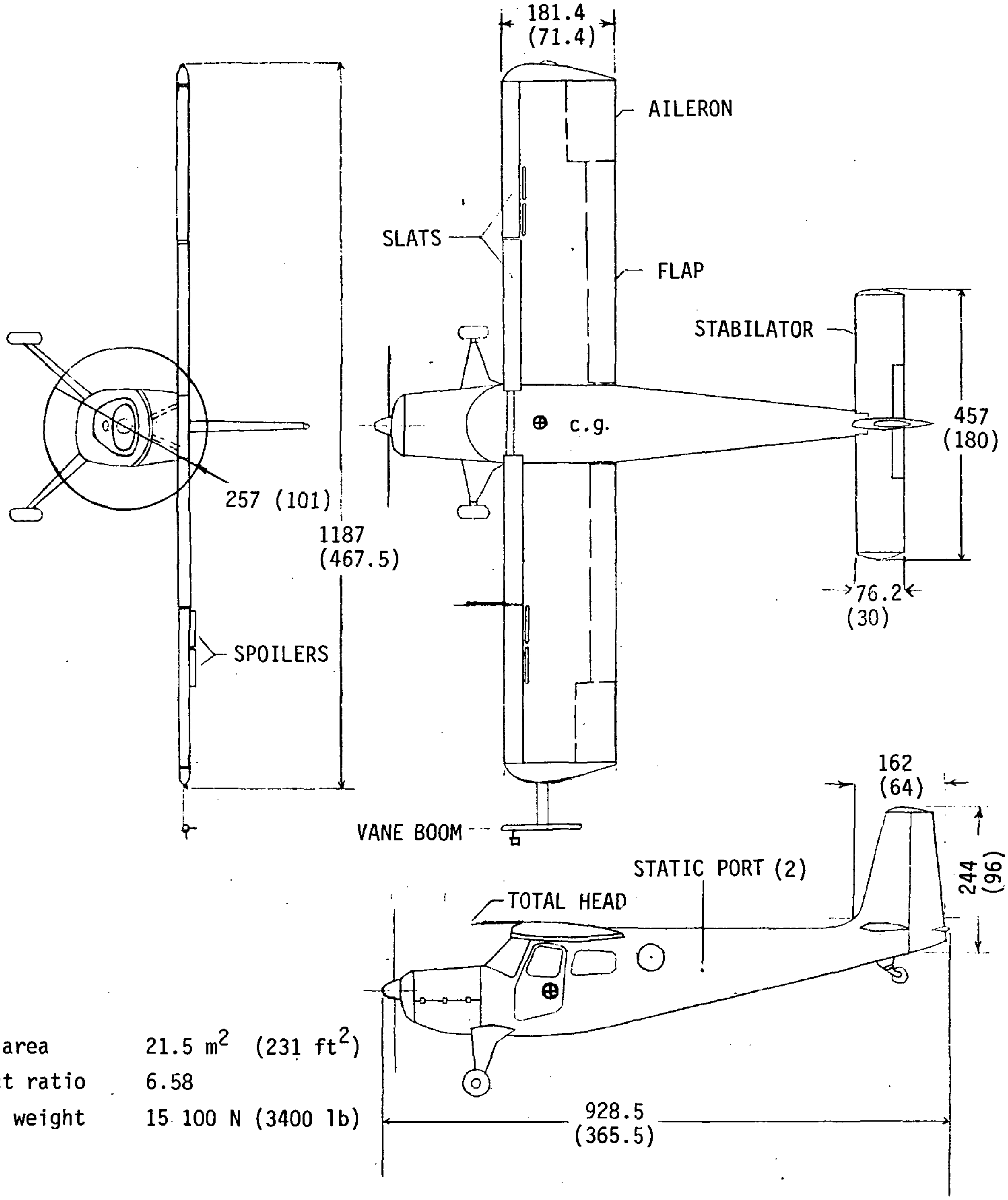
TABLE II.- AIRSPEEDS AND PITCH ATTITUDES FOR APPROACH AND LANDING

	Approach pitch attitude* (for $\delta_f = 40^{\circ}$), θ, deg					Pitch attitude change from approach to three-point touchdown, $\Delta\theta$, deg				
V_c, knots / γ, deg	40	45	50	55	60	40	45	50	55	60
0	1.3	-1.7	-3.8	-5.2	-6.3	5.7	8.7	10.8	12.2	13.3
-3	-1.7	-4.7	-6.8	-8.2	-9.3	8.7	11.7	13.8	15.2	16.3
-6	-4.7	-7.7	-9.8	-11.2	-12.3	11.7	14.7	16.8	18.2	19.3
-7.5	-6.2	-9.2	-11.3	-12.7	-13.8	13.2	16.2	18.3	19.7	20.8
-9	-7.7	-10.7	-12.8	-14.2	-15.3	14.7	17.7	19.8	21.2	22.3

*Approach pitch attitude is measured with respect to leveling lugs for which the ground attitude is approximately 7°

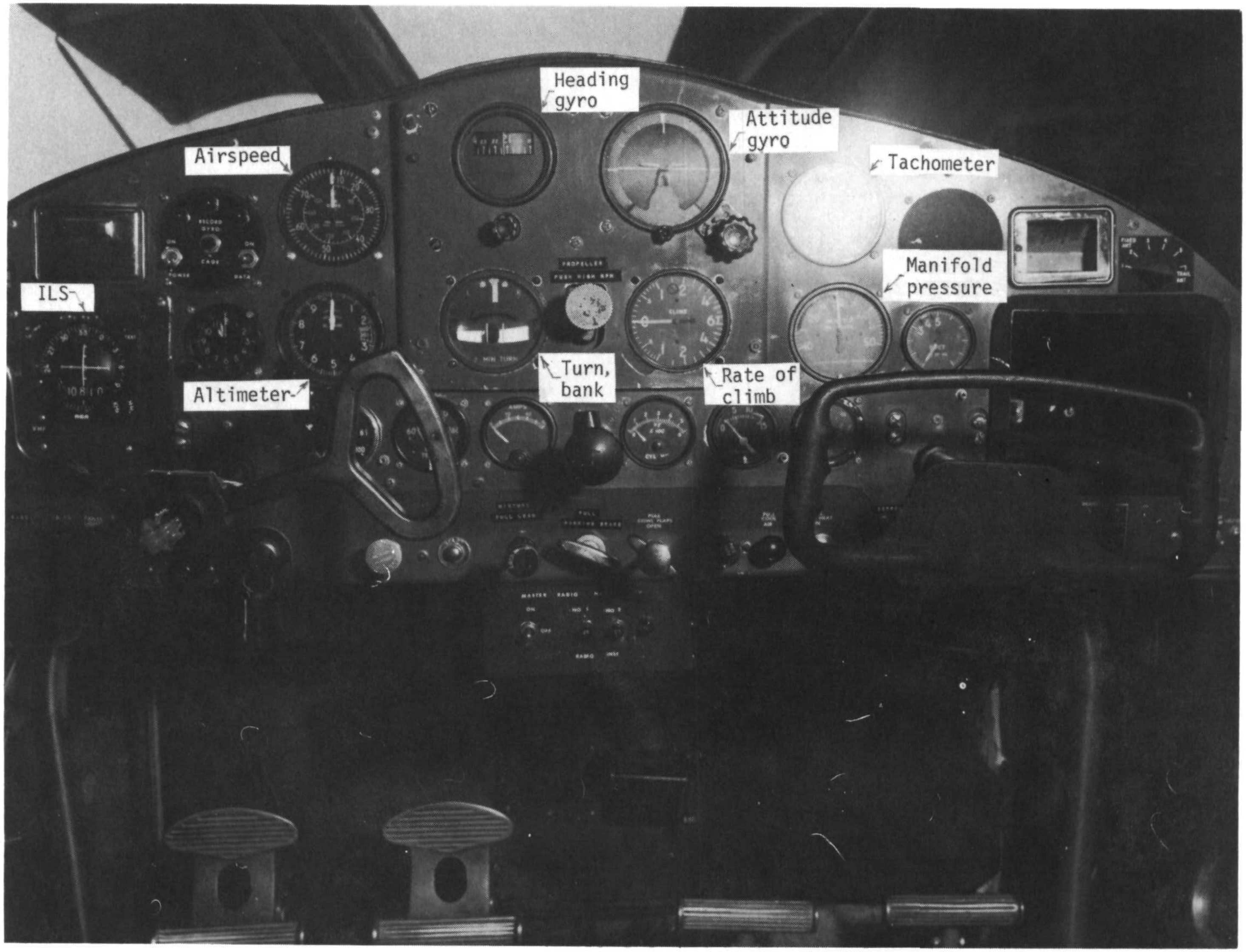
L-70-6389

Figure 1.- Light STOL test airplane.



Wing area	21.5 m^2 (231 ft^2)
Aspect ratio	6.58
Gross weight	15 100 N (3400 lb)

Figure 2.- Three-view drawing of light STOL test airplane. All dimensions are in centimeters (inches).



L-70-5926.1

Figure 3.- Cockpit instrument panel.

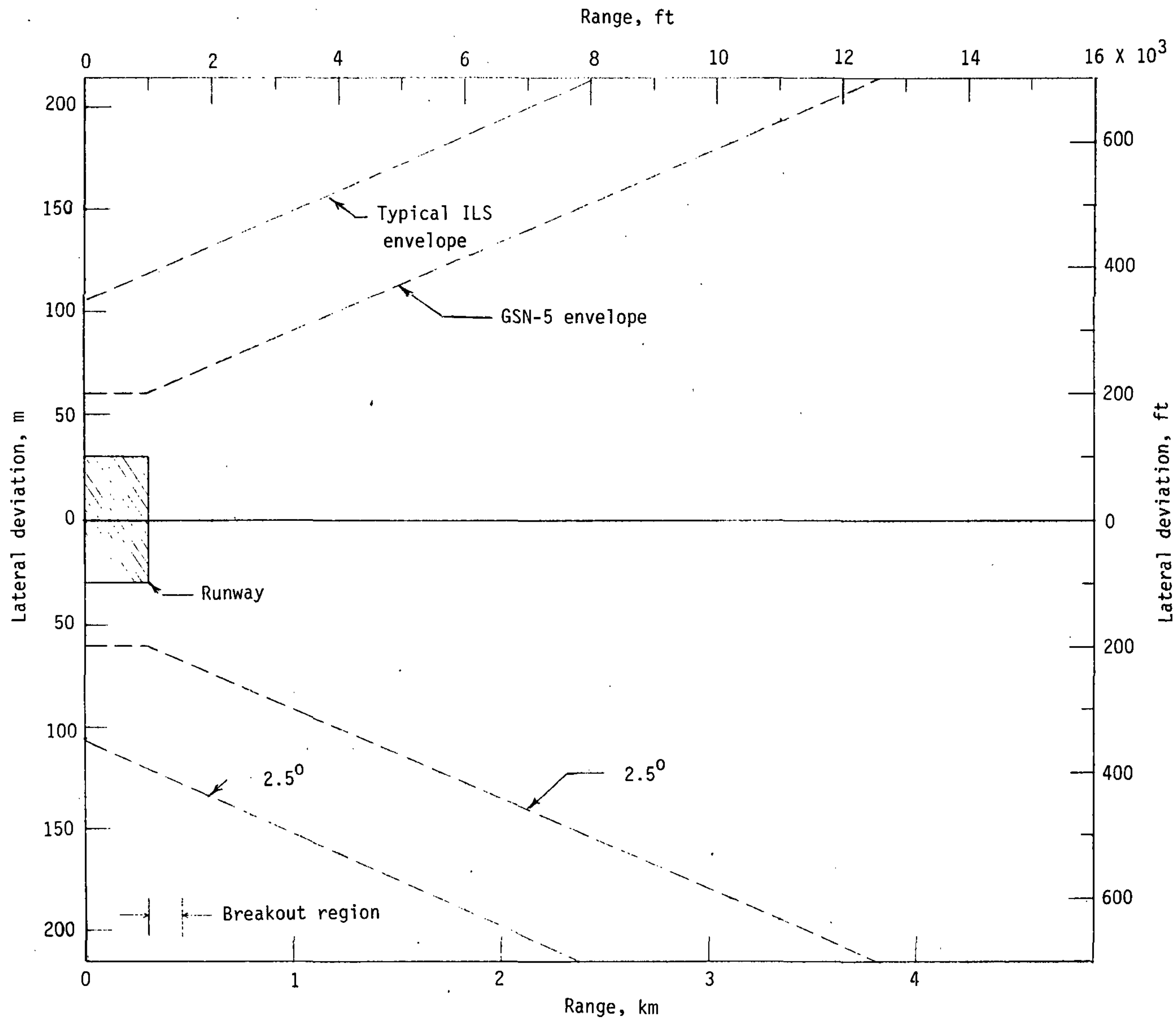
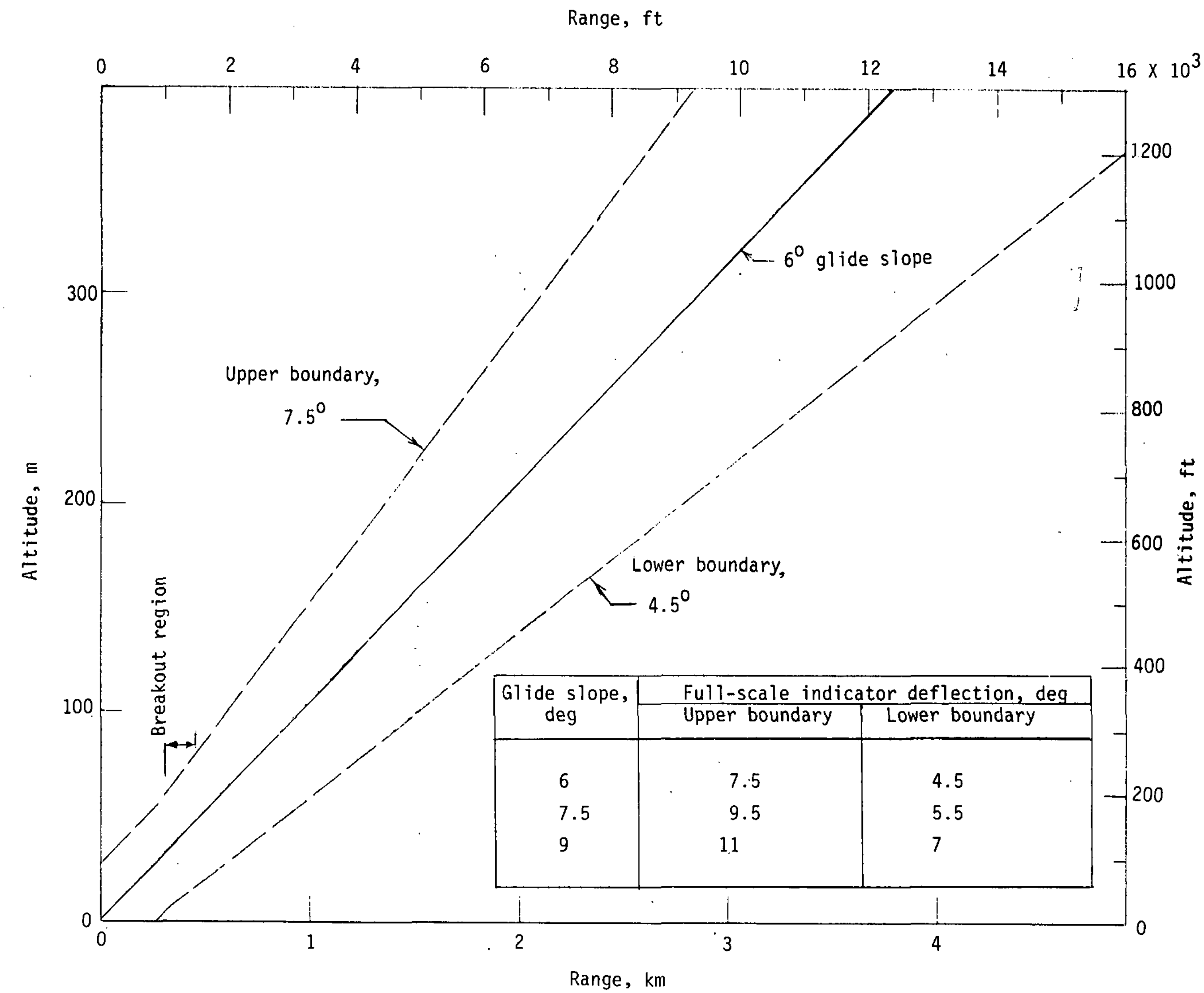


Figure 4.- GSN-5 localizer boundaries used for all glide-slope patterns.



Glide slope, deg	Full-scale indicator deflection, deg	
	Upper boundary	Lower boundary
6	7.5	4.5
7.5	9.5	5.5
9	11	7

Figure 5.- Single-segment glide-slope boundaries.

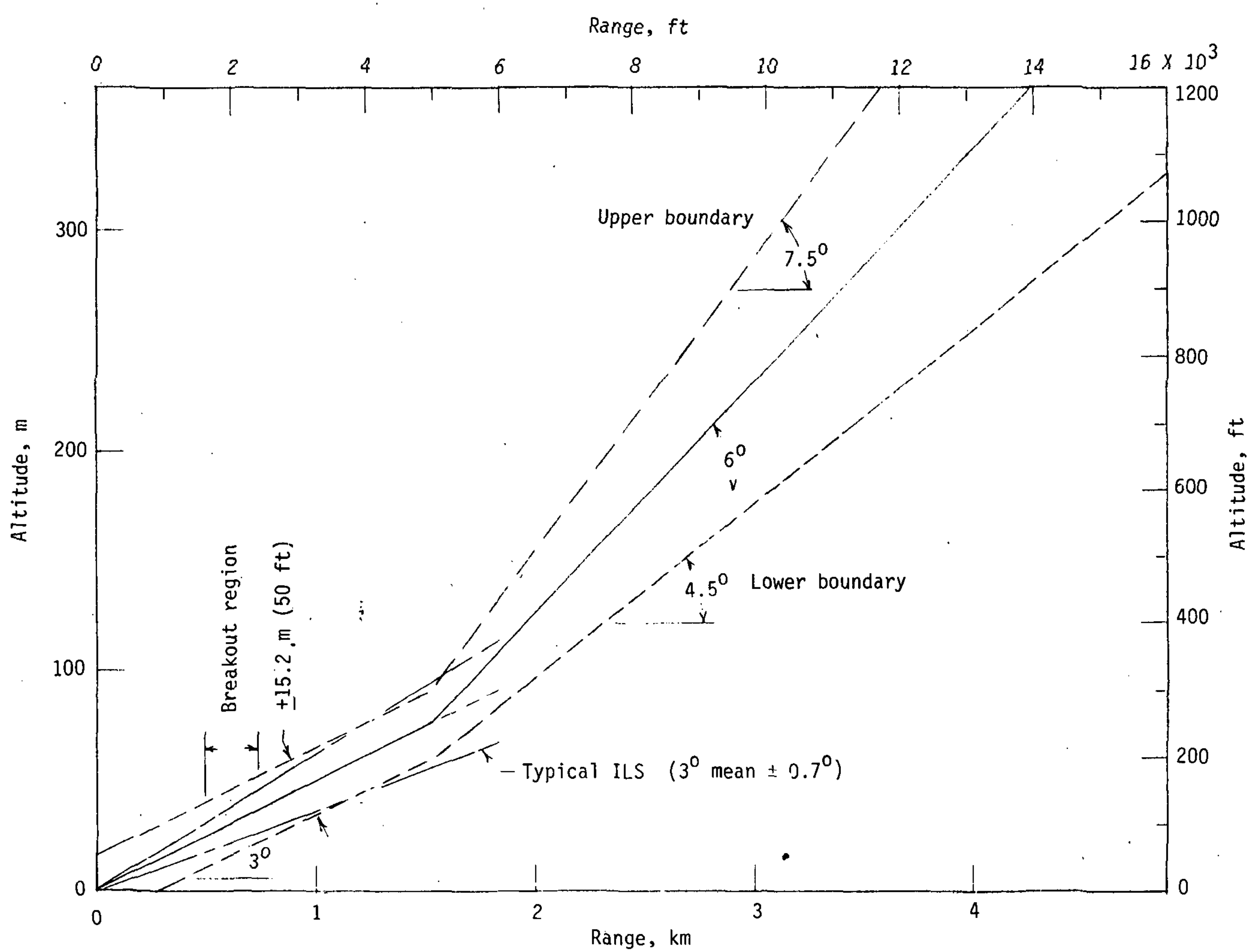


Figure 6.- Typical two-segment 6° to 3° glide slope with signal boundaries.

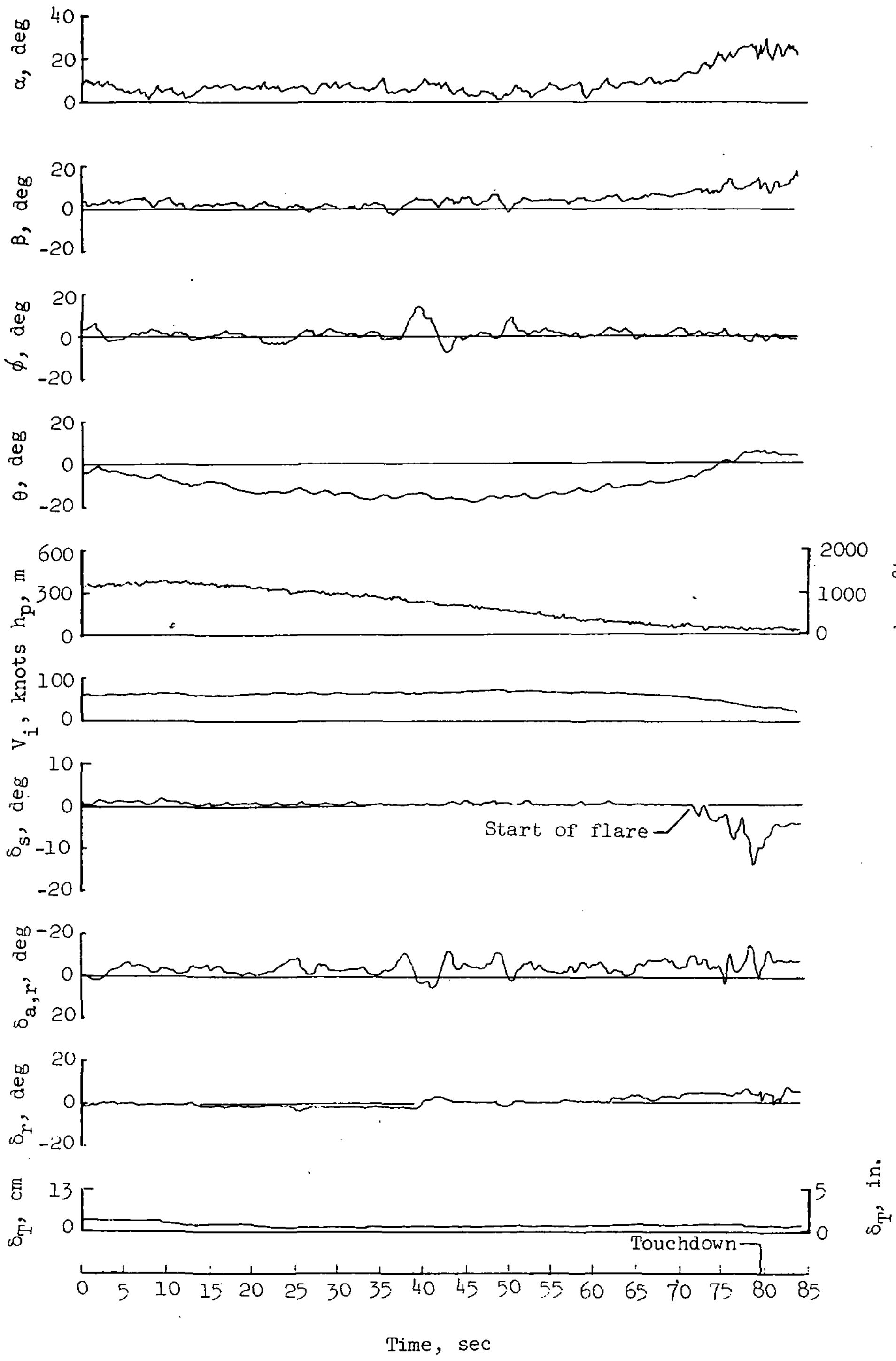


Figure 7.- Time history of a VFR approach and landing. $\gamma = -10.5^{\circ}$; $\delta_f = 40^{\circ}$.

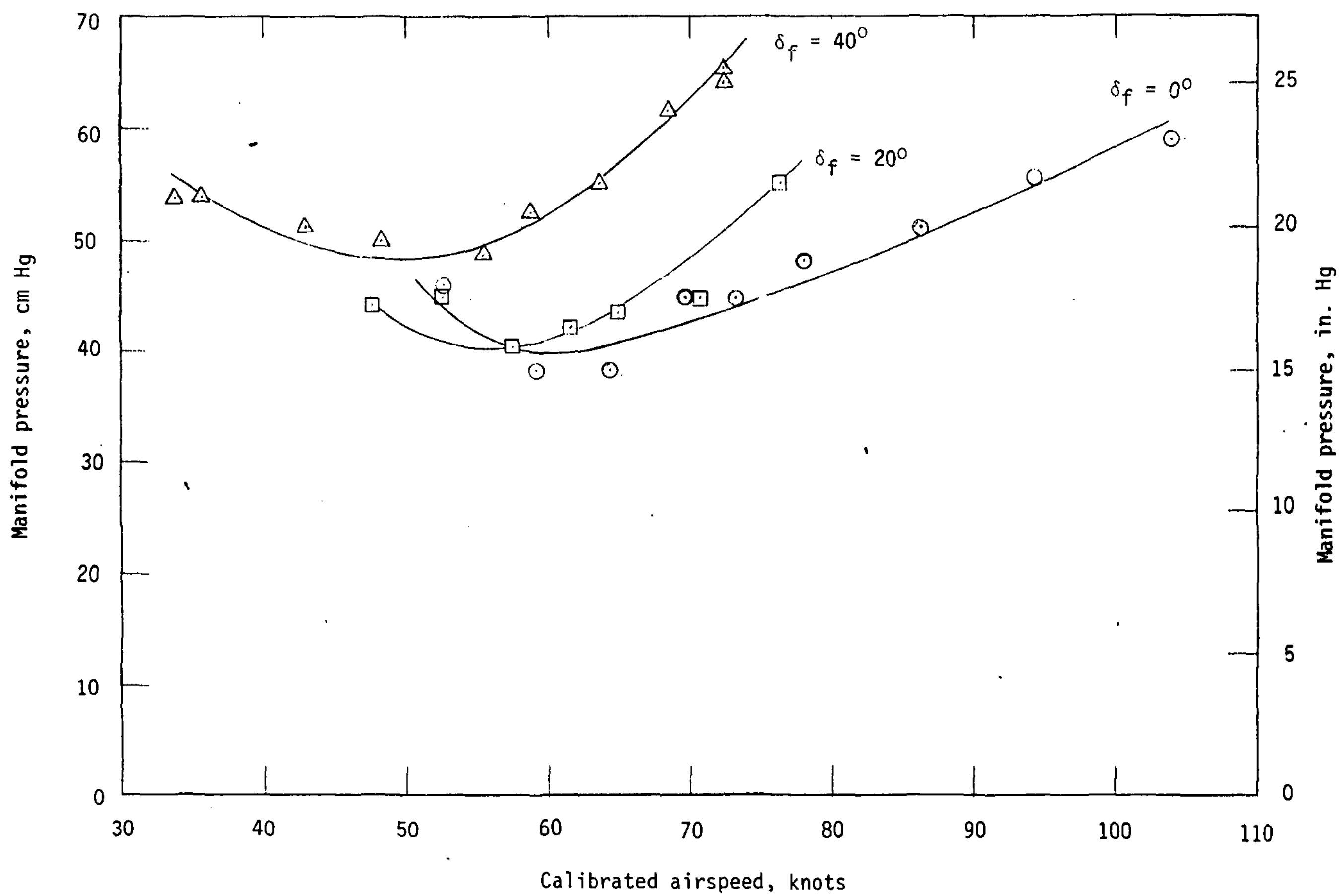
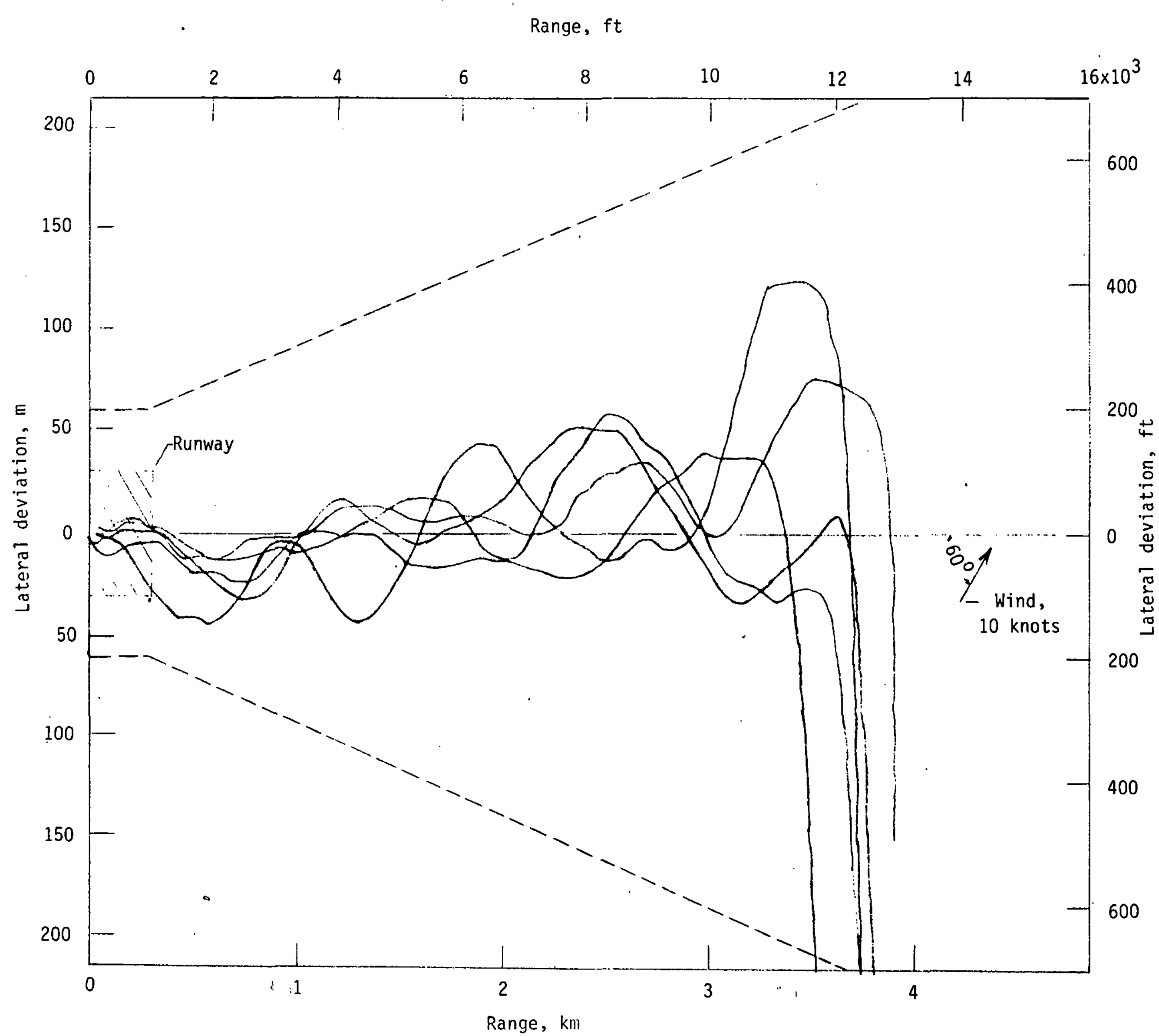
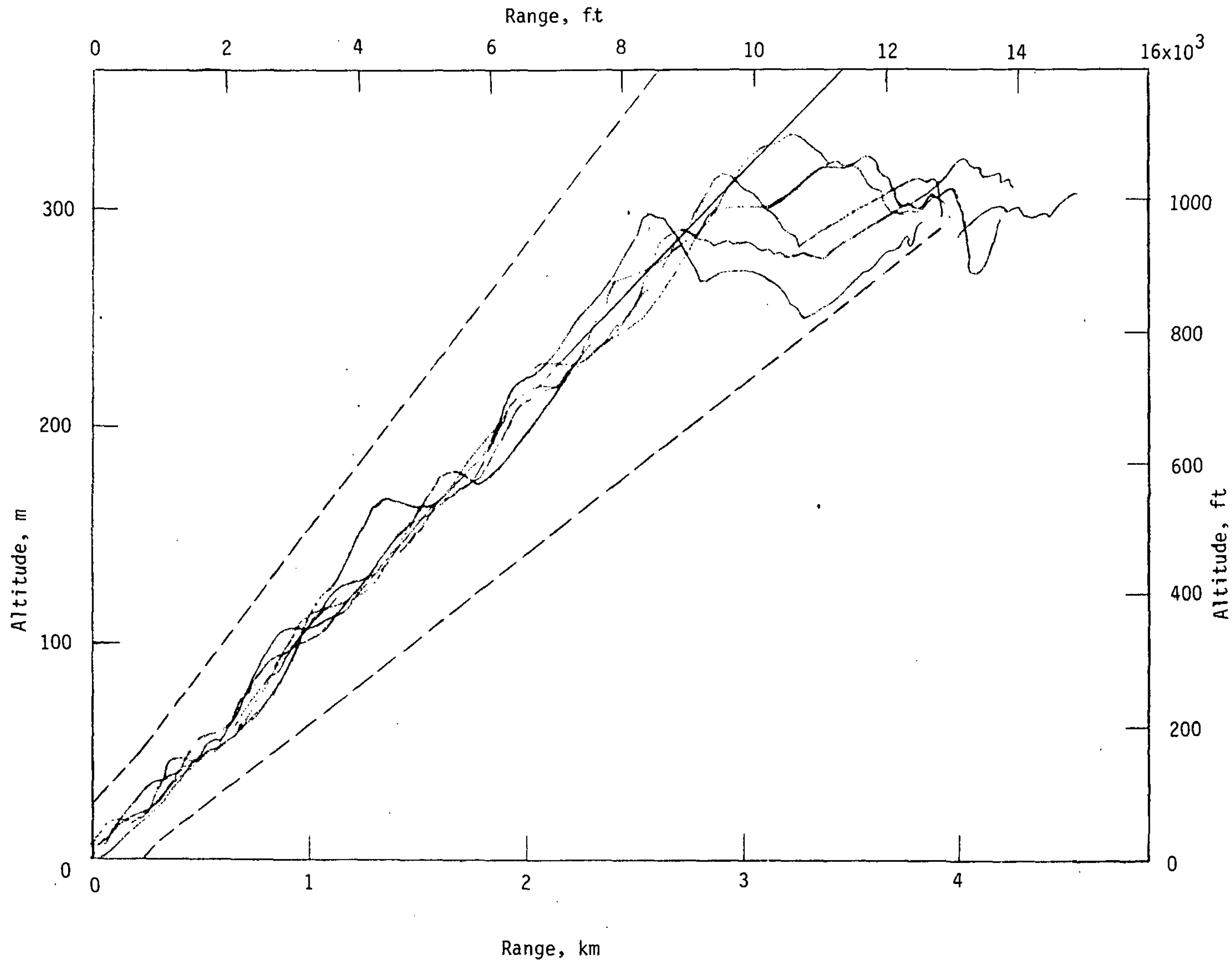


Figure 8.- Manifold pressure required for level flight at 2750 rpm.



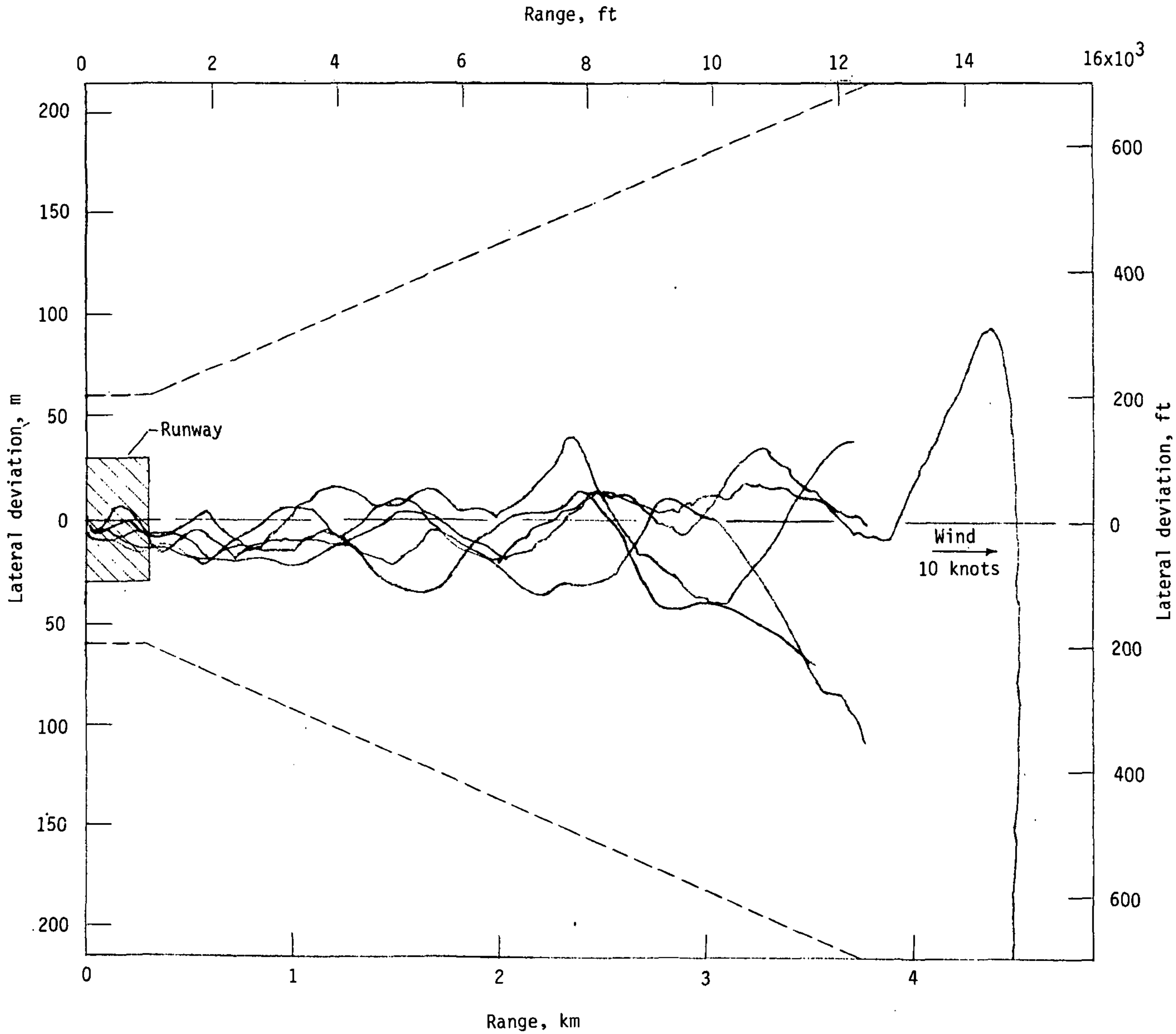
(a) Localizer tracking (x-y plot).

Figure 9.- Tracking for hooded approaches at $\gamma = -6^{o}$.



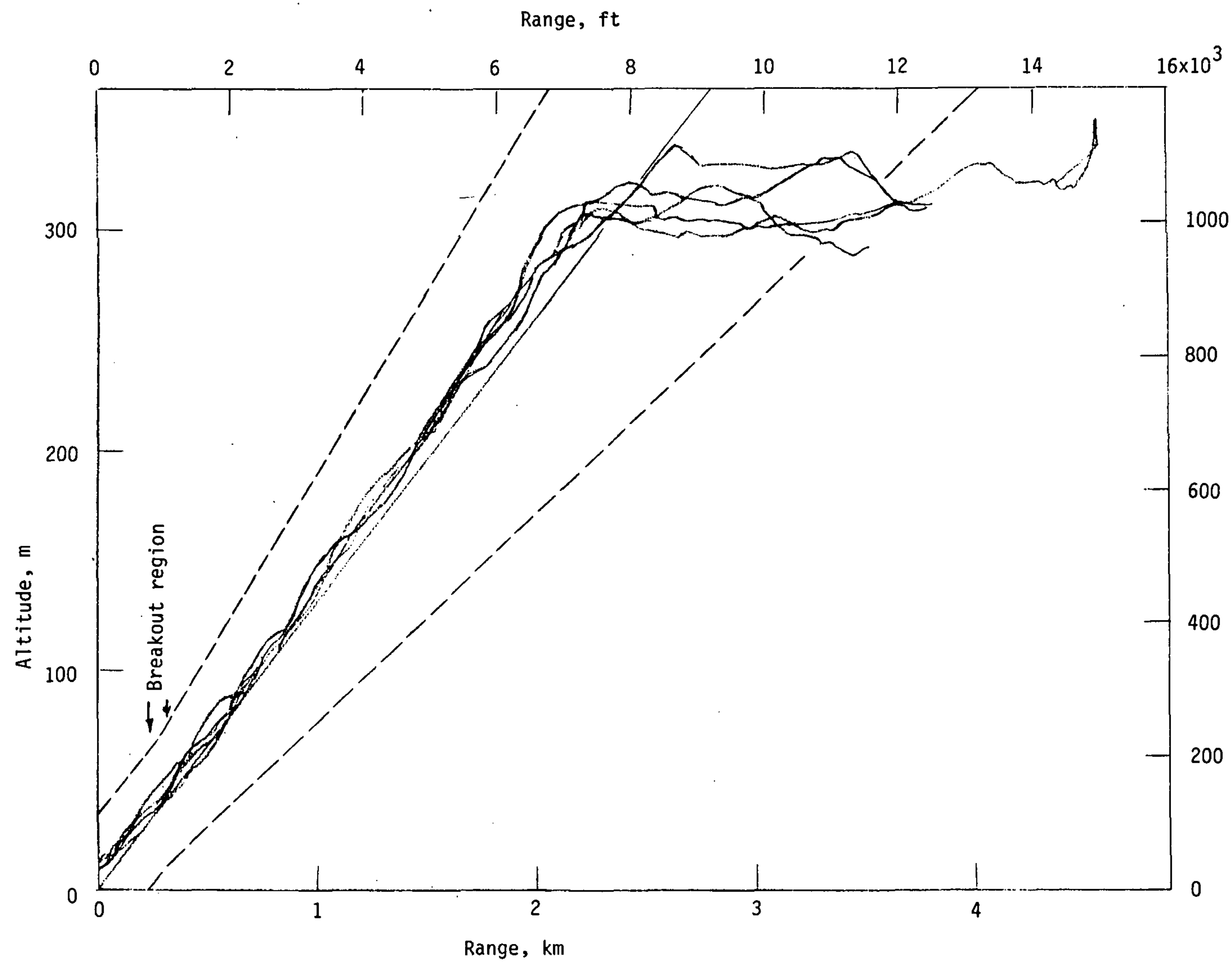
(b) Tracking of 6° glide slope (x-z plot).

Figure 9.- Concluded.



(a) Localizer tracking (x-y plot).

Figure 10.- Tracking for hooded approaches at $\gamma = -7.5^{\circ}$.



(b) Tracking of 7.5^{o} glide slope (x-z plot).

Figure 10.- Concluded.

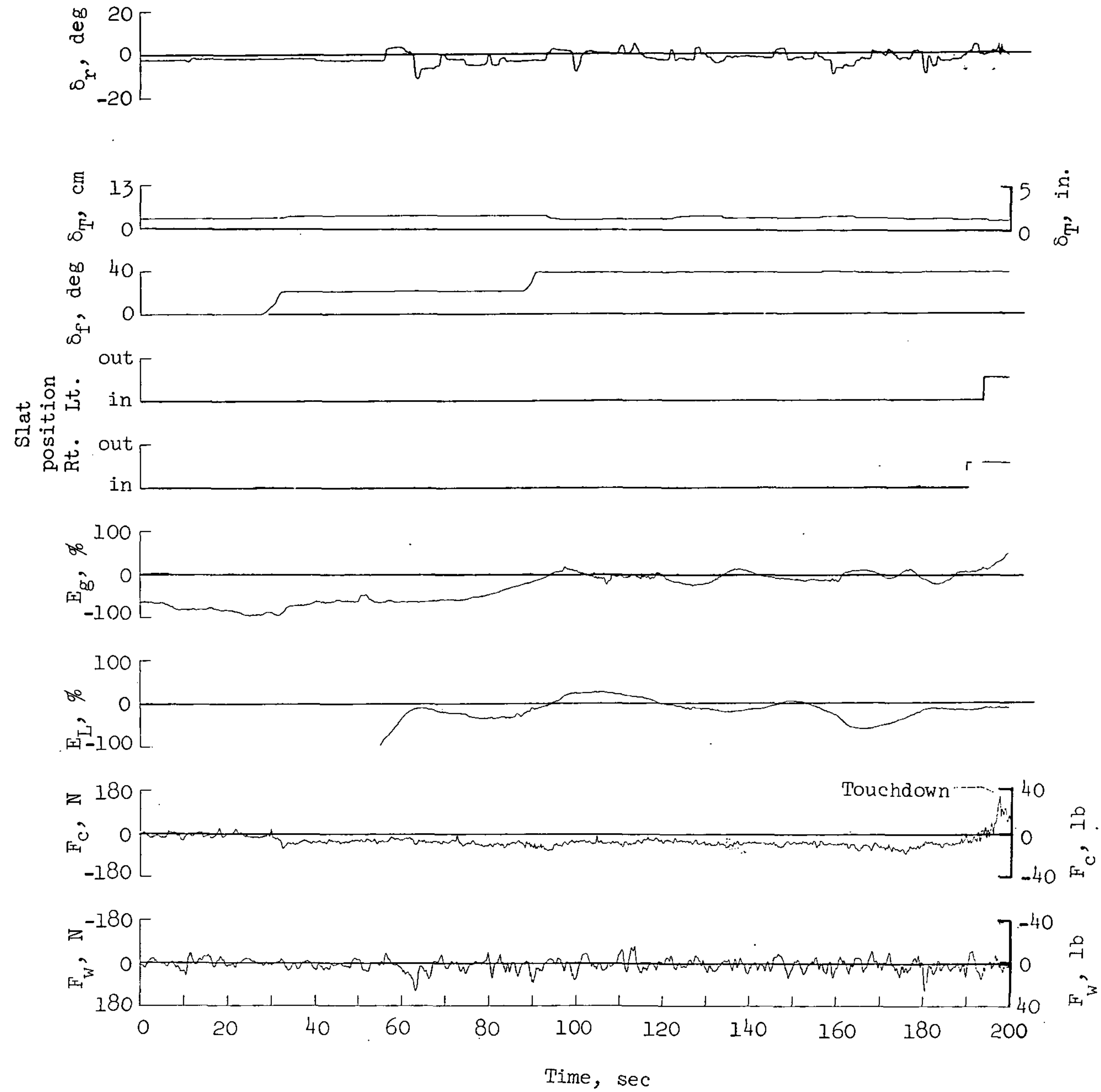


Figure 11.- Time history of a hooded approach and landing at $\gamma = -6^{o}$.

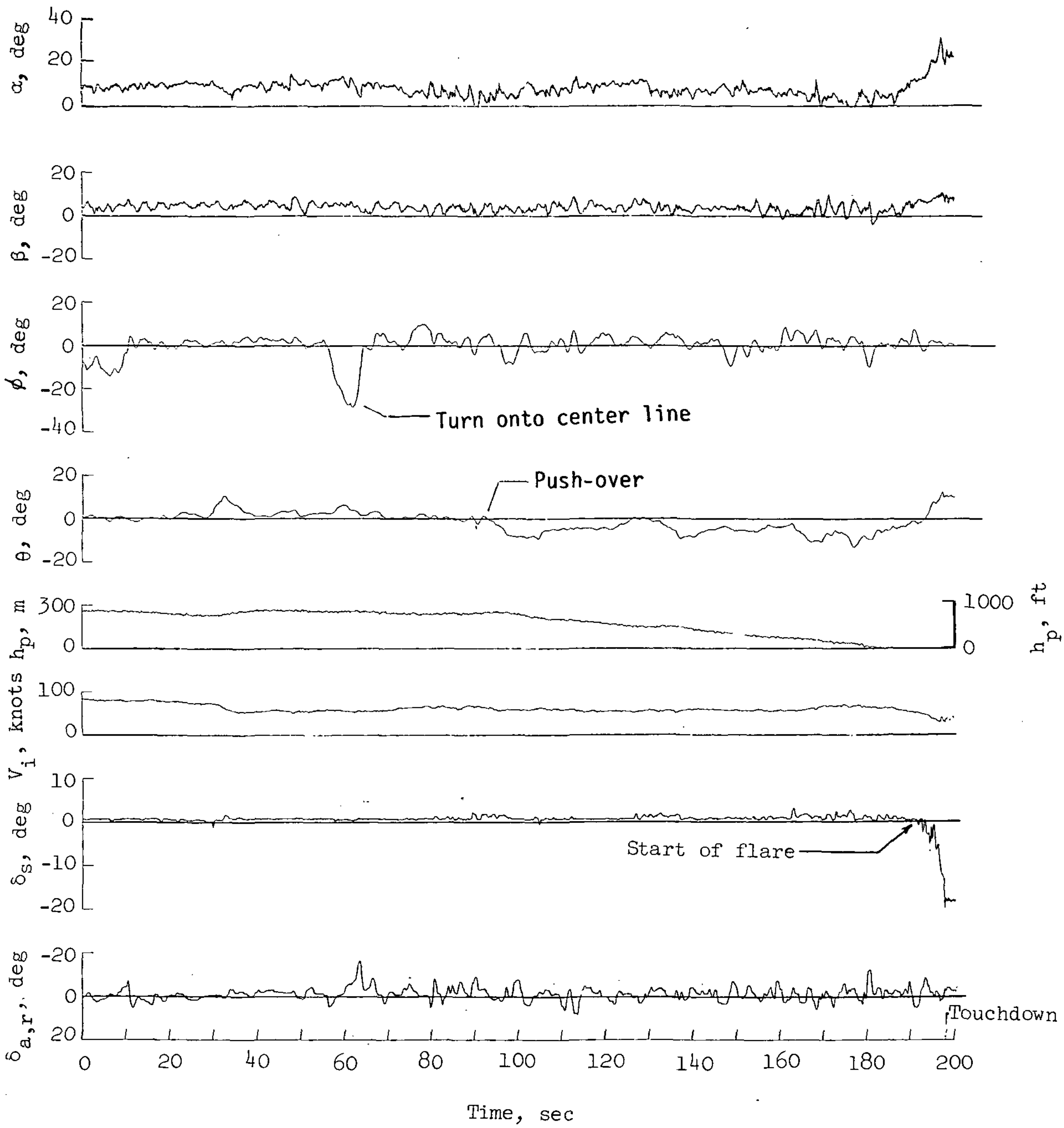


Figure 11.- Continued.

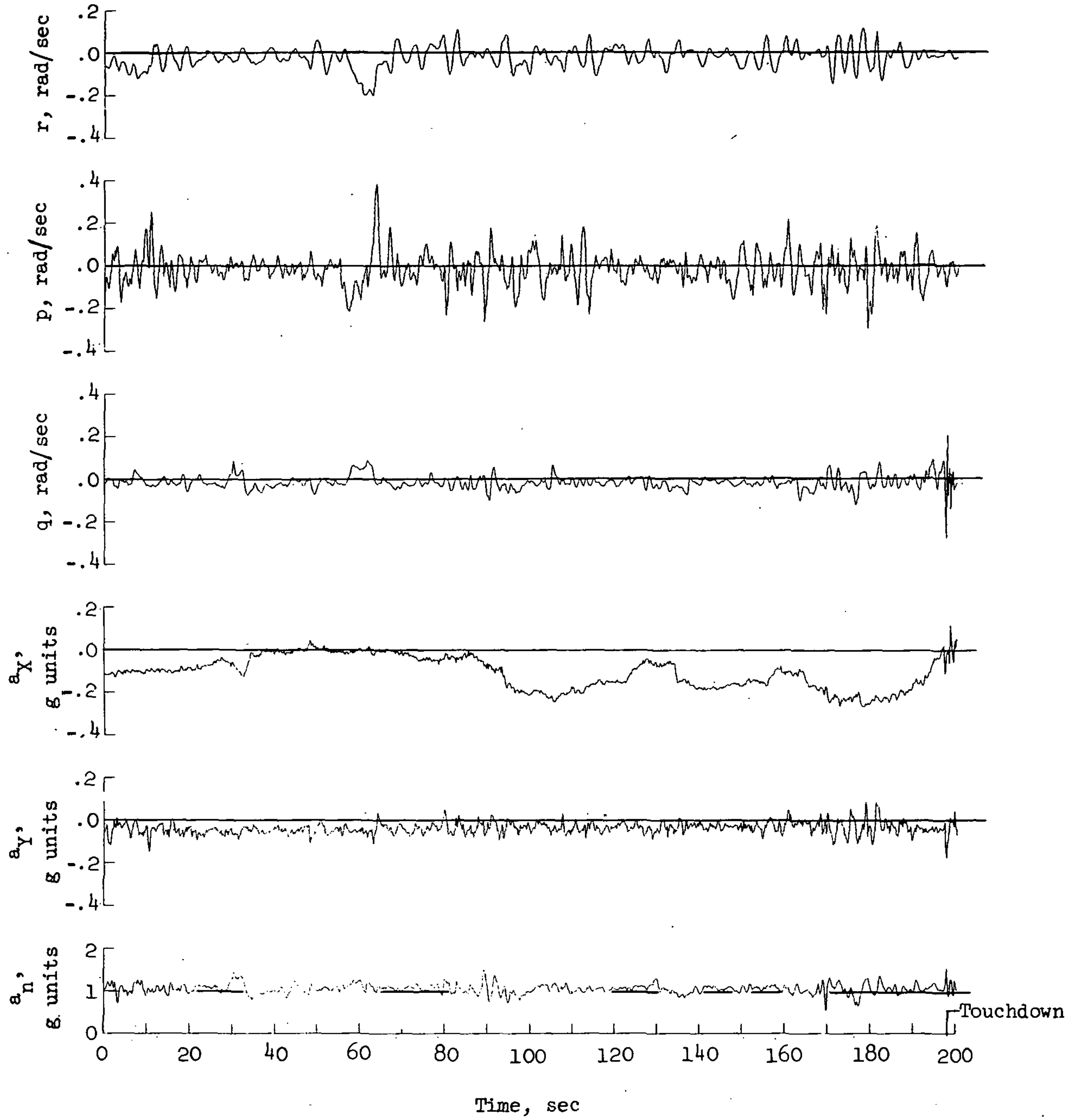


Figure 11.- Concluded.

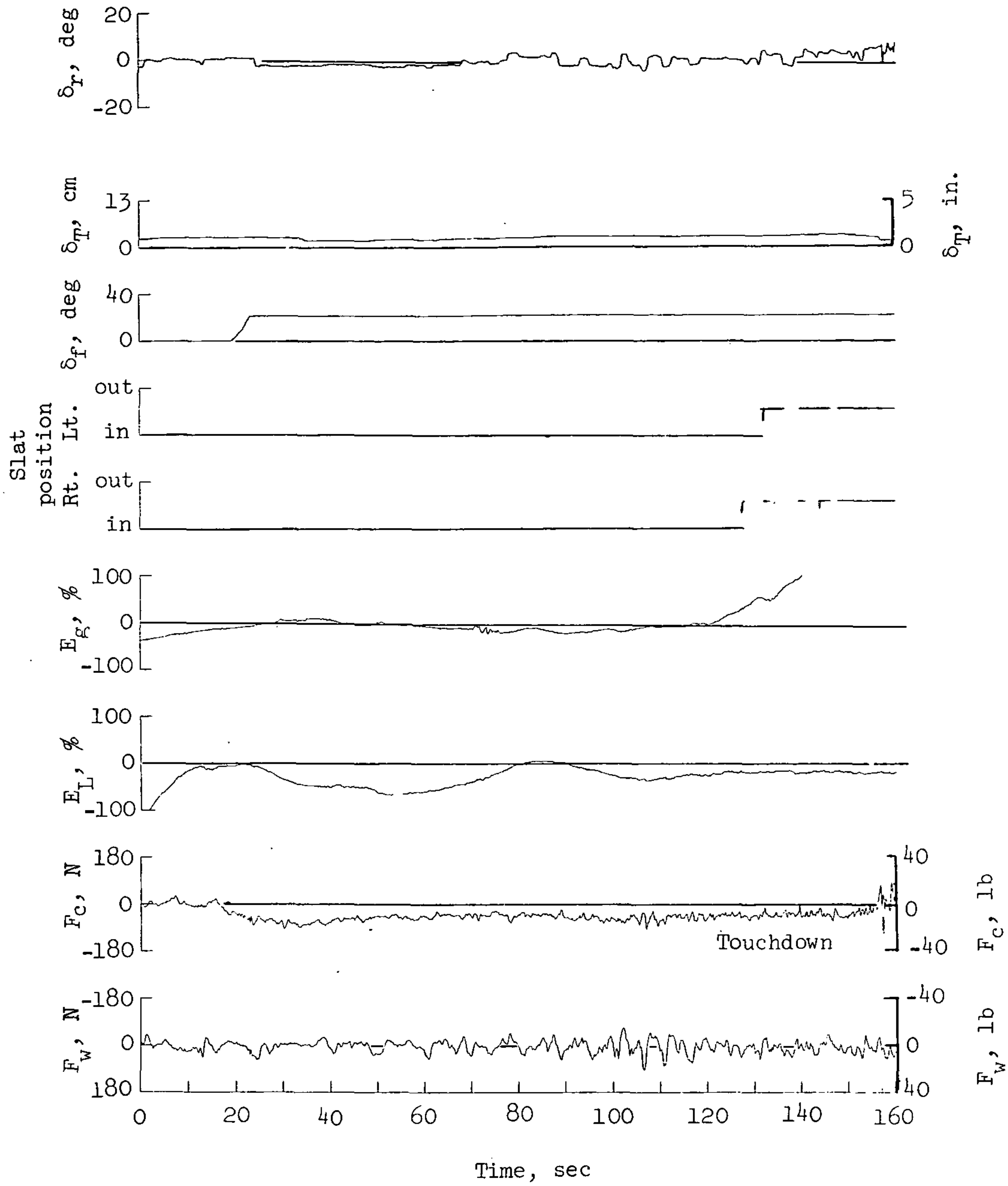


Figure 12.- Time history of a two-segment 6° to 3° hooded approach and landing.

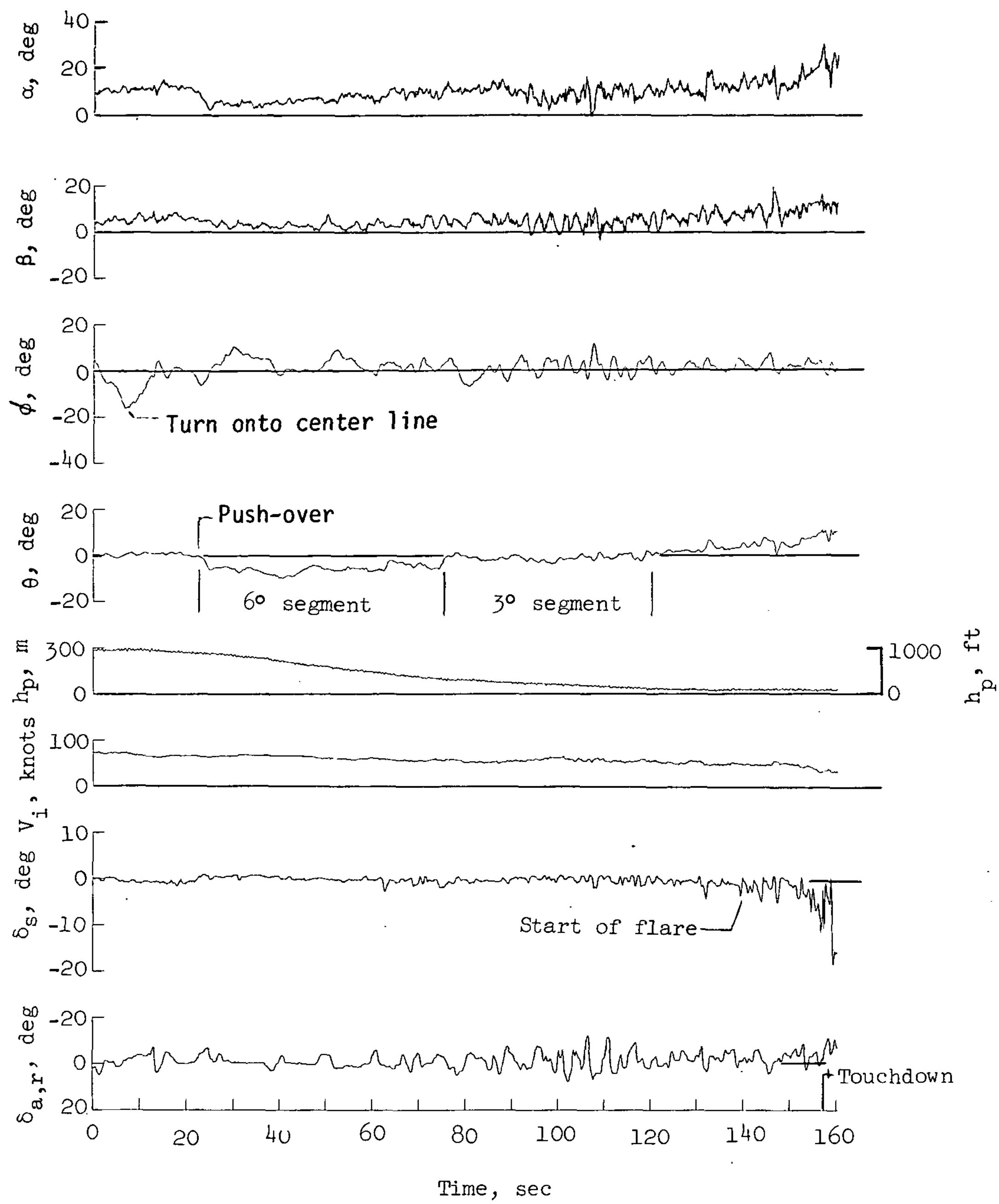


Figure 12.- Continued.

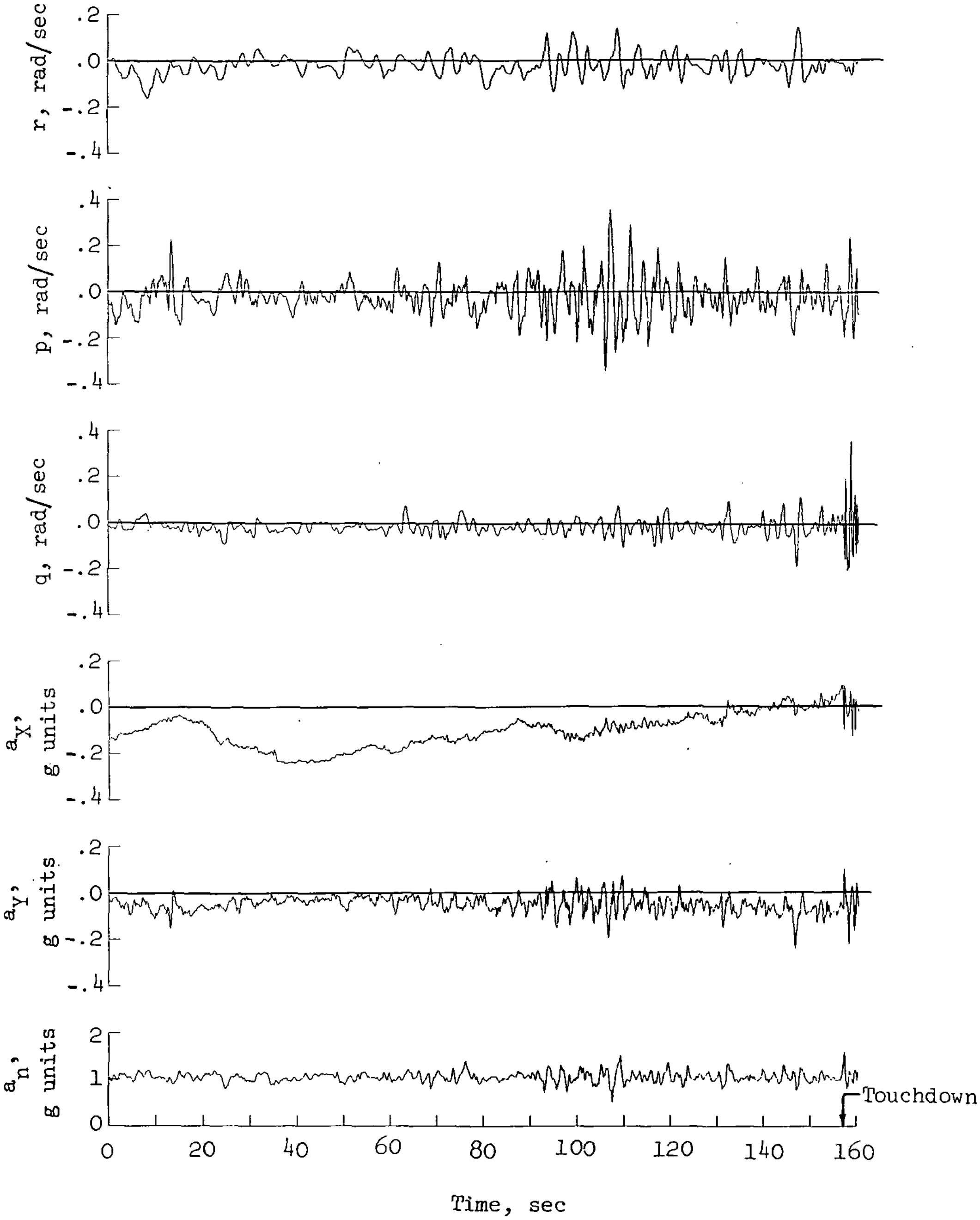


Figure 12.- Concluded.

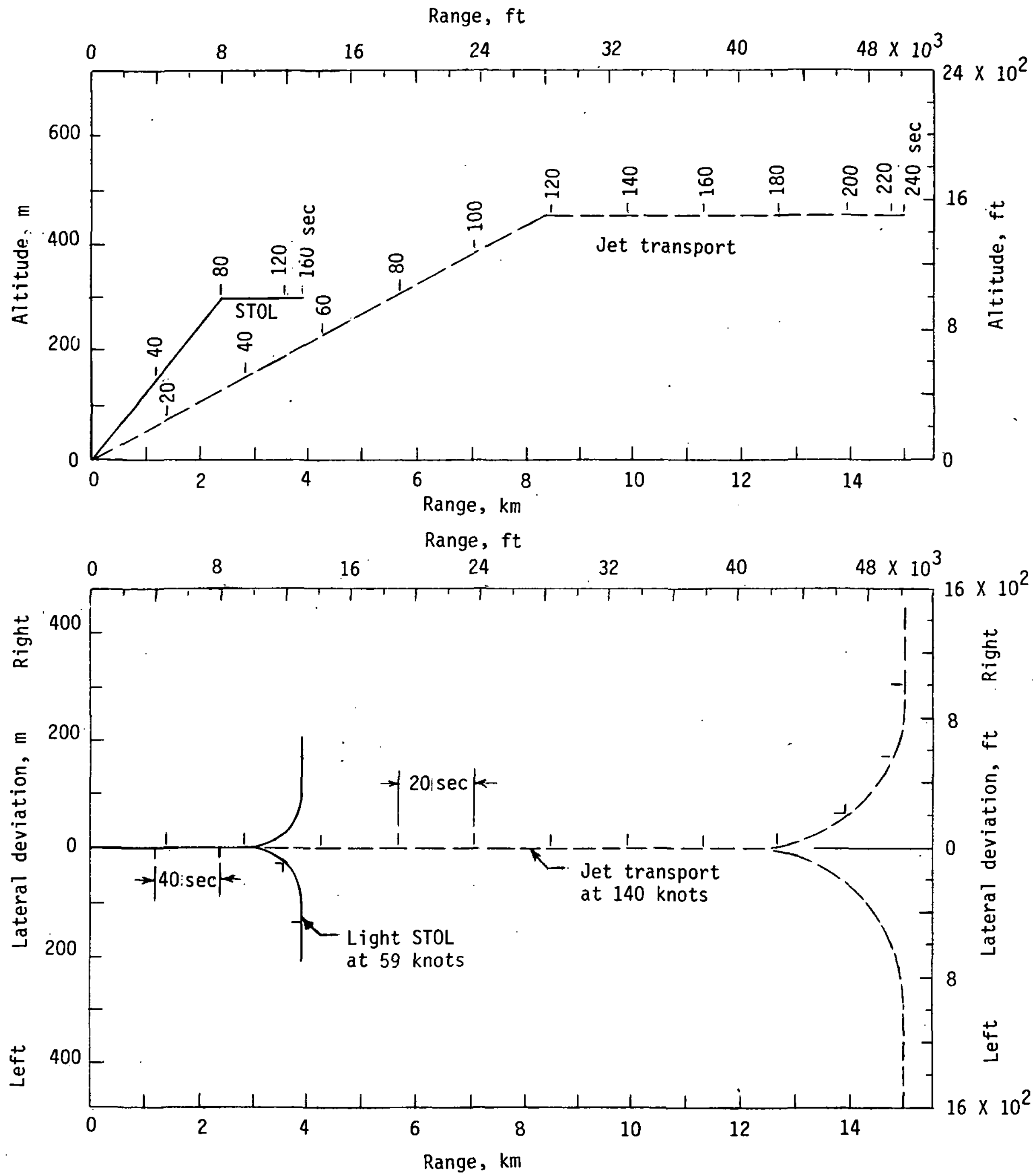
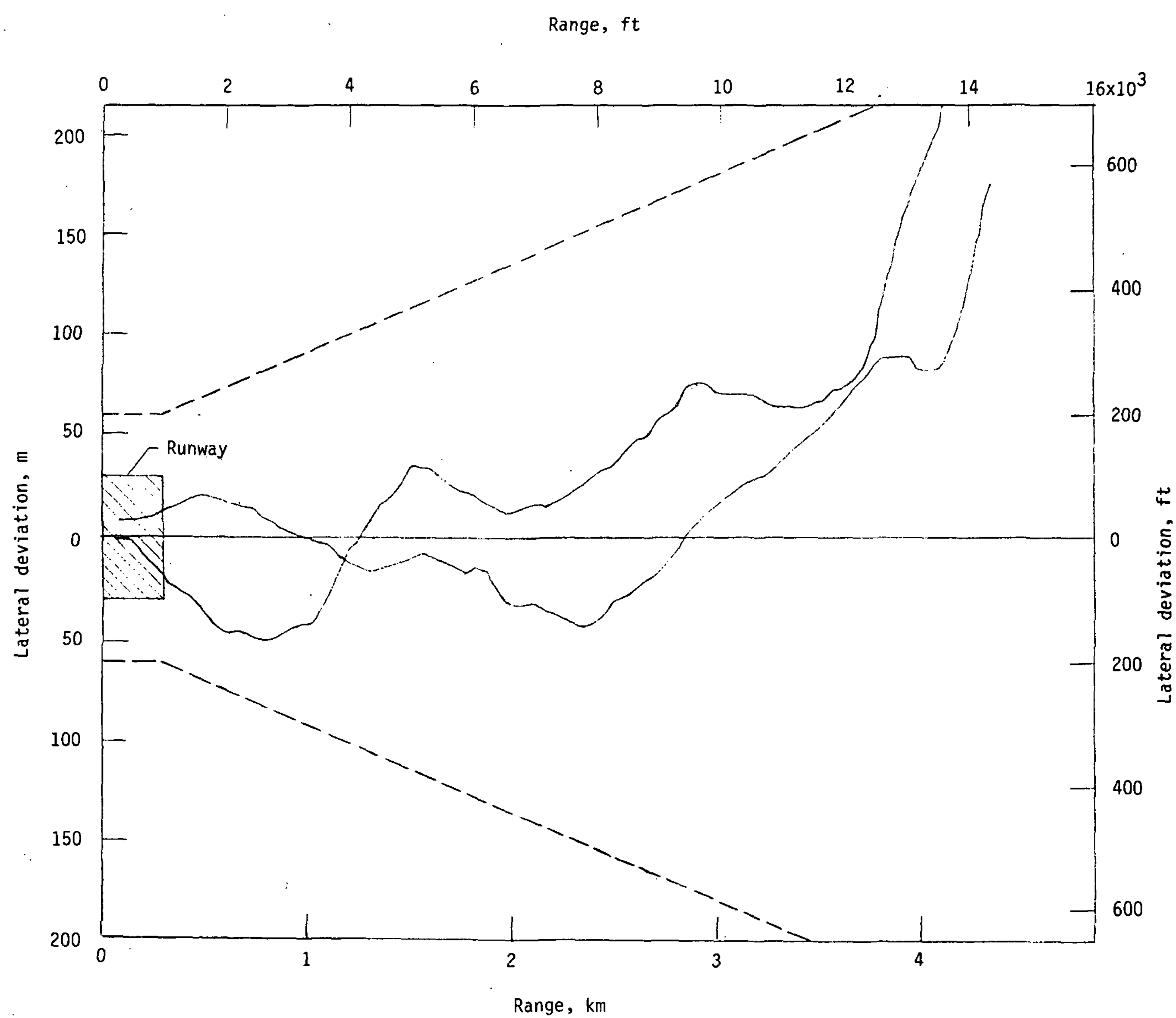
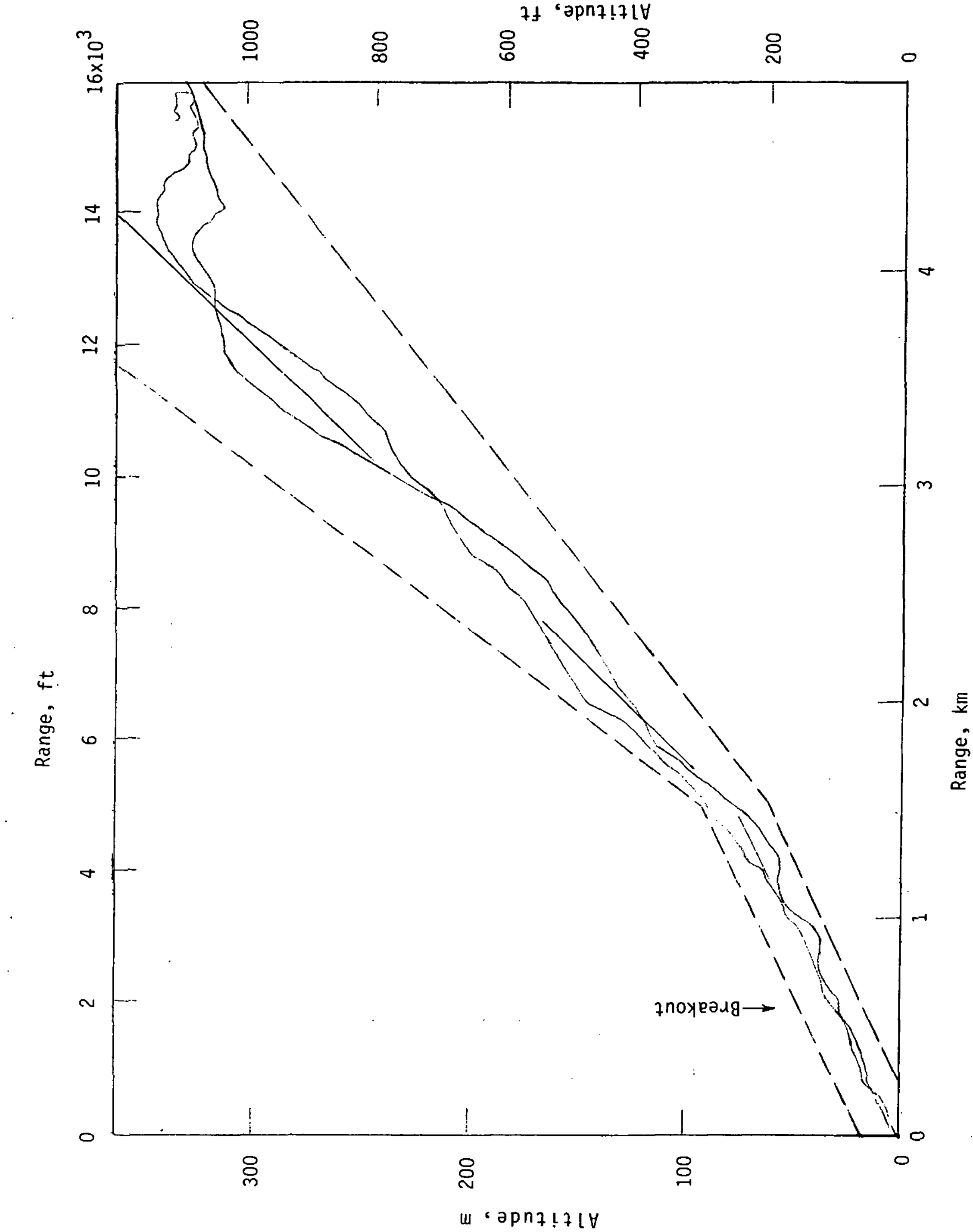


Figure 13.- Comparison of CTOL jet transport and light STOL terminal area instrument approach patterns.



(a) Localizer tracking (x-y plot).

Figure 14.- Tracking for hooded approaches at $\gamma = -6^{\circ}$ to -3°.



(b) Two-segment 6° to 3° glide-slope tracking (x-z plot).

Figure 14.- Concluded.

NASA-Langley, 1974 L-9155

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