NASA TECHNICAL NOTE

NASA TN D-4939

NASA TN D-4939

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • DECEMBER 1968

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SUMMARY

An STOL transport was studied in instrument flight. This aircraft was flown on 7-1/2° and 2-1/2° ILS approaches. It could be flown comfortably and accurately on the 7-1/2° ILS at 60 knots to 200 feet above the runway. The descent and deceleration capabilities were more than adequate in the approach and landing configuration, but were not sufficient in the preapproach configuration. The handling characteristics during instrument flight were generally satisfactory, except for moderate heading excursions at low speeds and moderate angle-of-attack excursions at the rear center of gravity. These characteristics, while not satisfactory, were acceptable and are considered general problems of STOL aircraft operations.

INTRODUCTION

STOL aircraft can be flown slowly and steeply, and therefore can be operated into small airfields and restricted spaces. This capability has aroused interest by airlines and governmental agencies for their use in commercial air travel (refs. 1 to 6). In addition to providing added convenience to the air traveler, landing and taking off slowly and steeply also offers potential for improved all-weather reliability, reduced nonproductive time, and increased safety (ref. 7). Several STOL aircraft have shown the desired low-speed performance in visual flight conditions (refs. 8 and 9), and some helicopter work has been done at STOL speeds on instruments (refs. 10 and 11). However, practically no flight work has been done with STOL aircraft operating in the terminal area under Instrument Flight Rules (IFR) to ascertain their potential as well as limitations and to examine the effect this environment has on the required performance, handling qualities, and operational characteristics.

Tests were conducted with the Breguet 941, an STOL propeller driven transport, because previous tests by NASA (ref. 9) showed it to have good STOL performance with satisfactory to acceptable handling qualities under Visual Flight Rules (VFR). The airplane was comfortable to fly at low speeds and was capable of descending or climbing at angles greater than 10° at 60 knots. Landing and takeoff distances of 1000 feet over an obstacle were safely attained because the propellers were interconnected and good control was provided about each axis.

The tests were made on a standard 2-1/2° Instrument Landing System (ILS) and on its 7-1/2° secondary lobe to determine the difficulty in tracking an ILS at low speeds to low altitudes. It was anticipated that this task would expose any handling qualities problems. The tests included transitions to the ILS at various altitudes to find acceptable intercept altitudes and operational procedures. Some maneuvering flight work at low altitudes was done to ascertain the capabilities of STOL aircraft operating in restricted airspaces. These results were then used to look at nonproductive time of STOL aircraft when operated in the terminal area.

The tests were conducted by NASA and USAARL in cooperation with Societe Anonyme des Ateliers D'Aviation, Louis Breguet, and the French Air Force. The chief pilot of New York Airways also participated in a portion of the tests.

NOTATION

A_x	longitudinal acceleration of center of gravity as measured by an accelerometer, g units
A_z	normal acceleration of center of gravity as measured by an accelerometer, g units
c.g.	center of gravity
$\bar{c}$	mean aerodynamic chord, ft
C_m	pitching-moment coefficient
C_{m_α}	longitudinal stability derivative, $\frac{\partial C_m}{\partial \alpha}$, per radian
C_{m_V}	longitudinal stability derivative, $\frac{\partial C_m}{\partial V}$, per ft/sec
C_{m_q}	longitudinal pitch damping derivative, $\frac{\partial C_m}{\partial q}\frac{2V}{\bar{c}}$, per radian
$C_{m_{T'_c}}$	pitching-moment change with thrust coefficient, $\frac{\partial C_m}{\partial T'_c}$
g	acceleration of gravity, ft/sec^2
h	height above runway, ft
i_t	horizontal stabilizer angle (leading edge up, positive), deg
I_{xx}, I_{yy}, I_{zz}	moments of inertia, slug-ft^2
L-MKR	nondirectional beacon and fan marker

L_p damping in roll, $\frac{\partial L/I_{xx}}{\partial p}$, 1/sec

M_q damping in pitch, $\frac{\partial M/I_{yy}}{\partial q}$, 1/sec

M_T' pitching moment due to thrust change, $\frac{\partial M/I_{yy}}{\partial T/W}$, $1/sec^2$

M_V speed stability, $\frac{\partial M/I_{yy}}{\partial V}$, $1/sec^2/ft/sec$

M_α angle-of-attack stability, $\frac{\partial M/I_{yy}}{\partial \alpha}$, $1/sec^2$

$M_{\dot{\alpha}}$ pitching moment due to angle-of-attack change, $\frac{\partial M/I_{yy}}{\partial \dot{\alpha}}$, 1/sec

M_{δ_e} longitudinal control power per radian deflection, $\frac{\partial M/I_{yy}}{\partial \delta_e}$, $1/sec^2$

N_g gas generator speed, percent

p roll angular velocity (right roll, positive), radians/sec

PR pilot rating

q pitch angular velocity (nose up, positive), radians/sec

q_∞ free-stream dynamic pressure, lb/ft^2

r yaw angular velocity (nose right, positive), radians/sec

R/C rate of climb, ft/min

R/S rate of sink, ft/min

s horizontal distance, ft or nm (nautical mile)

S wing area, ft^2

SHP shaft horsepower

t time, sec

T transparency, average inboard propeller blade angle minus average outboard propeller blade angle, deg

T_c' thrust coefficient, $\frac{\text{total thrust}}{q_\infty S}$

V true airspeed, knots or ft/sec

V_c calibrated airspeed, $V\sqrt{\sigma}$, knots

W gross weight, lb

α corrected angle of attack, deg

α_u uncorrected angle of attack (measured at nose boom), deg

β angle of sideslip, deg

γ flight-path angle (climb, positive), deg

δ_e elevator angle (trailing edge down, positive), deg

δ_{e_p} longitudinal stick deflection (forward, positive), in.

δ_f inboard trailing-edge flap deflection, deg

δ_{r_p} rudder pedal position, in.

δ_s spoiler deflection, deg

δ_{s_p} lateral stick deflection (right, positive), deg

δ_{th} throttle position (approximately equal to the average gas generator speed), percent

ε_g glide slope error, deg

ε_l localizer error, deg

θ pitch attitude (nose up, positive), deg

θ_p propeller blade angle (subscripts refer to propeller location, numbered from left outboard as 1 to right outboard as 4), deg

σ density ratio

ϕ bank angle (right wing down, positive), deg

$\ddot{\phi}$ roll angular acceleration, radians/sec^2

ψ heading angle, deg

DESCRIPTION OF AIRPLANE AND EQUIPMENT

The Breguet 941 is a high-wing, assault-transport airplane with four turbo-propeller engines. It was designed and built for STOL operation by Societe Anonyme des Ateliers D'Aviation, Louis Breguet, in France. The U.S. licensee is the McDonnell-Douglas Aircraft Corporation. Figure 1 is a photograph of the airplane in the landing configuration. Pertinent details of the airplane are given in figure 2 and table 1. The description that follows pertains primarily to configuration changes made since the previous (1963) tests. Further discussion of some changes is included in the appendix. Reference 9 contains additional information on the geometry and control systems.

Cockpit Instrumentation

Figure 3 illustrates the instruments used and their arrangement. The primary indicators used during instrument flight tests have been labeled. It should be noted that the aircraft was a prototype, and no attempt was made to optimize either the instruments or their location. The attitude indicator was rather small, and some difficulty was experienced in discerning small bank angles. Since no flight director was provided, the pilot was required to fly the ILS solely by means of the displacement information provided by the course deviation indicator. The angle-of-attack indicator was considered a primary flight instrument. It was used in lieu of the airspeed indicator to provide the pilot a reference by which he could maintain an adequate margin from the stall independent of aircraft configuration, weight, or flight condition. Similar information was provided by paravisual lights located at the side of the windscreen; however, these lights were not too useful during instrument flight since they were outside the pilot's normal instrument scan pattern.

Flight Controls

Figure 4 is a schematic drawing of the flight control system. Since the 1963 NASA tests (ref. 9) the ailerons have been deactivated and the outboard flap deflection has been increased slightly for a given inboard flap deflection. The inboard deflection is used as the reference flap deflection. In addition, a propeller mode termed "transparency" has been incorporated, which increases the inboard propeller blade pitch and decreases the outboard blade pitch to distort the span loading at low speeds, so that the descent capability can be increased in the approach. Transparency is given as the difference in blade angle between inboard and outboard propellers.

The flaps were positioned between 0° and 85° by means of a conventional console-mounted switch; the flap actuation rate was about 2-1/2° per second. A thumb-operated rocker-type switch mounted on the inboard side of the power lever positioned the flaps between 72° and 98°, and simultaneously increased transparency from 0° to 12°. During this mode of operation, the flap rate was increased to about 15° per second so that the flap and transparency changes were more synchronous and could be used as a control rather than a configuration change. The following table lists the flap deflections used for the various operational configurations.

Configuration	Flap deflection, deg		Transparency, deg	δ_f, deg	T, deg
	Inboard	Outboard			
Cruise	0	0	0	0	0
Take-off and Maneuver	45	32	0	45	0
Preapproach and Wave-off	72	52	0	72	0
Approach and Landing	72-98	52-72	0-12	98	12

The stabilizer was interconnected with the flap position as shown in figure 5(a). The throttle and elevator also were interconnected as shown in figure 5(b), and a longitudinal feel system that changed the force and force gradient as speed was increased above 90 knots was provided to reduce the longitudinal control sensitivity and to increase the stick-free stability in cruise (fig. 6).

The lateral control system was changed as follows: since the ailerons were deactivated, the spoilers were re-rigged and the differential propeller pitch was increased for the transparency mode (fig. 7). The magnitude of differential pitch with pedal position was also changed (fig. 8).

Propulsion System

In 1963, all engines were prototypes with ratings of 1165 hp each. For the current tests, the outboard engines were replaced with production versions of the Turmo III D3 engine delivering 1480 hp. The propellers included variable blade angle stops as a safety device to limit blade angle excursion in the event of a propeller control failure. For increased safety the propeller reversing mechanism was modified to include an electrical interlock that required one of the wheels to contact the ground before reverse pitch was actuated.

Guidance

Guidance for the instrument approaches was provided by the ILS based at Toulouse-Blagnac Airport in France. The approach aids, procedures, and geometry are illustrated in figure 9. For these tests, both the normal 2-1/2° lobe and a secondary lobe of the glide slope was used. The elevation of the secondary lobe was 3 times that of the primary lobe (i.e., 7-1/2°). Since the polarity of this lobe is opposite that of the primary lobe, a switch was provided in the cockpit to reverse the glide slope signal at the cockpit course deviation indicator.

Instrumentation

All quantities were recorded by oscillographs. In addition to conventional flight test parameters (rotational rates and attitudes, linear accelerations, angles of attack, sideslip, airspeed, etc.), the glide slope and localizer errors were recorded. At altitudes below 200 feet, the radar altimeter signal was also recorded.

TEST PROCEDURES AND CONDITIONS

The tests were conducted at Toulouse-Blagnac Airport in France under VFR and IFR conditions. The flights were made by a NASA or New York Airways pilot and a Breguet test pilot with a flight test engineer aboard. All landings and take-offs were made from a concrete field at an elevation of 499 feet.

The airplane was primarily flown with the center of gravity at 30.8 percent $\bar{c}$ and a take-off gross weight of 39,000 pounds. A few flights were made with the center of gravity at 25.0 percent $\bar{c}$ and a take-off weight of 41,000 pounds. The loading consisted of the test instrumentation, water ballast, and 5,500 pounds of fuel. Final landing gross weights were about 36,000 and 38,000 pounds at 30.8 and 25.0 percent $\bar{c}$, respectively.

During the course of the tests, atmospheric conditions were observed and relayed by the control tower adjacent to the active runway. Winds were reported as velocity and direction at the surface; winds aloft were not recorded. The reported conditions varied from calm to 15 knots of tail wind and up to 10 knots of crosswind. Some of the flights were under actual IFR conditions with the ceiling reported as low as 150 feet.

RESULTS AND DISCUSSION

The first part of this section will present the operational envelopes for the different configurations used prior to and during the IFR approaches. Generally, these configurations are similar to those tested in reference 9 with minor flap deflection changes. A notable exception, however, is the inclusion of transparency to steepen the landing descent. Several other changes have been made to the aircraft to improve its operation and handling; these were described in the previous section and are further discussed in the appendix. The second part of the section will be based on the results of flying under IFR on 7-1/2° and 2-1/2° glide slopes. The discussion will be based on about 25 instrument approaches with several under actual IFR conditions. In the final section an overall look will be taken of the operation in the terminal area. This will include low altitude maneuvering on take-off and landing, and a comparison of different deceleration and descent profiles starting from cruise configuration, intercepting and tracking the ILS, and following through to a landing.

Operational Envelopes

Take-off and maneuvering.- The envelope given in figure 10(a) is the same as that presented in reference 9 for the take-off flap deflection of 45°, except that the curves are extended to different power levels. For take-off the aircraft was rotated at 55 knots (W = 39,000 lb) and the lift-off was at 60 to 65 knots. After lift-off the angle of attack was reduced to about 3°, and angle of attack was then used as a primary reference. The take-off climb gradient was about 10° with one engine out and the higher power production engines installed. This flap configuration also was used for maneuvering when it was desired to maintain intermediate airspeeds at low power.

Preapproach and wave-off.- This configuration (δ_f = 72°, T = 0°) was used prior to final approach when it was desired to maintain level flight for extended periods at landing approach speeds and also during wave-off when high climb gradients were required. The envelope for this configuration (fig. 10(b)) is the same as reported in reference 9 except that it is expanded to different power levels. The maximum climb gradient was about 8° with one engine out.

Approach and landing.- The flap deflection was not fixed for approach and landing configuration, but rather was controlled between 72° and 98° (with simultaneous change in transparency between 0° and 12°) by the rocker-type switch on the power lever. The envelope with maximum flap deflection and transparency (δ_f = 98°, T = 12°) is presented in figure 10(c). Comparison of these data with those for wave-off (fig. 10(b)) shows that the flight path can be changed about 8° by the thumb-controlled rocker switch with no change in power. A comparison of figure 10(c) and 10(d) shows that the addition of transparency at fixed flap deflection contributes about half of this change.

Over the range of flap deflections from 72° to 98° (and transparency from 0° to 12°), there were little differences in stall speeds or characteristics at the approach power. The airplane had no definitive stall in the usual sense; it was established as the minimum airspeed attainable as angle of attack was slowly increased. Increasing angle of attack beyond this point caused an increase in airspeed and rate of descent, accompanied by light buffeting. Control was adequate about all three axes; because of the opposite rotation propellers, symmetry was maintained with no buildup of sideslip or rolling moment. Figure 11 is a time history of a typical stall.

The ILS approaches were conducted at 0° to 3° uncorrected angle of attack, which provided about 10° corrected angle of attack and 10-knot speed margin from the stall. This corresponds to an approach speed of 60 to 65 knots on a 7-1/2° glide slope, and required about 600 hp per engine at maximum flap deflection and transparency. Operation at this approach condition was quite comfortable and the stall margin was considered adequate. With the flaps fully deflected and transparency at 12°, applying full power arrested the descent, but provided little climb gradient. Moving the rocker switch on the throttle, however, quickly changed the flap deflection and transparency which could be stopped any place between 72° and 98° and 0° to 12°, respectively. This control was effective for providing large changes in flight path without changing power, airspeed, or stall margins, and it permitted a quite comfortable wave-off with one engine inoperative.

IFR Operation

The heart of successful STOL operations lies, of course, in the ability to perform steep approaches and climbouts safely and expeditiously under all types of operational conditions. The ability of the test airplane to accomplish this in visual flight conditions has been amply demonstrated in previous tests (ref. 9). In the current tests aircraft performance and handling qualities were evaluated primarily during instrument approaches made on 2-1/2° and 7-1/2° glide slopes in the more stringent environment of instrument flight. These ILS approaches and conditions are summarized in table II.

7-1/2° ILS approaches.- An example of a 7-1/2° ILS approach and landing performed under actual IFR conditions is given in figure 12. Prior to glide slope intercept, the aircraft was decelerated and the flaps were positioned to the preapproach configuration. The uncorrected angle of attack during this transition was maintained at about 0°. Just prior to intercepting the glide slope, the aircraft was pitched about 7-1/2° nose down; simultaneously, the flaps were deflected to 98° and full transparency (12°) was incorporated by use of the thumb-actuated switch on the left-hand throttle. Using this technique, only minor power adjustments were required to track the glide slope while the uncorrected angle of attack was maintained between -2° and +3° by the longitudinal control. The approach speed was about 65 knots and the average rate of descent was about 800 ft/min. During the approach shown in figure 12, the ceiling and visibility were reported as 150 feet and 1 mile, respectively; however, the pilot was able to acquire the touchdown spot visually at least 50 feet before breaking out of the overcast. Assuming a breakout altitude of 200 feet, the slant range to touchdown on the 7-1/2° slope was 1500 feet; this allowed about 12 seconds during which minor corrections to the aircraft's flight path could be made before initiating the landing flare. The pilot felt that the time available to maneuver the aircraft, make decisions, and correct for crosswind and offset was more than ample, and provided a feeling of security seldom enjoyed by pilots of conventional aircraft landing at higher speeds under similar atmospheric conditions.

To reduce the number of variables that must be monitored during the approach, the pilot likes to maintain a constant angle of attack, particularly since this parameter is used to maintain an adequate margin from the stall. The requirement for good angle-of-attack stability is greater during instrument flight, since there are no visual references, and the pilot must interpret the indications of several instruments to control his flight path properly. During the current tests, angle-of-attack excursions of ±3° occurred when the c.g. was at 30 percent $\bar{c}$. These excursions were considered somewhat excessive, and considerable pilot effort was required to maintain the desired value. The static longitudinal stability for the test aircraft in visual flight conditions was reported in reference 9 to be somewhat low

(PR = 4-1/2). The same rating and comments apply under instrument conditions. When the c.g. was at 25 percent $\bar{c}$, the longitudinal stability was considered satisfactory in smooth air for VFR and IFR (PR = 3). Figure 13 shows the variation of elevator angle with uncorrected angle of attack for these two c.g. locations. The variation of elevator angle with angle of attack at 3° angle of attack is roughly doubled when the c.g. is moved from 30 percent to 25 percent $\bar{c}$; however, in either case, the angle-of-attack stability (M_α) is so low (table III) that the pilot could discern little difference in the dynamic response. Consequently, it is assumed that the stick force gradient, which also was doubled, played an important part in improving the handling of the aircraft at these low speeds. References 12 and 13 also show that acceptable to satisfactory ratings can be obtained with such low M_α and that small changes in M_α can cause significant changes in pilot ratings.

It is seen in figure 12 that heading changes of ±10° occurred during the IFR approach; however, because of the low airspeed, these excursions did not cause large lateral displacements. This poor heading control is characteristic of vehicles operating at low airspeeds where small bank angles result in large turn rates that quickly lead to large heading changes. With experience, this problem became less significant. Several factors contributed to the difficulty in maintaining wings level flight; (1) an attitude indicator which was not easy to read; (2) attention being diverted from the attitude indicator; and (3) a lag in the lateral control system, which effectively reduced the roll damping (discussed in the appendix). The effective damping with the lag was acceptable (PR = 4), and if the lag were eliminated the aerodynamic damping would be satisfactory. The spiral stability was positive and considered satisfactory (PR = 3); the aircraft attitude was reduced to 1/2 amplitude in 10 seconds. The problem of heading control could probably best be alleviated with a bank command indicator, such as is commonly used in the lateral axis of a standard flight director.

In spite of the angle of attack and heading excursions noted previously, all 7-1/2° ILS approaches were tracked to a "window" at 200 feet altitude that was ±10 feet high ($\varepsilon_g = \pm 0.4°$) and ±100 feet wide ($\varepsilon_l = \pm 0.5°$). This accuracy is comparable to that required for category II type approaches with conventional aircraft on the 2° to 3° ILS.

Acquiring the 7-1/2° ILS.- The nondirectional radio beacon (NDB) normally used to indicate the 2-1/2° glide slope intercept point was located 5.46 nm from the end of the runway, and the 7-1/2° ILS intercepted it at an altitude of 4500 feet. When this intercept altitude was used, the time required to traverse this distance and make the approach was considered excessive. The glide slope intercept altitude was pregressively lowered to determine the minimum time required for the pilot to properly establish the aircraft on the ILS. From these tests (runs 6-3, 6-4, 6-5, 16-6, and 18-1) it was concluded that 1500 feet would be about the lowest altitude acceptable to the pilot under instrument conditions; this altitude would provide at least 90 seconds on the glide slope before the pilot reached a minimum decision altitude of 200 feet, and is consistent with the findings of reference 10 for a comparable task with a helicopter. Glide-slope intercept at 1500 feet occurred rather rapidly, and could easily have been missed by the pilot, particularly since the nondirectional beacon was noncoincident with the 7-1/2° glide slope intercept at 1500 feet. The secondary lobe of the ILS used for final approach guidance during the 7-1/2° approaches was considered adequate for test purposes; however, it would not be acceptable for operational use because of the high sensitivity at lower altitudes.

The required rate of descent on the 7-1/2° approach is affected by wind velocity to a much greater degree than on the standard ILS. To track the 7-1/2° ILS successfully with a 10-knot tail wind, the aircraft must be capable of at least a 1000 ft/min descent compared to 800 ft/min with no wind. In addition to this "steady state" or average descent capability, a margin of flight path control is required by the pilot to adequately acquire, or reacquire, the glide slope. A margin of 1° to 2° is believed sufficient for a 7-1/2° ILS glide slope. It was noted by the pilot that without transparency the descent capability on a 7-1/2° ILS was marginal. With transparency the descent capability was adequate for all wind conditions encountered. Although approaches steeper than 7-1/2° were not attempted during the course of these tests, the pilots indicated a reluctance to exceed 1000 ft/min rate of descent when close to the ground. This value is believed to be a practical limit to the maximum sink rate the pilot will tolerate below about 100 feet.

Flight-path control.- During the approach, the elevator was used to maintain the desired angle of attack but was not considered the primary flight path control, because a simultaneous change in power was required to avoid undesirable airspeed and angle-of-attack excursions. The modulation of engine power was considered the primary control for tracking the glide slope or making small adjustments to the flight path. The direct change in lift associated with power changes quickly produced the desired change in flight-path angle. The pitching moments resulting from these power changes without the throttle-elevator interconnect, however, compromised the pilot's ability to maintain the desired angle of attack.

Figure 14 presents the response characteristics produced by a throttle step without the throttle-elevator interconnect (fig. 5) normally used. The time history of a throttle decrease (fig. 14(a)) shows that a negative acceleration was obtained in about 1 second; however, the nose-up moment produced by the thrust change increased the angle of attack, which in turn reduced both the desired change in vertical acceleration and the airspeed. As indicated in reference 9, these undesirable effects were reduced to a satisfactory level by the throttle-elevator interconnect. The lag between throttle actuation and power (thrust) output of over 1 second was acceptable.

Since transparency significantly increased the steady-state flight-path angle without increasing the approach speed (cf. figs. 10(c) and 10(d)), and since the magnitude could be controlled by means of the throttle mounted switch, transparency was evaluated as a flight-path control. It was found that the initial flight-path change was in the wrong direction. This is shown in figure 15(a) which gives the time history for the aircraft response to a transparency step with the flap deflection and longitudinal stick position fixed. Corresponding static trimmed data (fig. 16) show that only a small portion of the elevator range is required to trim the nose-up pitching moments caused by increasing transparency; however, it can be seen in figure 15(a) that the nose-up pitching acceleration is sufficient to increase angle of attack, which produces a vertical acceleration and a positive flight-path angle change before the negative change, corresponding to the steady-state increment, is attained. This incorrect response negates the use of transparency, by itself, as a precise flight-path control. To reduce this pitching moment, the flaps were operated simultaneously with transparency. The aircraft response to this combination is shown in figure 15(b). The incorrect initial response is reduced; however, it still takes several seconds to produce a significant increase in descent angle. While this combination was still considered unsatisfactory for precise control, it was very useful for making gross changes in flight path, such as intercepting the glide path or initiating a go-around because flight-path changes up to 10° could easily be made without changing power. To further reduce the incorrect response, it would be necessary to interconnect transparency and elevator or increase the static stability of the aircraft.

Landing: The normal landing procedure is to initiate a flare about 20 feet above the ground. The aircraft is rotated to at least a level attitude, and the increase in angle of attack produces sufficient vertical acceleration to reduce the descent velocity from about 800 to about 300 ft/min at touchdown. This "half flare" takes about 4 seconds. It was made at altitude for better documentation. The results (fig. 17) show that 0.1 g vertical acceleration is developed within 2 seconds, the glide angle is reduced 4°, and the airspeed is reduced 5 knots. The maximum vertical acceleration measured for an abrupt attitude change at altitude was 0.25 g; when power was applied in addition to elevator, 0.4 g was obtained. It was found that the maximum acceleration used during any approach or landing was 0.1 g. The pilots felt that sufficient vertical acceleration was available for STOL type approaches and landings.

The half flare landing increases precision in touchdown because the contact point is closer to a straight line extension of the approach flight path, and hence, eases the judgment problem. Further, the large dispersions associated with floating down the runway when a fully flared landing is performed are eliminated. The pilots also reported greater consistency in landing performance with transparency than without transparency. While this was not documented, it seems reasonable to expect that the aircraft would be less disturbed near the ground with transparency since the span loading is distorted to simulate a lower aspect-ratio wing.

Landing gear design is important in making these half flare landings; not only do the higher touchdown velocities necessitate a higher design sink speed, but more important, the energy absorption characteristics must avoid rebound and impart low acceleration to the passengers. The "soft" gear of the Breguet satisfied these requirements, and the peak vertical acceleration at the c.g. was 0.5 g at 300 ft/min touchdown velocity.

2-1/2° ILS approaches.- The 2-1/2° approaches were examined because STOL aircraft are at times required to operate with conventional approach facilities. Also some reports have suggested that approaching at shallow angles and decelerating during the approach reduces the nonproductive time for

V/STOL aircraft. The initial approaches were made in a STOL configuration and speed using the same pattern and 1500-feet intercept altitude normally used by conventional aircraft on the standard 2-1/2° ILS. The time required to traverse the distance from glide slope intercept at 1500-feet altitude to the end of the runway (5.46 nm) at about 60 knots was about 6 minutes, which the pilot considered excessive. In addition, the thrust required during the approach was quite high and the rate of descent was so low that at times, when corrections were being made to the glide slope, the aircraft was not descending at all. Breakout to visual conditions from these approaches at an altitude of about 250 feet left the pilot in the uncomfortable position that the aircraft was still some distance from the runway at a low altitude. The tendency was to level the aircraft and fly to a point where a more normal STOL descent could be initiated. The time required to complete the IFR approach was reduced by lowering the glide slope intercept altitude so that the final approach leg on the 2-1/2° ILS was shortened (fig. 9). During one approach (no. 8-8), the glide slope was intercepted at 600 feet. Although there was adequate time to establish a stabilized descent before breakout, the approach was not considered comfortable for the same reasons pointed out earlier, and, hence, would not be recommended as an operational procedure.

A more practical way to approach on the conventional 2-1/2° ILS is to use a reduced flap deflection, which permits a higher initial approach speed. However, with intermediate flap deflections (40° to 50°), the descent capability was not sufficient to permit the 2-1/2° glide slope to be tracked adequately at the desired angle of attack. In addition, the increased approach speed incurred an excessive deceleration distance before touchdown. Figure 18 presents a time history of an approach made at about 115 knots with 25° flap deflection until breakout at 200 feet where the aircraft was decelerated to the STOL configuration and then landed at 60 knots. This landing procedure was not considered very satisfactory because of the poor deceleration and associated long distance from breakout to landing. The most satisfactory configuration tested on the 2-1/2° approach was a 55° flap deflection at 80 knots. This approach (run 15-31 in Fig. 19) provided an adequate descent capability and also permitted a comfortable transition to the STOL configuration to be accomplished between breakout (200 ft) and touchdown. Following this procedure the total approach and landing distance was little more than if the STOL configuration had been maintained throughout the 2-1/2° approach.

A decelerating approach would be most attractive as a means of reducing nonproductive time since it allows a relatively high speed to be maintained until the final descent to a landing is commenced. In an attempt to fly such an approach (run 16-3) it was found that the pilot was unable to control the many changing variables properly while simultaneously tracking the ILS glide slope. Figure 20 illustrates the complexity of this task by the large excursions in airspeed, glide slope error, and localizer error. Further work with improved guidance and display information - for example, flight director or altered beam width as in reference 11 - and improved handling qualities, such as stability augmentation, should be done to determine methods of reducing nonproductive time without increasing pilot workload.

Terminal Area Operation

Take-off and climb.- The acceleration and climb characteristics of the aircraft are illustrated by two take-off time histories of figure 21. The first time history shows that after take-off, the aircraft could be accelerated at 0.2 g to cruise configuration; the second shows that the aircraft can be maintained at 80 knots with a 12° climb angle. As discussed in reference 9, the pilot was not greatly concerned about the loss of an engine during take-off because the cross-shafted transmission system maintained symmetry, control, and a high climb gradient (loss of an engine reduced climb angle from 12° to 8°). The climb procedure had been simplified since the 1963 NASA tests by reducing the flap retraction rate from 10 to 2-1/2°/sec and by interconnecting the stabilizer and flap to permit flap retraction in one step without constant retrimming. These take-offs and climbouts were simple to perform during VFR or IFR conditions; the procedures and handling characteristics were similar to those of a conventional turboprop transport.

In some cases, it may be desired or required to change heading shortly after take-off. Figure 22 presents a spiral take-off in which the aircraft is banked shortly after take-off. By the time the aircraft reached 150-feet altitude, it was in a climbing turn at about 20° bank angle and 80 knots. For this maneuver, the flaps were left in the take-off position (45°) and the resulting spiral was less than 4,000 feet in diameter. With the satisfactory stability, control, stall margins, and safety of this STOL aircraft, the take-off maneuver was easy and comfortable to make.

Approach and landing.- A time history of the transition from cruise configuration to landing speed at constant altitude is presented in figure 23. This transition was made with three engines at ground idle to reduce the power level and increase the maximum deceleration capability, but the average deceleration was only 0.1 g. This low deceleration is directly related to the inadequate descent capability in the intermediate flap configuration. Although the low flap extension rate of 2-1/2°/sec contributed to limiting the deceleration capability, the higher rate of 10°/sec used in 1963 (ref. 9) did not solve the problem. In those tests it was difficult to avoid "ballooning" and it was necessary to make the transition in steps. At these intermediate speeds, increased drag (from spoilers or reduced thrust levels) should be provided to increase deceleration capability and reduce nonproductive time for STOL transports.

Data from the 2-1/2° and 7-1/2° approaches and the transition were used to look at the terminal area operation of a STOL aircraft under IFR. It was assumed that (1) the aircraft is decelerated to 120 knots and simultaneously vectored to the desired point where the approach is initiated; (2) additional beacons and markers provide the pilot with a better reference for the 7-1/2° ILS; (3) the ILS beam height is ±1/2°; (4) the intercept altitude rather than horizontal intercept is 1500 feet; and (5) the ceiling is 200 feet. Further, a 30-second stabilization period is assumed between major changes in aircraft configuration and flight path while under IFR.

The results of three types of approaches are summarized in figure 24. In the first approach (A) the aircraft decelerated to 60 knots before intercepting the 7-1/2° ILS. This glide slope was tracked through breakout and landing at an airspeed of 60 knots. The total time required was calculated to be 190 seconds. In the second approach (B) the aircraft intercepted the 2-1/2° ILS at 120 knots, continued at this speed till breakout at 200 feet, decelerated to 60 knots under VFR conditions, and completed the landing. The total calculated time was 240 seconds. (The touchdown point is not a continuation of the ILS beam because of the combined requirement for deceleration and preference for a steeper final approach than 2-1/2°.) In the third approach (C) the aircraft intercepted the 2-1/2° ILS at 120 knots; at 1200 feet, the aircraft was decelerated to 60 knots, and continued the 2-1/2° path till breakout after which the path was steepened to 7-1/2°. This landing was calculated to require 260 seconds. As noted earlier, decelerating along this 2-1/2° ILS with the display, guidance, and handling characteristics that existed exceeded the pilot's capability.

According to these three approaches, the least air maneuver time was used when the aircraft was decelerated to the landing configuration at the intercept altitude and a steep approach was made. This maneuver was similar to that proposed in reference 10, but the time was shorter because different terminal guidance was assumed. In the exercise of reference 14, it was concluded that the least air maneuver time would be obtained with a shallow flight path and rapidly decelerating just prior to landing. This approach is closest to approach (B) which consumed more nonproductive time than (A). Further, it should be noted that a steep, straight-in approach such as (A) is preferable because of improved obstacle clearance, safety, and pilot workload.

The average airborne deceleration from cruise to landing configuration was 0.1 g in level flight (fig. 23) and 0.03 g in descending flight (figs. 20 and 24). These values were limited by the aircraft descent and deceleration capabilities and by the pilot workload in IFR, and are considerably lower than those used in many V/STOL short-haul studies (refs. 1 to 4 and 14). Considerable aerodynamic and guidance work will have to be done to obtain the higher values since the test aircraft had descent capabilities at least as large as those available on the designs studied and was at least as simple to transition.

Close-in patterns.- Several VFR approaches were made to simulate operation in a restricted area or in a manner to avoid conventional traffic patterns. Figure 25 presents approaches at STOL speeds where the final 90° turn is made at about 300-feet altitude. In case A, the pre-approach configuration is used prior to the 90° turn and the rate of sink is low until the 90° turn is completed; after the turn, the landing configuration is used with an 800 ft/min descent (glide angle about 8°). For case B, a descending approach and turn are made maintaining final landing configuration and a descent rate of 800 ft/min. Little difficulty was encountered in making these landings with adequate precision in touchdown point. Approaches were also made when the altitude of the 90° turn was reduced to 200 feet. The pilot considered this altitude too low because it allowed insufficient time for making final corrections to touchdown on the desired spot.

A 360° circling approach and landing is shown in figure 26. This pattern was started in level flight at 1000 feet in the approach configuration. When the aircraft was directly over the desired touchdown point, the configuration was changed to the landing configuration and the aircraft was banked to about 20°. The power was adjusted for descent at approximately 800 ft/min and bank angle was varied to compensate for the crosswind so that an approximately circular pattern could be maintained to roll out at about 200-feet altitude over the runway. The time required to complete this maneuver from its initiation over the runway at 1000 feet to touchdown was only 80 seconds, and the diameter of the maneuver was roughly 3000 feet. The primary problem of such an approach is adequate compensation for crosswind so that it is not necessary to increase the bank angle just prior to the rollout. To perform this approach under IFR conditions would require a different type of guidance system, and the pilot would require different position information.

CONCLUDING REMARKS

It was reported in NASA TN D-2231 that the Breguet 941, a STOL transport aircraft, had acceptable performance, handling qualities, and operational characteristics in the VFR conditions. The current tests were made with the same aircraft flown in the more severe environment of IFR on a 7-1/2° and 2-1/2° ILS with relatively austere displays; that is, conventional course deviation indicator, attitude indicator, and angle-of-attack indicator. The following conclusions were drawn.

The aircraft could be comfortably flown at 60 knots on the 7-1/2° ILS down to 200 feet above the runway, which corresponds to a 1500-foot slant range till touchdown. For these approaches the aircraft was tracked to an accuracy comparable to that required for Category II-type approaches with conventional aircraft.

To acquire and track the 7-1/2° ILS, approximately a 9° descent capability was needed; this capability was available in the approach and landing configuration. Higher descent angles at 60 knots are not attractive because of the high descent rates at breakout; an upper practical limit is about 1000 ft/min. The level flight deceleration capability in the intermediate flight regime, used prior to ILS intercept, was less than 0.1 g and was considered to be inadequate for a short-haul STOL aircraft.

The pilot considered the overall handling characteristics satisfactory for IFR operation at STOL speeds. There were several specific characteristics, however, which, although rated acceptable, were not quite satisfactory. Moderate heading excursions occurred during the approach because the pilot could not pay sufficient attention to maintaining wings level and moderate angle-of-attack excursions occurred at the rear center of gravity. Similar problems reported during VFR flight are general problems of STOL operation. Since power was a primary control of flight path, pitching moments produced by power significantly increase the pilot's workload; a throttle-elevator interconnect reduced these moments to a satisfactory level. A maximum vertical acceleration of 0.4 g was obtained by applying power and full elevator deflection, compared to 0.25 g by elevator only. These levels of vertical acceleration were considered sufficient for all approach and wave-off conditions encountered during these tests.

The shortest time from cruise configuration to a landing was with a level deceleration to 60 knots at the ILS intercept altitude, proceeding down the 7-1/2° ILS, breaking out, and continuing until touchdown at the same descent angle and speed. It was less comfortable to fly a 2-1/2° ILS at high speed and then decelerate to STOL after breakout because of the inadequate deceleration capability in the intermediate speed regime. Decelerating during the 2-1/2° ILS approach was unacceptable because it was very difficult for the pilot to stay within the ILS boundaries.

Ames Research Center
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Moffett Field, Calif., 94035, Aug. 28, 1968
721-06-00-01-00-21

APPENDIX

CONTROL SYSTEM CHANGES SINCE THE 1963 NASA TESTS

LATERAL CONTROL

The initial roll acceleration measured in the current tests for the landing configuration is compared with the 1963 tests in figure 27. It is seen that the values with transparency are about the same as without transparency. The pilots found the control power and sensitivity satisfactory for all the configurations tested, and rated it 3. The pilots reported that the roll damping appeared to decrease when transparency was used. Additional flight tests were made cycling the lateral control. The results (fig. 28) show that the spoilers lag the control input very little, whereas, the differential pitch is 90° out of phase and is rate limited; at the frequency of control used, the effective lag is about 0.2 seconds. Similar tests without transparency also show a rate limited condition, but the propeller contribution is less (fig. 7) and the effect of lag is not evident to the pilot.

Due to lag, it was difficult to ascertain the aerodynamic damping (L_p) only; however, tests with pulses and steps have shown that L_p was reduced 20 percent by transparency. The NASA pilot rated the effective damping acceptable (PR = 4); however, certain other pilots were more troubled by it, and indicated it to be unacceptable. The Breguet Company believed the low pitch rate to be associated with the variable blade angle stops used in the production propeller. If the lag is eliminated, the aircraft roll damping should then be satisfactory.

PROPELLER REVERSING

The procedure for reversing the propellers during the landing roll has been simplified, which makes it comparable to conventional transport aircraft. In addition, an interlock has been provided that requires one of the five landing gear struts to be compressed before the throttle can be moved into the reverse range. This avoids the possibility of inadvertently actuating reverse pitch while the aircraft is airborne. Although a small performance penalty might be incurred by this revision, it is warranted by increased ease and safety of operation.

LONGITUDINAL STABILITY

Reference 9 indicated that the static longitudinal stability in the cruise configuration was unsatisfactory (PR = 5-1/2). Since those tests, an artificial feel device has been incorporated in the longitudinal control system that changes stick force as a function of dynamic pressure at airspeeds above 90 knots (see fig. 6). Static longitudinal stability and stick force per g are now considered satisfactory.

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TABLE I.- GEOMETRIC DATA

Wing	
Area, sq ft	889
Span, ft	76.1
Mean aerodynamic chord (reference), ft	12.15
Incidence root, from fuselage reference line, deg	3
Twist, deg	0
Dihedral, deg	4
Airfoil section with cambered leading edge from internal nacelle to wing tip	63A416
Aspect ratio	6.52
Taper ratio	0.507
Flap deflection (maximum), deg	Inboard 98; Outboard 72
Flap chord (percent wing chord)	38.5
Spoiler spanwise location	From 56 to 97 percent of span
Spoiler deflection, deg	45
Spoiler chord, percent chord	7
Horizontal tail	
Total area, sq ft	320
Span, ft	32.8
Mean aerodynamic chord, ft	9.92
Airfoil section	63A212 inverted with cambered leading edge
Elevator area, sq ft	119
Elevator deflection, deg	
Maximum trailing edge up	-30
Maximum trailing edge down	+24
Stabilizer deflection, deg	+1 to +9 to fuselage ref. (leading edge up)
Vertical tail	
Total area, sq ft	219
Span, ft	17.9
Mean aerodynamic chord, ft	13.1
Airfoil section (modified)	63A013
Rudder area, sq ft	82.6
Rudder deflection, deg	
First rudder	±20
Second rudder	±40
Moment of inertia (approximate for 38,500 lb gross weight)	
I_{xx}, slug-ft^2	225,000
I_{yy}, slug-ft^2	140,000
I_{zz}, slug-ft^2	400,000

TABLE II.- SUMMARY OF ILS APPROACHES

(a) 2-1/2° ILS

Run	Condition	Wind*	Configuration Power, percent	 Flaps, deg	 Trans. deg	Average airspeed	Primary evaluation parameter	Intercept altitude	
3-1	Partial IFR	260°/9 k	Vary	85	Off	65-62	Flight-path control	1500	Slightly sluggish, but response in correct direction. Heading control poor.
3-2	Partial IFR	260°/9 k	87	Vary	Off	65	Flight-path control	1600	Not very responsive or effective.
3-3	Partial IFR	260°/9 k	88	Vary	Vary	63	Flight-path control	1500	Rapid response, but initial response in wrong direction
5-1	Visual	310°/11 k	Idle Vary	30 46	Off Off	100 85	Increased air-speed on approach	1500	Unable to descend adequately. Unable to descend adequately until 2-engines at ground idle.
5-2	Visual	310°/11 k	92 Vary at end	Vary	Vary	60	Flight-path control	1500	Glide slope tracking not too good; initial pitch response in wrong direction.
5-3	Visual	310°/11 k	Vary	88	7	63	Reduced intercept altitude	1000	Glide slope tracking with power was better, particularly at low altitude.
7-22	Hooded to 300 ft	310°/6 k	↓			65	Initial look at sim. inst. conditions	1500	Data not reduced. Heading control terrible. Approach took too much time.
8-8	Hooded to 300 ft	Calm	↓	Vary	Vary	68	Reduced intercept altitude	600	Not comfortable. Glide slope intercept indeterminate.
15-31	Hooded to 200 ft	180°/8 k	↓	52	Off	80	Increased approach speed	1600	Quite comfortable. Was able to make transition and land after breakout without significant deviation from glide slope.
16-2	Hooded to 200 ft	320°/4 k	↓	24	Off	105-120	Increased approach speed	1300	Comfortable to breakout. Deceleration to landing configuration too slow.
16-3	Hooded to ?	320°/4 k	↓	Vary	Vary	115-67	Decelerating approach	1500	Unsatisfactory; too many changing parameters. Work load too high.

(b) 7-1/2° ILS

Run	Condition	Wind*	Power, percent	Flaps, deg	Trans. deg	Average airspeed	Primary evaluation parameter	Intercept altitude	
1-35	Visual	Calm	Vary	Vary	Vary		Steep ILS	4500	Glide slope seemed sensitive below 1000 ft. Data not reduced.
6-1	Visual	↓	↓	98	12	62	Steep ILS	4500	Glide slope tracking begins to deteriorate between 400-500 ft, but reasonable to 250 ft
6-3	Visual	↓	↓	98	↓	62	Reduced intercept altitude	3000	Feels quite comfortable.
6-4	Visual	↓	↓	98	↓	65	Reduced intercept altitude	2000	
6-5	Visual	↓	↓	98	↓	62	Reduced intercept altitude	2000	Intercept occurs quite rapidly and would require some warning.
8-4	Hooded to 145 ft	↓	↓	98	↓	62	Simulated inst. condition	1300	Tracking not too good. Descent capability quite adequate.
8-5	Hooded to 165 ft	↓	↓	98	↓	62		1400	
8-7	Hooded to 175 ft	↓	↓	98	0	65	Transparency OFF	1500	Descent capability marginal.
9-17	Hooded to 200 ft	160°/8 k	↓	98	12	60	Forward c.g.	1500	Seemed easier to hold desired angle of attack in approach.
16-5	Hooded to ?	320°/4 k	Idle	65	↓	70-80	Increased approach speed	1300	Insufficient descent capability. Did not like feel of A/C close to ground. Laterally unsteady.
16-6	Hooded to ?	320°/4 k	Vary	98	↓	65	Reduced intercept altitude	1100	Flew through glide slope awfully fast. Was barely able to get back on.
18-1	IFR to 150-250 ft	Calm	↓	↓	↓	↓	Actual IFR, forward c.g.	1650	Quite comfortable - Static long stab sat. (smooth air). Runway became visible before break out.
18-2	IFR to 150-250 ft	↓	↓	↓	↓	↓	Actual IFR, forward c.g.	1000	Not enough trim on glide slope to get squared away.
18-3	IFR to 150-250 ft	↓	↓	↓	↓	↓	Actual IFR, forward c.g.	1600	Heading control not too bad. Glide slope too sensitive below 300 ft.

*Wind given as absolute heading and speed; the runway heading is 149°.

TABLE III.- LONGITUDINAL CHARACTERISTICS OF BR 941 AT 98° FLAP DEFLECTION

	Reference 9	Current tests
W, lb	38,500	39,000
V_c, knots	60	57
T, deg	0	12
c.g., percent $\bar{c}$	30	30
T_c'	0.57	0.72
SHP, per engine	450	600
$\frac{d(\text{total thrust})}{dV}$, lb/ft/sec		-41
$\frac{dT_c'}{dV}$, 1/ft/sec	-0.016	-0.018
M_T', 1/sec^2	-0.41	-0.27[1]
$C_{m_{T_c'}}$	-0.12	-0.08
M_V, 1/sec^2/ft/sec		0.00123
C_{m_V}, 1/ft/sec	0.00156	0.00145
M_α, 1/sec^2	-0.09[2]	-0.20[2]
C_{m_α}, 1/radian	-0.09	-0.22
M_q, 1/sec	-1.02	-0.66[1]
C_{m_q}, 1/radian	-18	-13.2
$M_{\dot{\alpha}}$, 1/sec	-0.43[3]	-0.28[3]
$C_{m_{\dot{\alpha}}}$, 1/radian	-7.6	-5.6
M_{δ_e}, 1/sec^2	-1.72	-0.96[1]
$M_{\delta_e} \delta_{e_{max}}$ (assuming -5° trim, so $\delta_{e_{max}} = \pm 30°$), 1/sec^2	-0.90	-0.50[1]

[1]Based on more accurate measurements than made in 1963 tests.

[2]Difference between previous and current value may be related to configuration; however, M_α computed from δ_e versus velocity. Therefore revised M_T' and M_{δ_e} also have strong input.

[3]Estimate based on M_q.

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Figure 1.- Test airplane in landing configuration.

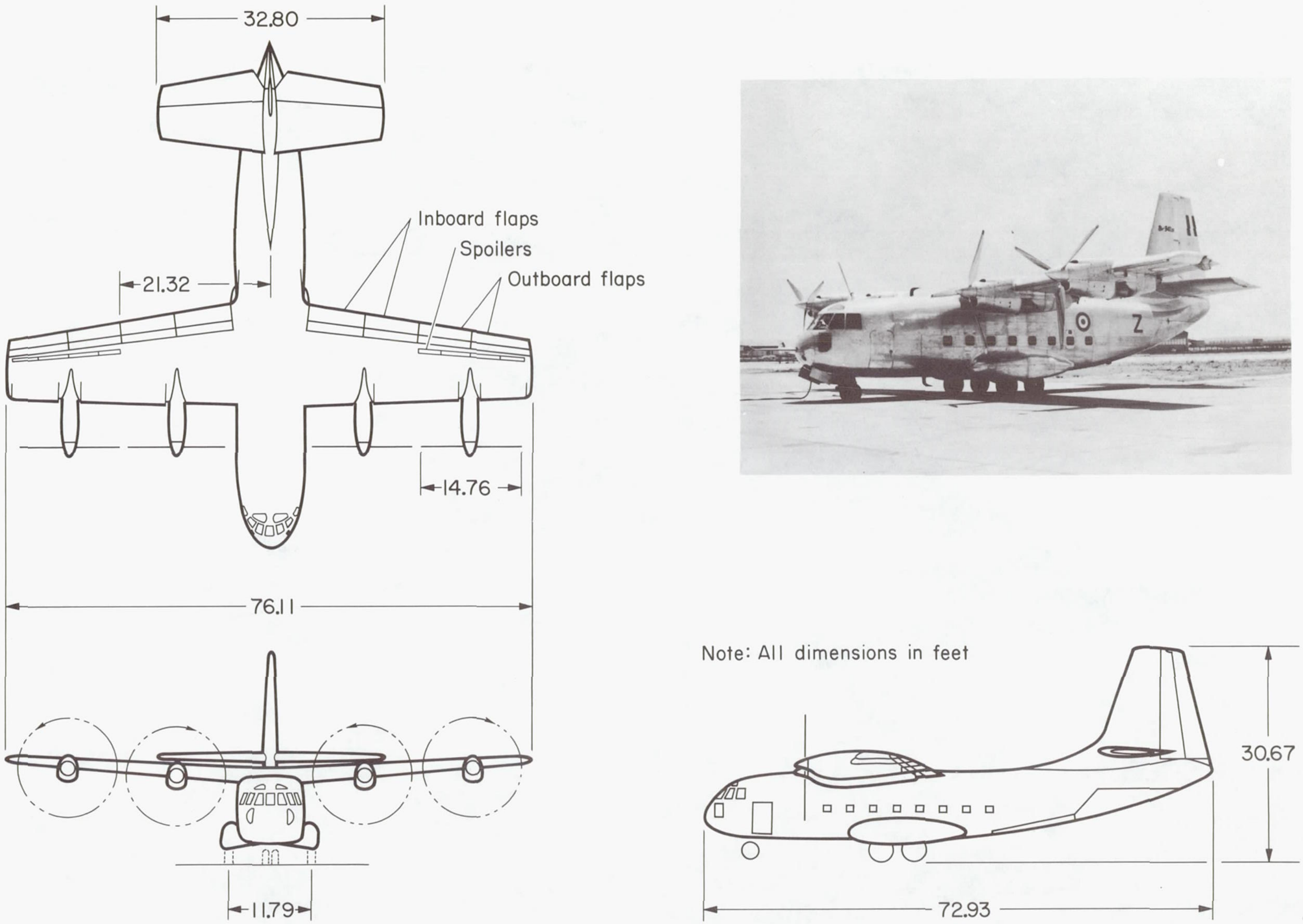


Figure 2.- Dimensions of test airplane.

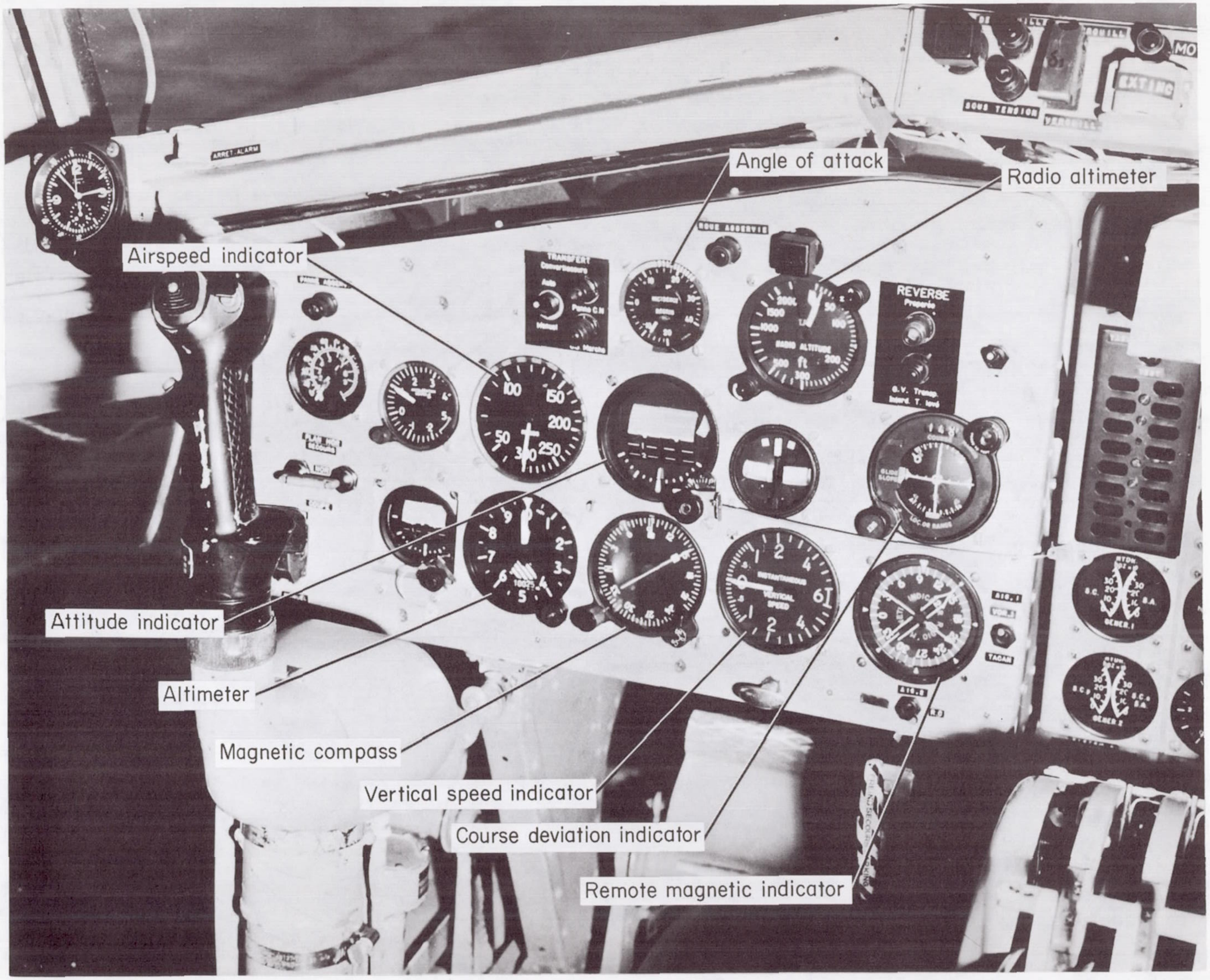


Figure 3.- Pilot's instrument panel.

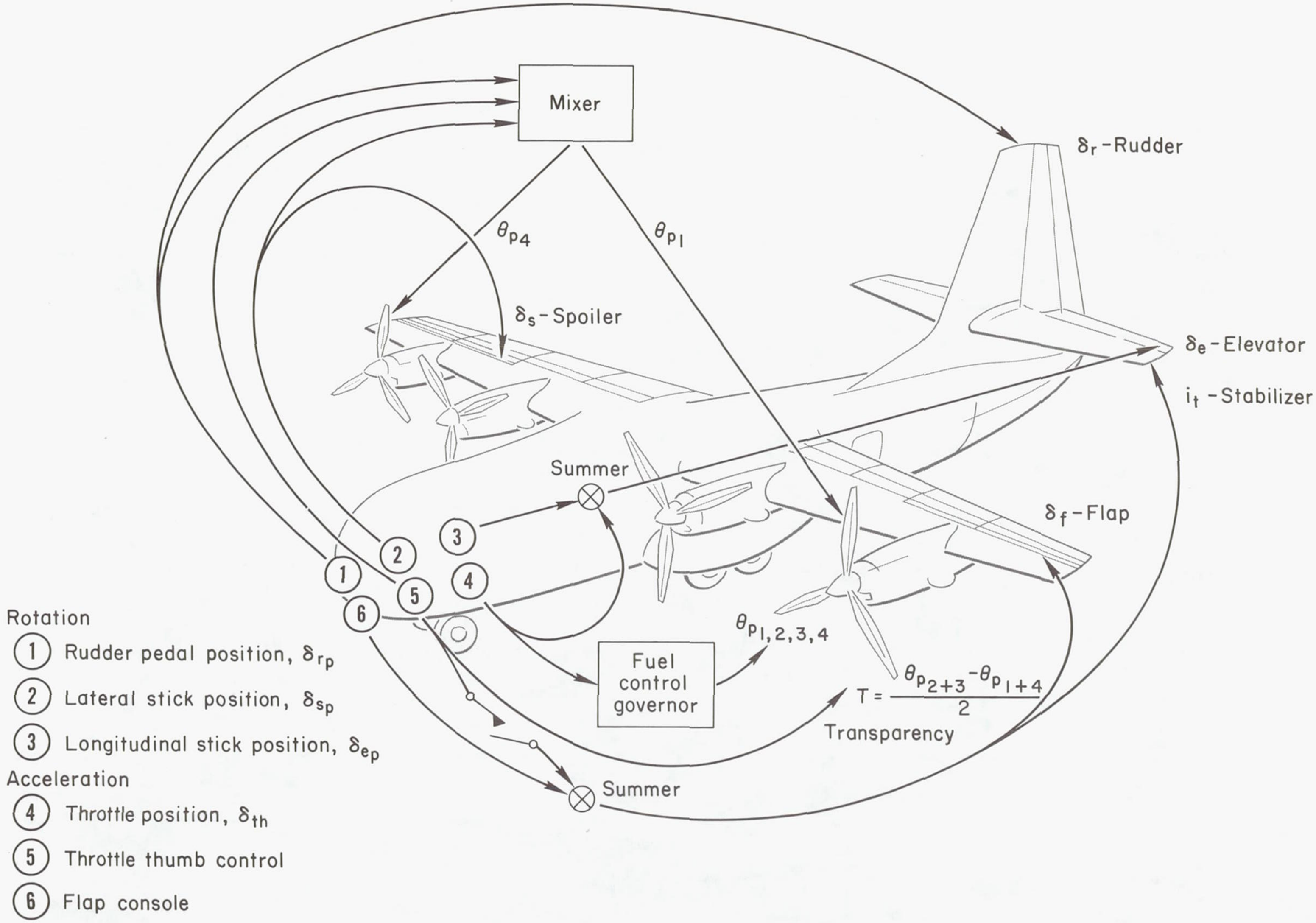
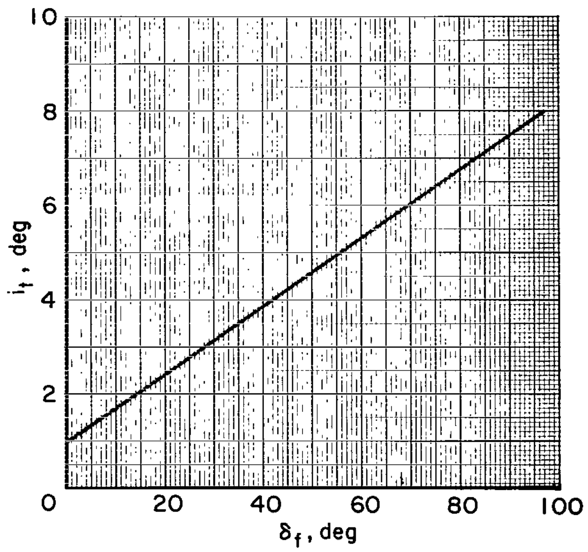
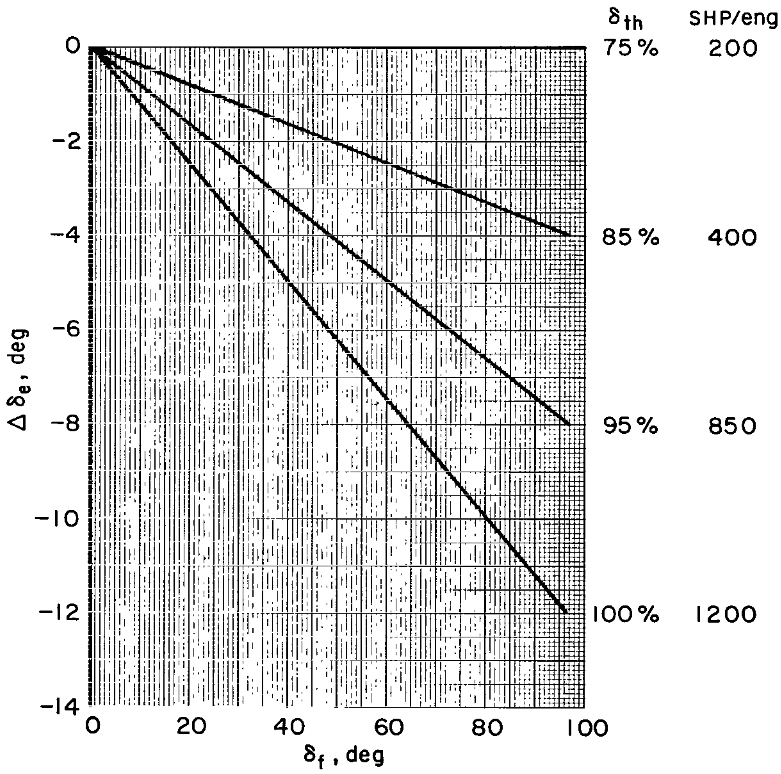


Figure 4.- Schematic drawing of flight control system.



(a) Stabilizer flap.



(b) Throttle elevator at sea level standard conditions.

Figure 5.- Interconnect relations.

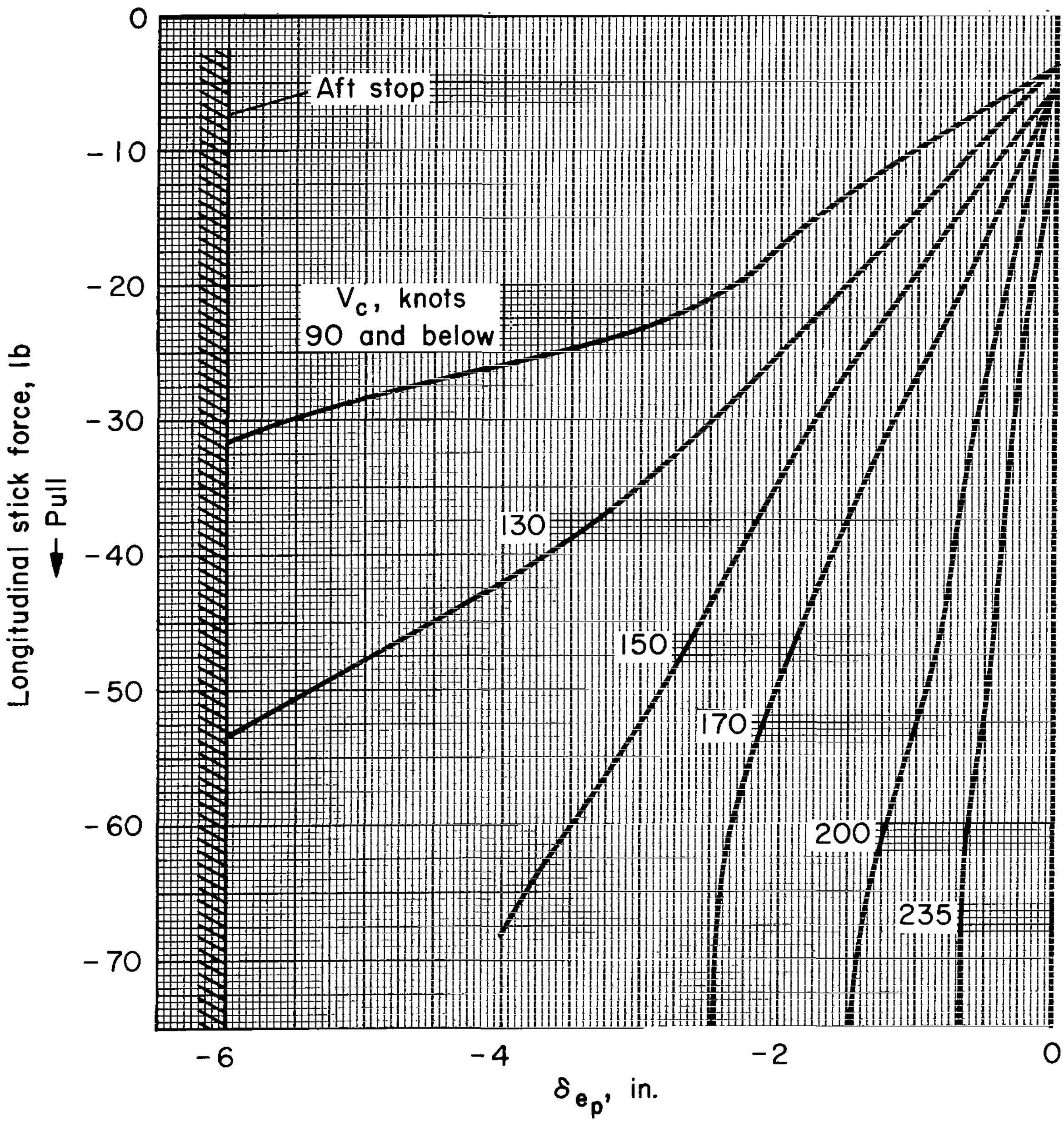


Figure 6.- Longitudinal force at various forward speeds.

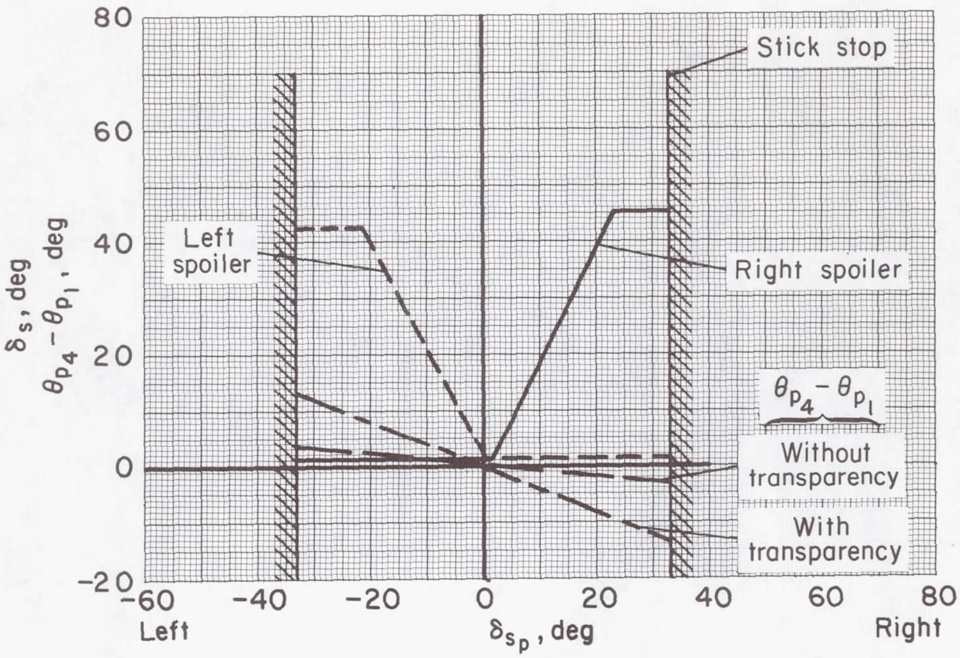


Figure 7.- Lateral control displacement with lateral stick input.

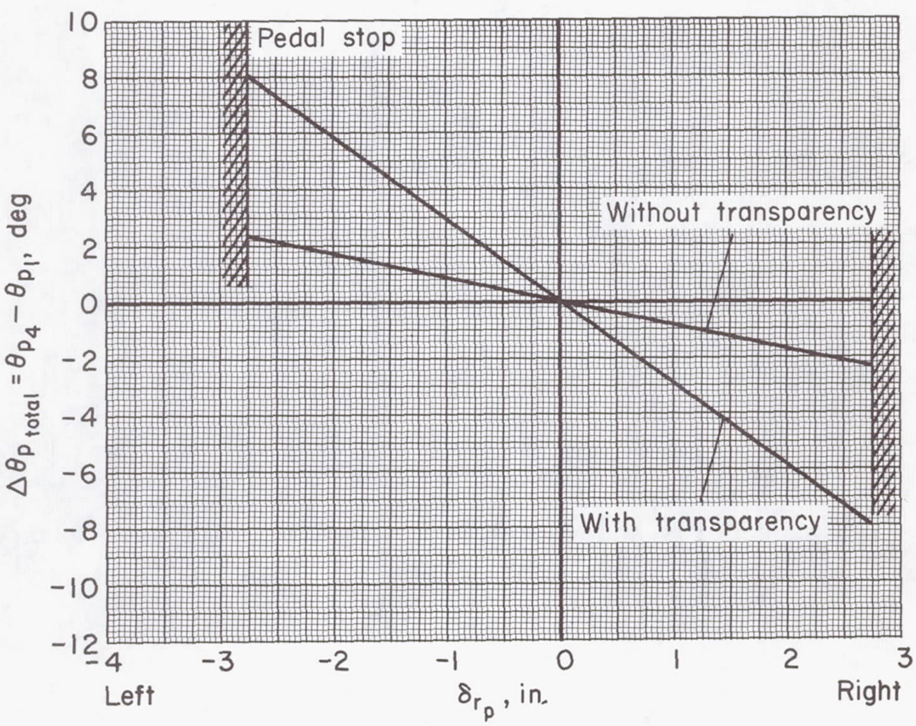
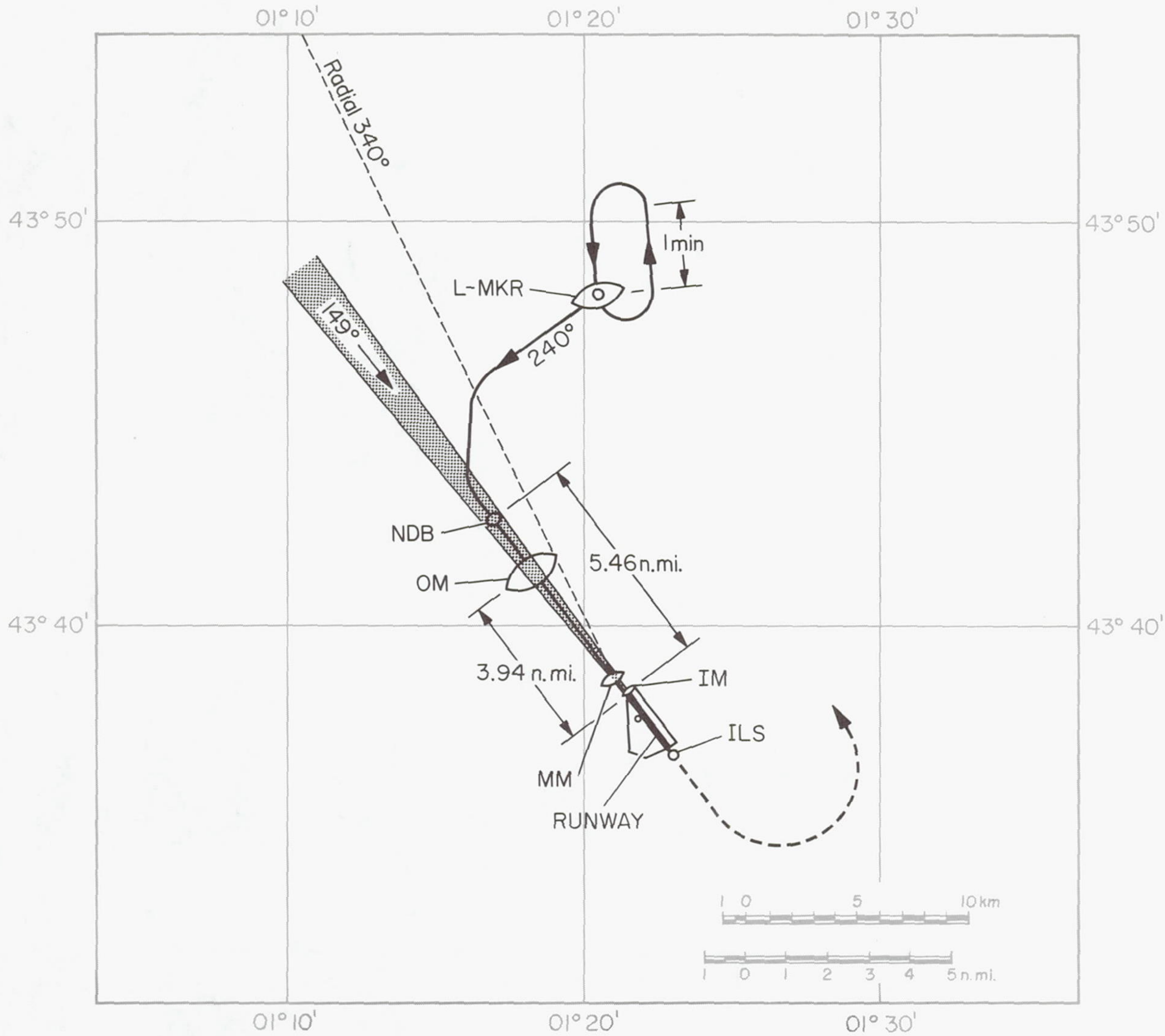
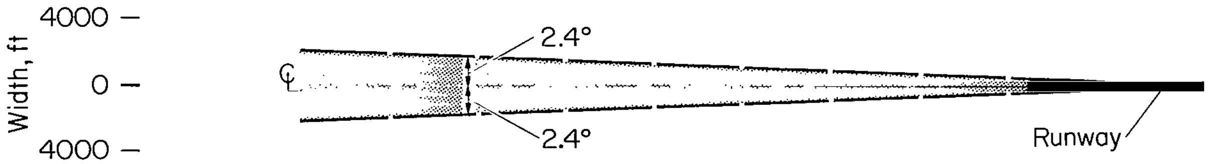


Figure 8.- Differential propeller pitch variation with rudder pedal position.

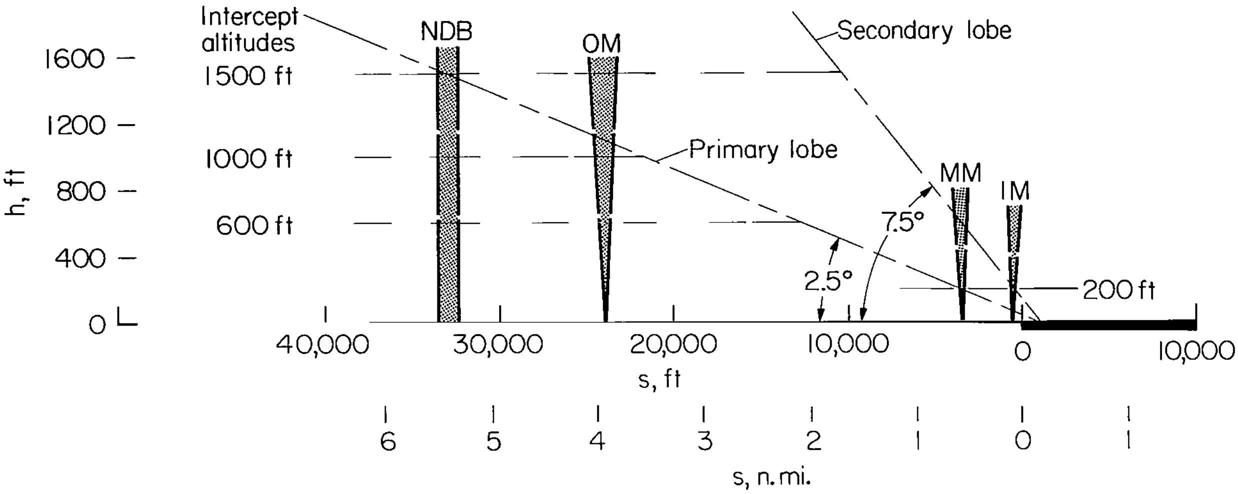


(a) ILS procedures.

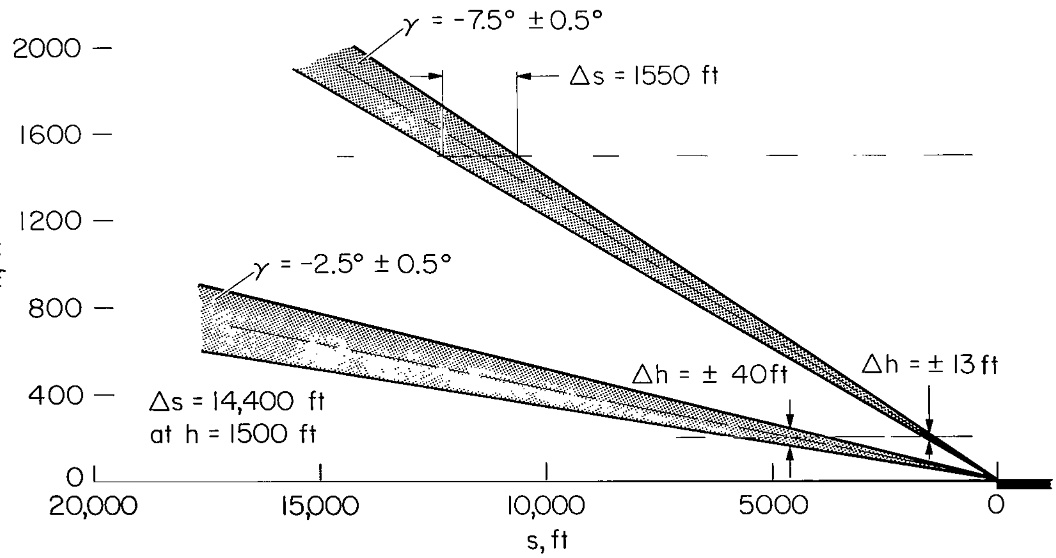
Figure 9.- ILS procedures and geometry for Toulouse Blagnac (France) airport. Runway 15, elevation 499 feet (152 m).



(b) Localizer geometry.

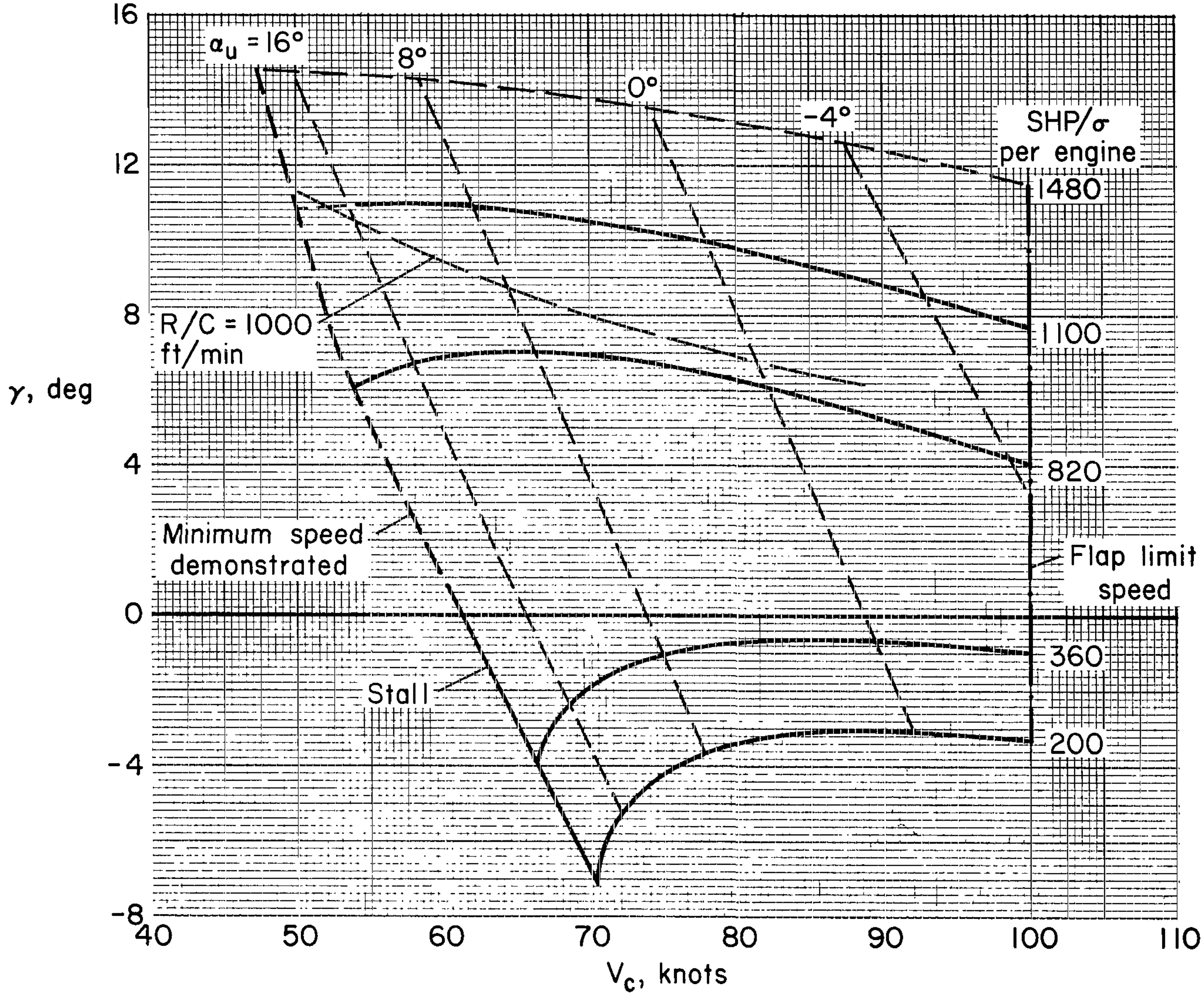


(c) Glide-slope geometry.



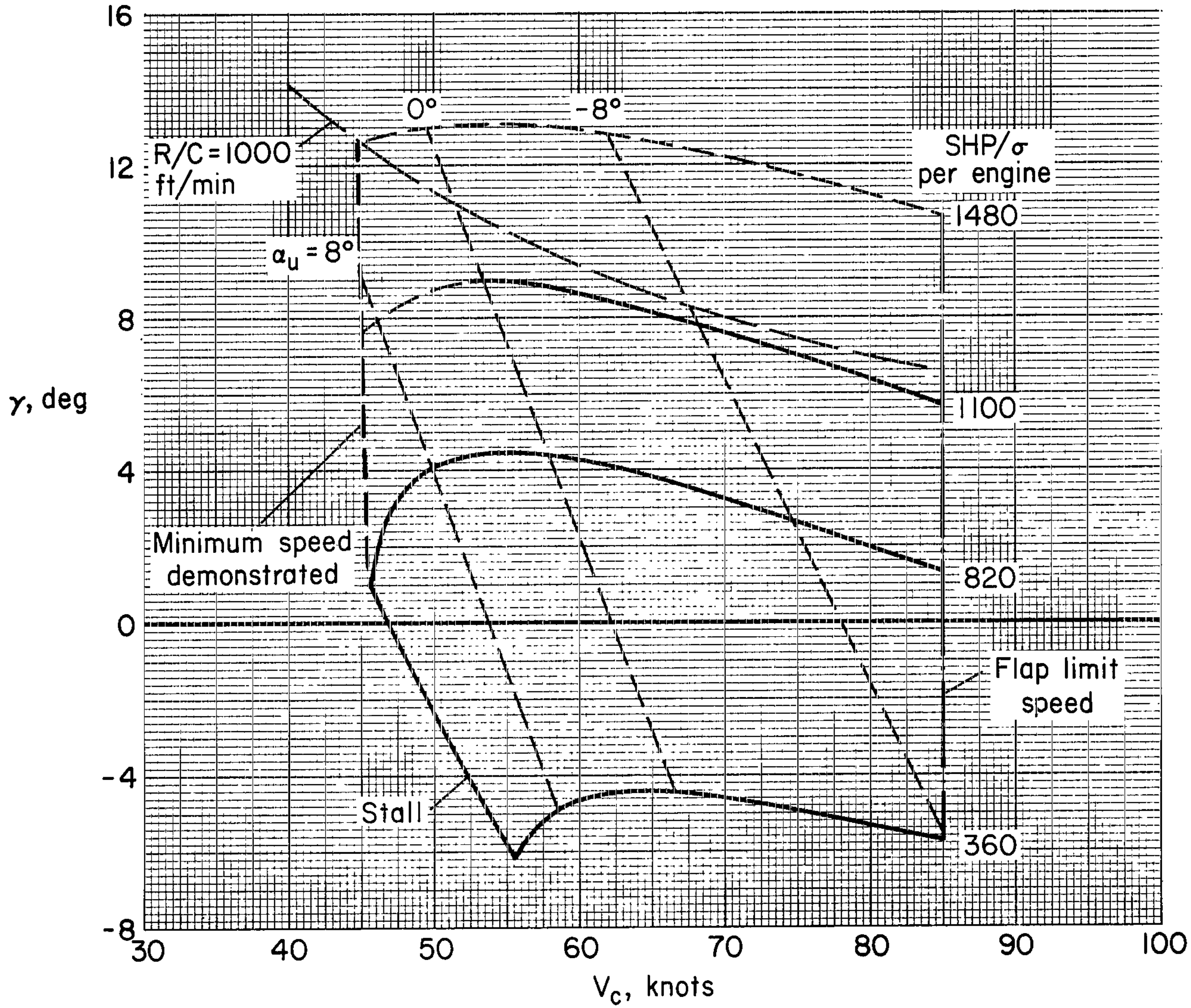
(d) Geometry of glide slope for two dots of course deviation indicator.

Figure 9.- Concluded.



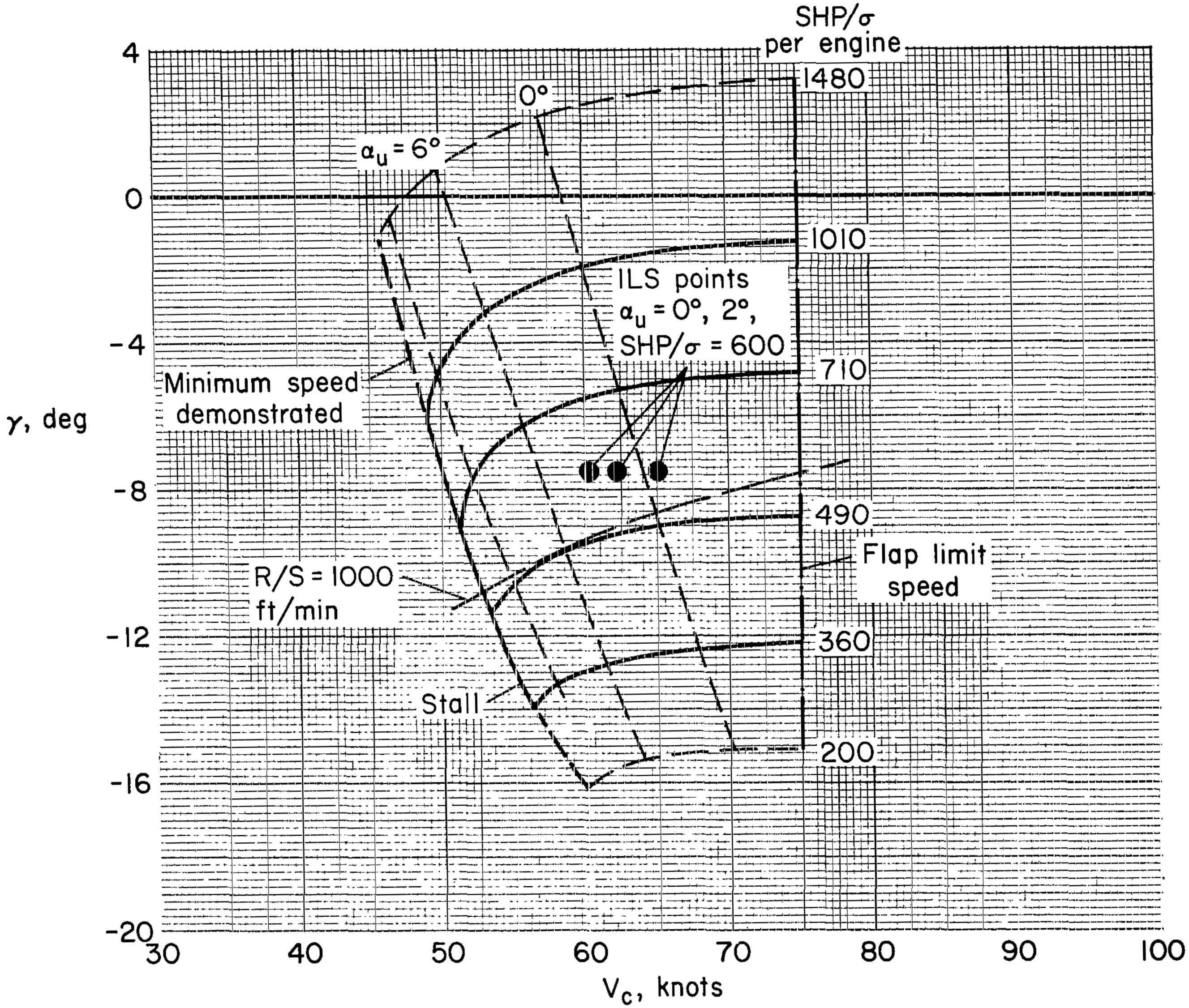
(a) Take-off configuration; δ_f = 45°, T = 0.

Figure 10.- Operational envelopes; W = 38,500 lb.



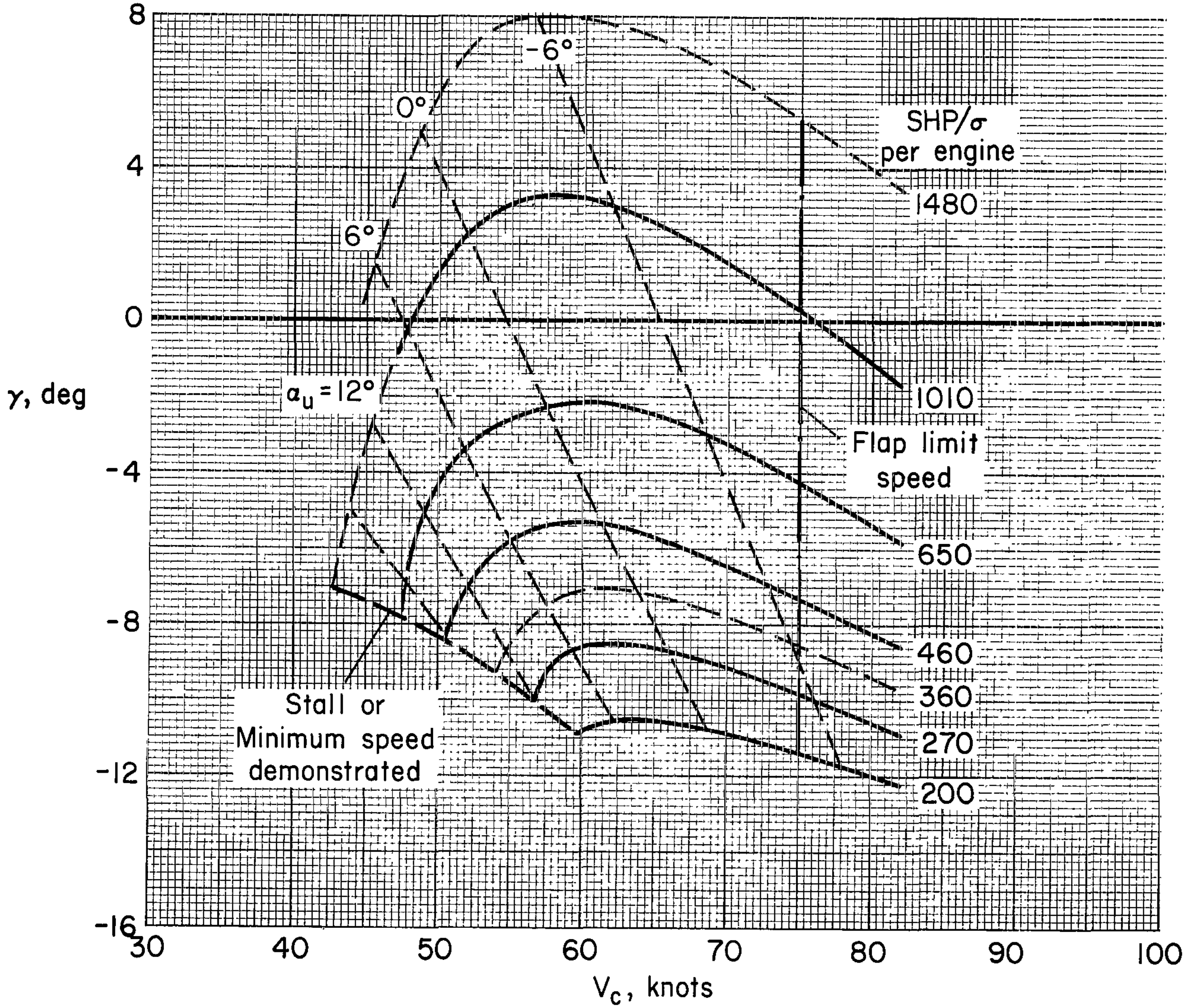
(b) Preapproach and wave-off configuration; δ_f = 72°, T = 0.

Figure 10.- Continued.



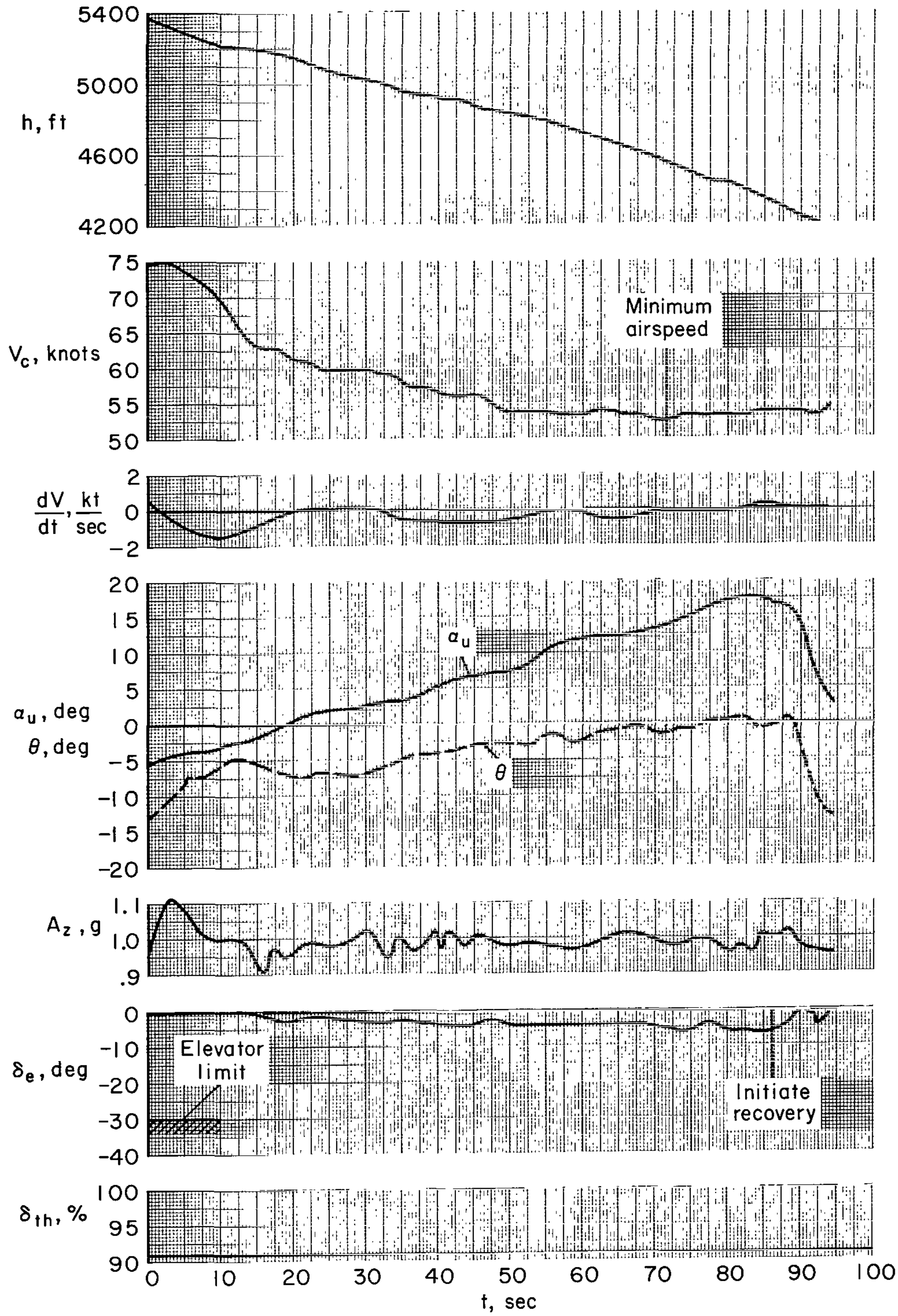
(c) Approach and landing configuration with transparency; δ_f = 98°, T = 12°.

Figure 10.- Continued.



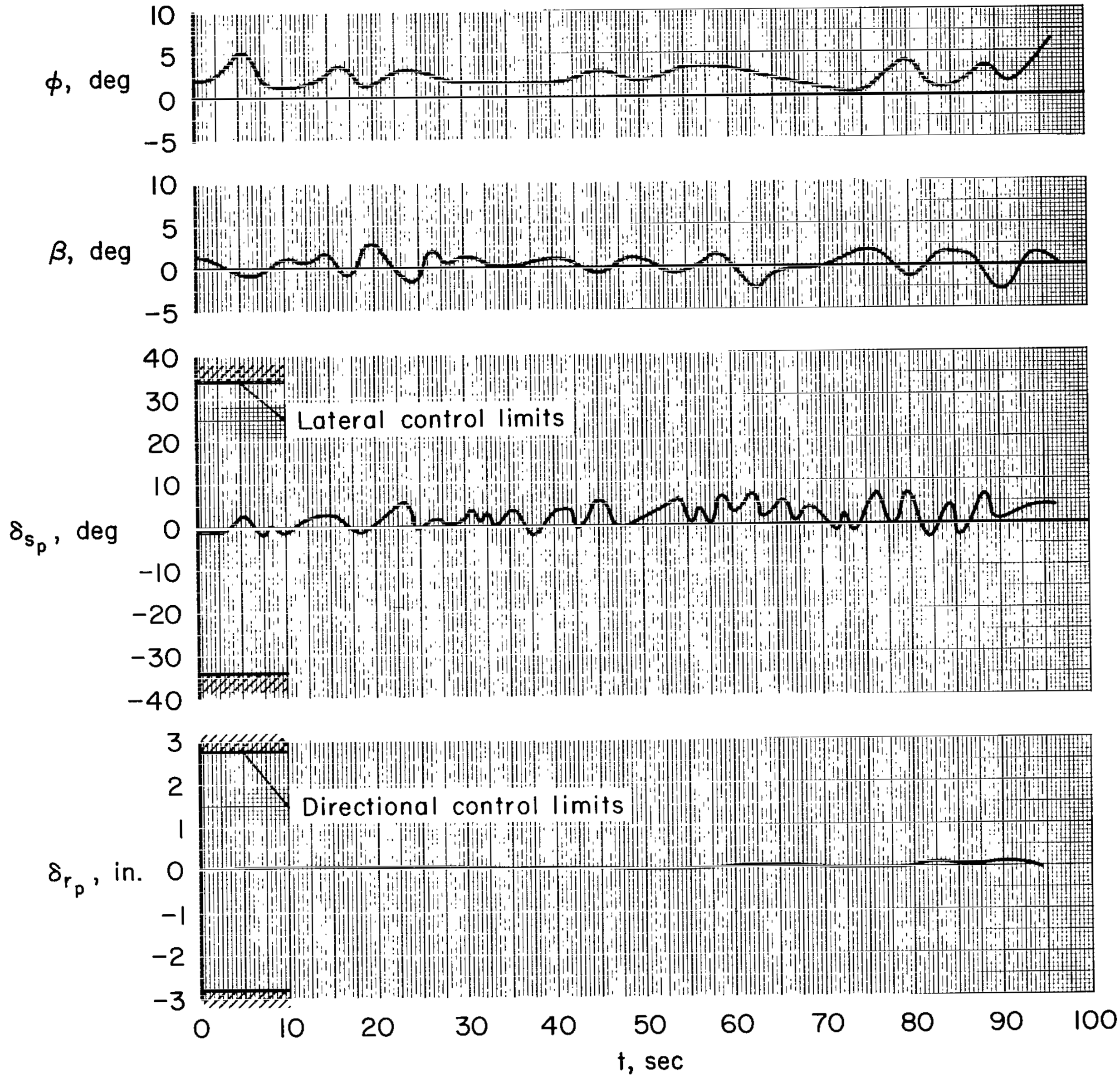
(d) Approach and landing configuration without transparency, 1963 tests; $\delta_f = 98°$.

Figure 10.- Concluded.



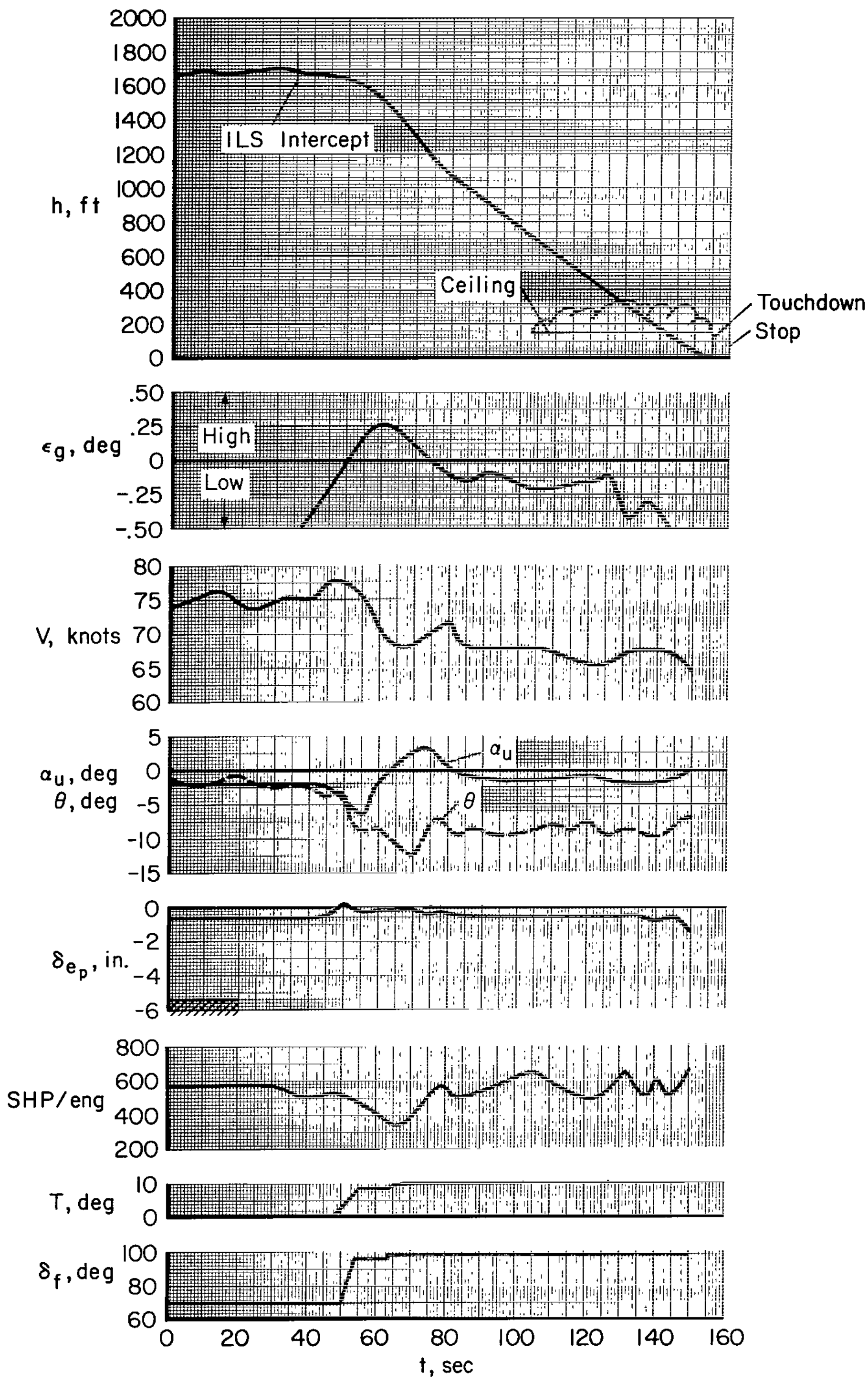
(a) Longitudinal parameters.

Figure 11.- Time history of unaccelerated stall; δ_f = 98°, T = 12°, W = 39,200 lb, c.g. = 30.8 percent $\bar{c}$, SHP/σ = 670/eng, σ = 0.87.



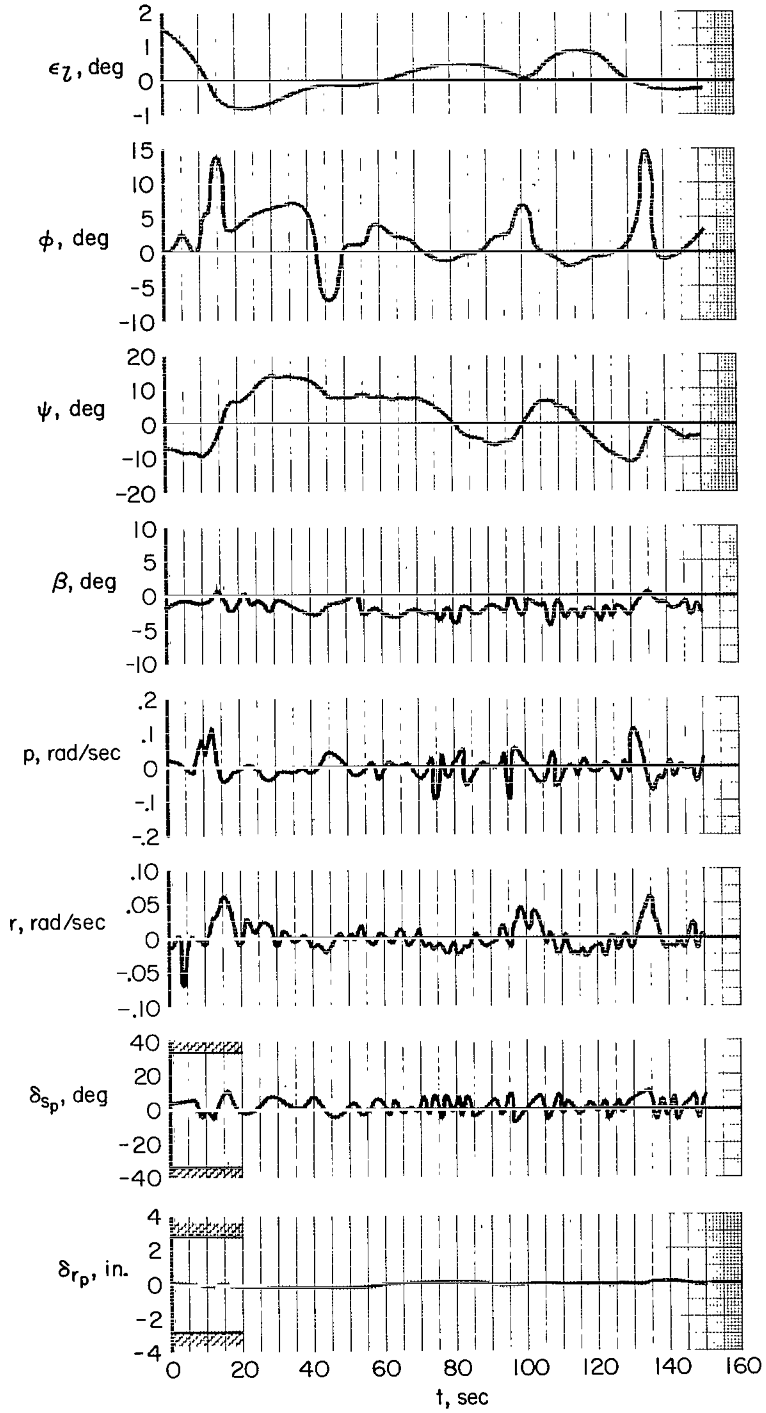
(b) Lateral-directional parameters.

Figure 11.- Concluded.



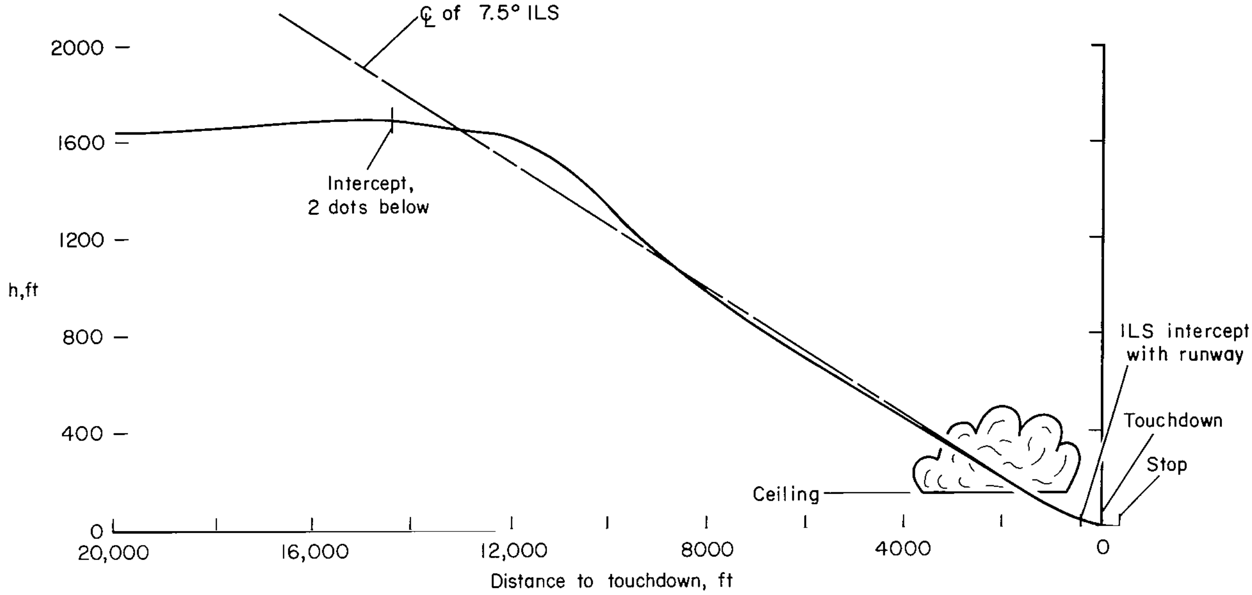
(a) Longitudinal parameters.

Figure 12.- Time history of landing on 7-1/2° ILS under actual IFR conditions; 3-knot wind, 70° left of runway center line.



(b) Lateral-directional parameters.

Figure 12.- Continued.



(c) Profile of approach.

Figure 12.- Concluded.

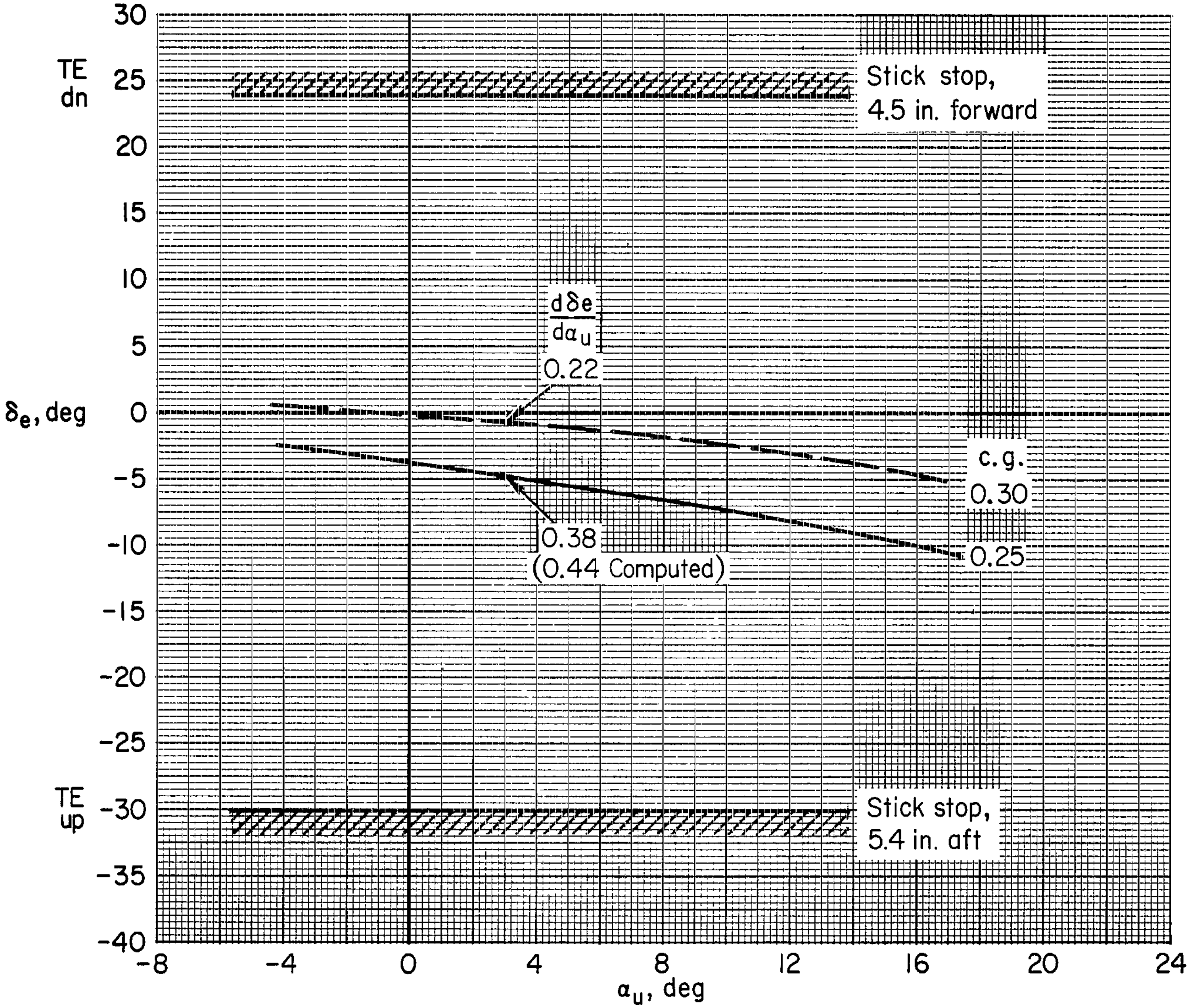
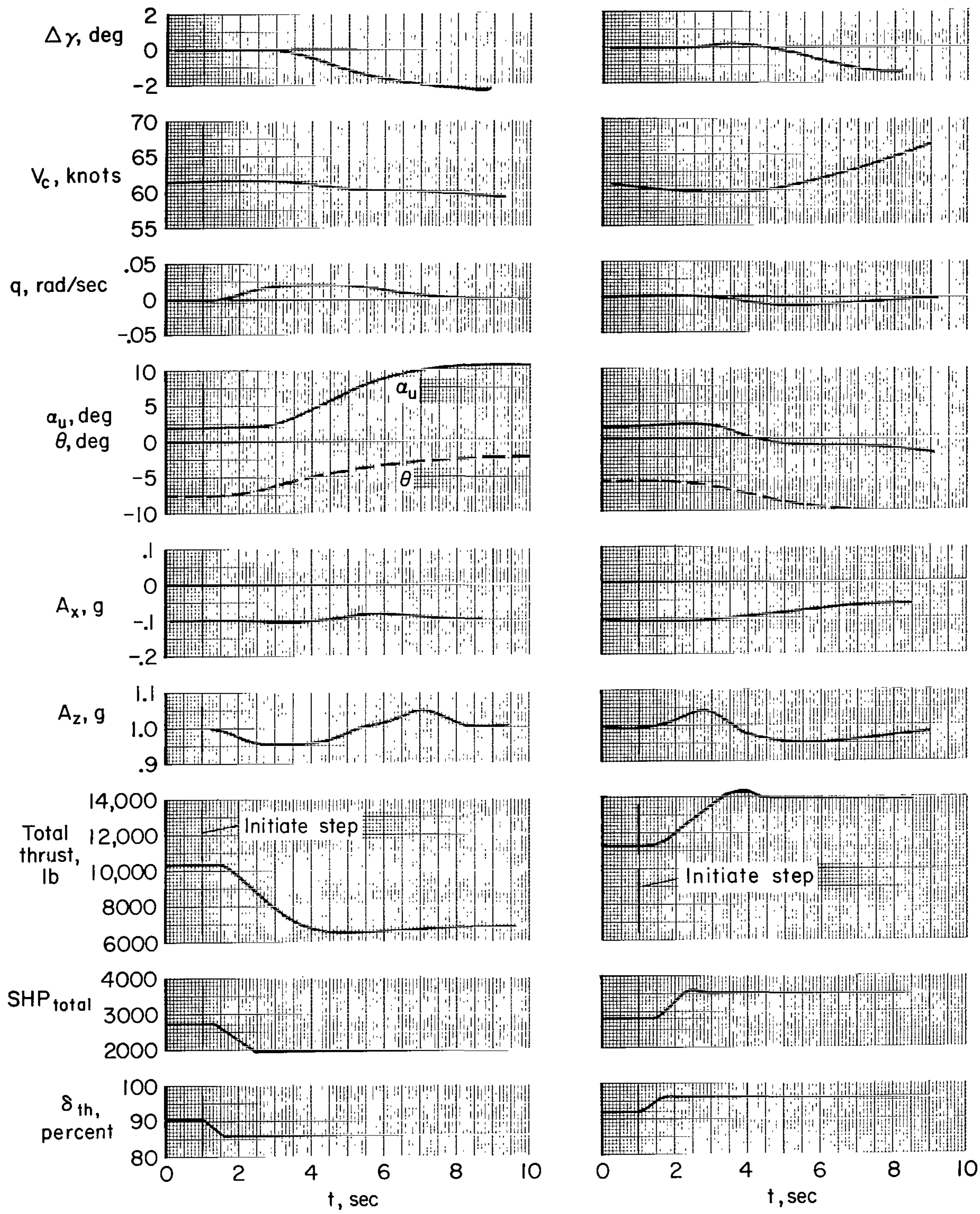


Figure 13.- Effect of center of gravity on stick position stability at $\delta_f = 98°$, $T = 12°$, $SHP/\sigma = 500/eng$, $W = 39{,}000$ lb.



(a) Decrease in power.

(b) Increase in power.

Figure 14.- Throttle steps without elevator interconnect; δ_f = 98°, T = 12°, δ_e = -7°.

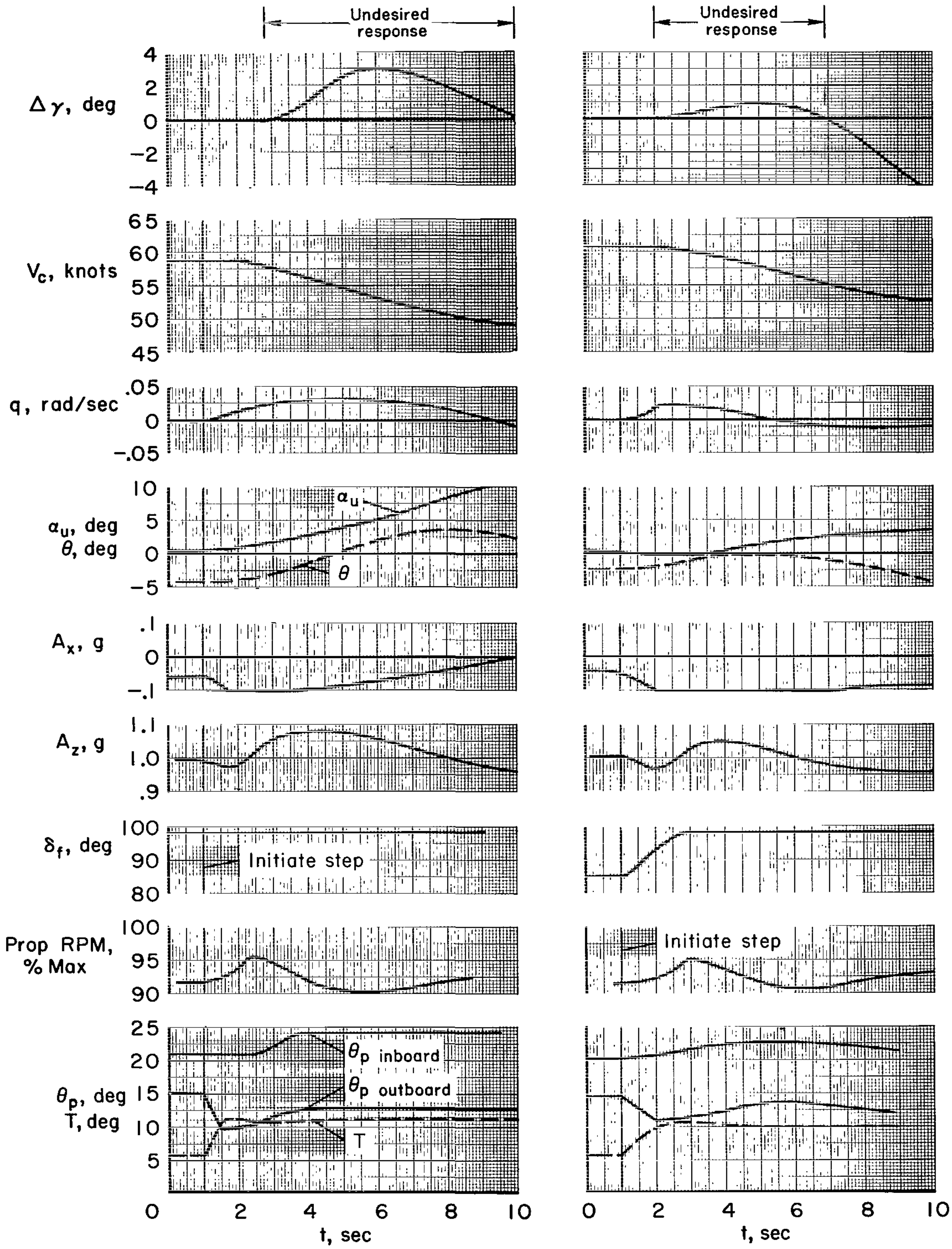


Figure 15.- Transparency step with constant δ_e = -6.5°; constant HP/prop = 750.

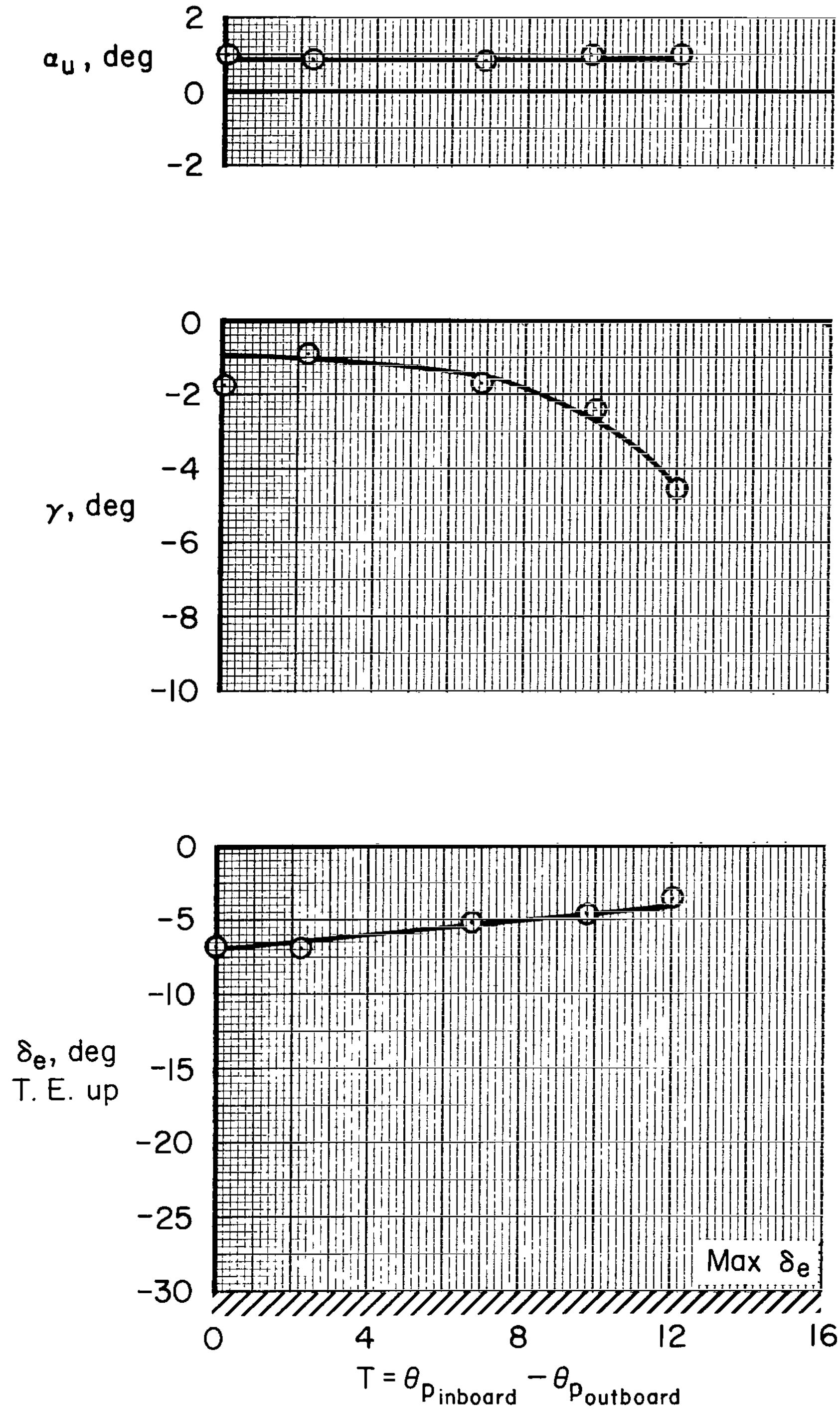


Figure 16.- Static effects of transparency; δ_f = 98°, SHP/σ = 940/eng, V_c = 55 knots.

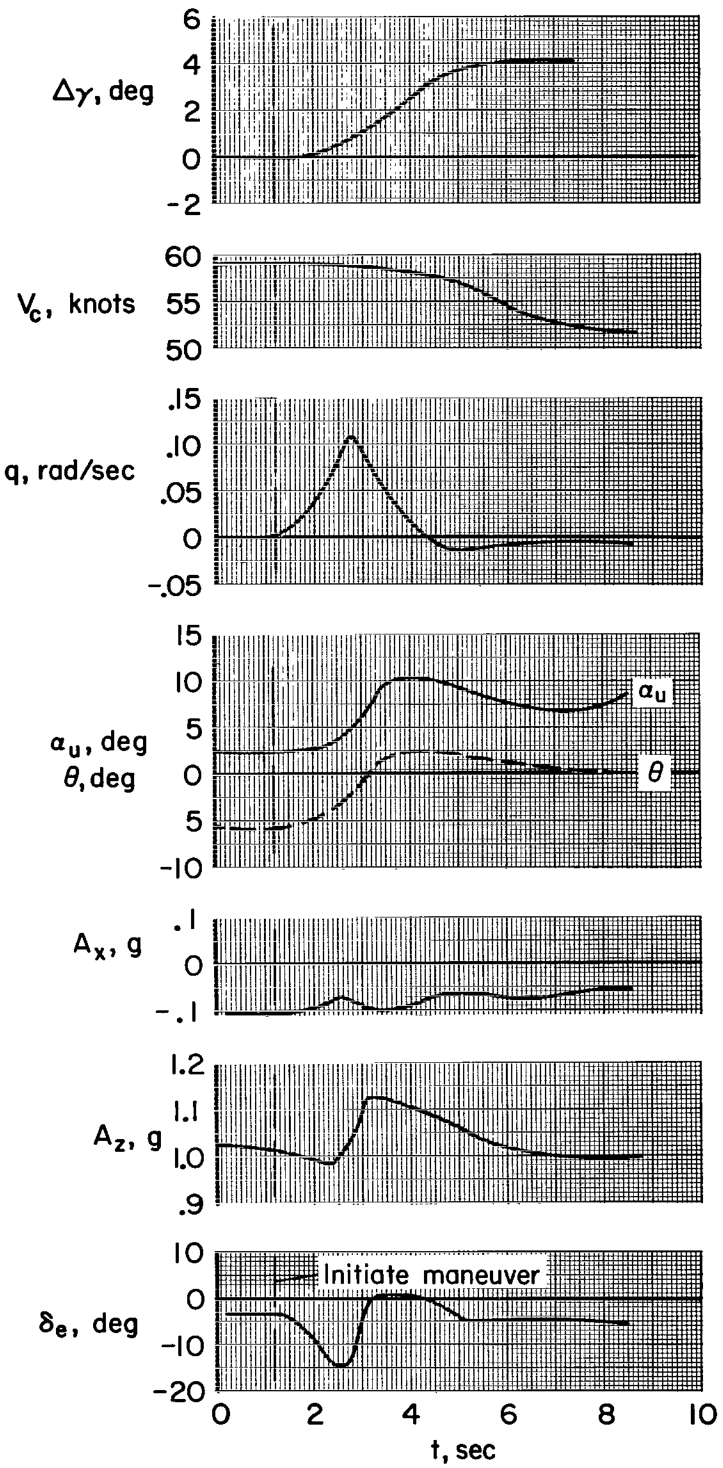
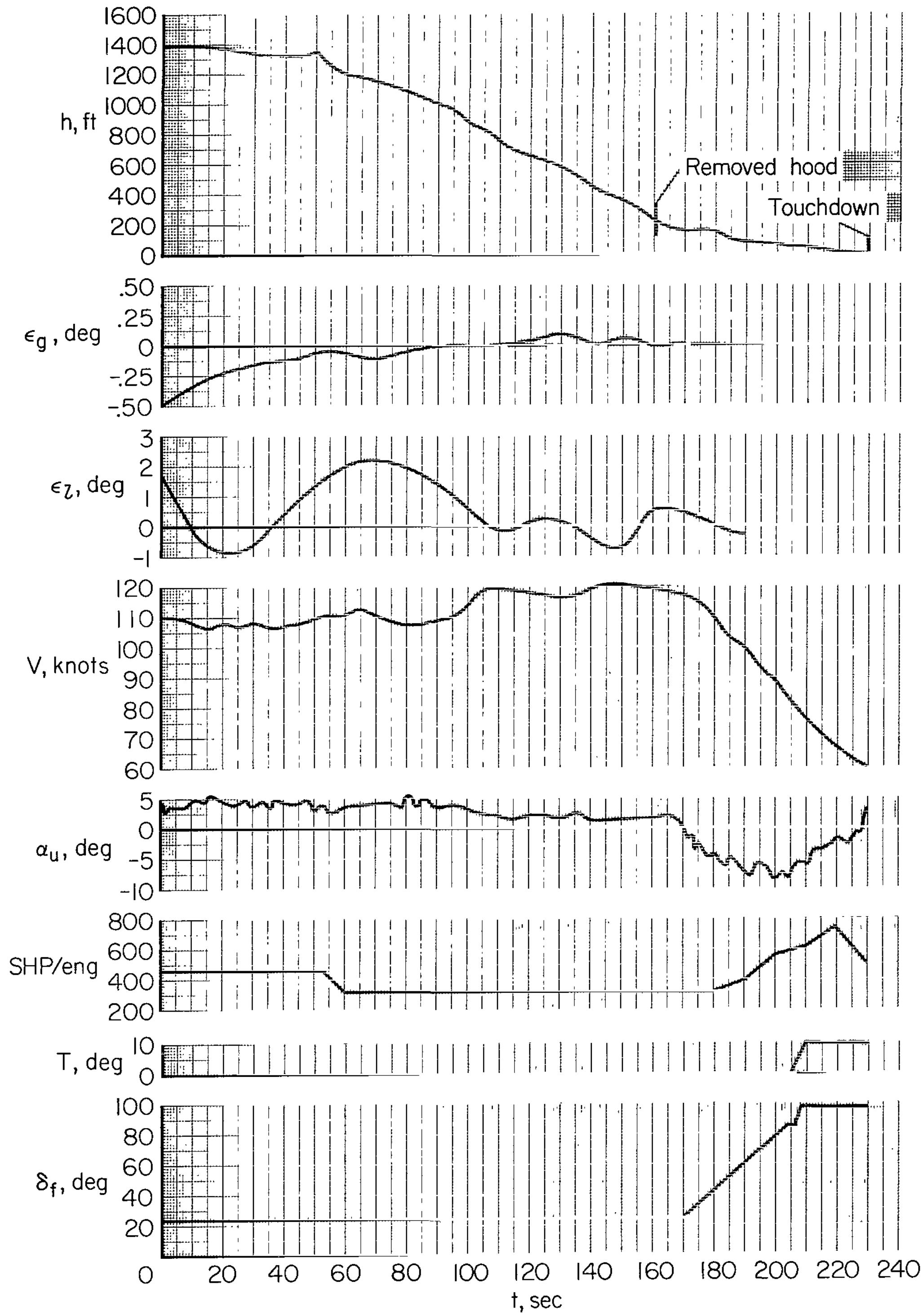
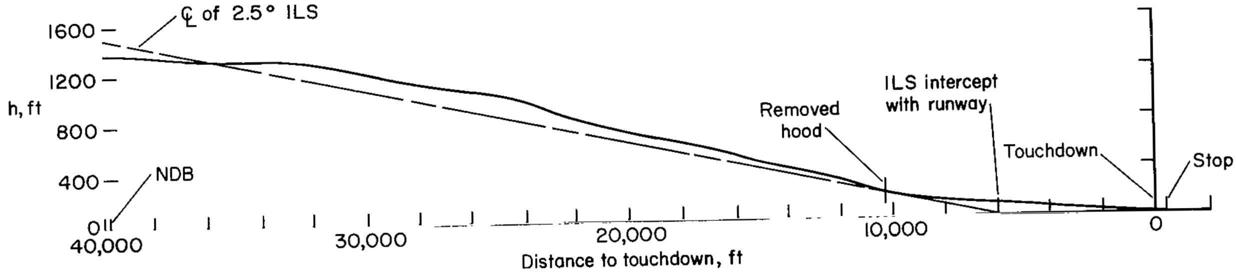


Figure 17.- Simulated "half flare"; δ_f = 98°, T = 12°, SHP/eng = 600, γ_o = -7-1/2°, h = 5,000 ft.



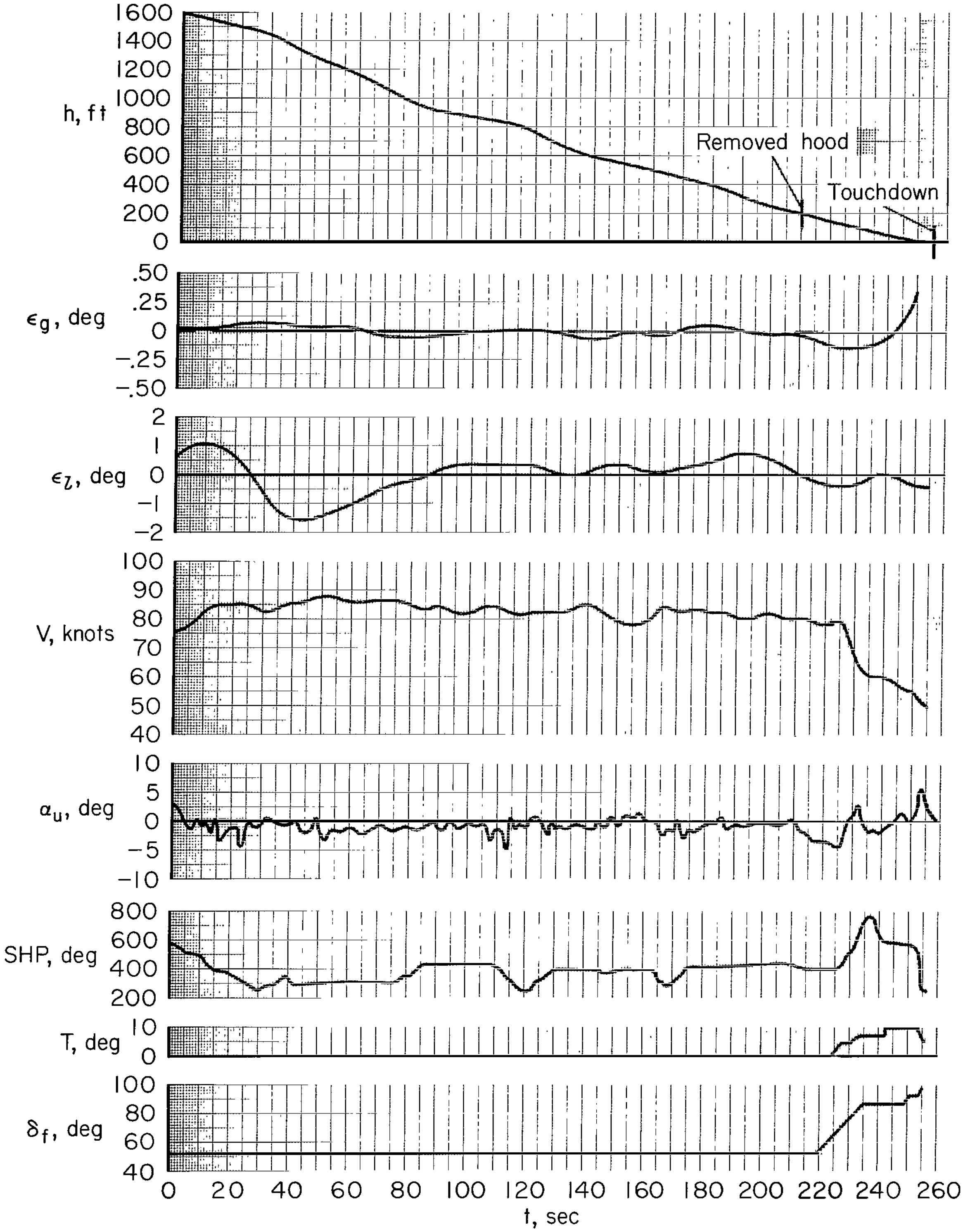
(a) Time history.

Figure 18.- 2-1/2° ILS approach at 115 knots, decelerating to STOL landing after breakout; 4-knot tailwind.



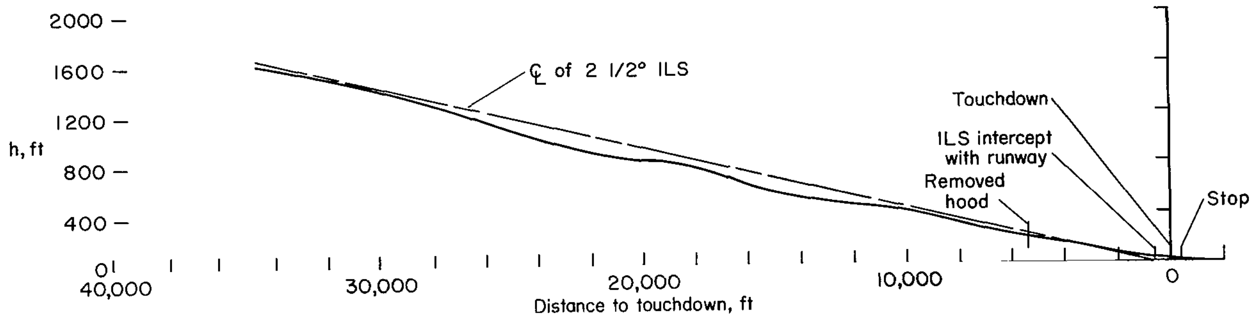
(b) Profile of approach.

Figure 18.- Concluded.



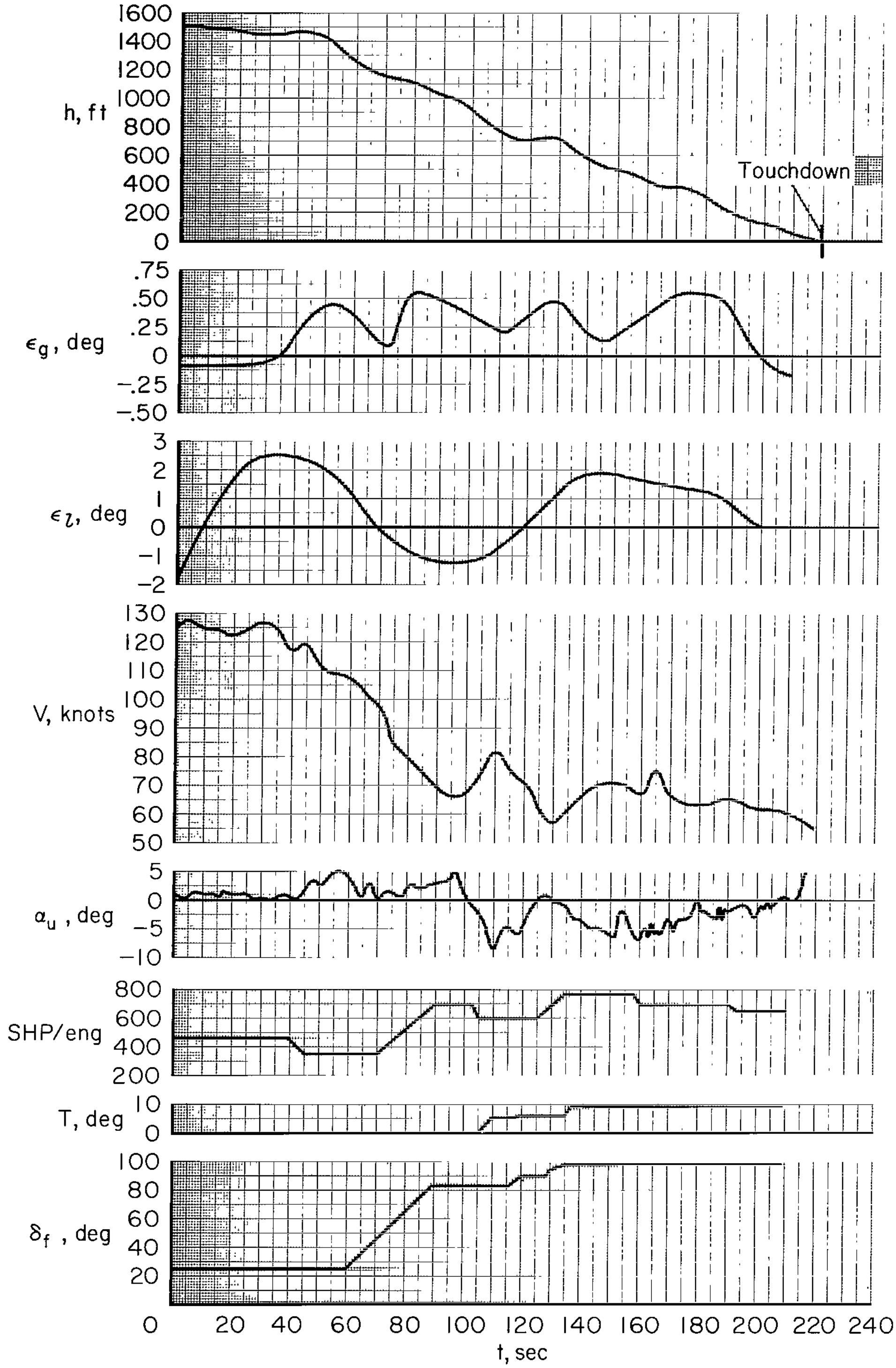
(a) Time history.

Figure 19.- 2-1/2° ILS approach at 80 knots, decelerating to STOL landing after breakout; 8-knot wind, 30° left of runway center line.



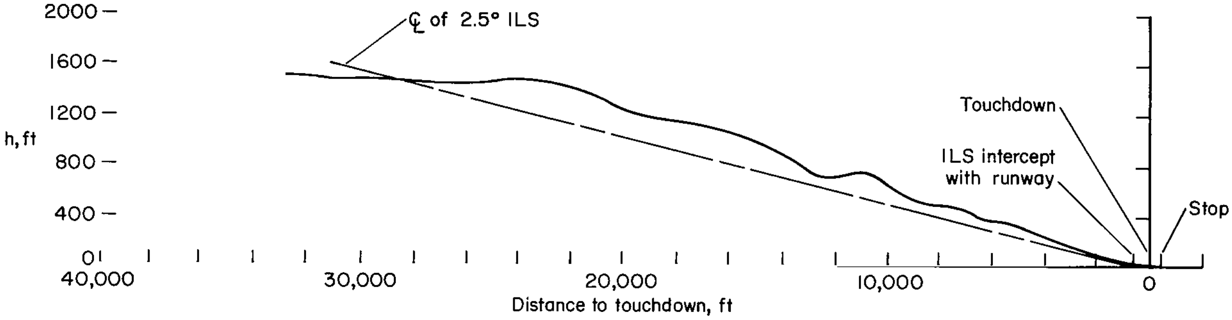
(b) Profile of approach.

Figure 19.- Concluded.



(a) Time history.

Figure 20.- 2-1/2° ILS approach decelerating to STOL speeds during IFR; 4-knot tailwind.



(b) Profile of approach.

Figure 20.- Concluded.

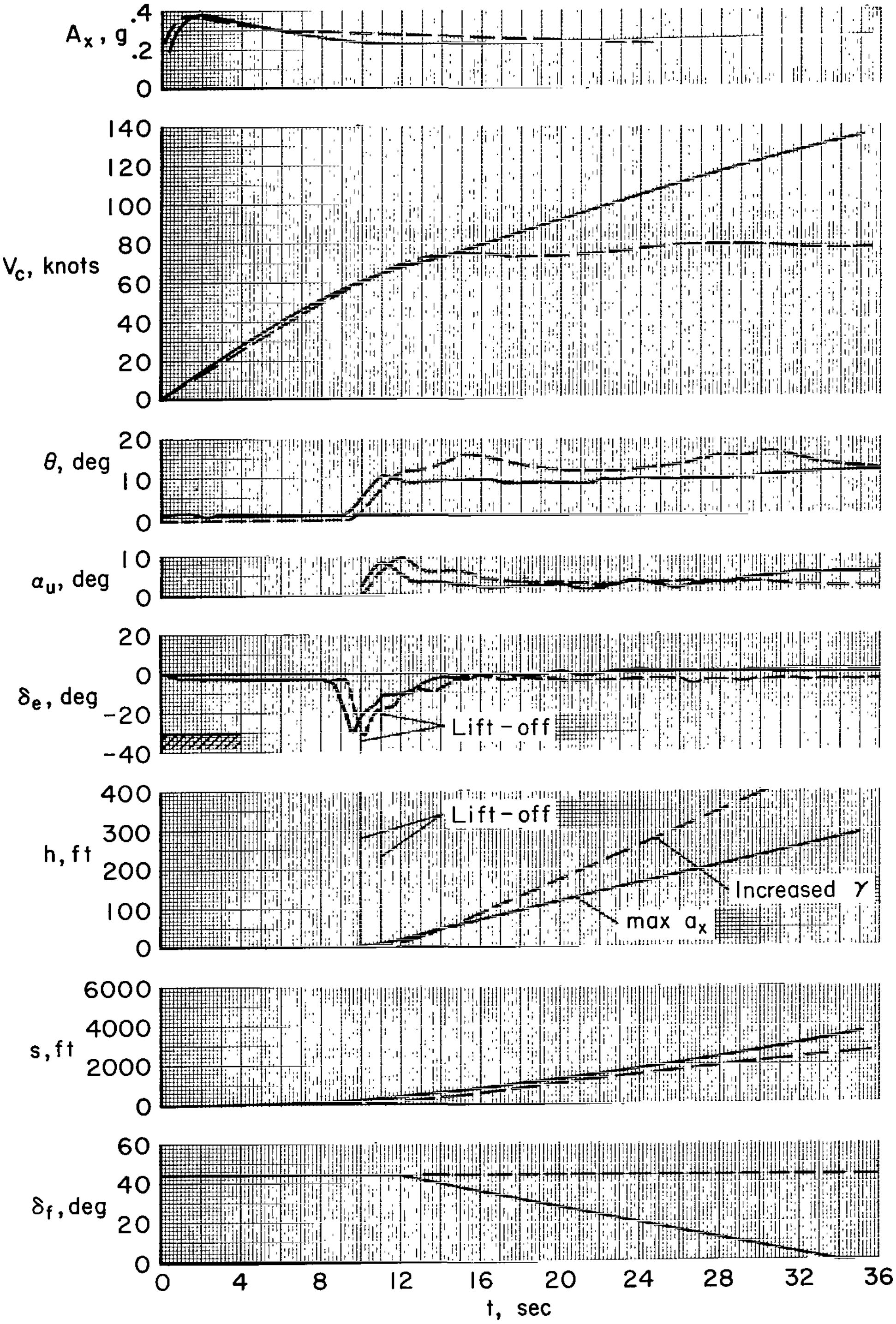


Figure 21.- Comparison of take-off at high acceleration during climb with take-off at high climb gradient and no acceleration; W = 39,500 lb, SHP/eng = 1240, σ = 0.98.

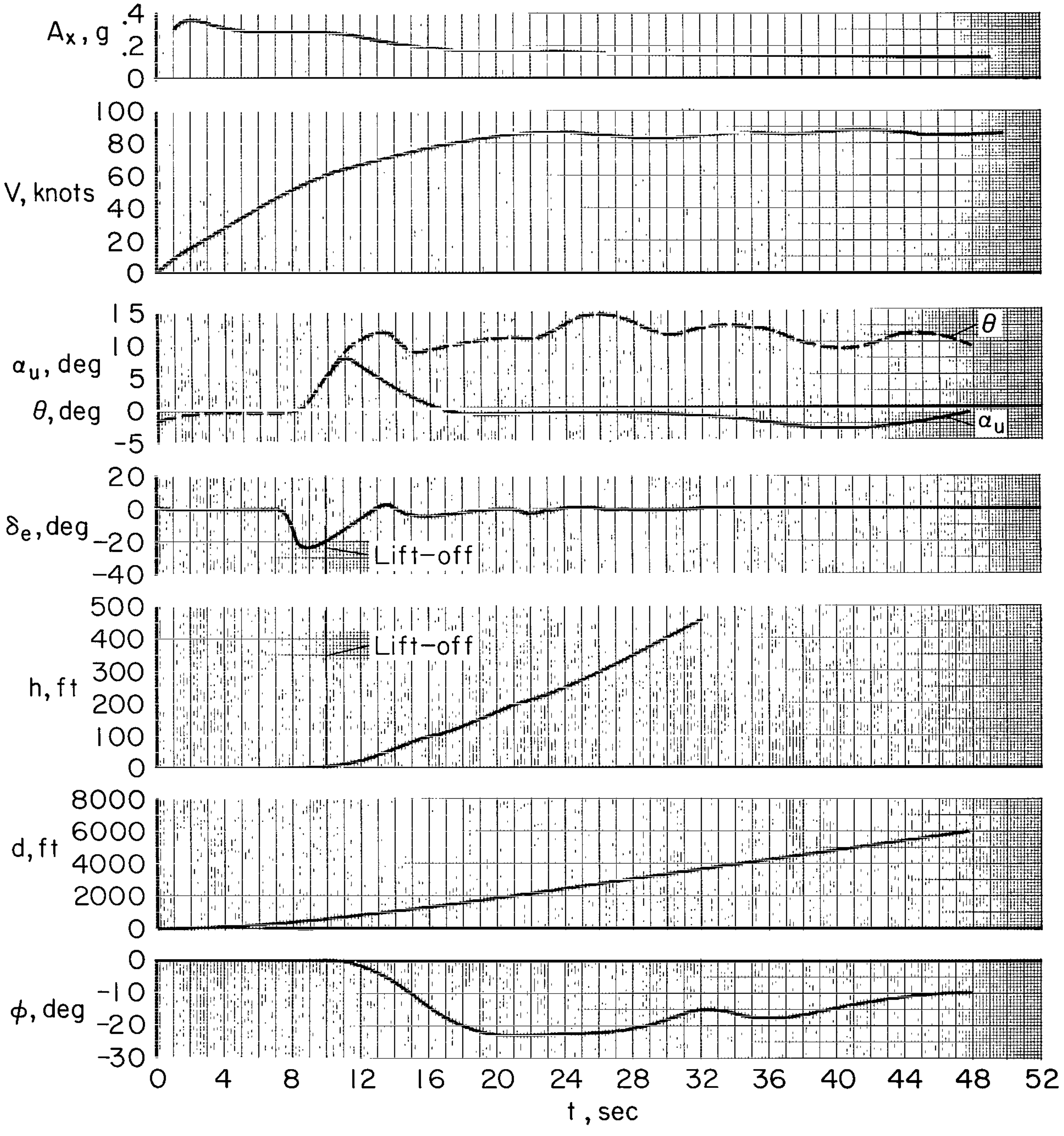


Figure 22.- Time history of a spiral take-off; W = 39,000 lb, SHP/eng = 1230, $\delta_f = 45°$, $\sigma = 1.02$.

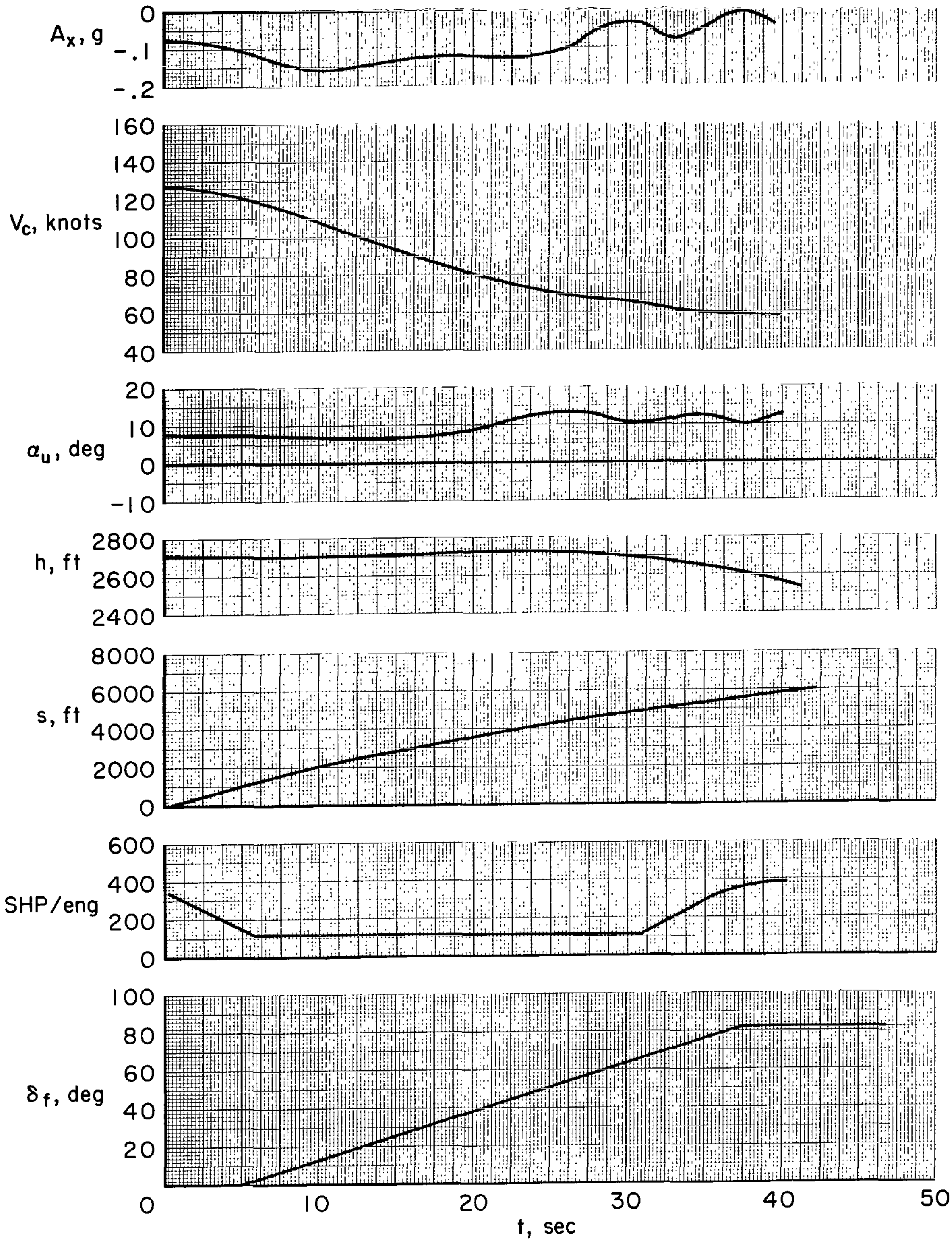


Figure 23.- Time history of level flight deceleration to approach configuration, no transparency.

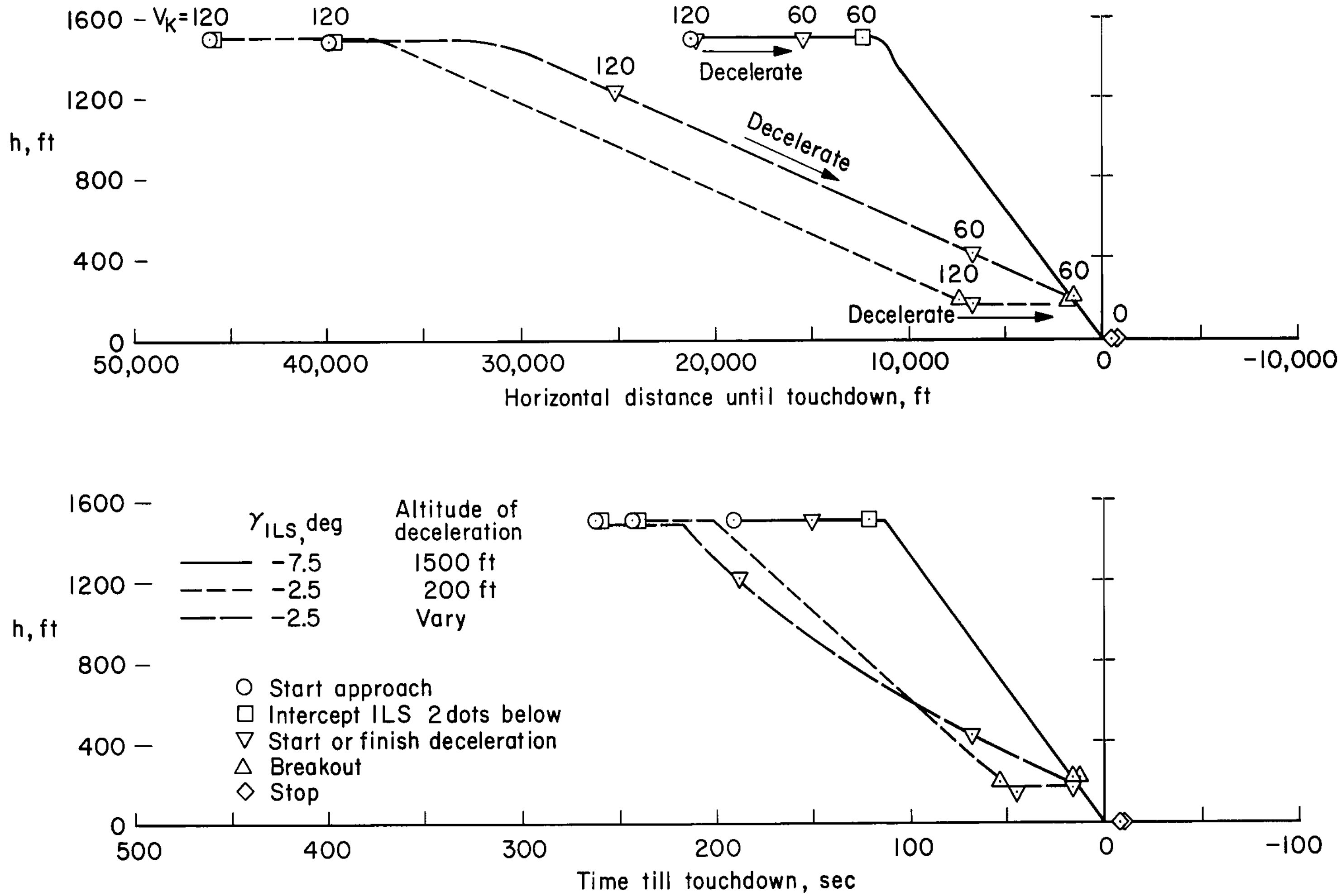
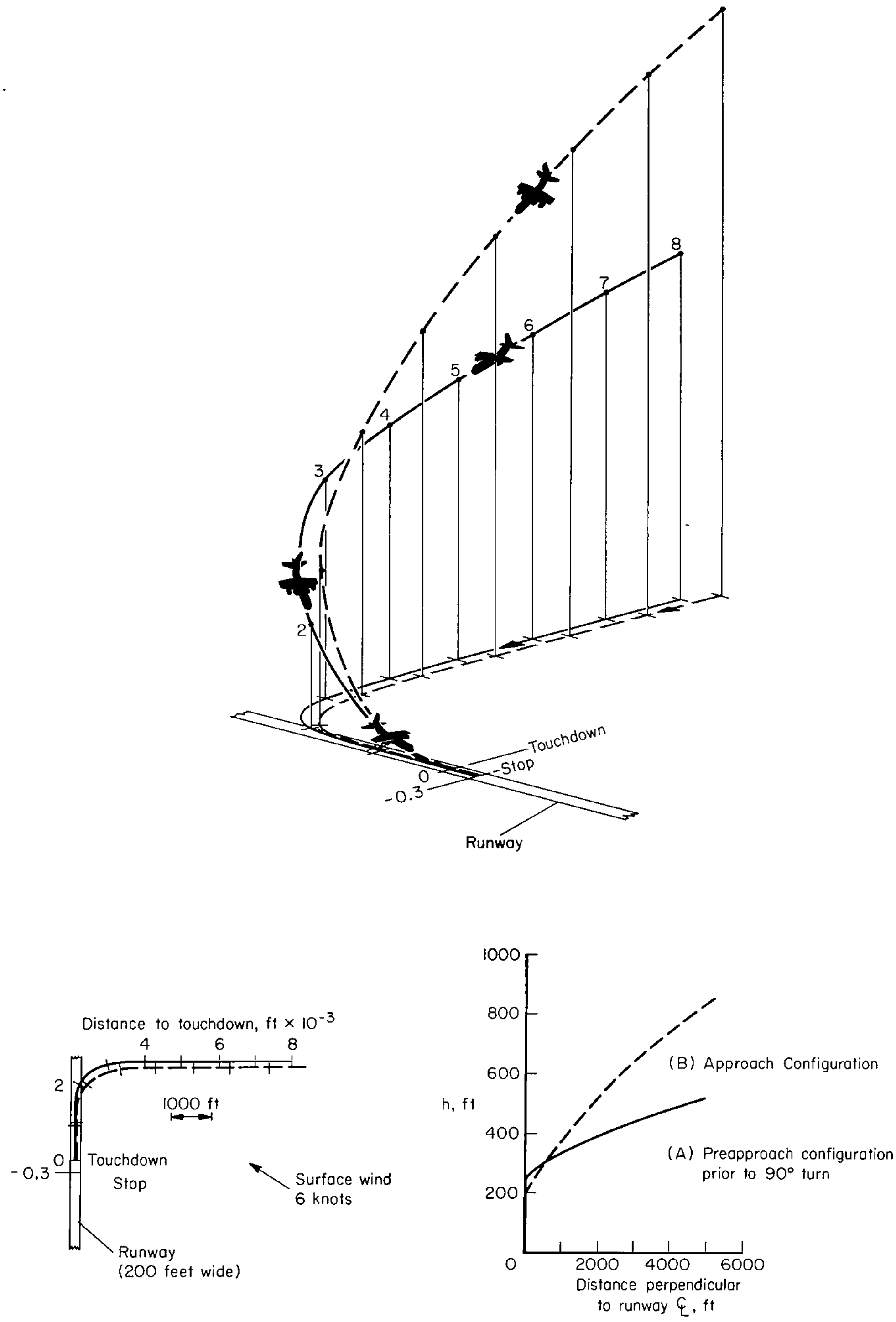
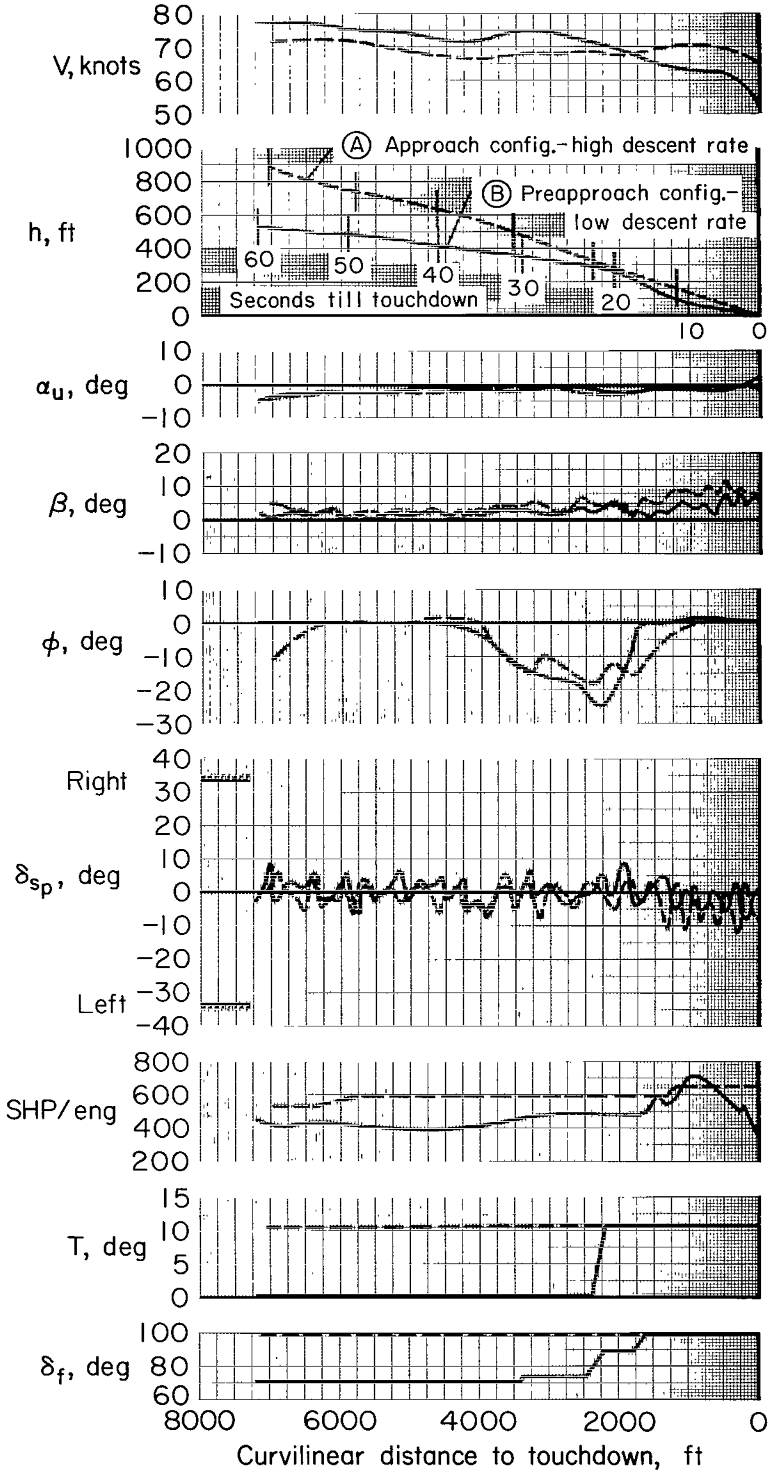


Figure 24.- Comparison of time and distance for three different ILS approaches.



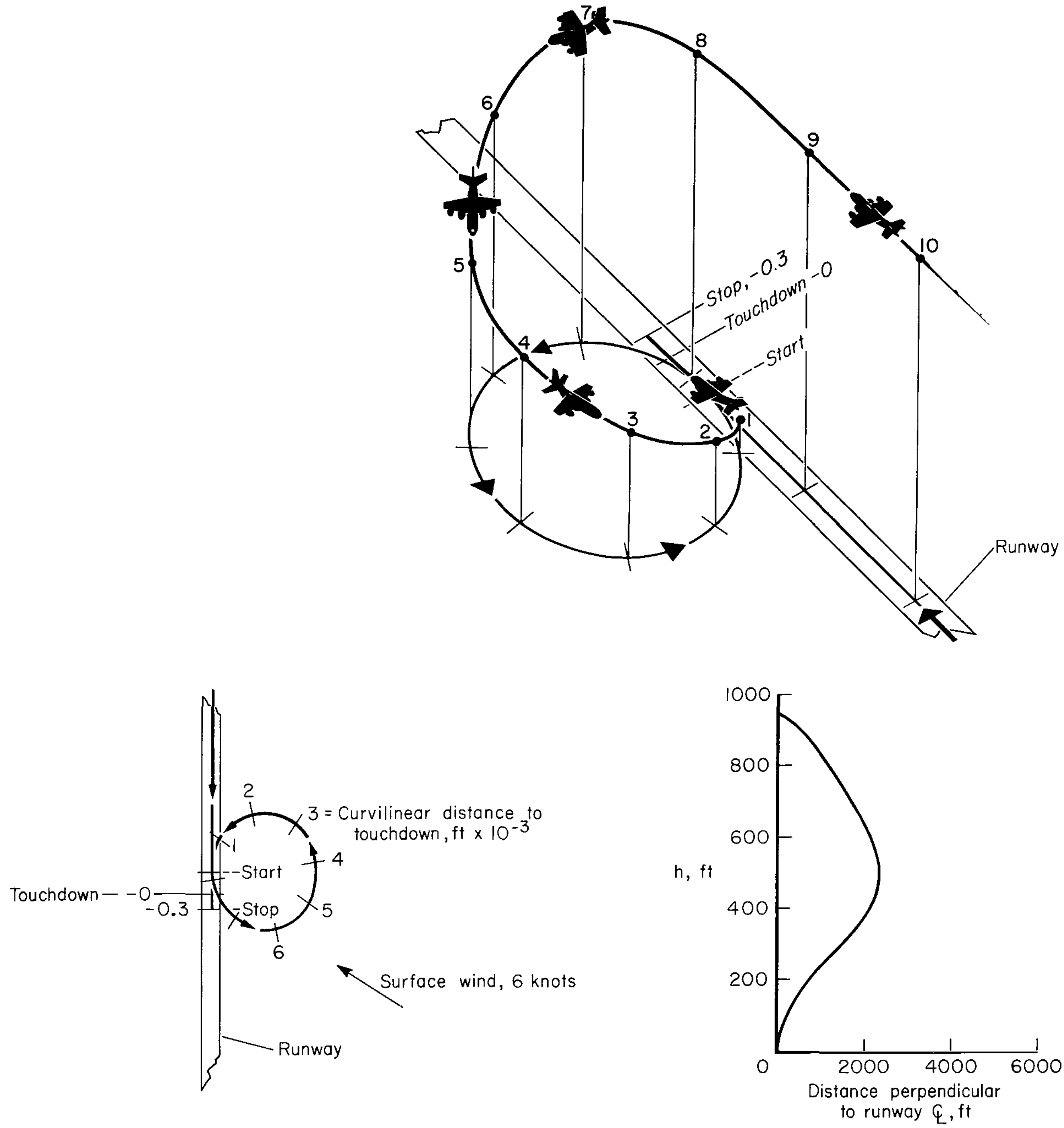
(a) Plan view. (b) Front view.

Figure 25.- Profiles and parameters for a low altitude 90° turn prior to landing; 6-knot wind, 70° left of runway center line.



(c) Variation of control parameters.

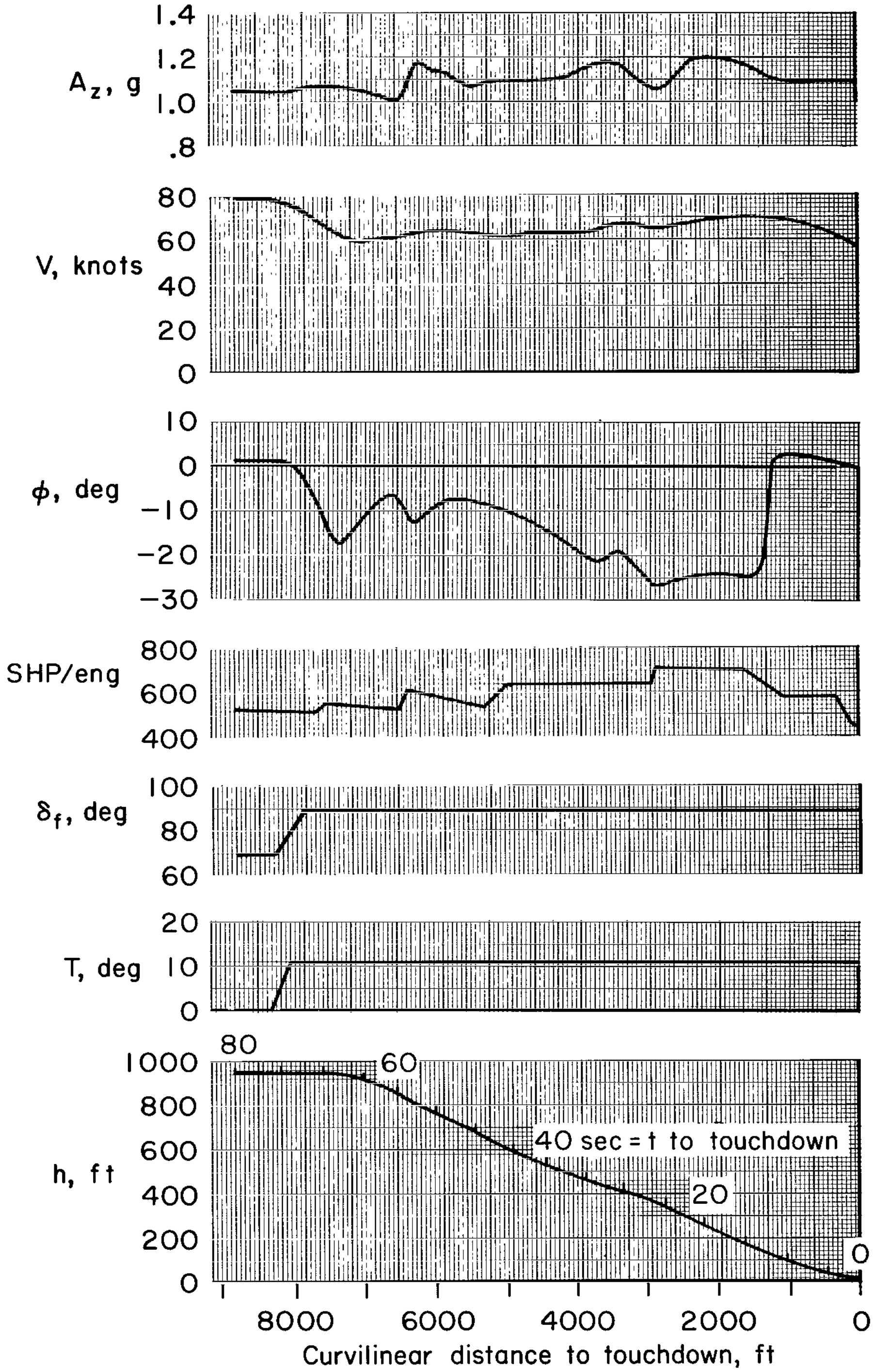
Figure 25.- Concluded.



(a) Plan view.

(b) Front view.

Figure 26.- Profiles and parameters for a circular approach and landing; 6-knot wind, 70° left of runway center line.



(c) Variation of control parameters.

Figure 26.- Concluded.

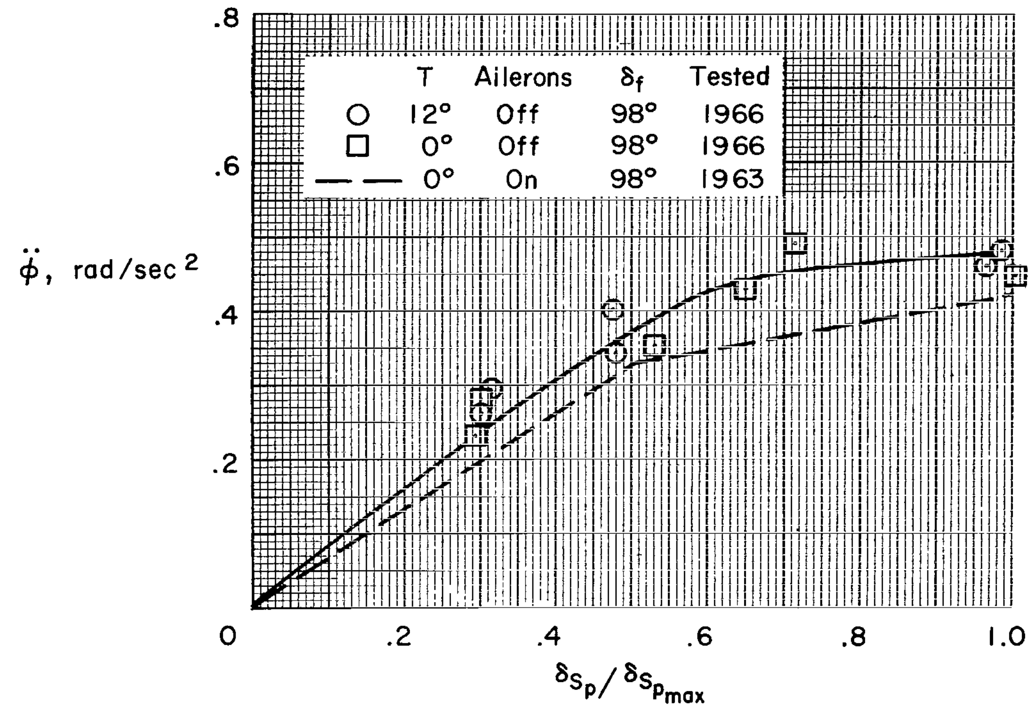


Figure 27.- Comparison of current lateral control in landing configuration with that tested previously.

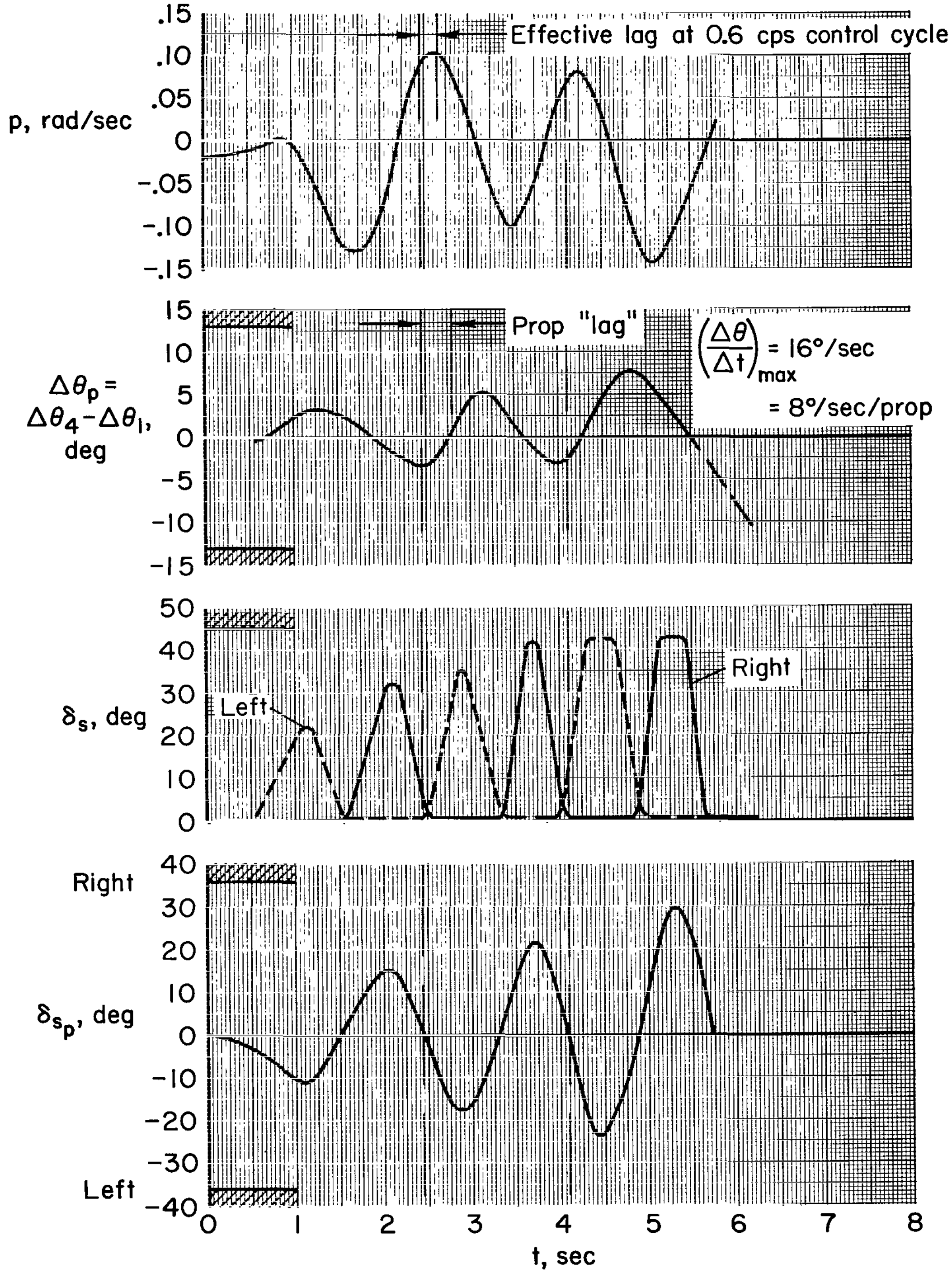


Figure 28.- Time history of lateral control cycling to determine reduction in damping due to propeller pitch rate limiting; δ_f = 98°, T = 12°, V_c ~ 60 k, SHP/prop ~ 800.

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