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HANDLING QUALITIES OF THE XB-70 AIRPLANE IN THE LANDING APPROACH

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16. Abstract

Approaches and landings during the XB-70 program were performed at various approach speeds, glide-slope angles, gross weights, runway offsets, and operational conditions. Representative time histories, pilot comments, and pilot ratings were obtained from these maneuvers. Stability and control data and limited correlations with predictions and handling-qualities criteria were also obtained.

The XB-70 flight experience indicated that the height of the cockpit above the runway in combination with nose-high landing attitudes and high approach speeds made the landing task more difficult than that for current subsonic jet transports. Three-degree glide slopes were considered unsatisfactory at the 200-knot indicated airspeed approaches required by the XB-70. The high rate of descent reduced the time available to accomplish the flare and, therefore, increased the possibility of a hard landing. Large changes in lift due to elevon deflection were satisfactory because of the high control effectiveness.

Laterally, the aircraft was sensitive to turbulence. Lateral-offset maneuvers simulating breakout from an overcast were not difficult; however, because of the higher approach speeds, excessive runway distances would be covered prior to touchdown and the adverse yaw accompanying aileron deflection was considered excessive. Sidestep maneuvering performance was adequately predicted by a simple technique.

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INTRODUCTION

As part of a continuing effort to document the significant characteristics of advanced aircraft for the benefit of aeronautical researchers and designers, the NASA Flight Research Center directed the joint NASA/USAF flight tests of the XB-70 aircraft from March 1967 to December 1968. The size, weight, and operational envelope of the XB-70 put it in the same class as proposed supersonic transports, therefore there is much interest in the characteristics of the XB-70 and the applicability of this information to the proposed supersonic transport as well as to large subsonic jet transports.

An area of concern for such large, high-performance aircraft is the handling qualities during landing approach. These aircraft are typified by long fuselages and high gross weights, which result in a large pitch inertia and long distances between the cockpit and main landing gear. Delta wings also contribute to nose-high attitudes, relatively large lift changes with pitch-control deflection, and adverse yaw due to aileron deflection. These characteristics have been studied on ground-based and airborne simulators (e.g., refs. 1 to 3), but flight with a vehicle of this class had not been possible before the XB-70 program.

Although the study of landing-approach handling qualities was not a primary objective of the XB-70 flight research program, data were obtained from approaches and landings made at various approach speeds, glide-slope angles, gross weights, runway offsets, and varying operational conditions such as crosswinds and light-to-moderate turbulence. Consequently, sufficient data were gathered to provide a useful compilation of landing-approach characteristics for this class of airplane.

This report presents pilot comments and rating data, representative time histories, stability and control data, and a limited correlation of flight results with predictions and handling-qualities criteria.

SYMBOLS

a_{n_p}	normal acceleration at pilot's location, g units
a_x	longitudinal acceleration at center of gravity, g units
a_{y_p}	lateral acceleration at pilot's location, g units

b	wing span, feet (meters)
C_L	lift coefficient, $\frac{\text{Lift}}{\bar{q}S}$
C_{L_α}	lift-curve slope, $\frac{\partial C_L}{\partial \alpha}$, per degree
$C_{L_{\delta_e}}$	variation of lift coefficient with elevon deflection, $\frac{\partial C_L}{\partial \delta_e}$, per degree
C_l	rolling-moment coefficient, $\frac{\text{Rolling moment}}{\bar{q}Sb}$
C_{l_p}	damping-in-roll derivative, $\frac{\partial C_l}{\partial \frac{pb}{2V}}$, per radian
$C_{l_r} = \frac{\partial C_l}{\partial \frac{rb}{2V}}$, per radian	
C_{l_β}	effective dihedral derivative, $\frac{\partial C_l}{\partial \beta}$, per degree
$C_{l_{\delta_a}}$	roll-control derivative, $\frac{\partial C_l}{\partial \delta_a}$, per degree
$C_{l_{\delta_r}} = \frac{\partial C_l}{\partial \delta_r}$, per degree	
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{\bar{q}S\bar{c}}$
$C_{m_{q+\dot{\alpha}}}$	pitch-damping derivative, $\frac{\partial C_m}{\partial \frac{(q+\dot{\alpha})\bar{c}}{2V}}$, per radian
C_{m_α}	static pitch-stability derivative, $\frac{\partial C_m}{\partial \alpha}$, per degree
$C_{m_{\delta_e}}$	pitch-control derivative, $\frac{\partial C_m}{\partial \delta_e}$, per degree
C_N	normal-force coefficient, $\frac{\text{Normal force}}{\bar{q}S}$, (approximately equal to C_L)

$C_{N_q} = \dfrac{\partial C_N}{\partial \frac{q\bar{c}}{2V}}$, per radian

$C_{N_\alpha} = \dfrac{\partial C_N}{\partial \alpha}$, per degree

$C_{N_{\delta_e}} = \dfrac{\partial C_N}{\partial \delta_e}$, per degree

C_n yawing-moment coefficient, $\dfrac{\text{Yawing moment}}{\bar{q}Sb}$

$C_{n_p} = \dfrac{\partial C_n}{\partial \frac{pb}{2V}}$, per radian

$C_{n_r} = \dfrac{\partial C_n}{\partial \frac{rb}{2V}}$, per radian

C_{n_β} static directional-stability derivative, $\dfrac{\partial C_n}{\partial \beta}$, per degree

$C_{n_{\delta_a}} = \dfrac{\partial C_n}{\partial \delta_a}$, per degree

$C_{n_{\delta_r}} = \dfrac{\partial C_n}{\partial \delta_r}$, per degree

C_y lateral-force coefficient, $\dfrac{\text{Lateral force}}{\bar{q}S}$

$C_{y_\beta} = \dfrac{\partial C_y}{\partial \beta}$, per degree

$C_{y_{\delta_a}} = \dfrac{\partial C_y}{\partial \delta_a}$, per degree

$C_{y_{\delta_r}} = \dfrac{\partial C_y}{\partial \delta_r}$, per degree

$\bar{c}$ mean aerodynamic chord, feet (meters)

d lateral-offset distance from runway, feet (meters)

F_n thrust, pounds (newtons)

g	acceleration of gravity, feet/second^2 (meters/second^2)
h_p	pressure altitude, feet (meters)
I_X, I_Y, I_Z	moments of inertia about X-, Y-, and Z-body axes, respectively, slug-foot^2 (kilogram-meter^2)
I_{XZ}	product of inertia referred to the body X- and Z-axes, slug-foot^2 (kilogram-meter^2)
L_α	dimensional lift-curve slope, $\frac{57.3\,\bar{q}S}{mV}C_{L_\alpha}$, per second
$L_{\delta_{c'}}$	dimensional variation of lift coefficient with control-column deflection, $\frac{\bar{q}S}{mV}C_{L_{\delta_e}}\frac{\delta_e}{\delta_{c'}}$, radians/second/inch (radians/second/centimeter)
L_{δ_e}	dimensional variation of lift coefficient with elevon deflection, $\frac{\bar{q}S}{mV}C_{L_{\delta_e}}$, radians/second/degree
$M_{\delta_{c'}}$	dimensional pitch-sensitivity derivative, $\frac{\bar{q}S\bar{c}}{I_Y}C_{m_{\delta_e}}\frac{\delta_e}{\delta_{c'}}$, radians/second^2/inch (radians/second^2/centimeter)
M_{δ_e}	dimensional pitch-control derivative, $\frac{57.3\,\bar{q}S\bar{c}}{I_Y}C_{m_{\delta_e}}$, degrees/second^2/degree
m	mass, slugs (kilograms)
N_{Z_α}	normal acceleration change per unit angle of attack, $\frac{V}{g}L_\alpha$, g per radian
$N_{Z_{\delta_e}}$	normal acceleration change due to elevon deflection, $\frac{V}{g}L_{\delta_e}$, g per degree
p, q, r	body-axis roll rate, pitch rate, and yaw rate, respectively, radians/second unless otherwise indicated
$\bar{q}$	dynamic pressure $\frac{1}{2}\rho V^2$, pounds/foot^2 (newtons/meter^2)
S	wing area, feet^2 (meters^2)
t	time, seconds

t_o	time for transition into and out of a sinusoidal bank-angle variation in a lateral-sidestep maneuver, seconds
V	true airspeed, feet/second (meters/second)
V_{apr}	approach airspeed, knots
V_i	indicated airspeed, knots
V_{td}	touchdown airspeed, knots
W	gross weight, pounds (kilograms)
α	angle of attack, degrees
$\dot{\alpha}$	time rate of change of angle of attack, radians per second
β	angle of sideslip, degrees
γ	flight-path angle, $\theta - \alpha$, degrees
$\delta_a, \delta_e, \delta_r$	average aileron, elevon, and rudder deflections, respectively; total aileron deflection that produces right roll, positive; trailing edge of both rudders to left, positive; trailing edge of elevon down, positive, degrees
$\delta_{c'}$	longitudinal control-column deflection, inches (centimeters)
δ_{max}	maximum average elevon deflection available from trim, degrees
ζ_d	Dutch roll damping ratio
ζ_{sp}	longitudinal short-period damping ratio
θ	pitch angle, degrees
ρ	mass density of air, slugs/foot^3 (kilograms/meter^3)
τ_r, τ_s	roll- and spiral-mode time constants, respectively, seconds
φ	bank angle, degrees
φ_{max}	maximum bank angle used in a lateral sidestep maneuver, degrees
ω_d	Dutch roll undamped natural frequency, radians/second
ω_{sp}	longitudinal short-period undamped natural frequency, radians/second

ω_{φ} constant term in numerator of the $\frac{\varphi}{\delta_a}$ transfer function

DESCRIPTION OF AIRPLANE

The XB-70 is a large, high-performance, delta-wing airplane designed for cruise flight at Mach 3. A three-view drawing of the airplane in the landing configuration is shown in figure 1, and a photograph of an actual landing is shown in figure 2. Physical dimensions of the aircraft are listed in table I.

In cruise flight, longitudinal control is provided by elevons and a canard. For takeoff and landing, however, the canard is locked, and all longitudinal control is provided by the elevons. The canard has flaps which are lowered full down (20°) for landing, as shown in figures 1 and 2. Lowering the flaps automatically locks the canard at 0° incidence. Down-elevon is required to trim out the canard-flap pitching moment. This down-elevon provides additional lift and additional control margin between trim and maximum up-elevon.

Roll control is provided by differential movement of the elevons. Yaw control is obtained by rotation of the two vertical stabilizers.

The airplane has a flight augmentation control system (FACS) that provides artificial damping about the pitch, roll, and yaw axes. Additional details on the XB-70 are given in reference 4.

INSTRUMENTATION

A pulse code modulation system was used that recorded approximately 1100 parameters. The system converts analog signals from the sensor to digital format and records the digitized data on tape on a time-sharing basis.

The instrumentation pertinent to this report is listed in table II. Included are instrument location, accuracy, range, and sampling rate of the sensor signals.

The Euler attitude, angular rate, and linear accelerometers were alined to within approximately 0.5° relative to the body axes.

The Edwards Air Force Base takeoff and landing phototheodolite facility was also used during the tests. This facility consists of Askania cinetheodolite equipment located in two towers positioned approximately 1 mile north and 1 mile in from each end of the 15,000-foot (4600-meter) main runway. (The main runway lies approximately east-west.) This facility can determine aircraft position to an accuracy of 1 foot to 5 feet (0.3 meter to 1.5 meters) and velocity to an accuracy of 2 feet per second (0.6 meter per second). Additional details on this facility are presented in reference 5.

CONDUCT OF TESTS

In the initial phases of the XB-70 testing, experience was gained primarily with routine approaches on shallow glide slopes of 1° to 2° and near the recommended approach speeds (e.g., 199 knots for 300,000 pounds (136,000 kilograms) gross weight). The main, 15,000-foot (4600-meter) runway was normally used. In the latter phases of the program, landing approaches and touchdowns were made from a 3° glide slope using a visual glide-slope-indicator light system.

A typical landing pattern for the XB-70 is illustrated in figure 3. Landing-pattern speeds were referenced to the recommended flare speed, which was a function of gross weight (table III). On most flights the landing weight was approximately 300,000 pounds (136,000 kilograms), and the center of gravity was between 23 percent and 24 percent of the mean aerodynamic chord. Typical speeds used on the downwind leg were 240 to 250 knots indicated airspeed (KIAS). Speeds on the base leg were 220 to 230 knots indicated airspeed, and final approach speeds were 200 to 210 knots. Touchdown speeds were typically 175 to 185 knots indicated airspeed. Thrust was normally reduced at flare initiation.

Also performed were ILS approaches, lateral- and vertical-offset approaches, and approaches at speeds 20 knots below the recommended final-approach speed. Throughout the program, there were several instances of turbulence and crosswinds during landing, as noted in table IV.

Because the ILS beam at Edwards intersected the runway 2400 feet (730 meters) from the approach end, a visual glide-slope indicator was used for all 3° glide-slope landings and most of the 3° glide-slope approaches. This enabled touchdowns to be made nearer the runway threshold so that more runway was available for runout in the event of brake or tire failure. The visual glide-slope indicator consisted of a unit installed approximately 800 feet (240 meters) from the approach end and 15 feet (4.6 meters) to the left of the runway. A high-intensity light source was projected on a concave mirror and beamed through a series of amber, white, and red filters. The center beam, which was white and approximately one-half degree in depth, served as the glide-path reference. The amber light indicated aircraft position above the glide path, and the red light indicated aircraft position below. Under typical weather conditions the light was detectable as far away as 8 miles.

Data were obtained from full-stop landings, touch-and-go landings, and low approaches. Tables IV(a), IV(b), and IV(c) summarize the landing and approach maneuvers performed during the program. In addition, stability and control maneuver sets and handling-qualities evaluations were performed at representative approach speeds at altitudes of 8000 feet to 15,000 feet (3000 meters to 4600 meters). These test conditions are summarized in table IV(d). Stability and control sets generally consisted of a pull-up and release, wind-up turn, double aileron pulse, double rudder pulse, and steady sideslip. Some phugoid oscillations were also obtained. The handling-qualities maneuvers included altitude changes of plus and minus 2000 feet (610 meters) and lateral-directional maneuvers. The lateral-directional maneuvers consisted of a roll into a turn at a normal rate followed by a 20° heading change utilizing a 25° bank angle. A relatively high roll rate was used to recover from the turn. The maneuver was performed both coordinated and uncoordinated. In addition, some aileron roll maneuvers were obtained.

Occasionally, landings were made on a dry lakebed adjacent to the main runway because of emergencies such as hydraulic failure. The lakebed provided a runway approximately 7 miles long with unrestricted approaches. These landings were not typical of normal landings, but they did contribute to the pilots' background and experience.

Four pilots participated in the flight-research program with the XB-70 airplane. Two of these pilots (A and B) participated in the Air Force envelope-expansion program and were qualified in the airplane before the NASA/USAF program began. The other two pilots (C and D) were checked out in the vehicle during the NASA/USAF program.

Pilot ratings and comments were obtained throughout the program by using the rating scale of table V (from ref. 6) and the questionnaires of tables VI and VII as guidelines. Ratings and comments were based on the suitability of the observed characteristics for civil transport missions.

The indicated airspeeds listed in table IV were obtained from the pilot's reports where possible. When these speeds were not reported, data recorded onboard the airplane were analyzed to obtain the information. A cross-check of speeds reported by the pilot, onboard recorded data, and speeds determined by the phototheodolite facility was made for several landings. All three speeds usually agreed within ±5 knots.

RESULTS AND DISCUSSION

Longitudinal and lateral-directional handling qualities are discussed in this section. General comments and typical time histories are presented, as well as pilot comments and ratings and criteria and quantitative results. The criteria and nominal characteristics were calculated from flight-determined stability derivatives.

Longitudinal Handling Qualities

Table IV presents approach and landing conditions for several XB-70 landings. Estimates of sink rates at touchdown obtained from phototheodolite data are also included. It can be seen that the pilots were successful in attaining low sink rates.

Most of the approaches were flown near the recommended approach speeds (fig. 4), with touchdown speeds also near the recommended speeds. However, the recommended approach speeds in figure 4 are 8 knots higher than the original estimates obtained from the Pilot's Handbook, and the minimum touchdown speeds are 12 knots higher. These increments were added early in the XB-70 program to allow for uncertainties in the airspeed indication resulting from instrument and position error and to provide additional insurance against hard landings. Thus, during normal approaches and landings, the XB-70 indicated approach and touchdown speeds were 10 to 20 knots higher than originally estimated. Some landings were made on the lakebed runway with an indicated touchdown speed equal to or slightly less than the original minimum value. However, these were emergency landings on which shallow glide slopes were used and the airplane was often allowed to "float" for a considerable distance before touching down.

Later tests in the XB-70 program indicated that the airspeed position error during approach and landing was approximately 5 knots; that is, actual airspeeds were 5 knots higher than the airspeeds presented to the pilot. If this is taken into account, XB-70 approach and landing speeds were 15 to 25 knots higher than the original estimates.

Figure 5 is a time history of a typical landing from a 3° glide-slope approach. Elevon deflection varies from the approach-speed trim value of approximately 10° trailing edge down to approximately 1° in the flare. Angle of attack varies from the trim value of 7.5° to a peak of about 9° in the flare. The pilots had a tendency on the steeper approaches to "duck under" the reference glide slope as they got near the runway. This enabled them to perform the last part of the approach at a somewhat reduced glide slope and touch down nearer the runway threshold.

Two approaches (without touchdown) were made on a 3° glide slope at 185 knots, which was approximately 15 knots below the recommended speed shown in table III and approximately 7 knots below the speed originally recommended (fig. 4). If position error is considered, however, these approaches were within 2 knots of the original recommended approach speed. A time history of one of these approaches is shown in figure 6. Since a touchdown was not made, a flare was not performed. The trim angle of attack was approximately 10°. Although speed was held fairly constant until power was increased for a go-around at approximately 45 seconds, much more throttle activity was used in these approaches than in normal landings, as shown in figure 7. This figure presents time histories of the throttle activity from the landing and approach maneuvers in figures 5 and 6. As shown, much larger throttle changes were required when the approach was made at 185 knots than at the normal speed of 210 knots.

An ILS approach with a vertical offset was flown to evaluate the handling qualities of the airplane when descending to intercept the normal ILS glide slope after crossing the outer marker higher than the prescribed altitude. The outer marker was located 7.0 nautical miles from the runway and should have been intercepted 2300 feet (700 meters) above the runway elevation. For this test the outer marker was intercepted 3150 feet (960 meters) above the runway elevation; however, the airplane was reestablished on the correct glide slope by the time it was 1000 feet (300 meters) above the runway. The maneuver was considered routine.

Pilot comments and ratings. – Pilot comments on the longitudinal handling qualities are summarized in table VIII. Detailed comments are presented in the appendix. Generally, the pilots had high praise for the longitudinal handling qualities of the XB-70 in the landing approach. Speed stability and engine response were described as "excellent;" control response was described as "very good." The pilots also felt that ground effect assisted them in making smooth landings. However, pilots A and C commented on the difficulty of judging height during the shallow approaches and landings, and pilots A and B commented on this factor during 3° glide-slope approaches and landings. The comments also indicated that the difficulty in judging height was related to the high approach speed and height of the pilot above the ground at touchdown. Pilot A provided an insight to the relative difficulty of these factors by rating the various tasks in his comments on shallow approaches and landings. He rated speed control 1 to 2, longitudinal control 2 to 4, and height judgment 7; thus, except for the height-judgment problem, pilot A would have given the longitudinal characteristics of the XB-70 a high overall rating. Steeper approaches and the associated higher descent rates allowed less time to judge height, as reflected in pilot A's comment that the "chances of misjudging height in the flare are too great" from a 3° glide slope. This increased the possibility of a hard landing.

Pilots B and C also commented on the difficulty of judging height, but did not seem to give it the same weight that pilot A did. However, pilot C did not perform any 3° glide-slope approaches. Although pilots A and B both had extensive experience in the XB-70 (table IV), pilot B appeared to have developed a better than average ability to judge the height of the airplane above the ground. This was evidenced on several flights by his accurate call out of flare heights and landing without altitude callouts from escort aircraft. The difference in outlook between pilots A and B, therefore, is considered to be a good representation of the range of capabilities to be found in any group of highly qualified pilots. Considering the overall pilot population, due regard must be given to the more pessimistic ratings.

The ILS approach with vertical offset was easily accomplished because of the excellent thrust response and longitudinal control of the aircraft. Height judgment was not a factor, since the aircraft was returned to the correct flight path considerably before the flare.

Pilot ratings of the longitudinal handling qualities are summarized in figure 8. These ratings represent an overall average for each pilot weighted with the aid of pilot comments. Most of the ratings apply to the relatively favorable weather conditions that existed during the tests. The ratings designated by squares, however, represent an extrapolation by the pilots of their experience in this program to the more adverse weather and visibility conditions that would be encountered in everyday airline operations.

Pilot A rated the shallow approaches poorer than pilots B and C, as indicated in the pilot comments (table VIII). Overall, however, these maneuvers were considered satisfactory. For the 3° glide-slope approaches, the difference between the overall ratings of pilots A and B was greater than the difference in their overall ratings for the shallow approaches. This reflects pilot A's concern for the increased demands placed on height judgment by the increased rate of descent. The incremental rating applied by pilots A and B to allow for adverse-weather operation, however, was the same. The adverse-weather ratings fall in the unsatisfactory but acceptable category for pilot B, and in the unacceptable category for pilot A. Nevertheless, these ratings are close to the satisfactory boundary (pilot rating (PR) = 3.5) for pilot B and the acceptable boundary (PR = 6.5) for pilot A. It is concluded, therefore, that 3° glide-slope landings are unsatisfactory for the XB-70 for adverse-weather or visibility operation, or both, because of the high approach speed (200 KIAS or more) and the height of the pilot above the ground at touchdown. However, as noted previously, due regard must be given to the more pessimistic ratings when considering the average pilot. To make operation satisfactory, approach speeds must be reduced without a deterioration in handling qualities or glide slopes must be limited to approximately 2°, or both. An indication of the necessary reduction in glide-slope and approach speeds can be deduced from the comment of pilot B that landings will never be as easy as in a 707 aircraft because of cockpit height. This implies that the approach speeds or glide slopes, or both, for a vehicle in the XB-70 class must be the same or somewhat less than those used for subsonic jet transports to maintain the same level of safety, unless improved displays or pilot aids are incorporated.

The rating for the vertical-offset approach by pilot B was the same as his ratings for the shallow and steep approaches made at the same speed, and reflects the excellent longitudinal and speed control of the XB-70. For the slow 3° glide-slope approaches, however, the rating drops to the unsatisfactory level because of the decrease in speed control and visibility plus increased pilot workload at this approach speed. It should be noted that these slow approaches were within 2 knots of the original recommended approach speed.

It should also be noted that the preceding discussion applies to the airplane with the longitudinal FACS on or off. The basic longitudinal damping of the XB-70 is sufficiently high at landing-approach speeds that the influence of the FACS was barely noticeable to the pilot. Moderate-to-heavy turbulence, however, did cause a rough ride and make airspeed and altitude control difficult.

Criteria and quantitative results. – The nominal longitudinal airplane landing-approach characteristics are presented in table IX and the corresponding flight-determined stability derivatives in table X. Because of the relatively high approach speeds, the dynamic pressure was fairly high. This contributed to good airplane characteristics despite the high inertia.

Table IX also presents the nominal landing characteristics for a subsonic jet transport from reference 7. It can be seen that longitudinal frequency and damping are not too different from those of the XB-70. The main difference is in steady-state normal acceleration per unit of angle of attack N_{Z_α}; the XB-70 had almost twice the N_{Z_α} (as the subsonic jet). This implies that smaller attitude excursions are required to change flight path on the XB-70 than on the subsonic jet.

Two key longitudinal control parameters in the landing approach are the maximum control power available from trim and the change in lift associated with this control power. Figure 9 compares XB-70 control power and change in lift associated with this control power to that of subsonic jets and a minimum boundary (unpublished) suggested by the Boeing Company for aircraft in the supersonic transport class. The XB-70 elevon deflection limits are ±20°. During landing the elevon deflection required for trim at normal approach speeds was approximately 10° trailing edge down, out of ground effect. Unpublished flight data indicate that an incremental 4° trailing-edge-up elevator deflection is required to trim out ground effects. The maximum up-elevator observed in the actual landings was about 0°; however, this includes the elevon deflection required to flare. Because of the uncertainties in ground-effects measurements, a conservative estimate of 20° deflection available between the limit and trim was used to estimate XB-70 control power.

As shown in figure 9, the XB-70 control power greatly exceeds the minimum values based on supersonic-transport studies and also exceeds those for typical subsonic jets. The acceleration due to the lift change with elevon deflection is also large. The pilots rated the longitudinal control for the XB-70 satisfactory at the points shown, indicating that large $N_{Z_{\delta_e}}$ effects are satisfactory if control effectiveness is high.

Another important factor in longitudinal control is control sensitivity. Figure 10 shows a tentative boundary (ref. 2) for longitudinal control for airplanes in the large-transport category in terms of the lift change and moment change per inch of column deflection. XB-70 ratings of longitudinal control for the points indicated were all satisfactory. The satisfactory ratings are somewhat more favorable than the boundary indicates; however, as indicated in the figure, the dynamics of the XB-70 are better than those of the aircraft of reference 2 because of higher dimensional lift-curve slope L_α and natural frequency. Considering this, the XB-70 results tend to substantiate the general trend of the criterion.

The XB-70 pilots commented frequently on the excellent speed stability (i.e., speed control) of the XB-70 during landing approach. Figure 11 shows a thrust-required curve for the XB-70 determined from flight data. The fairing and extrapolation are based on a straight-line fairing of the test data on a plot of drag coefficient versus lift coefficient squared. It is interesting to note from this figure that at the nominal approach speed (210 KIAS), the speed-thrust stability is virtually neutral. The apparently good speed stability is attributed to the high level of basic static longitudinal stability and the associated good stick-force/speed relationship. Other contributing factors are the high longitudinal control power and excellent response to throttle. An example of the power response of the XB-70 during a landing approach is shown in figure 12. It can be seen that the lag between a throttle-angle change and airplane reaction is on the order of only 0.5 second.

The 185 KIAS approaches made by pilot B were rated 4 to 4.5 as compared to his rating of 2 for normal approaches, primarily because of the increased throttle activity (fig. 7). As shown in figure 11, the change of two units in pilot rating was associated with a change in the speed-thrust-curve slope (as expressed by the ratio $\frac{\partial F_n/W}{\partial V_i}$) of -0.0006 per KIAS. Ground-based (ref. 1) and airborne-simulator (ref. 8) results indicated pilot rating changes of only one-half unit for a similar change in speed-thrust-curve slope. The greater change in pilot rating with speed-thrust-curve slope for the XB-70 may be attributed to the limited pilot sample in the present study and normal interpilot variations. The main factors, however, were probably the relatively high approach speed and large distance between pilot and landing gear, which contributed to difficulties in judging height. Under these circumstances, the increased workload caused by a given level of speed-thrust instability would be much less tolerable.

Lateral-Directional Handling Qualities

The most noteworthy lateral-directional characteristics observed during XB-70 landing approaches were good roll control response, excessive adverse yaw, and sensitivity to turbulence. Because of the turbulence sensitivity, the effect of the FACS was definitely noted in the pilot comments. In smooth air, however, the influence of the FACS was small.

Lateral-offset approaches were performed to simulate the maneuver that would be needed under IFR conditions when breaking out of an overcast and finding the runway offset from the flight track. The airplane was lined up approximately 200 feet (61 meters) off the runway centerline under the co-pilot's direction with the pilot "under the hood." As the airplane passed through 200 feet (61 meters) above the runway elevation, the pilot established visual contact and maneuvered the airplane to line up with the runway. The lateral maneuver itself was not considered difficult; however, the high approach speeds and turbulence made rapid control inputs necessary to aline with the runway in time. The rapid control inputs made the adverse-yaw effects more pronounced. As a result, the pilots usually held the airplane at about 50 feet (15 meters) altitude with power until alinement with the runway was assured before they proceeded with the flare. This caused estimated touchdown points to be 5000 to 6000 feet (1500 to 1800 meters) down the runway.

A typical time history of a lateral-offset maneuver is shown in figure 13. Light-to-moderate turbulence existed during this maneuver. A high degree of aileron activity is evident, and the bank angle is oscillatory. These factors are probably related to the adverse yaw and turbulence.

Several landings were made in turbulence and crosswinds. The most severe is illustrated in figures 14(a) to 14(d), time histories of a landing that was made in moderate-to-heavy turbulence and crosswinds of 20 knots with gusts to 30 knots, 55° to the runway. More aileron deflection was used during this landing than at any other time in the XB-70 flight-test program. Peak aileron deflections of approximately 12° were used, and peak roll rates near 10 deg/sec were experienced. Right bank was used to stop the drift to the left. Difficulties in controlling speed accurately were also experienced.

Crosswind landings were not considered difficult in the XB-70 except when accompanied by turbulence. The usual technique was to fly with one wing down to cancel the drift. In gusty crosswinds a crab down final approach with a transition to slight wing down from flare to touchdown was used; however, bank angles of less than 5° were usually adequate. Although crosswind landings in calm-to-light turbulence were not rated, the pilot comments indicate that the airplane characteristics were satisfactory.

The crosswind landing in moderate-to-heavy turbulence (fig. 14), on the other hand, was considered unsatisfactory by pilot D for a landing at Edwards and unacceptable for landing on runways of normal length in adverse visibility. These comments, however, relate to the overall airplane characteristics, not just lateral-directional. The workload imposed by difficult airspeed control and the rough ride was also a factor.

Only one set of aileron rolls was performed in the landing configuration. Figure 15 presents the XB-70 response to the maximum aileron deflection used in aileron roll maneuvers. Larger aileron inputs were not used because of the magnitude of the adverse sideslip generated. As a result of the interaction between the adverse-yaw effects and dihedral, roll-rate reversal tendencies also occurred. The parameter $\frac{\omega_\varphi}{\omega_d}$ is a good indicator of roll-rate-reversal tendencies. As was shown in table IX, the $\frac{\omega_\varphi}{\omega_d}$ value for the XB-70 is approximately 0.68. Reference 9 shows that when $\frac{\omega_\varphi}{\omega_d}$ is less than 0.7, there is a tendency for roll-rate reversal to occur.

Time histories of a typical lateral-directional handling-qualities-evaluation maneuver are presented in figures 16(a) and 16(b). These maneuvers are much smoother than the aileron rolls because of the smaller and gentler inputs. A typical roll rate used for a moderate-rate turn entry was on the order of 2.5 deg/sec. For a "fast" turn entry, about 5 deg/sec were used. The pilots considered these rates representative of normal transport-aircraft maneuvering. Under these circumstances the adverse-yaw characteristics of the XB-70 were not bothersome, in that significant roll reversals did not occur, and the sideslip angles in uncoordinated turns were not large. However, the effort required to coordinate turns was excessive, and attention to bank angle and yaw often resulted in heading overshoots. The pilots concluded that it was best not to try to coordinate the rudder-aileron control.

Pilot comments and ratings. – Pilot comments on the lateral-directional handling qualities are summarized in table XI. Detailed pilot comments are included in the appendix.

Pilot ratings of the lateral-directional characteristics are summarized in figure 17. The data are for landing conditions as they existed at Edwards Air Force Base, except for one point. The square is an extrapolation by the pilot to the more adverse visibility and runway conditions that would be encountered in airline operations.

The ratings for the straight-in approaches show good agreement among pilots A, B, and C. With the FACS on, the airplane's lateral-directional characteristics were satisfactory in smooth or rough air. In smooth air and with the FACS off, the airplane was still rated satisfactory. In turbulence with the FACS off, however, the rating was unsatisfactory. Yaw oscillations could not be damped out, and the airplane was downrated because of adverse yaw.

Comments on the lateral-offset approaches also show the influence of adverse yaw, turbulence sensitivity, and the FACS. Overcontrol tendencies were noted with the FACS off in turbulence. The trend of the ratings is quite similar to that obtained from the straight-in approaches. It appears that the suitability of the XB-70 handling characteristics for lateral-offset maneuvers could be estimated from experience with straight-in approaches.

The lateral-directional maneuvers were rated the same with the FACS on and off, which reflects the fact that the maneuvers were smooth and gentle and were performed in smooth air.

Criteria and quantitative results. – The nominal lateral-directional characteristics are presented in table IX, and the corresponding flight-determined stability derivatives are presented in table X. Also shown in table IX are the characteristics of a typical subsonic jet transport. The principal difference between the XB-70 and the subsonic jet transport is in the value of $\frac{\omega_\varphi}{\omega_d}$. The XB-70 value is much less than 1.0, indicating, as previously discussed, higher adverse-yaw effects than for the subsonic jet transport.

The study of reference 10 theorized that the sidestep maneuver involves, ideally, a sinusoidal variation in bank angle. On the basis of this assumption, reference 10 developed a formula for the time required to accomplish a sidestep as a function of the maximum bank angle used. With this time and the average speed, the distance required to perform a sidestep maneuver can be calculated. Figure 18 compares XB-70 flight results with this prediction technique. The formula, as indicated in the figure, includes a time t_0 to allow for a transition into and out of the sinusoidal bank-angle variation.

This technique gave good results when applied to Viscount, DC-6, and 707 aircraft. It is interesting to note that it applies fairly well to the XB-70 also, despite the airplane's adverse-yaw characteristics and slender, delta geometry. In turbulence, however, there is some indication that the correlation deteriorates, probably because of the adverse yaw and resultant overcontrol tendencies that cause the bank-angle variation to deviate from a pure sinusoid. This could be compensated for by increasing t_0 as a function of turbulence.

CONCLUDING REMARKS

Flight experience with the XB-70 airplane provided information pertinent to the landing-approach characteristics of large, advanced aircraft.

The height of the cockpit above the runway in combination with nose-high landing attitudes and high approach speeds made the landing task more difficult than that presented by a subsonic jet transport. Because of these factors, 3° glide slopes were considered unsatisfactory for routine operation of the XB-70 at its approach speed of 200 knots indicated airspeed or greater. The approach speeds or glide slopes, or both, for a vehicle in the XB-70 class must be the same or somewhat less than those used for subsonic jet transports to maintain the same level of safety, unless improved displays or pilot aids are incorporated.

Large changes in lift due to elevon deflection were satisfactory when accompanied by good elevon pitch control effectiveness. The longitudinal control sensitivity boundary proposed in NASA CR-635 shows general agreement with XB-70 flight results.

Good longitudinal control and fast power response to throttle are important factors in apparent speed stability.

A greater change in pilot rating with speed-thrust-curve slope was observed during XB-70 flight tests than in previous simulator studies of other airplanes. This sensitivity is believed to be the result of the complicating factors of nose-high attitude, height of the cockpit above the runway, and high approach speeds. Under these circumstances, a speed-thrust instability would have been less tolerable.

Longitudinally, turbulence caused a rough ride which made speed and attitude control difficult. Laterally, turbulence caused yawing oscillations and overcontrol due to adverse yaw.

Crosswind landings without turbulence were relatively easy because the drift could be compensated for by small bank angles.

Ground effects helped the pilots make a smooth touchdown.

Lateral-offset maneuvers simulating breakout from an overcast were not difficult; however, because of the higher approach speeds, excessive runway distances would be covered prior to touchdown. Ability to correct for a lateral offset during landing approach was adequately predicted by the simple formula presented in British A. R. C. R. & M. No. 3347.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., October 30, 1969.

APPENDIX

DETAILED PILOT COMMENTS

Flight 55, Pilot A

General comments.– Landings are easy and enjoyable, except that lateral-directional control in gusty air is not good, rated 5; speed control, longitudinal control, and trim are rated 2.

Flight 57, Pilot A

Aileron rolls.– Two aileron rolls to the left were performed at 234 and 238 KIAS. Eighteen degrees left-wheel-down aileron were applied at a moderate rate, which generated 4° to 4.4° right yaw. These were not comfortable and represented near the maximum rate I would want to apply this amount of aileron. Overall rating of the maneuver is 6.

Flight 58, Pilot A

General comments.– My biggest landing problem is judging height above the ground from the threshold to touchdown. The cockpit height and distance to the main gear prevents this from being an exacting science for me. I maintain a safe height and speed until I'm over concrete and let it settle in from there. Therefore, my touchdown is usually 2500 feet from the end of the runway. This is unacceptable for a commercial transport; I rate this particular phase of the landing 7. The individual task ratings for the landing were: speed control, 1; longitudinal control, 4; and lateral-directional control, 5.

Flight 58, Pilot B

ILS approaches from copilot seat.– The first approach was flown with all augmentation on. A concentrated attempt was made to keep all observations inside the cockpit, and the runway was not observed until the call was received to go around at 50 feet elevation. Speed was held with the throttle, and the elevator was used to hold the glide slope. Speed control and pitch control were excellent, and the lateral control was satisfactory. With the smooth air that existed, the airplane was easily flown down the glide slope and on the centerline. Yaw angles produced by lateral-control inputs were under 1°, since the required control inputs were small. The "ILS mode" selection, which shows displacement from centerline and glide slope, was used for the approach. The aim airspeed of 220 knots was held very close throughout the approach, and the workload required to hold the centerline was low. The airplane could have been landed easily from below a ceiling of 200 feet or less. The Cooper ratings assigned for this ILS task were 2 for longitudinal control and 3 for lateral-directional control.

The second ILS approach was flown with all augmentation off and using the "ILS approach mode" selection, which shows the rate of correction to make to return to glide slope or centerline. The same techniques were used as on the first ILS approach. There was only a slight observable difference between this approach and the previous approach, since the air was very smooth and the airplane did not tend to make random deviations from the desired path. The yaw angles produced by lateral-control inputs were slightly higher and occasionally reached 1 1/2°. The workload to hold the centerline and glide slope was still low. The approach had to be discontinued when approximately 400 feet above the ground because of a traffic conflict, but it was felt that under the existing smooth-air conditions, the airplane could have again been landed from below a ceiling of 200 feet. The ratings assigned for this FACS-off ILS were again 2 for longitudinal control and 3.5 for lateral-directional control.

Very good ILS approach handling qualities were exhibited under smooth-air conditions.

Flight 60, Pilot B

Approach and landing.– Light turbulence and crosswind (wind 270°, 18 knots gusting to 28, using runway 22). Fly with sideslip on approach—switch to one wing down, no sideslip near runway—touched down on one wheel. Overcontrolling tendency with the ailerons not present. Crosswind not nearly as much problem as turbulence.

Flight 60, Copilot A

Descent and landing.– The landing runway was 22 with the wind from 270° at 18 to 28 knots. Best flare speed was 189 KIAS for a gross weight of 298,000 pounds. The gusty crosswind required crab down final and slight right wing down from flare to touchdown. All augmentation was on for the landing. The touchdown, within the first 1000 feet of the runway, right gear first, at 180 KIAS, was a very nice one. The turbulence experienced on final created considerable bouncing around in the cockpit and greater than normal pilot effort.

Flight 62, Pilot B

Lateral-directional maneuver.– A lateral-directional maneuver at 260 knots was performed where ailerons only were applied at a normal rate to establish a 25° bank. After turning for approximately 30 seconds, the airplane was rolled out on a desired heading using only the ailerons which were applied at a fast rate. The maneuver was then repeated in the opposite direction using coordinated rudder and ailerons for the bank entry and exit. The ailerons only bank establishment caused 1° of adverse yaw which built up slowly and then stabilized at 2/3° during the turn. The rapid leveling of the wings was done with approximately 14° wheel movement and generated 1 1/4° of yaw. The roll-in was rated 3 and the roll-out 3.5. The coordinated roll-in at a normal rate produced 1/4° adverse yaw but required high rudder force. The fast roll-out did not result in a coordinated maneuver. The rapid aileron input caused the yaw to increase too quickly for proper rudder coordination as the roll-out was started, and the yaw excursion went to 2° to 2.5° as the wings were leveled. It was too difficult to properly coordinate the rudder with the aileron. The lateral control was rated 2 at the normal rate and 4.5 at the fast rate. The overall lateral-control rating was 3.5.

ILS offset approach.– The flare speed was computed to be 190 knots for the ILS offset approach, and the final approach was flown at 210 knots. Turbulence was moderate during the approach and ±1° of sideslip was frequently encountered without any pilot input to the controls. The glide slope was flown using the glide-path indicator, and the copilot gave heading instructions to place the airplane approximately 200 feet to the right of the runway centerline. At 200 feet above the ground, a correction was started to line up with the runway and be in a position to land. This was to simulate breaking out below an overcast. Approximately 2° of adverse yaw occurred during the initial lateral-control input, and the runway centerline was crossed before getting lined up with the runway.

The airplane could have been easily landed, although the touchdown would have been farther down the runway than desired. This was due, in part, to the Edwards ILS glide-slope interception point at 2400 feet from the approach end of the runway. When maneuvering close to the ground in a large airplane, there is always (or should be) a strong awareness of the reduced ground clearance of the wing when banking. This maneuver was more comfortable in the XB-70 than when practiced a day earlier in the larger-span B-52 (185 feet versus 105 feet for the XB-70). The rating for this maneuver was 4 and was based primarily on the adverse yaw developed during the initial correction.

Landing. – With 26,000 pounds of fuel remaining, the flare speed was computed as 187 knots. The airplane encountered fairly heavy turbulence on final approach, and strong lateral oscillations were felt in the cockpit. It was interesting to note the strong airplane response to turbulence on the final approach, which was contrasted by docile handling qualities during the flare and landing. Power was reduced to idle prior to touchdown at about 185 knots, and the airplane was held off until a smooth touchdown came at 170 knots.

Flight 65, Pilot A

Lateral-directional maneuver. – A lateral-directional turn maneuver was completed at 220 KIAS and 8000 feet. Twenty-degree heading changes were made using 20° banks, both coordinated and uncoordinated. The usual 2° of yaw was observed during turn initiation. Coordination is not easy, and for such short periods of turn I consider it a waste of time to attempt coordination. Altitude hold ±100 feet was easy, even in the turbulence. Rated 2. Holding speed was also rated 2, but the overall maneuver rating was 3 due to the coordination effort required and yaw generated by use of ailerons.

Overall approach. – Light turbulence with occasional moderate chop. The aircraft responded very well to correct the lateral disturbances in the turbulence. Rated 3 to 4.

Flight 65, Copilot D

General comments. – The single most impressive observation during the flight was the severity of the aircraft response to low-altitude turbulence. At 250 to 300 KIAS, an apparent 1 to 2 cps "snaking" lateral-directional mode (almost entirely directional, with hardly any accompanying roll) was of such amplitude and frequency as to compromise pilot capabilities in accomplishing routine cockpit duties. It appeared to be poorly damped, FACS on or off, and the pilot does not have much capability to damp the oscillation.

APPENDIX

Flight 68, Pilot B

Descent and landing.– After the airplane was slowed below 260 knots, the landing gear was extended at approximately 25,000 feet. The flare speed was computed as 190 knots. A straight-in approach was made to runway 4 on a 3° glide slope using the glide-slope approach lights. The 3° glide slope was slightly steeper than most XB-70 approaches but was a comfortable angle. The light source which was located 800 feet from the end of the runway was easy to follow, and the XB-70 remained in the 1/2° beam until approximately 100 to 150 feet above the ground. The airplane was then flared and touchdown occurred approximately 1,400 feet down the runway. Touchdown speed was near 180 knots. The drag chute was deployed, but the brakes were not used until the speed was decreased to approximately 25 knots when an apparent brake fade was noted.

Additional comments.– Light-beam glide-slope approach (3°). Picked up light 3 to 4 miles out. Flew on white light (center beam ±0.25°) to 100 to 150 feet. Chopped throttle before flare. Touched down at about 180 knots, 1400 feet down runway. Landing was routine. It would never be as easy as a 707 because of the cockpit height, but this is a problem that can be coped with. Radar altimeter would enhance safety. This light system is easier to fly than the ILS. Landing the XB-70 is easier than the B-58 because of better centering and better control system. Rated 2.

Flight 70, Pilot B

Three-degree approach angle and full-stop landing.– The final landing approach was flown using glide-slope approach lights set to give a 3° angle. This was the second use of a 3° approach angle in the XB-70 by this pilot. As on flight 1-68, the approach appeared a little steep but was comfortable. The light source was followed down to approximately 100 feet above the ground. At that time the power was reduced slightly and the descent angle increased to "duck" down to the runway. A flare was initiated 25 to 30 feet above the ground and power reduced to idle just before touchdown. The ground effect cushioned the airplane nicely, and a smooth touchdown occurred 1500 feet down the runway. This touchdown point was within 100 feet of the touchdown point of flight 68 in which the same 3° approach light system was used. The speed at touchdown was not observed, since attention was concentrated outside the airplane during the steeper than normal flare. The touchdown speed was estimated to be 180 knots.

A 3°-glide-slope final approach appears to be acceptable for the XB-70.

Flight 70, Copilot C

Landing approaches.– A low approach was made from Rosamond Dry Lake to runway 4. The lowest altitude on the low approach was 30 feet, as noted by the chase. The handling qualities in the lateral and longitudinal mode were considered good, and there was no tendency to overcontrol in either axis. I did not monitor the yaw needle, but there was no obvious yaw with roll inputs. Roll and pitch inputs were moderate in the landing-approach maneuver. An estimated glide slope of 1.5° to 2° was flown. It appeared that the 3° approach as indicated by the special NASA approach light was rather steep, and I did not desire to fly the XB-70 on that angle for my first approaches. The lower approach angle seemed more comfortable. The chase pilot's callouts of gear height above the ground were helpful because accurate judgment of gear position is a little difficult. I have noticed this on earlier flights when just observing another pilot land.

The next approach was made similar to the first, with the addition of a touch-and-go landing at the completion of the approach. The approach was similar to the other, and it was noted that speed control was good. The approach speed used was 210 knots; the computed flare speed was 190 knots. As the touchdown was near (about 30 feet), a cushioning effect was noted, and the rate of sink was arrested prior to touchdown. A Cooper rating for the overall landing configuration is 2. The primary problem I noted on the approaches was the judgment of altitude from about 200 feet on to touchdown.

Flight 71, Pilot C

Approach and landing.– Yaw oscillations were noticed in turbulence and could not be damped out. Roll response was good as was longitudinal response. Overall lateral-directional rated 2.5, longitudinal 1.5 to 2. Lateral-directional downrated for adverse yaw due to aileron input.

Flight 72, Pilot B

Heavyweight offset approach maneuvers.– All approaches were flown with the landing gear and flaps extended. The first approach angle was established visually and appeared to be between 2° and 2.5°. The second and third approaches were flown using the light source along the runway to establish a 3° glide-slope angle. The flare speed was computed as 223 knots as the approach was initiated with 170,000 pounds of fuel indicated. The airplane was lined up approximately 200 feet right of the runway centerline with all FACS on, and, when passing 200 feet elevation, a correction was made to line up with the runway. This condition was to simulate the maneuver that would be needed under IFR conditions when breaking out of an overcast and finding the runway offset from the flight track. Approximately 15° of bank was used on the initial correction toward the runway. The airplane responded well, but corrections had to be made without delay since the 240-knot approach speed caused the runway to pass underneath at a rapid rate.

The second major correction which was needed to line up with the runway centerline appeared to be the most critical and difficult to execute properly, since another bank angle of approximately 15° was needed. However, the airplane was close enough to the ground to cause some apprehension. The tendency was to hold about 50 feet of altitude until the airplane was on or close to the centerline of the runway. The airplane was then eased down toward the runway. The airplane was not allowed to touch down; however, it appeared that the maneuvering necessary to line up would have resulted in a touchdown approximately 4500 to 5000 feet down the runway. The rapid control inputs necessary to make the required corrections caused yaw oscillations of close to 2°. The airplane accelerated slowly but satisfactorily during the military power go-around. The handling characteristics for the offset maneuver were rated 4 and were based on the difficulty in correcting to the centerline, the adverse-yaw characteristics, and the required rapidity of corrections due to the high approach and flare speed.

The second approach was lined up 200 feet to the right of the runway centerline and was very similar to the first, except that the approach speed was reduced slightly since the gross weight was lower (fuel weight, 155,000 pounds). The 3° approach angle used did not seem to make any noticeable difference in the maneuver, since the approach angle was slightly reduced after initiating the correction toward the centerline. This was required to allow ground clearance during the maneuvering. The airplane became lined up on the runway centerline 2500 to 3000 feet down the runway, and touchdown would have probably occurred 4000 to 4500 feet down the runway. Yaw angles during the maneuvering were very similar to the first approach, and the handling characteristics were again rated 4. Military power was satisfactory for the go-around.

The third approach was flown with all FACS off and again using the ground light source for establishing a 3° approach angle. The total fuel was down to approximately 140,000 pounds, and the flare speed computed as 215 knots. The approach was flown at 230 knots, and the offset was established at 200 feet to the left instead of to the right as on the previous approaches. Considerably more yaw oscillations were noted during this FACS off approach. The light and occasionally moderate turbulence encountered in the XB-70 (reported as only a trace of turbulence in the chase TB-58) seemed to have a greater effect on the handling qualities with the FACS off. Yaw oscillations reached 3° during some combination of turbulence and lateral-control inputs. During the correction to the centerline, the tendency to overcontrol laterally was greater with FACS off, and some oscillation in bank angle and yaw was apparent. The runway distance required, however, was about the same as for the two previous runs. The airplane could have been landed approximately 4500 feet down the runway. The handling characteristics were rated 5.5. The deterioration in rating was due primarily to the increased lateral-control workload and the increased yaw excursions. The cross-cockpit view of the runway when correcting from the left-side offset caused no detectable difference in ability to see the runway or position the airplane in the desired location.

The final approach and landing were flown by the pilot (left seat). Total fuel remaining was 50,000 pounds, and the flare speed was computed as 193 knots. A 3° approach angle was flown by using the external light source positioned 800 feet down and alongside the runway. The airplane was held on the 3° approach angle until approximately 150 feet above the ground. At that time, power was reduced slightly and the approach angle steepened slightly to cause the touchdown to be on the first part of the runway. Chase altitude callouts were not utilized; however, at approximately 30 feet above the ground, the airplane was flared. When the flare was felt to "take hold," the power was reduced to idle. Touchdown was smooth and occurred approximately 1700 feet down the runway. The ground effect of the XB-70 is very good and makes the landing characteristics excellent. The time between flare and touchdown was noticeably shorter on the 3° approaches than on flatter approaches. Whereas on flat approaches, airspeed indications during the flare and at touchdown have generally been observed, the airspeeds were not noted during the steeper flares and touchdowns because of the short time span.

Heavyweight landing-approach offset maneuvers will cause the touchdown point to be 4000 to 5000 feet down the runway because of the maneuvering characteristics and the high approach speeds.

APPENDIX

The ground cushion (ground effect) of the airplane allows smooth touchdowns to be accomplished easily even with a 3° approach angle. The time between flare and touchdown was noticeably shorter on the steeper approaches than on the shallow approaches used on most previous XB-70 landings.

Flight 73, Pilot A

Landing approaches. – The turn to final approach was made over the center of Rosamond Dry Lake at 235 to 240 KIAS at an indicated altitude of 4500 feet. The approach light could be seen at this point, but the color could not be identified. The tower reported that the wind was calm. The 4500-foot altitude was maintained to the east edge of Rosamond Dry Lake where the white sector of the approach light was identified and the approach initiated with the cockpit camera and data on. The approach speed varied between 225 and 230 KIAS, and the tendency was to hold slightly high in the amber sector. The amber and red of the approach light are too similar to permit quick and positive identification. On the approach to the threshold, the angle of attack was 10° and the approach speed was 230 KIAS. The data were evented at the center taxiway. A right turn to downwind for the next approach was initiated. Two main observations were: (1) holding a 3° glide slope at this approach speed and using this approach light was difficult; and (2) transition from the approach to flare at the threshold was done with much less comfort than from the 1 1/2° to 2° glide slopes which I prefer with a big, heavy airplane. In short, I did not like the 3° glide-slope approach at the weight and speed flown. The chances of misjudging height in the flare, even under day and good weather conditions, are too great and could easily result in a hard landing or long touchdown. At lighter gross weights and much slower speeds, I might be more receptive to the 3° glide-slope approach for the XB-70.

The next 3° glide-slope landing approach to runway 04, with a 200-foot lateral offset to the left of centerline, was initiated from a right-hand closed traffic pattern. The approach light could be seen, but the color was not distinguishable at 4500 feet over the east edge of Rosamond Dry Lake. The best flare speed was 214 KIAS. The tower reported the runway wind calm. At an indicated altitude of 4000 feet, the white sector of the approach light was clearly identified. The intention and attempt was to fly the final approach alined with the runway distance markers to the left of the runway. The approach speed was 225 KIAS, with a rate of descent once observed at 2000 feet per minute. It was difficult to stay in the white sector of the approach light; I again had a tendency to ride high in the amber sector. At approximately 1 mile from the threshold, I dropped in the red sector, but at one-half mile, where the lateral sidestep was performed, I was up and on the 3° glide slope. The initial offset was greater than 200 feet, but near the 2-mile point the alinement to the left was near optimum. At the threshold, on the 3° glide slope, at 225 KIAS the lateral sidestep maneuver to the right was performed. The lateral maneuver to aline with the runway was not difficult— rated 3.5. However, the combination of alinement and descending to the runway would not permit landing near the normal touchdown point. The approach was continued to within 5 to 15 feet of the runway, and the data were evented at the center taxiway at 235 KIAS with a fuel totalizer of 134,000 pounds.

The most significant observation was that the touchdown would have been between 5000 and 6000 feet down from the approach end of the runway. I certainly would not care to be confronted with a 3° glide-slope instrument approach and, after breakout at the threshold, be required to perform a lateral sidestep to aline with the runway before allowing the airplane to slow and settle to touchdown. If I were confronted with this on actual instruments, I would execute a missed approach. If fuel did not permit this, I would hope for a long runway and thrust reversers. Handling the airplane is no big problem, but the runway sacrificed, at 225 KIAS, to achieve a satisfactory touchdown attitude is unacceptable.

Lateral-directional maneuvers at 190 KIAS and 15,000 feet. – With FACS on, a slow entry, uncoordinated (aileron only), 20° banked turn to the right was initiated to make a 20° heading change. The roll-out was also uncoordinated, and, although faster than the entry, the desired heading was overshot by 4°. The speed and altitude were virtually unchanged throughout the maneuver. Again, with FACS on, a slow entry, coordinated turn was initiated to the left. Left rudder was applied to hold zero yaw, and again the heading was overshot by 2°. The airspeed increase was 2 knots with a loss of 100 feet of altitude. My opinion after these two turns was that 20° banks are excessive for precision 20° heading changes, and the coordinated turn is more difficult and less precise than the uncoordinated maneuver.

The FACS was turned off, and an uncoordinated right turn was established. The aim bank angle of 15° was overshot by 3°. A fast, uncoordinated roll-out was accomplished on the desired heading. An 18° bank, coordinated left turn was initiated, and, as left rudder was applied to zero the yaw needle, the bank angle increased to 22°. Attention to bank angle and yaw caused a heading overshoot of 3° in spite of the fast roll-out. At constant power the speed had dropped 5 knots, with an altitude increase of 100 feet. The overall comment remained: coordination requires excessive attention, results in larger yaw excursions than uncoordinated turns, and is more trouble than it is worth for 20° heading changes. Rating for the uncoordinated turns both FACS on and off was 2.5. The coordinated turns were rated 4.5.

General comments. – Three-degree glide-slope approaches are unacceptable for normal operation of an aircraft of the size and weight of the XB-70. Instrument and night approaches for an aircraft of this size, at the high approach speeds (200 to 220 KIAS), should be made on 2° to 2.5° glide slopes.

The high-speed, 200-foot, lateral-offset approach illustrated that the touchdown point would have been 5000 to 6000 feet down the runway.

Flight 73, Copilot B

Vertical-offset ILS approach. – A vertical-offset ILS approach to runway 22 was flown from the copilot seat at a gross weight of approximately 390,000 pounds. This maneuver was an attempt to assess the ability to descend to and intercept a normal ILS glide slope after crossing the usual intercept point (outer marker) at a higher-than-prescribed altitude. At Edwards the altitude at the outer marker should normally be 2300 feet above the runway elevation; however, for this test the altitude at the outer marker was 3150 feet above the runway elevation. The outer marker is 7.0 nautical miles from the runway. After reaching the outer marker, a slightly higher than normal rate of descent was established to allow interception of the glide slope. Aim speed was 225 KIAS. The excellent longitudinal control and thrust response allowed the airplane to be easily established on the glide slope at a point 1000 feet above the ground and 3.0 nautical miles before reaching the runway (4.0 nautical miles after passing the outer marker). The normal ILS approach was continued until over the runway. The airplane was rated 2 for this maneuver.

APPENDIX

Flight 74, Pilot C

Heavyweight characteristics. — The control response in pitch and roll is very good, with no noticeable changes over a lightweight situation. The damping provided with SAS on is good, and only slight excursions in sideslip that occurred with adverse yaw and turbulence were noticeable. The longitudinal characteristics were rated 1.5, roll characteristics 2.0, and yaw characteristics 2.5. One of the more favorable characteristics of the XB-70 in the longitudinal axis in this configuration is the "speed stability" or ability to trim to and hold a given airspeed. The very positive thrust response is another very desirable characteristic. This is especially true when the weight is low enough to allow operation below military power. Afterburner response is positive also, but speeds and weights that require power adjustments between military power and minimum afterburner are awkward and usually result in several engines in afterburner and the others at military or slightly below.

A characteristic of the XB-70 in the landing configuration that is not related to heavyweight operation only is the visibility and horizon picture or reference to the pilot. With the nose-high attitude characteristics of low-speed flight, the pilot's pitch-attitude reference is poor and his judgment of altitude or change in attitude by visual reference is difficult; thus, a great deal of time is required for instrument scan or reference within the cockpit.

Landing. — The fuel was burned off to 130,000 pounds, which gave a total vehicle weight of about 400,000 pounds. Lakebed runway 18, north lakebed, was selected for landing. The approach and landing were made in light-to-moderate turbulence, and the primary attitude control task was in roll, in that some effort was required to keep the wings level in turbulence. Speed control was good. The aircraft weight on final approach called for a best flare speed of 212 KIAS. Touchdown was made at approximately 195 KIAS.

Flight 75, Pilot D, Copilot A

Approach and landing. — Pilot D completed two low approaches with fuel totals of 39,000 and 29,000 pounds. While in the pattern, the TB-58 chase crew reported continuous light, with occasionally moderate, turbulence; the XB-70 crew considered the turbulence continuous moderate and occasionally heavy. The cockpit ride was rough. The wind was 250° to 280° at 20 knots with gusts to 32 knots. The drift on final appeared to be 5° to 7°.

Pilot D completed the final landing. The fuel remaining on base leg was 23,000 pounds. Best flare speed was computed at 186 KIAS; however, because of the gusty surface winds, 210 knots was selected as a minimum final-approach speed. On final approach the left drift was very difficult to kill, and anything close to precise airspeed control seemed next to impossible to achieve. The overall landing task in the gusty crosswind was considered to be very difficult. The rough ride and flight control demands were lessened closer to the ground; in other words, it appeared that ground effect was a definite help during flare and touchdown.

Touchdown was within the first 2000 feet of the runway.

First landing—initial impression.— In overall consideration of the landing task in the existing wind conditions, the pilot gave the XB-70 a Cooper rating of 6.5 for those conditions at Edwards Air Force Base. The same characteristics under similar conditions but with the requirement of all-weather operations at a variety of airfields would lower the rating to 8.

Observations and comments.— Cockpit ride at low level was rough and uncomfortable in the moderate and occasionally heavy turbulence experienced. The overall landing task in the conditions of a gusty crosswind 30° to 60° off the runway at 20 knots, gusting to 32 knots, was considered to be very difficult. The pilot rated the difficulty sufficiently great to warrant proceeding to an alternate airfield without even attempting to approach with similar surface wind conditions if the destination airport were other than Edwards and had poor weather ceilings and/or visibilities.

Flight 78, Pilot B

Descent, low approach, and landing.— Gear extension was made at 25,000 feet.

With 35,000 pounds of fuel remaining, the normal flare speed was computed as 189 knots. Because of a request by Boeing for lower speed approaches, this approach was flown at 185 knots on a 3° glide slope. There was a noticeable decrease in over-the-nose visibility on the final approach. The most significant item, however, was the reduction in speed stability. Considerably more elevator motion and throttle manipulation was required to hold the glide slope and the desired airspeed. After descending to approximately 20 feet above the runway, a go-around was made. The acceleration and climbout were normal.

Flight 79, Pilot B

Descent, low approaches, and landings.— After descending to the pattern, the fuel remaining was 50,000 pounds, and the normal flare speed for that weight was 193 KIAS. The approach was a low-speed approach flown from the copilot seat at 185 KIAS. A 3° approach angle was established by using the light source located along the left side of the runway, 800 feet from the approach end. The approach speed of 185 knots, which was 8 knots below the normal flare speed, caused the airplane nose to be higher than normal. The light source along the runway could not be readily seen from the copilot's seat without moving the head outboard to improve over-the-nose visibility. Visibility was rated 5 under this condition. Speed stability was rated 4.5 because of the elevator and throttle attention required to hold the speed constant. The decrease in final-approach speed caused no detectable change in lateral-directional characteristics. The airplane was flown down to approximately 20 feet above the runway before initiating the go-around. The speed increase was immediate when power was advanced. The handling qualities appear to be acceptable for accomplishing a landing from a 185-knot approach.

A touch-and-go landing (at normal approach speeds) was performed from the copilot's seat with 41,000 pounds of fuel remaining, and a final- (landing) approach speed of 205 knots. There was a marked improvement in over-the-nose visibility and in speed stability.

APPENDIX

Miscellaneous Comments

Pilot A.– Three-degree landings with the XB-70 at Edwards at high gross weight, rated 5, based primarily on high degree of skill required and small margin for error, rapid closure rate, little time for decision, everything has to come out all right at the same time. I am afraid of a hard landing, and am not aware of strong ground cushion. My rating is based primarily on the longitudinal task posed by the high descent rate. For an operational situation, considering weather and/or night flying, I would rate it 7. If the airplane were slower, might rate it better.

I feel that if we had 8 to 10 pilots flying 3° glide slopes in the XB-70 program we would exceed 8 ft/sec sink rate before the end of the program. Present success is due to carefully controlled pilot group.

Pilot B.– VFR approaches, FACS on, longitudinal pilot rating of 2, lateral-directional pilot rating of 4, longitudinal rating based primarily on speed control.

Three-degree-glide-slope landings afford better visibility than "normal" approach angles.

Heavyweight approaches are similar to lightweight approaches in speed stability and control response. Increased speed is another factor, however.

Although 3° approaches at 205 to 210 knots are rated 2 for longitudinal characteristics, I might rate it 4.5 for an airline operational situation because of the high approach speed.

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TABLE I. – GEOMETRIC CHARACTERISTICS OF THE XB-70-1 AIRPLANE

Wing –	
Total area, includes 2482.34 ft^2 (230.62 m^2) covered by fuselage but not 33.53 ft^2 (3.12 m^2) of the wing ramp area, ft^2 (m^2)	6297.8 (585.07)
Span, ft (m)	105 (32)
Aspect ratio	1.751
Taper ratio	0.019
Dihedral angle, deg	0
Root chord (wing station 0), ft (m)	117.76 (35.89)
Tip chord (wing station 630 in. (16 m), ft (m)	2.19 (0.67)
Mean aerodynamic chord, in. (m)	942.38 (23.94)
Wing station, in. (m)	213.85 (5.43)
Fuselage station of 25-percent wing mean aerodynamic chord, in. (m)	1621.22 (41.18)
Sweepback angle, deg:	
Leading edge	65.57
25-percent element	58.79
Trailing edge	0
Airfoil section	0.30 to 0.70 HEX (MOD)
Thickness, percent chord:	
Wing station –	
Root to 186 in. (4.72 m)	2.0
460 in. to 630 in. (11.68 m to 16 m)	2.5
Elevons (data for one side) –	
Total effective area aft of hinge line, includes 3.33 ft^2 (0.31 m^2) air gap at wing-tip fold line, ft^2 (m^2)	197.7 (18.37)
Span, ft (m):	
Wing tips up	20.44 (6.23)
Chord, in. (m)	116 (2.95)
Sweepback of hinge line, deg	0
Canard –	
Area, includes 150.31 ft^2 (13.96 m^2) covered by fuselage, ft^2 (m^2)	415.59 (38.61)
Span, ft (m)	28.81 (8.78)
Aspect ratio	1.997
Taper ratio	0.388
Dihedral angle, deg	0
Root chord (canard station 0), ft (m)	20.79 (6.34)
Tip chord (canard station 172.86 in. (4.39 m)), ft (m)	8.06 (2.46)
Mean aerodynamic chord, in. (m)	184.3 (4.68)
Canard station, in. (m)	73.71 (1.87)
Fuselage station of 25-percent chord, in. (m)	553.73 (14.06)
Sweepback angle, deg:	
Leading edge	31.70
25-percent element	21.64
Trailing edge	-14.91
Airfoil section	0.34 to 0.66 HEX (MOD)

TABLE I. – GEOMETRIC CHARACTERISTICS OF THE XB-70-1 AIRPLANE - Concluded

Thickness chord ratio, percent:	
Root	2.5
Tip	2.52
Ratio of canard area to wing area	0.066
Canard flap (data for one side) –	
Area (aft of hinge line), ft^2 (m^2)	54.69 (5.08)
Inboard chord canard station 47.93 in. (1.22 m), ft (m)	7.16 (2.18)
Outboard chord canard station 172.86 in. (4.39 m), ft (m)	3.34 (1.02)
Ratio of flap area to canard semiarea	0.263
Vertical tail (one of two) –	
Area (includes 8.96 ft^2 (0.83 m^2) blanketed area), ft^2 (m^2)	233.96 (21.74)
Span, ft (m)	15 (4.57)
Aspect ratio	1
Root chord (vertical-tail station 0), ft (m)	23.08 (7.03)
Tip chord (vertical-tail station 180 in. (4.57 m)), ft (m)	6.92 (2.11)
Taper ratio	0.30
Mean aerodynamic chord, in. (m)	197.40 (5.01)
Vertical-tail station, in. (m)	73.85 (1.88)
Fuselage station of 25-percent chord	2188.50 (55.59)
Sweepback angle, deg:	
Leading edge	51.77
25-percent element	45
Trailing edge	10.89
Airfoil section	0.30 to 0.70 HEX (MOD)
Thickness chord ratio, percent:	
Root	3.75
Tip	2.50
Cant angle, deg	0
Ratio of vertical tail to wing area	0.037
Rudder –	
Area, includes 8.66 ft^2 (0.81 m^2) blanketed area, ft^2 (m^2)	191.11 (17.76)
Span, ft (m)	15.00 (4.57)
Root chord, vertical-tail station 0, ft (m)	9.16 (2.79)
Tip chord, vertical-tail station 180 in. (4.57 m), ft (m)	6.92 (2.11)
Sweepback of hinge line	-45.0
Ratio of rudder area to vertical-tail area	0.82
Fuselage (includes canopy) –	
Length, ft (m)	185.75 (56.62)
Maximum depth (fuselage station 878 in. (22.30 m)), in. (m)	106.92 (2.72)
Maximum breadth (fuselage station 855 in. (21.72 m)), in. (m)	100 (2.54)
Side area, ft^2 (m^2)	939.72 (87.30)
Planform area, ft^2 (m^2)	1184.78 (110.07)
Height of cockpit above ground at touchdown (approximate), ft (m)	35 to 40 (10.7 to 12.2)

TABLE II. – XB-70 INSTRUMENTATION PERTINENT TO LANDING-APPROACH STUDIES

Parameter	Sensor location			Accuracy, percent full range	Transducer range	Sampling rate, per sec
	Fuselage station, in. (m)	Buttock plane, in. (m)	Water plane, in. (m)			
Central air-data system altitude (coarse)	80 (2.03)	0 (0)	14 (0.36)	2.0	-1000 to 100,000 ft (-305 to 30,480 m)	40
Central air-data system altitude (fine)	80 (2.03)	0 (0)	14 (.36)	1.0	5000 ft/rev (152.4 m/rev)	40
Central air-data system airspeed (coarse)	80 (2.03)	0 (0)	14 (.36)	2.0	50 to 800 knots	40
Central air-data system airspeed (fine)	80 (2.03)	0 (0)	14 (.36)	2.0	70 knots/rev	40
Angle of attack	92 (2.34)	6 (0.15)	20 (.51)	.8	-10° to 30°	20
Angle of sideslip	121 (3.07)	0 (0)	13 (.33)	.8	±20°	20
Pitch attitude	1415 (35.94)	16 (.41)	-64 (-1.63)	2.0	-10° to 40°	20
Bank attitude	1415 (35.94)	16 (.41)	-64 (-1.63)	2.0	±45°	20
Pitch rate	1404 (35.66)	16 (.41)	-64 (-1.63)	2.0	±10 deg/sec	20
Roll rate	1404 (35.66)	16 (.41)	-64 (-1.63)	2.0	±100 deg/sec	20
Yaw rate	1404 (35.66)	16 (.41)	-64 (-1.63)	2.0	±10 deg/sec	20
Normal acceleration	1485 (37.72)	11 (.28)	-71 (-1.80)	2.0	±2g	20
Transverse acceleration	1486 (37.74)	0 (0)	-37 (-.94)	2.0	±1g	20
Left-hand canard position	---- ------	-- ----	--- ------	2.0	0° to 6°	20
Left-hand vertical-stabilizer position	---- ------	-- ----	--- ------	1.0	±12°	20
Right-hand vertical-stabilizer position	---- ------	-- ----	--- ------	1.0	±12°	20
Position of individual elevon segment	---- ------	-- ----	--- ------	1.2	±30°	20

TABLE III. – RECOMMENDED XB-70 FINAL-APPROACH, FLARE, AND MINIMUM TOUCHDOWN SPEEDS

Gross weight, lb (kg)	Final-approach speed, KIAS	Flare speed, KIAS	Minimum touchdown speed, KIAS
450,000 (204,000)	235	225	209
400,000 (181,000)	224	214	198
380,000 (172,000)	219	209	193
360,000 (163,000)	215	205	189
340,000 (153,000)	210	200	184
320,000 (144,000)	204	194	178
310,000 (140,000)	202	192	175
300,000 (136,000)	199	189	173
290,000 (131,000)	196	186	170
280,000 (126,000)	193	183	167

Note: Landing-pattern speeds were: downwind, flare speed plus 50 knots; base leg, flare speed plus 30 knots; final approach, flare speed plus 10 knots.

TABLE IV. – SUMMARY OF XB-70 TEST CONDITIONS

[Center of gravity ≈ 23.5 percent $\bar{c}$]

(a) Full-stop landings.

Flight	W,		V_{apr},	V_{td},	Rate of sink at touchdown,		Pilot	Comments
	lb	kg	KIAS	KIAS	ft/sec	m/sec		
50	295×10^3	134×10^3	210	174	---	----	A	
51	305	138	---	175	---	----	B	
53	301	136	220	173	---	----	B	
55	295	134	202	174	1.9	0.58	A	Light turbulence
56	290	132	212	175	2.5	.76	B	
57	295	134	202	---	---	----	A	
58	292	132	210	177	1.6	.49	A	
59	295	134	225	180	1.0	.30	B	Crosswind
60	300	136	202	180	.9	.27	B	Crosswind, light turbulence
61	390	177	230	198	---	----	A	Lakebed landing
62	291	132	200	170	.9	.27	B	
63	292	132	200	---	---	----	A	
64	290	132	210	170	---	----	B	Light-to-moderate turbulence
65	293	133	210	165	---	----	A	Lakebed landing
66	293	133	210	180	---	----	B	Lakebed landing
67	285	129	---	155	---	----	A	Lakebed landing
68	305	138	205	186	2.4	.73	B	3° glide-slope approach light
69	284	129	200	173	---	----	A	Lakebed landing
70	298	135	203	188	3.2	.98	B	3° glide-slope approach light
71	294	133	212	172	3.6	1.1	C	
72	310	141	205	185	2.1	.64	B	3° glide-slope approach light
73	294	133	202	172	3.4	1.0	A	3° glide-slope approach light
74	393	178	230	195	---	----	C	Lakebed landing, light-to-moderate turbulence
75	292	132	210	183	2.4	.73	D	Crosswind, moderate-to-heavy turbulence
76	294	133	206	178	1.8	.55	C	
77	295	134	---	180	---	----	B	
78	298	135	---	180	---	----	C	
79	300	136	200	175	2.1	.64	D	

(b) Touch-and-go landings.

Flight	W,		V_{apr},	V_{td},	Rate of sink at touchdown,		Pilot	Comments
	lb	kg	KIAS	KIAS	ft/sec	m/sec		
70	304×10^3	138×10^3	210	182	2.3	0.70	C	
72	328	149	210	187	1.5	.46	D	
73	298	135	200	180	.8	.24	B	3° glide-slope approach light
76	298	135	210	176	4.3	1.3	B	3° glide-slope approach light
79	310	141	205	168	2.4	.73	B	

TABLE IV. – SUMMARY OF XB-70 TEST CONDITIONS - Concluded

(c) Low approaches.

Flight	W,		V_{apr},	Pilot	Comments
	lb	kg	KIAS		
50	301×10^3	136×10^3	---	B	
50	305	138	210	A	
58	300	136	---	B	ILS
58	308	139	220	B	ILS
62	305	138	210	B	Lateral offset and ILS
65	350	158	225	A	
70	310	140	210	C	
71	303	137	199	C	
72	435	197	240	B	Lateral offset, 3° glide-slope approach light
72	420	190	235	B	Lateral offset, 3° glide-slope approach light
72	405	183	230	B	Lateral offset, 3° glide-slope approach light
73	390	177	225	B	Vertical offset, ILS
73	400	181	225	A	Lateral offset, 3° glide-slope approach light
73	420	190	230	A	
75	304	138	---	D	
75	294	133	---	D	
78	304	138	185	B	3° glide-slope approach light
79	306	139	200	D	
79	311	141	185	B	3° glide-slope approach light

(d) Landing configuration up-and-away evaluations.

Flight	V_i, knots	h_p,		Pilot	Test
		ft	m		
57	230	10×10^3	3.05×10^3	A	Aileron rolls
62	220	15	4.58	B	Pull-up and release, wind-up turn, double aileron pulse, double rudder pulse, steady sideslip, and lateral-directional-maneuver pilot evaluation.
62	260	15	4.58	B	
65	220	8	2.44	A	
73	190	15	4.58	A	
74	265	15	4.58	C	

TABLE V. – PILOT RATING SCALE (ref. 6)

CONTROLLABLE CAPABLE OF BEING CONTROLLED OR MANAGED IN CONTEXT OF MISSION, WITH AVAILABLE PILOT ATTENTION	ACCEPTABLE MAY HAVE DEFICIENCIES WHICH WARRANT IMPROVEMENT, BUT ADEQUATE FOR MISSION. PILOT COMPENSATION, IF REQUIRED TO ACHIEVE ACCEPTABLE PERFORMANCE, IS FEASIBLE.	SATISFACTORY MEETS ALL REQUIREMENTS AND EXPECTATIONS, GOOD ENOUGH WITHOUT IMPROVEMENT CLEARLY ADEQUATE FOR MISSION.	EXCELLENT, HIGHLY DESIRABLE	A1
			GOOD, PLEASANT, WELL BEHAVED	A2
			FAIR. SOME MILDLY UNPLEASANT CHARACTERISTICS. GOOD ENOUGH FOR MISSION WITHOUT IMPROVEMENT.	A3
		UNSATISFACTORY RELUCTANTLY ACCEPTABLE. DEFICIENCIES WHICH WARRANT IMPROVEMENT. PERFORMANCE ADEQUATE FOR MISSION WITH FEASIBLE PILOT COMPENSATION.	SOME MINOR BUT ANNOYING DEFICIENCIES. IMPROVEMENT IS REQUESTED. EFFECT ON PERFORMANCE IS EASILY COMPENSATED FOR BY PILOT.	A4
			MODERATELY OBJECTIONABLE DEFICIENCIES. IMPROVEMENT IS NEEDED. REASONABLE PERFORMANCE REQUIRES CONSIDERABLE PILOT COMPENSATION.	A5
			VERY OBJECTIONABLE DEFICIENCIES. MAJOR IMPROVEMENTS ARE NEEDED. REQUIRES BEST AVAILABLE PILOT COMPENSATION TO ACHIEVE ACCEPTABLE PERFORMANCE.	A6
	UNACCEPTABLE DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT. INADEQUATE PERFORMANCE FOR MISSION EVEN WITH MAXIMUM FEASIBLE PILOT COMPENSATION.		MAJOR DEFICIENCIES WHICH REQUIRE MANDATORY IMPROVEMENT FOR ACCEPTANCE. CONTROLLABLE. PERFORMANCE INADEQUATE FOR MISSION, OR PILOT COMPENSATION REQUIRED FOR MINIMUM ACCEPTABLE PERFORMANCE IN MISSION IS TOO HIGH.	U7
			CONTROLLABLE WITH DIFFICULTY. REQUIRES SUBSTANTIAL PILOT SKILL AND ATTENTION TO RETAIN CONTROL AND CONTINUE MISSION.	U8
			MARGINALLY CONTROLLABLE IN MISSION. REQUIRES MAXIMUM AVAILABLE PILOT SKILL AND ATTENTION TO RETAIN CONTROL.	U9
UNCONTROLLABLE CONTROL WILL BE LOST DURING SOME PORTION OF MISSION.			UNCONTROLLABLE IN MISSION.	10

TABLE VI. – OVERALL PILOT RATING QUESTIONNAIRE

Longitudinal mode	Rating	Comments
Trimmability – Ability to hold airspeed, altitude, and attitude		
Maneuverability – Ability to change airspeed, altitude, and load factor		
Response to turbulence		
Response to configuration changes		
Overall		
Lateral-directional mode		
Trimmability – Ability to hold heading and bank angle		
Maneuverability – Ability to change heading and bank angle		
Response to turbulence		
Overall		
Control harmony		

TABLE VII. – DETAILED PILOT QUESTIONNAIRE - LANDING-APPROACH MANEUVERS

LONGITUDINAL

- Ease and precision of making small angular correction
  - Technique
  - Tendency toward pilot-induced oscillations
- Stability - Does airplane stay at given pitch angle and airspeed?
- Trim well defined? Does longitudinal response affect ability to locate trim?
- Trim sensitivity
- Response to throttle
- Turns - Does nose drop in turns?
  - Do you note anything unusual in pitch attitude in a turn?
- Forces (level of force)
  - Gradient
  - Friction
  - Suitability
- Stick travel - Suitability?

LATERAL

- Ease of initiating turn
  - Technique
- Ease of stopping turn on heading
  - Technique
- Roll authority
  - Start lateral roll correction
  - Stop lateral roll correction
  - Change heading
  - Pick up wing
- Lag - time to respond
  - Tendency to overshoot and oscillate
- What control is used for making a heading change?
  - What instrument is used?

ILS TASK

- Ability to hold altitude (straight and level, in turns)

TABLE VII. – DETAILED PILOT QUESTIONNAIRE - LANDING-APPROACH MANEUVERS - Concluded

Technique:

- Elevator
- Throttle
- Elevator and throttle
- Trim

Why: What is aggravating? What is good?

Ability to establish rate of descent (straight and level, in turns)

How do you do it?

Why this way? What aggravates? What is good?

Ability to hold rate of descent (straight and level, in turns)

Technique:

- Elevator
- Throttle
- Elevator and throttle
- Trim

Why: What aggravates? What is good?

Ability to hold heading

- Prior to localizer intercept
  - What instruments used for intercept?
  - Trim
- On localizer (straight and level and during descent)
  - Trim

Are you rushed for time anywhere during approach?

Where? Why?

Do you tend to oscillate the airplane in:

(a) Altitude
(b) Attitude
(c) Heading
(d) Airspeed

How do you stop an oscillation?

FLARE

How do you flare the airplane?

Where do you initiate flare? Why?

Does the flare require different technique or different emphasis of technique?

How? Why?

Do you misjudge the flare? How?

TABLE VIII. – SUMMARY OF PILOT COMMENTS ON LONGITUDINAL CHARACTERISTICS

Test	Pilot	Ratings	Comments
Shallow approaches and landings, $\gamma \approx -1.5°$, $V_{apr} = 200$ to 220 KIAS	A	Speed control 1 to 2. Longitudinal control 2 to 4. Height judgment 7.	Landings are easy and enjoyable. My biggest problem is judging height above the ground from threshold to landing.
	B	Overall 2 (based primarily on speed control).	Excellent speed stability. Rapid engine response. Airspeed can be held easily within 2 knots.
	C	Overall 2.	Speed control is good. Cushioning effect noted near touchdown. Primary problem is judgment of altitude from 200 feet to touchdown. Control response very good. Very positive thrust response is very desirable.
3° glide-slope approaches, $V_{apr} = 200$ to 220 KIAS, normal weight	B	Overall 2. For airline operation 4.5, due to high approach speed.	Speed held with throttle; elevator held glide slope. Speed and pitch control excellent. Approach appeared a little steep, but was comfortable. Landing is routine, but never as easy as 707 due to cockpit height. This can be coped with. Radar altimeter would enhance safety. The time between flare and touchdown noticeably shorter on steeper approaches. Ground cushion allows smooth touchdowns even with 3° glide slope.
3° glide-slope approaches, $V_{apr} = 225$ to 235 KIAS, heavyweight	A	Operation at Edwards 5. Weather and/or night flying at conventional airports 7. Ratings based primarily on longitudinal task posed by high descent rate.	Transition from approach to flare done with much less comfort than 1 1/2° glide slope. Chances of misjudging height in flare are too great. The 3° glide slope unacceptable for normal operation at high approach speeds. At lighter weights and much lower speeds, might be more receptive to 3° glide slope.
	B	Overall 2	Heavyweight approaches similar to normal weight in longitudinal control response.
ILS approach with vertical offset, $V_{apr} = 225$ KIAS	B	Overall 2.	Excellent longitudinal control and thrust response allowed airplane to be easily established on glide slope.
Slow approach, $\gamma \approx -3°$, $V_{apr} = 185$ KIAS	B	Visibility 5. Speed stability 4 to 4.5	Noticeable decrease in over-the-nose visibility. Reduction in speed stability most significant. Considerably more elevator and throttle manipulation required to hold glide slope and airspeed. Longitudinal response good. Handling qualities acceptable for landing.

TABLE IX. – NOMINAL LANDING-APPROACH CHARACTERISTICS FOR THE XB-70 AND A SUBSONIC JET TRANSPORT

	XB-70	Subsonic jet transport (ref. 7, DC-8)
W, lb (kg)	300,000 (136,000)	190,000 (86,000)
Center of gravity, percent $\bar{c}$	23.5	15.0
V_{apr}, KIAS	205	144
$\bar{q}$, lb/ft^2 (N/m^2)	143 (6850)	71 (3400)
Trim C_L	0.32	0.98
Trim α, deg	7.5	--------------
Trim δ_e, deg	10	--------------
ω_{sp}, radians/sec	1.2	1.6
ζ_{sp}	0.55	0.55
L_α, per sec	0.77	0.63
N_{z_α}, g/radian	8.28	4.75
ω_d, radians/sec	1.3	1.0
ζ_d	0.13	0.1
τ_r, sec	0.77	0.83
τ_s, sec	27	77
$\frac{\omega_\varphi}{\omega_d}$	0.68	0.95
I_X, slug-ft^2 (kg-m^2)	1,450,000 (1,960,000)	--------------
I_Y, slug-ft^2 (kg-m^2)	16,000,000 (21,700,000)	--------------
I_Z, slug-ft^2 (kg-m^2)	17,200,000 (23,300,000)	--------------
I_{XZ}, slug-ft^2 (kg-m^2)	-600,000 (-813,000)	--------------

TABLE X.—XB-70 LANDING-APPROACH-CONFIGURATION STABILITY DERIVATIVES OBTAINED FROM FLIGHT

[Center of gravity = 23.5 percent $\bar{c}$; $\alpha = 7.5°$]

Derivative	Value
$C_{N_{\alpha}}$, per deg	0.048
$C_{N_{q}}$, per radian	1.0
$C_{N_{\delta_e}}$, per deg	0.008
$C_{m_{\alpha}}$, per deg	-0.0039
$C_{m_{q+\dot{\alpha}}}$, per radian	-1.05
$C_{m_{\delta_e}}$, per deg	-0.0034
$C_{l_{\beta}}$, per deg	-0.0018
$C_{l_{p}}$, per radian	-0.15
$C_{l_{r}}$, per radian	0.02
$C_{l_{\delta_a}}$, per deg	0.00066
$C_{l_{\delta_r}}$, per deg	0.00001
$C_{n_{\beta}}$, per deg	0.0022
$C_{n_{p}}$, per radian	-0.08
$C_{n_{r}}$, per radian	-0.18
$C_{n_{\delta_a}}$, per deg	0.00008
$C_{n_{\delta_r}}$, per deg	-0.0011
$C_{Y_{\beta}}$, per deg	-0.0032
$C_{Y_{\delta_a}}$, per deg	-0.0011
$C_{Y_{\delta_r}}$, per deg	0.0021

TABLE XI. – SUMMARY OF PILOT COMMENTS ON LATERAL-DIRECTIONAL CHARACTERISTICS

Test	Pilot	Ratings	Comments
Approach and landing, $\gamma = -1.5^\circ$ to -3°, $V_{apr} = 200$ to 220 KIAS	A	FACS on 3 to 4 (light turbulence). FACS off 5 (light turbulence).	Light turbulence - the aircraft responded very well, FACS on. Lateral-directional control in gusty air not good, FACS off.
	B	FACS on 3. FACS off 3.5.	Lateral control satisfactory in smooth air.
	C	FACS on 2.5 (light turbulence).	Yaw oscillations were noticed in turbulence and could not be damped out. Roll response good. Down rated for adverse yaw.
Lateral-offset approach, $\gamma = -3^\circ$, $V_{apr} = 210$ to 240 KIAS	A	FACS on 3.5.	Lateral maneuver to aline with runway not difficult. However, combination of alining and descending to runway would result in touchdown 5000 to 6000 feet down runway.
	B	FACS on 4 (light to moderate turbulence). FACS off 5.5 (light to moderate turbulence).	Rapid control inputs, necessary because of high approach speed, caused yaw oscillation of 2°. Difficult correcting to centerline. FACS off, turbulence had a greater effect. Yaw oscillations reached 3°. Tendency to overcontrol is greater. Some oscillations in bank angle and roll.
	C	FACS on 4.	2° adverse yaw during initial lateral control input.
Lateral-directional maneuvers, 260 knots, FACS on;	B	Uncoordinated: moderate rate 3, fast 3.5. Coordinated: moderate rate 2.5, fast 4.5.	It was too difficult to coordinate the fast roll out.
220 knots, FACS off;	A	Overall 3.	Rating due to coordination effort required and yaw due to ailerons.
190 knots, FACS on or off	A	Uncoordinated 2.5. Coordinated 4.5.	Attention to bank angle and yaw causes heading overshoots. Coordination requires excessive attention.
Aileron rolls, $V_i = 235$ knots	A	Overall 6 (FACS off).	20-percent wheel deflection was applied at a moderate rate. These rolls were not comfortable.
Crosswind landings, wind: 55° to runway, 20 knots, gusts to 30 knots	B	--------------------	Light turbulence. Fly with sideslip on approach, switch to one wing down, no sideslip near runway. Crosswind not nearly as much trouble as turbulence.
	D	First landing - initial impression: at Edwards 6; all-weather airline operation 8.	Moderate and occasionally heavy turbulence, drift 5° to 7°, difficult to kill. Precise airspeed control impossible.

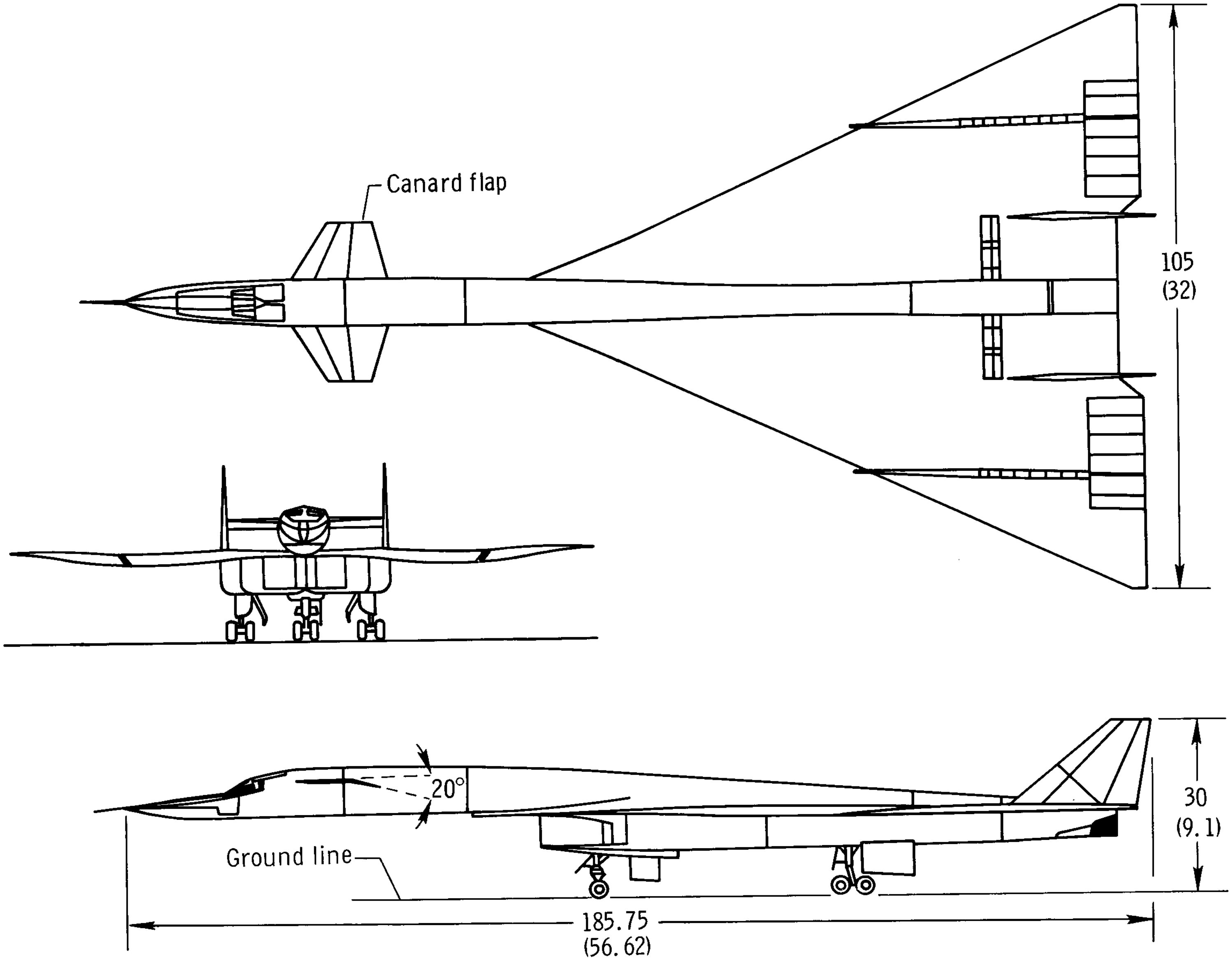

Figure 1. – XB-70 airplane. Landing configuration; dimensions in feet (meters) unless otherwise noted.

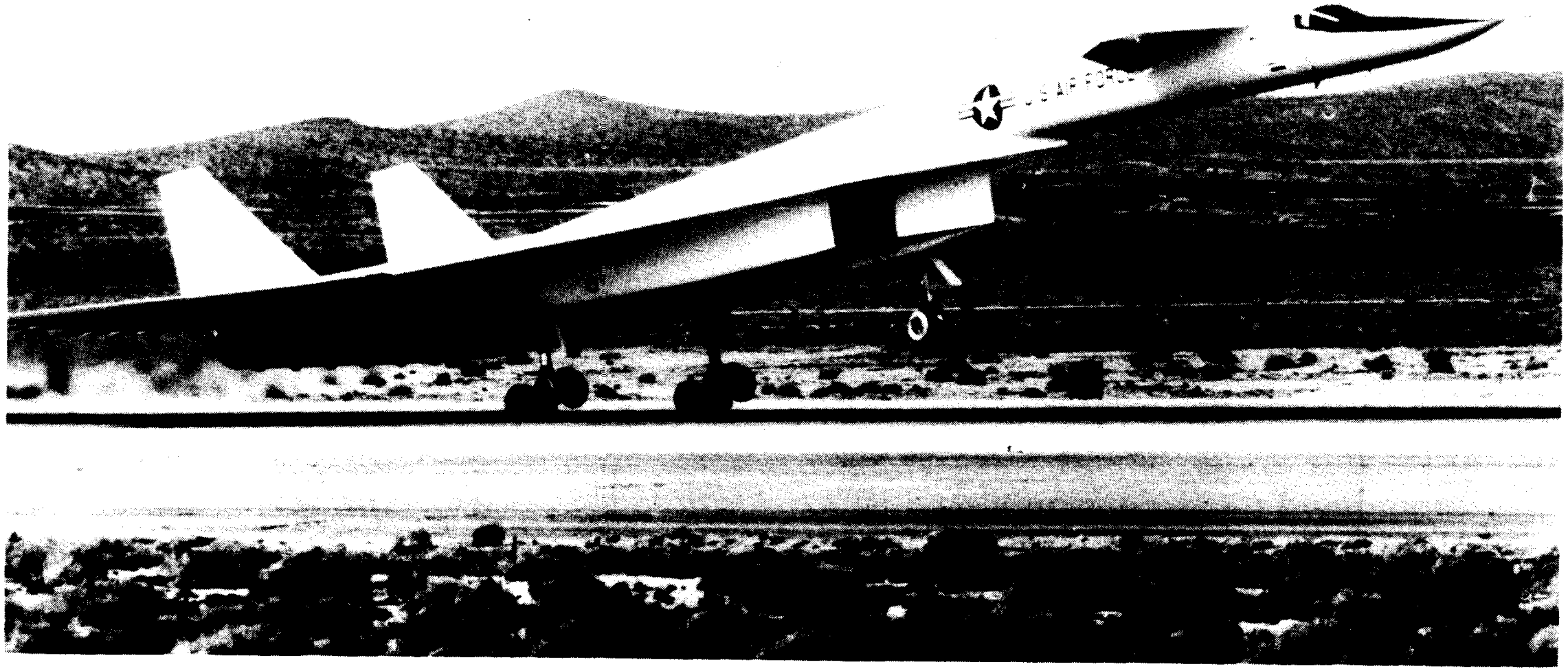

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Figure 2. —XB-70 airplane in the landing configuration.

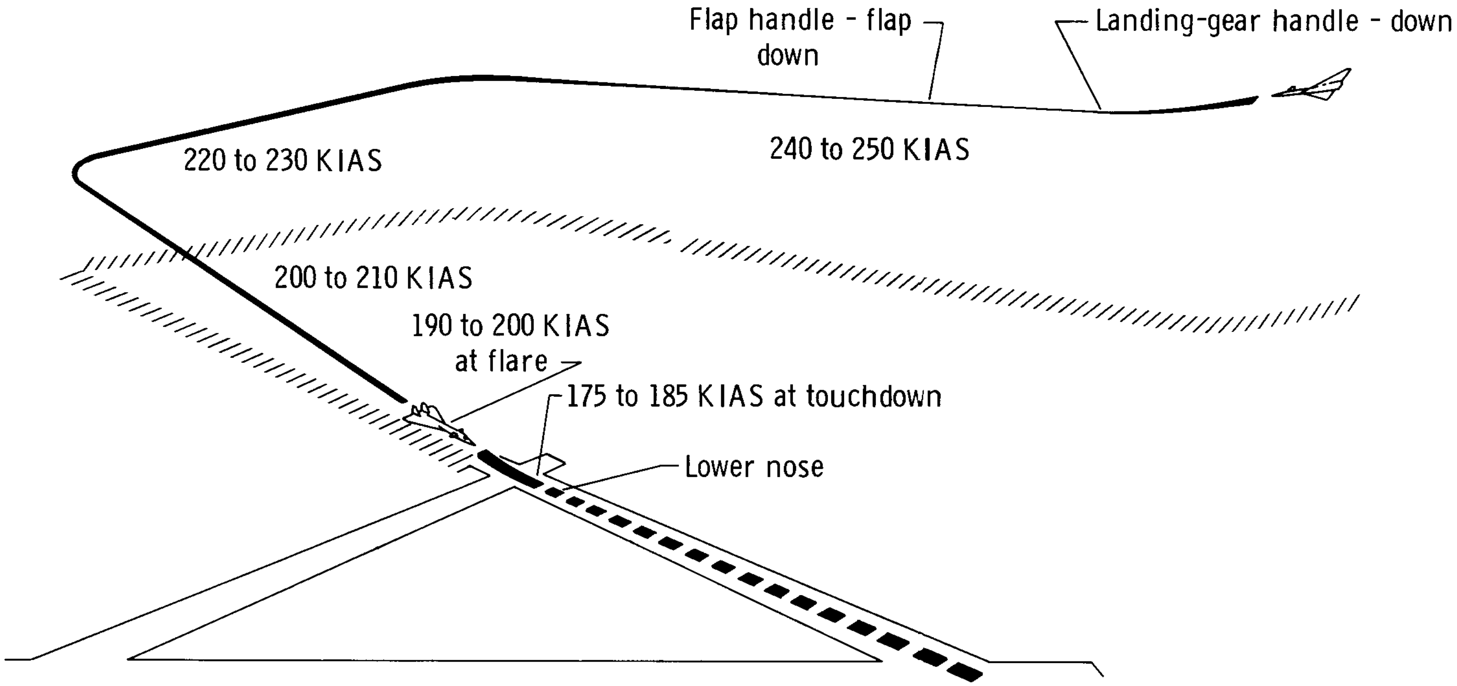


Figure 3. – Typical XB-70 landing pattern.

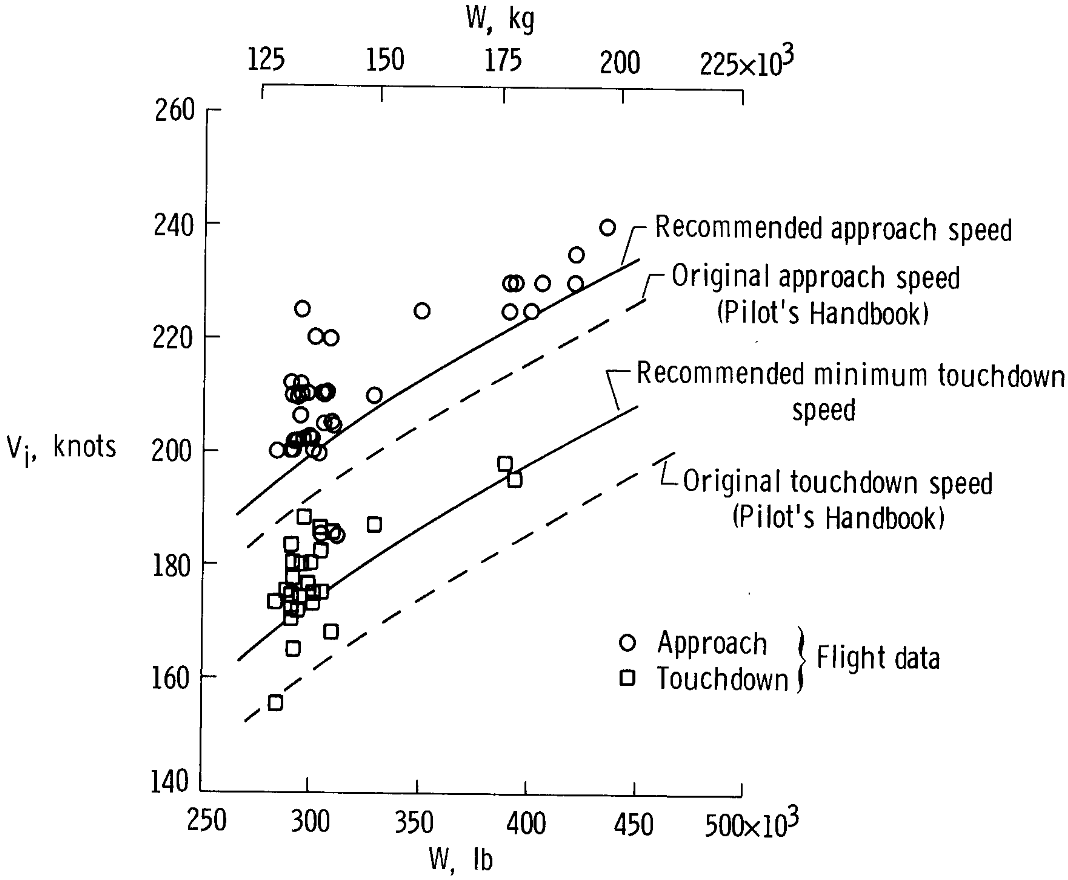


Figure 4. – Variation of XB-70 approach and touchdown speeds with gross weight.

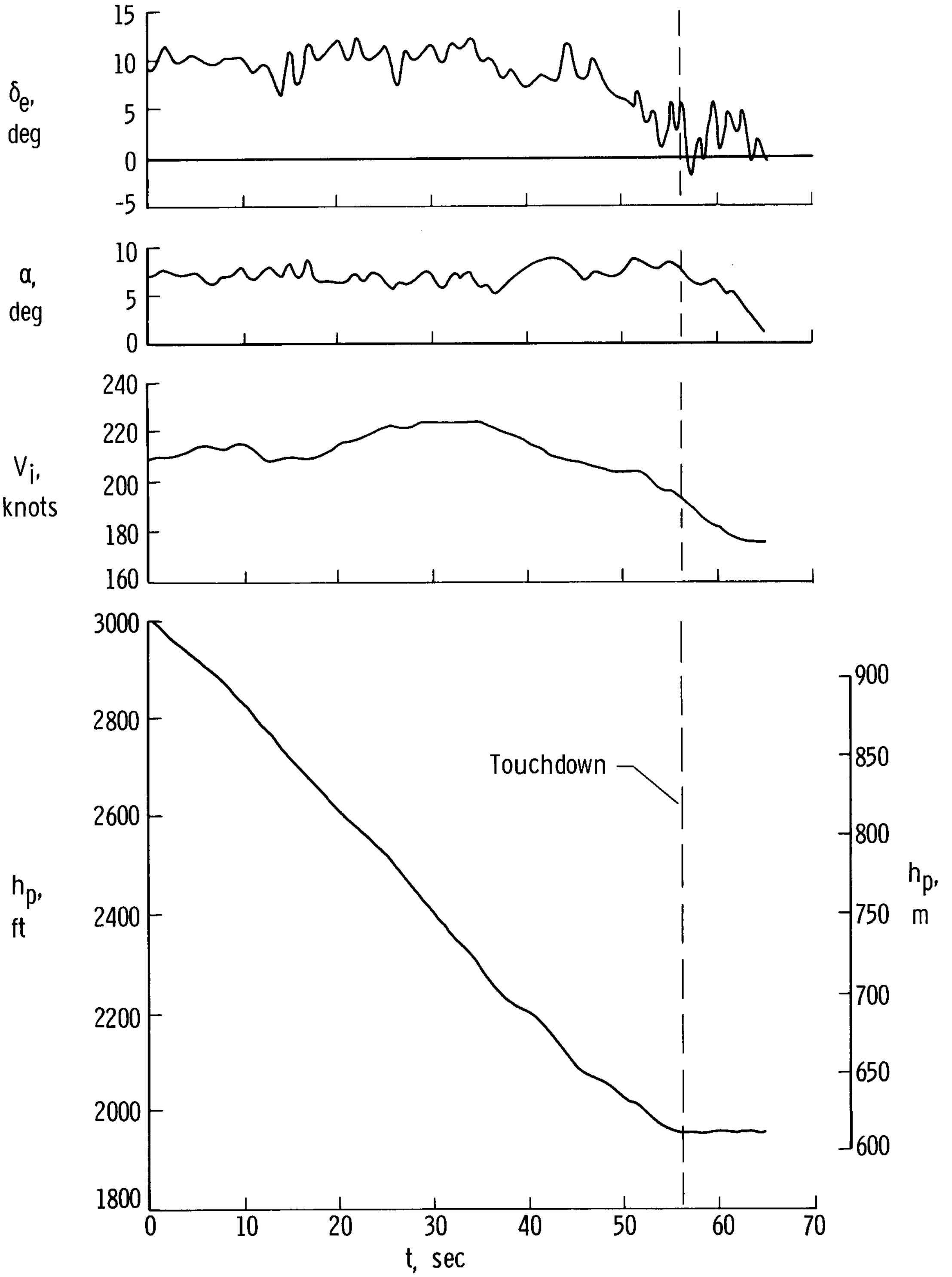


Figure 5. — Time history of typical XB-70 3° glide-slope approach and landing. V_{apr} = 210 KIAS, W = 310,000 lb (140,000 kg), center of gravity = 23.5 percent $\bar{c}$.

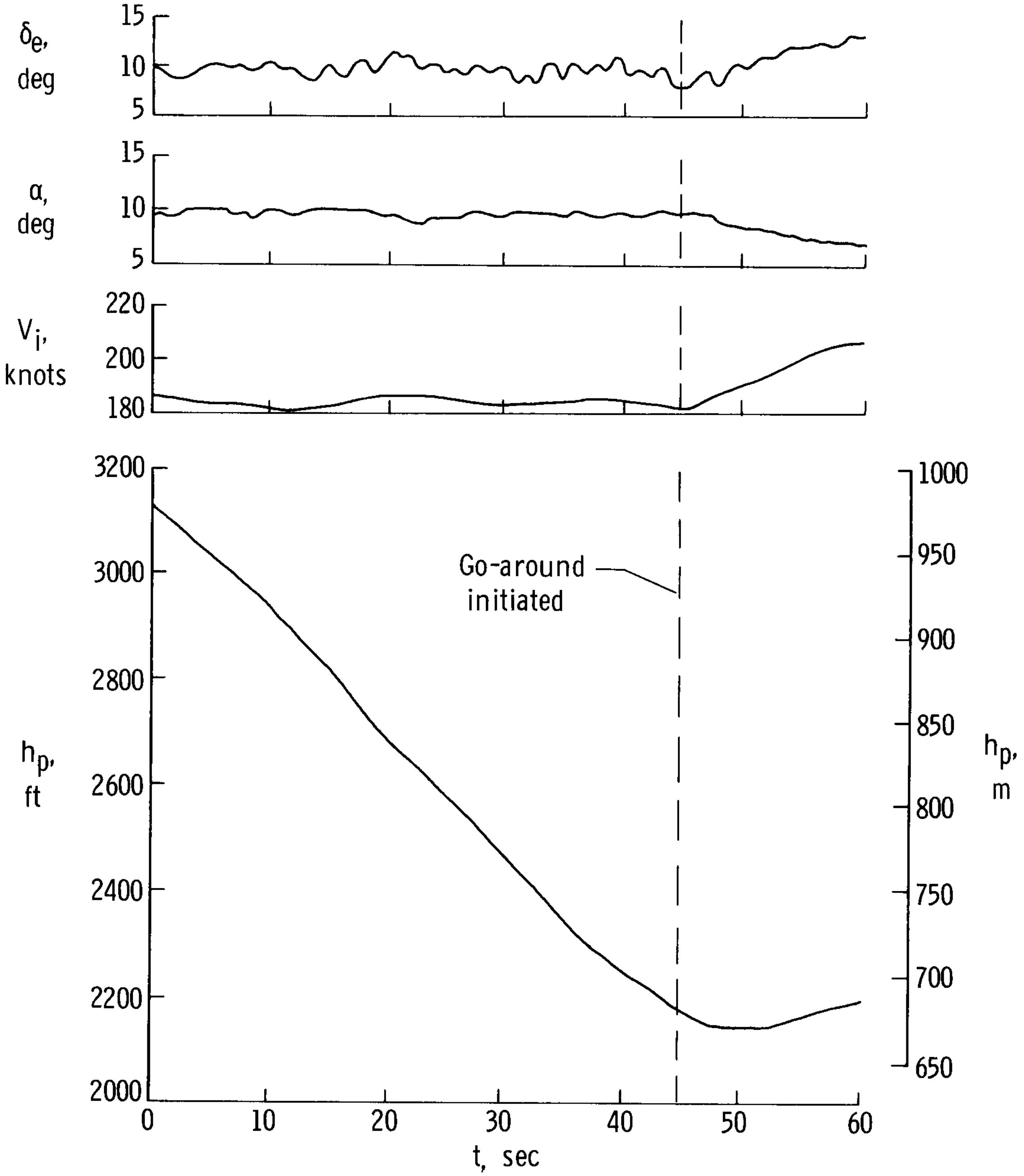


Figure 6. – Time history of XB-70 3° glide-slope approach at lower than recommended speed. V_{apr} = 185 KIAS, W = 311,000 lb (141,000 kg), center of gravity = 23.5 percent $\bar{c}$.

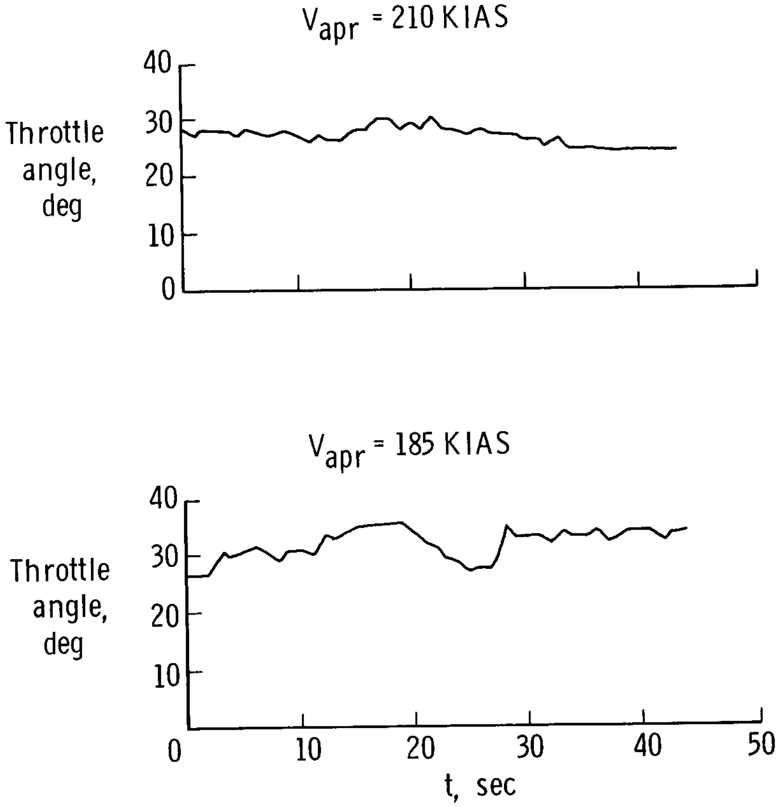


Figure 7. – Time history of throttle activity during XB-70 landing-approach maneuvers.

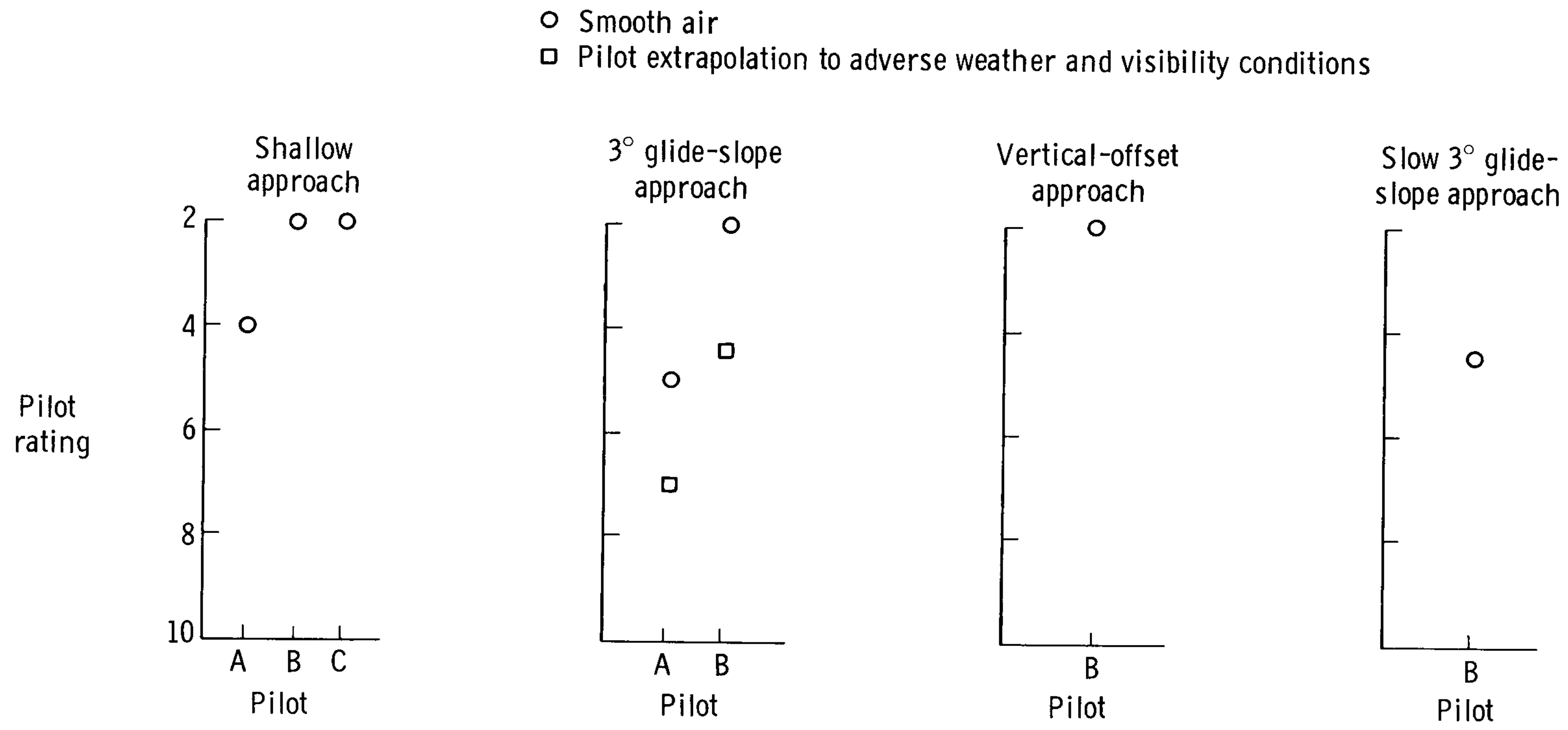


Figure 8. – Summary of pilot ratings of XB-70 longitudinal handling qualities.

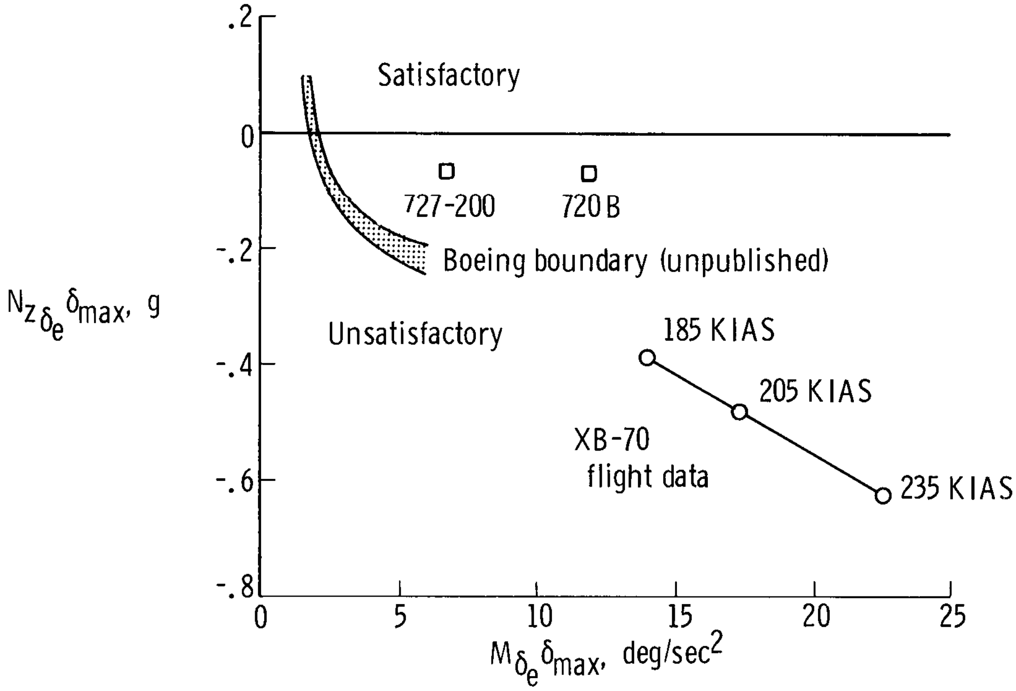


Figure 9. – Comparison of XB-70 control power with unpublished longitudinal-control-power criteria for the landing configuration.

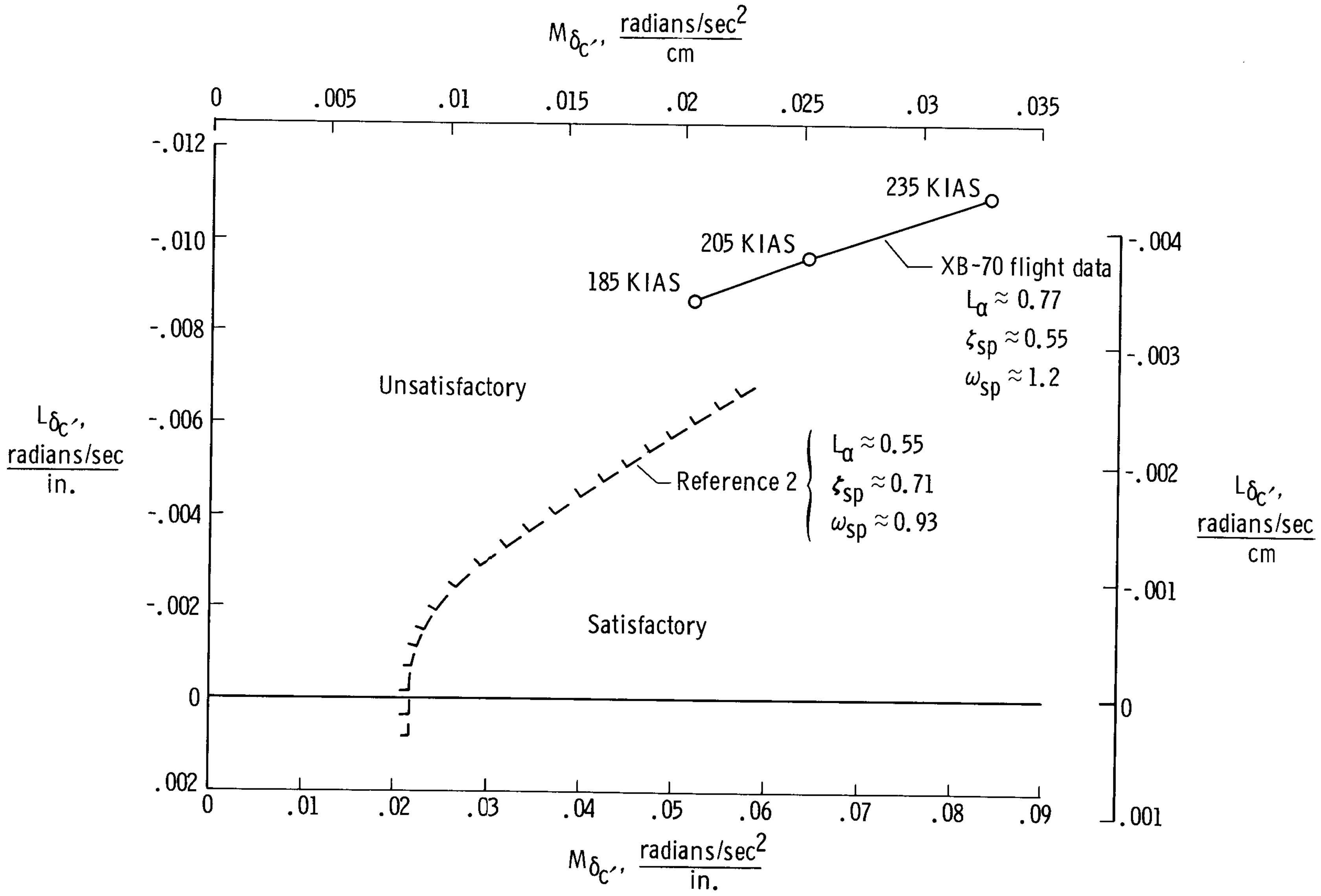


Figure 10. – Comparison of XB-70 longitudinal-control sensitivity with suggested longitudinal-control-sensitivity criterion for landing configuration.

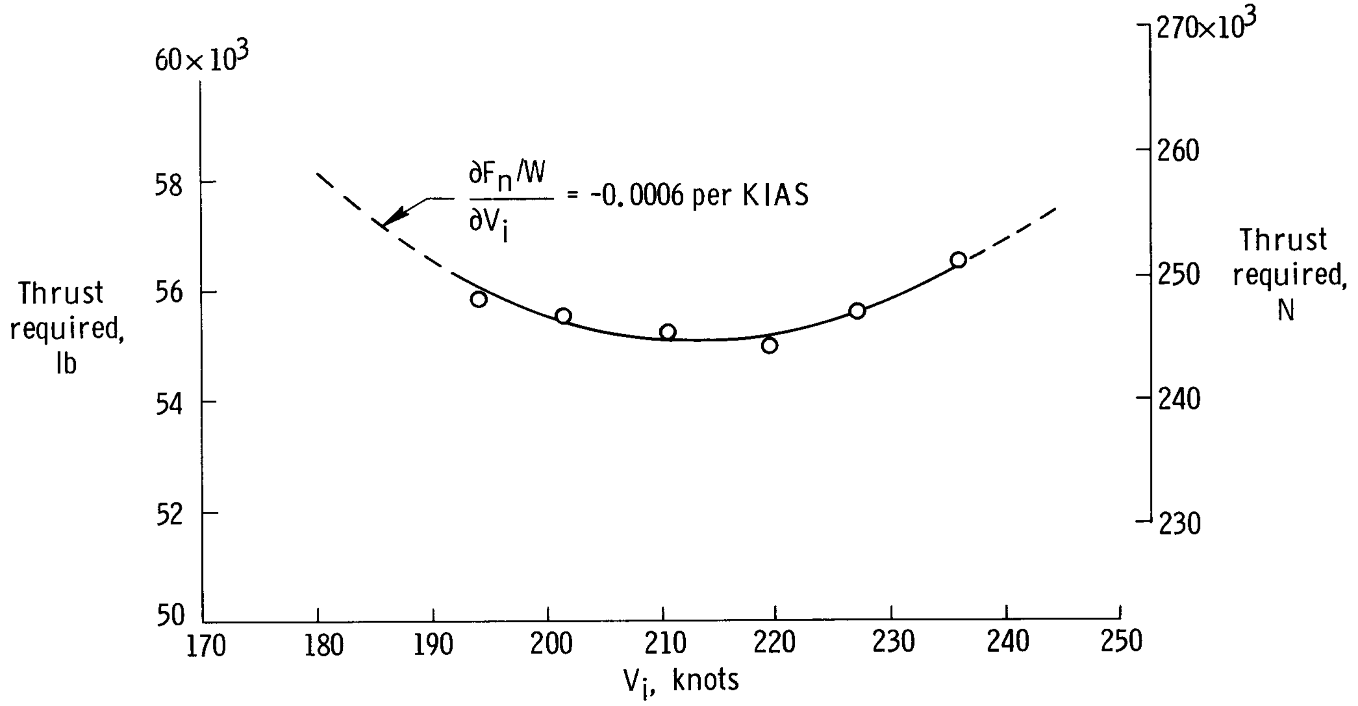


Figure 11. – XB-70 landing configuration speed-thrust variation. W = 300,000 lb (136,000 kg), center of gravity = 23.5 percent $\bar{c}$.

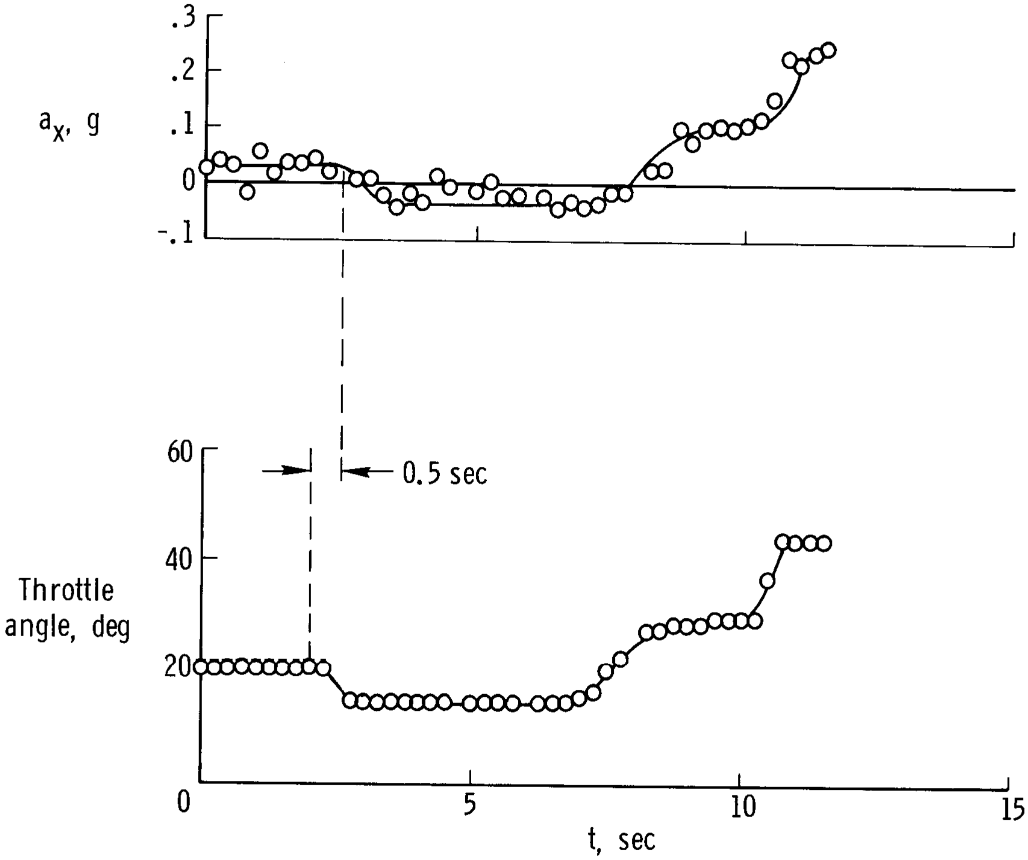


Figure 12. – XB-70 throttle response during a touch-and-go maneuver.

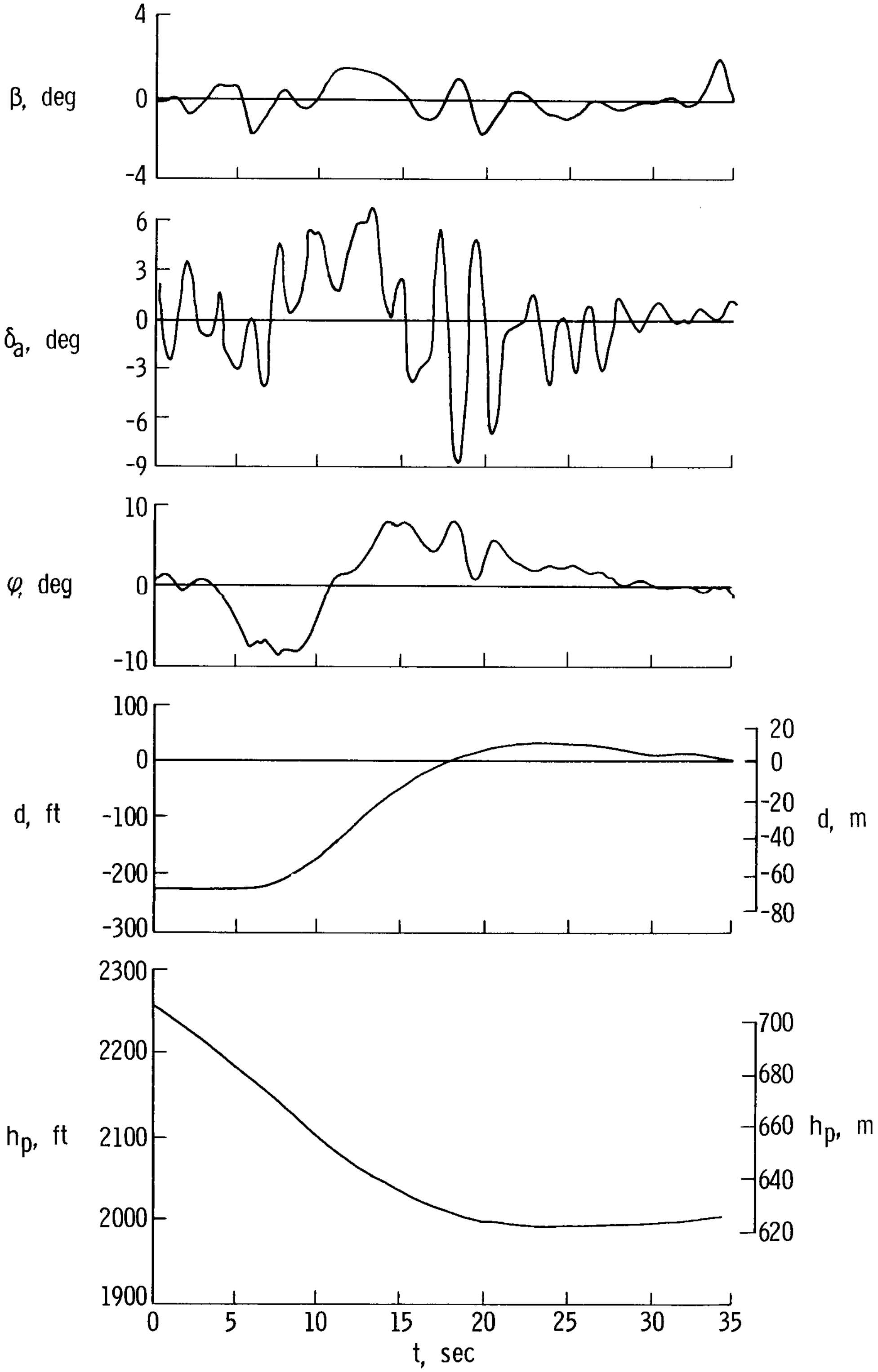
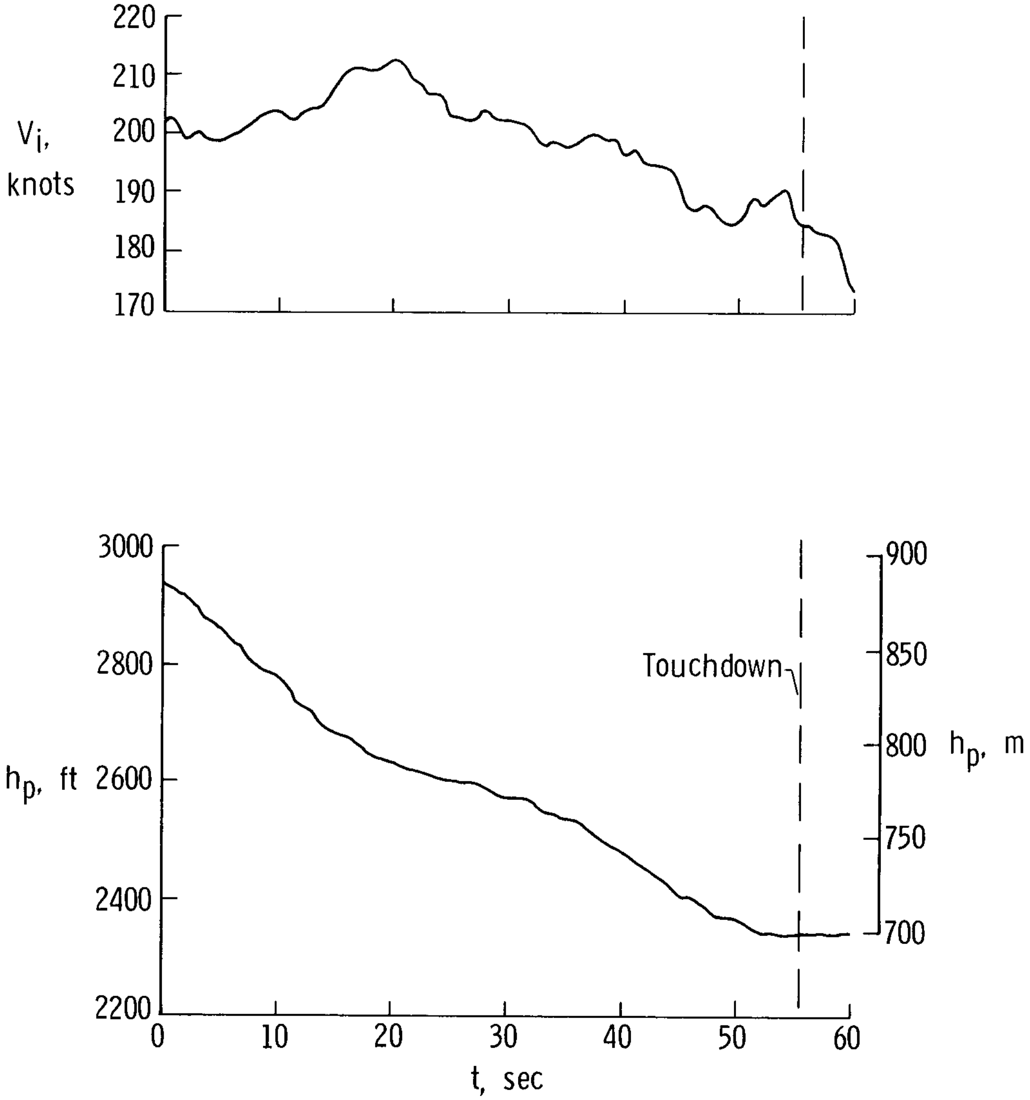
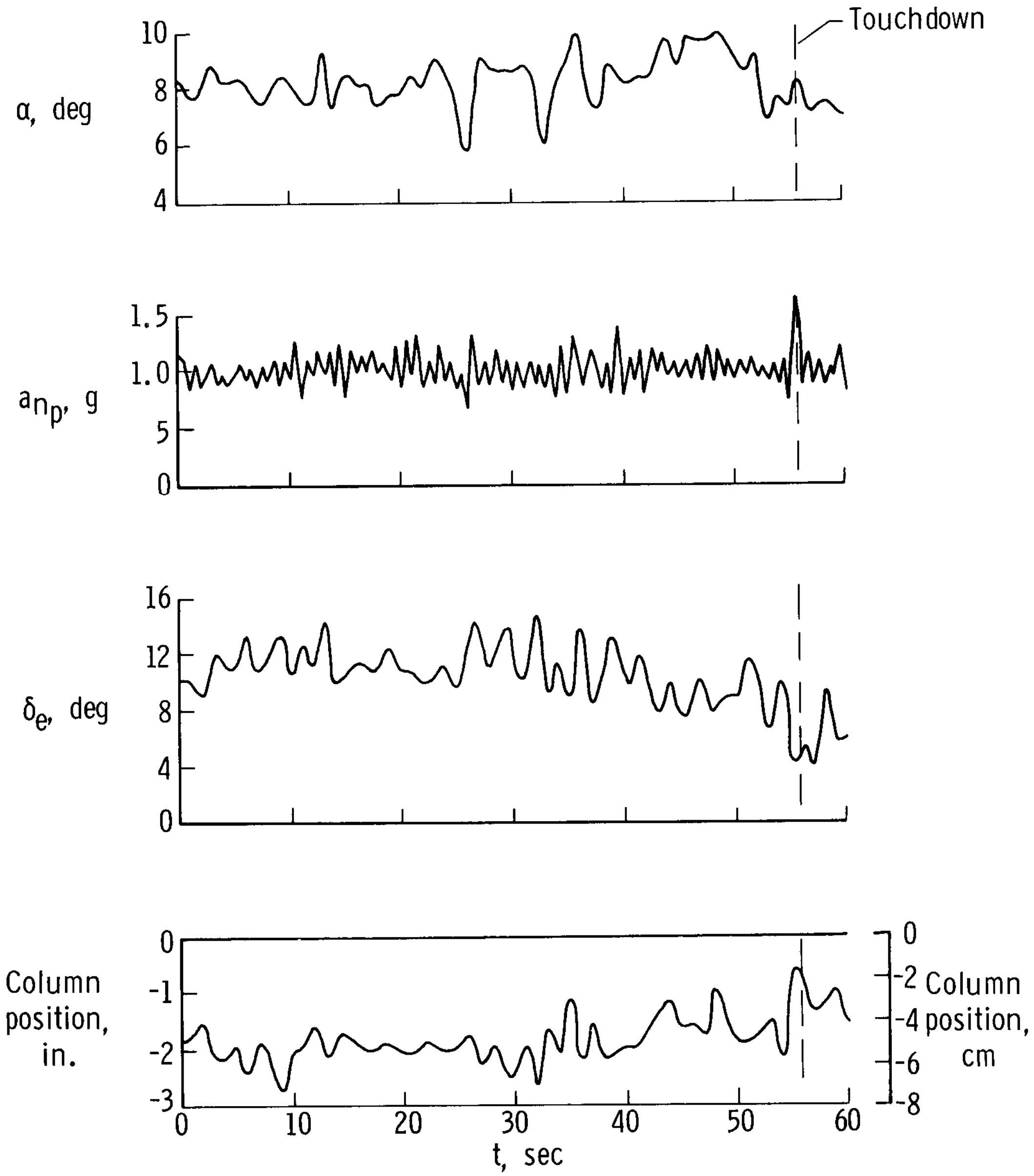


Figure 13. — Typical time history of an XB-70 lateral-offset maneuver. W = 446,000 lb (202,000 kg); center of gravity = 23.5 percent $\bar{c}$.



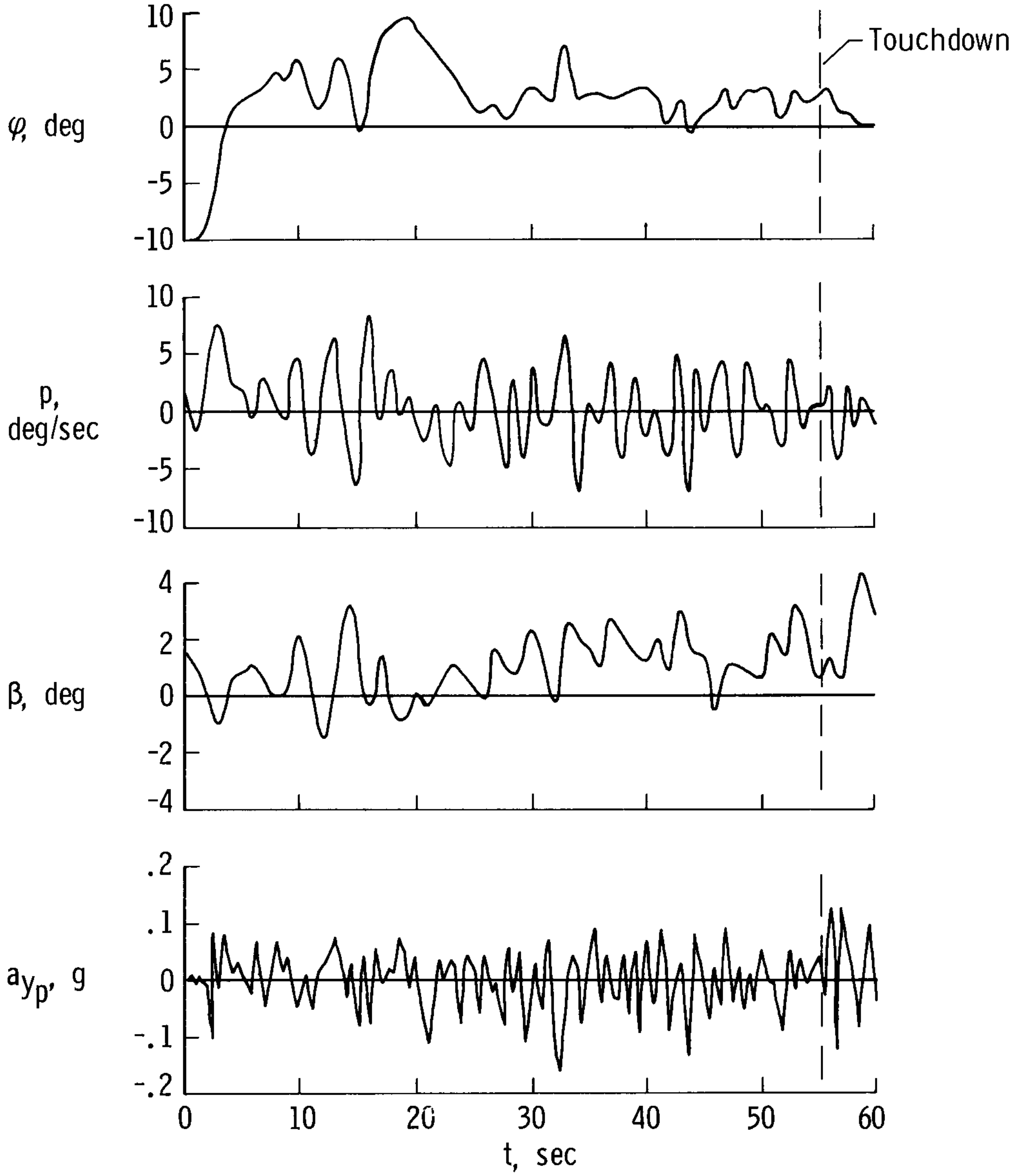
(a) V_i and h_p.

Figure 14. — Time histories of XB-70 crosswind landing. Wind 20 knots, gusts to 30 knots; 55° to runway; turbulence moderate-to-heavy; FACS on; center of gravity = 23.5 percent $\bar{c}$.



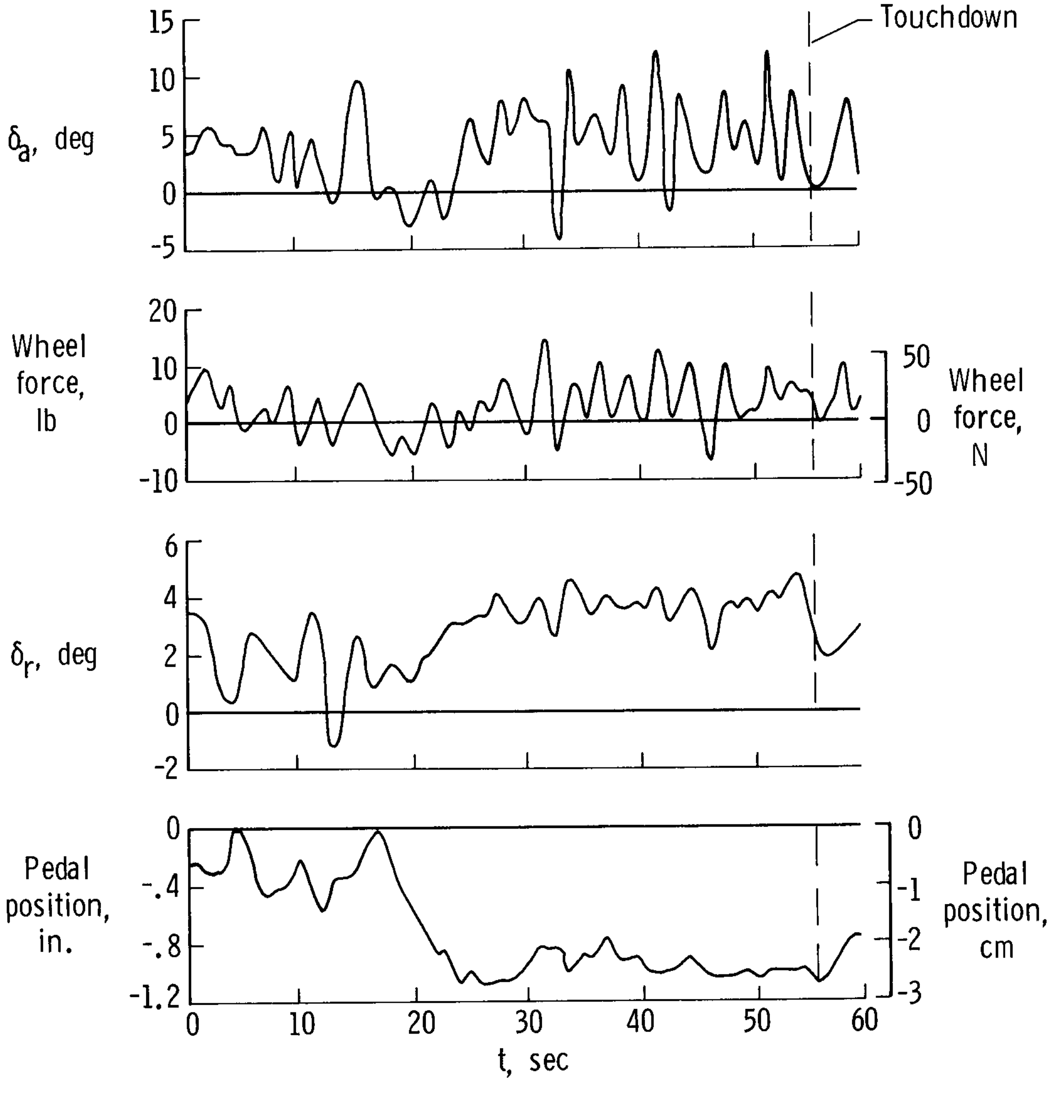
(b) α, a_{n_p}, δ_e, and column position.

Figure 14. – Continued.



(c) φ, p, β, and a_{y_p}.

Figure 14. – Continued.



(d) δ_a, wheel force, δ_r, and pedal position.

Figure 14. – Concluded.

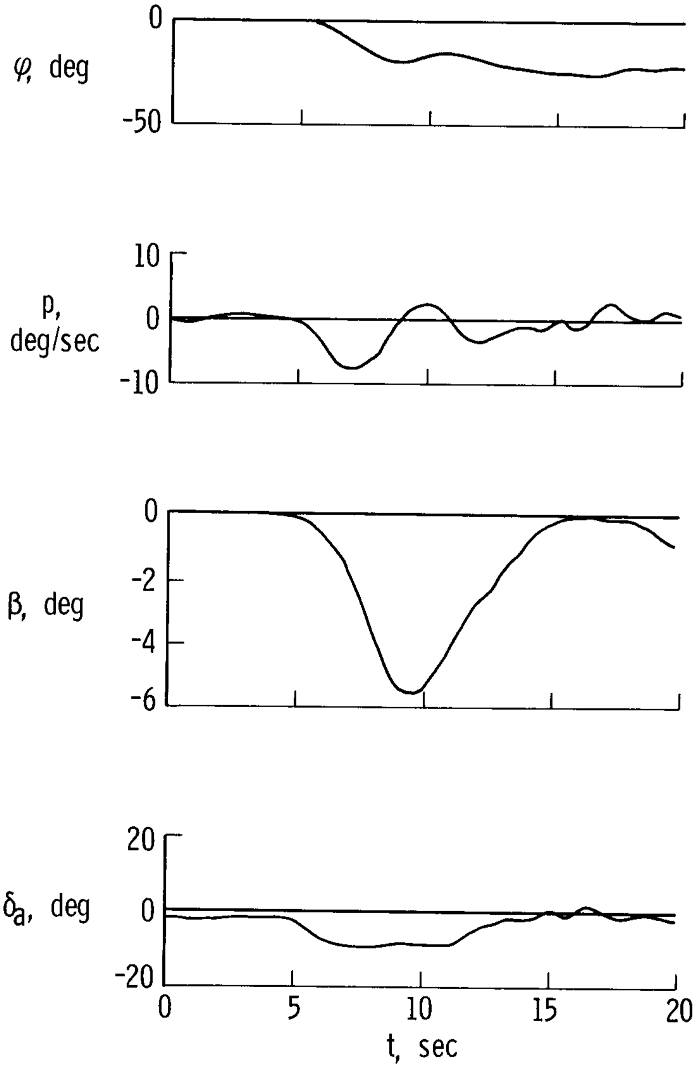
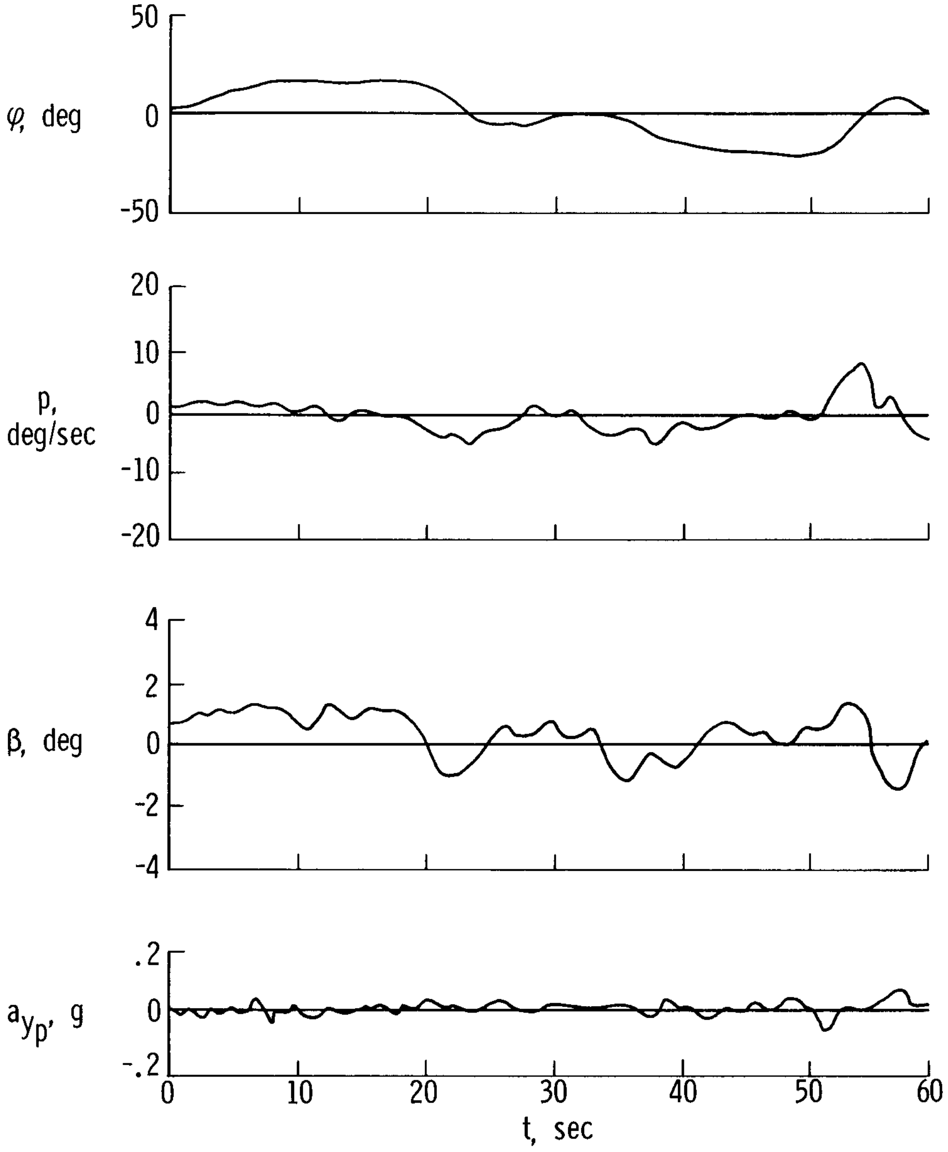
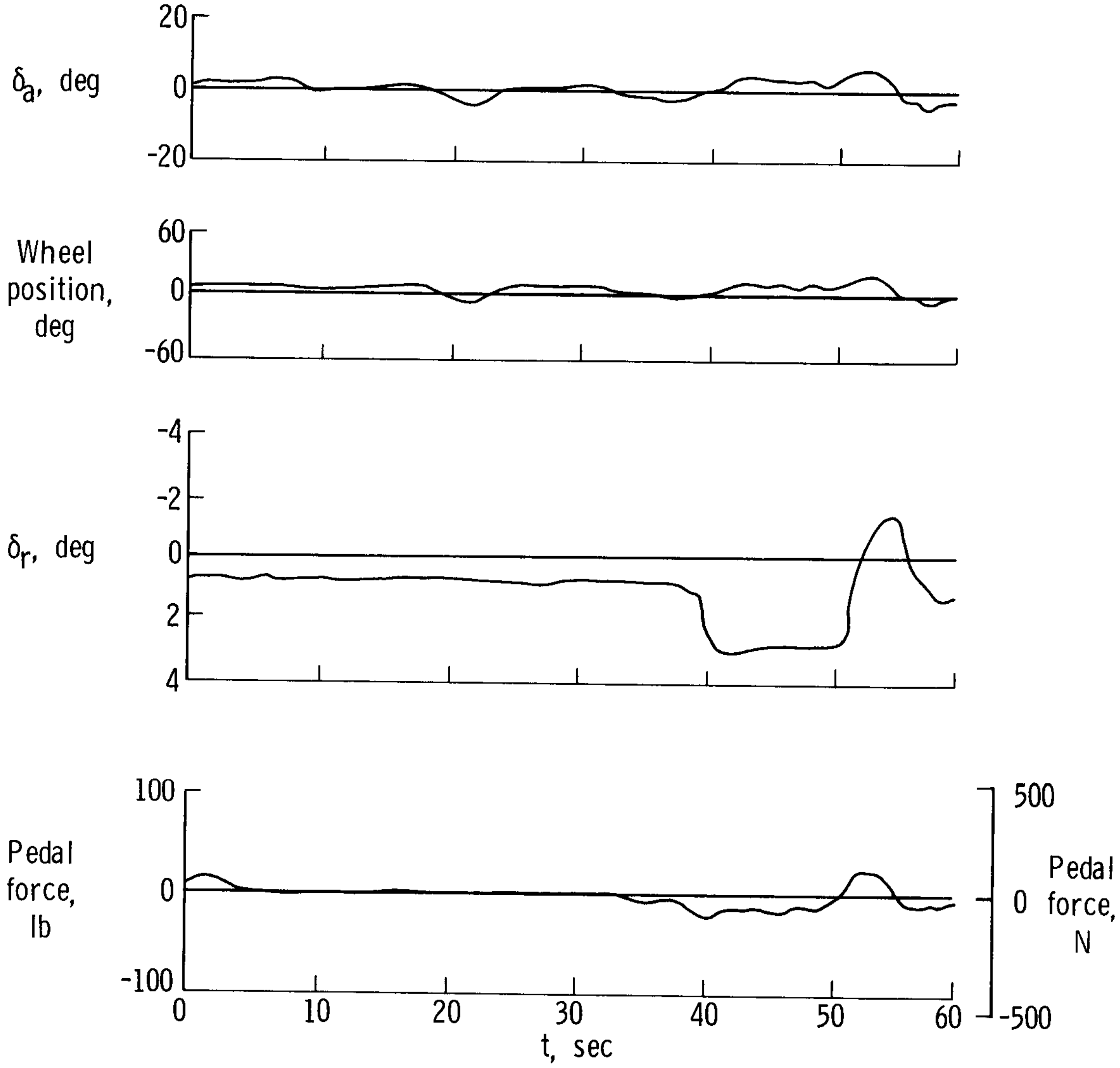


Figure 15.— Time history of XB-70 rudder-fixed, FACS-off, aileron roll. V_i = 230 knots; h_p = 10,000 ft (3050 m); center of gravity = 23.5 percent $\bar{c}$; landing configuration.



(a) φ, p, β, and a_{y_p}.

Figure 16. – Time histories of typical XB-70 lateral-directional evaluation maneuver. V_i = 190 knots; h_p = 15,000 ft (4570 m); FACS off; center of gravity = 23.5 percent $\bar{c}$.



(b) δ_a, wheel position, δ_r, and pedal force.

Figure 16. – Concluded.

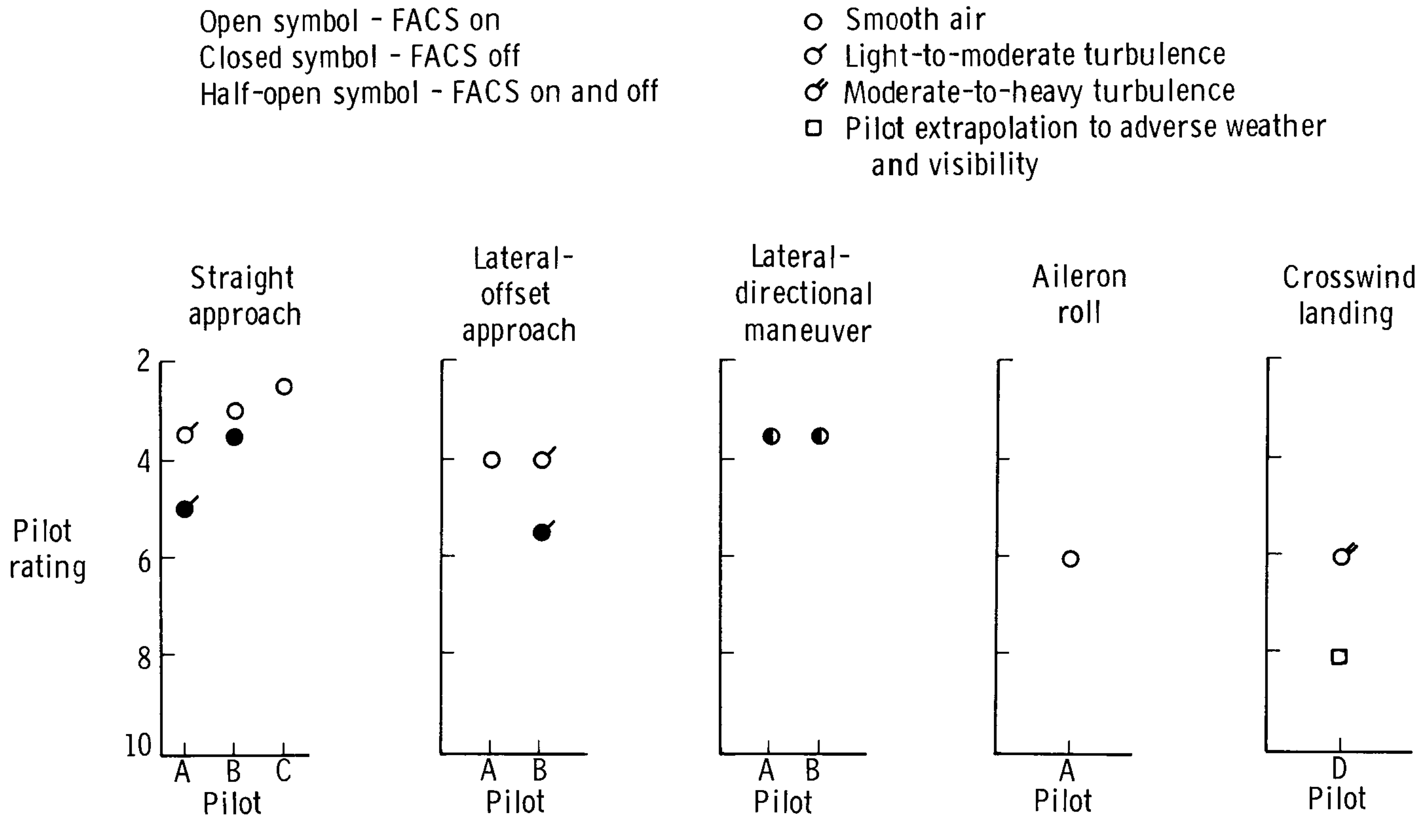


Figure 17. – Summary of pilot ratings of XB-70 lateral-directional characteristics.

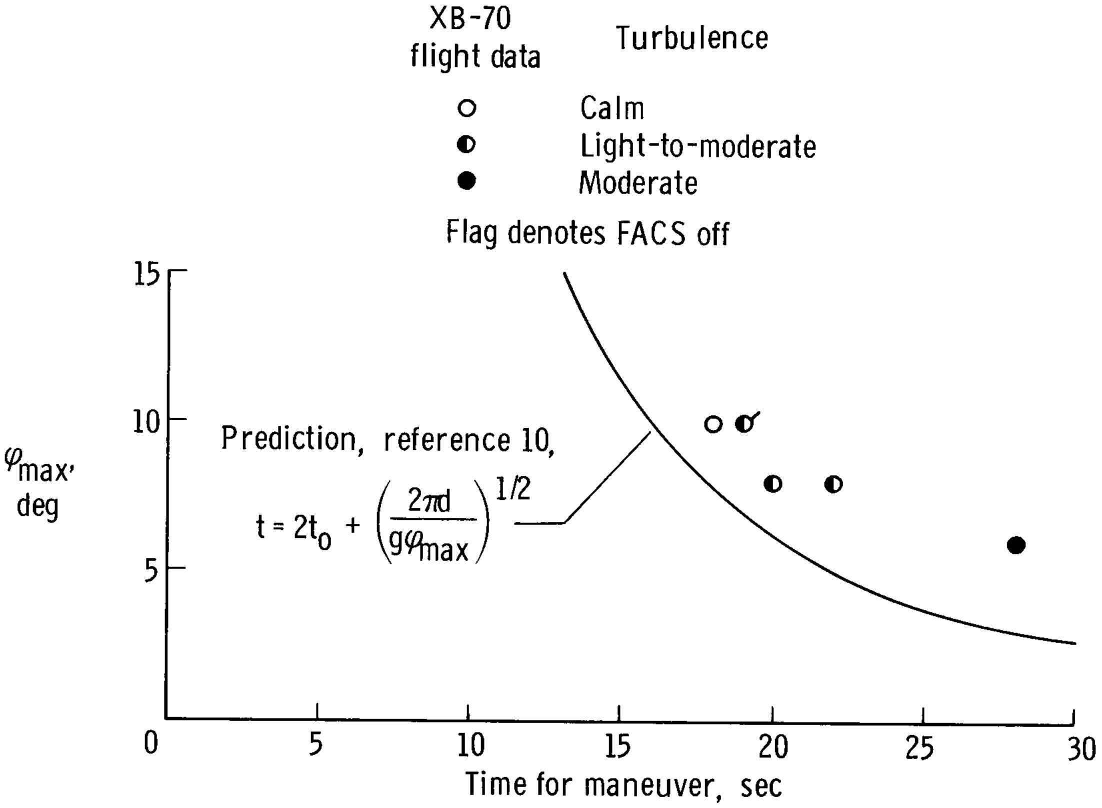


Figure 18.— Comparison of XB-70 flight results with predictions (ref. 10) of time to accomplish a sidestep maneuver during landing approach as a function of maximum bank angle used. 200-foot (61-meter) offset.

NASA-Langley, 1970 —— 2 H-587