NASA TECHNICAL NOTE

NASA TN D-4141

c. 1

NASA TN D-4141

RESULTS OF A BRIEF FLIGHT INVESTIGATION OF A COIN-TYPE STOL AIRCRAFT

by Terrell W. Feistel and Robert C. Innis

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1967

NASA TN D-4141

RESULTS OF A BRIEF FLIGHT INVESTIGATION OF A COIN-TYPE STOL AIRCRAFT

By Terrell W. Feistel and Robert C. Innis

Ames Research Center
Moffett Field, Calif.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

RESULTS OF A BRIEF FLIGHT INVESTIGATION

OF A COIN-TYPE STOL AIRCRAFT

By Terrell W. Feistel and Robert C. Innis

Ames Research Center

SUMMARY

The airplane tested to gain experience with a COIN (for COunter INsurgency) type STOL aircraft had two propellers driven by turbine engines, and double-hinged, single-slotted flaps to deflect the slipstream on the largely immersed wing. It was capable of good low-speed performance and had acceptable handling qualities in the STOL regime (with landing and take-off distances consistently less than 800 feet over a 50-foot obstacle), provided the possibility of engine failure was ignored. This performance was achieved, despite flaps with only medium effectiveness, because the aircraft had a low aspect ratio, a high power loading, and a "no-flare" landing gear design. It is shown (for the sake of an interesting comparison) that the performance of the test aircraft, as flown (ignoring engine failure), compared favorably with that of a large four-engined STOL aircraft, tested previously, which was much more sophisticated (it included a fail-safe propulsion system). If flown above the minimum single-engine control speed, however, in compliance with the normal safety restrictions for twin-engine airplanes, major aspects of the performance of the test aircraft are no better than that obtainable with many small "twins" in current production and most of the original objectives of the COIN concept are compromised.

INTRODUCTION

The NASA has for several years studied COIN-type STOL aircraft with primary emphasis on STOL operational problems, low-speed handling qualities, the desirability of propeller interconnect (cross shafting), and high-lift devices. Recently, in extensive wind-tunnel tests, NASA studied various small-scale COIN models (ref. 1) to determine low-speed stability and control problems and the effect of configuration changes. Results of simulator studies (ref. 2) and flight tests of the Ryan VZ-3 were used to analyze handling qualities of COIN aircraft. The first flying prototype COIN, the Convair Model 48 "Charger," was flight tested for 10 hours to examine the problems further and to obtain additional operational experience with STOL aircraft. The results of these flight tests which are considered to be pertinent to a general understanding of COIN-type (i.e., relatively small, simple, and inexpensive) STOL aircraft are presented here.

SYMBOLS

A actual geometric aspect ratio

a_x axial acceleration, g

C_L lift coefficient

$\overline{C}_D$ net drag coefficient (power on), drag coefficient minus thrust

$\overline{C}_F$ mean equivalent skin-friction coefficient in cruise $\equiv C_{D_{cruise}} - \frac{C_L^2}{\pi A}$

F_{δ_a} lateral stick force, lb

F_{δ_e} longitudinal stick force, lb

f equivalent flat plate area, sq ft $\equiv C_{D_{cruise}}S$

h ground clearance, ft

h_i indicated pressure altitude, ft

p roll rate, deg/sec

$\frac{R}{C}$ rate of climb, fpm

$\frac{R}{D}$ rate of descent, fpm

$\frac{R}{S}$ rate of sink, fps

$\overline{Re}$ mean Reynolds number in cruise, $\overline{l} \times \frac{V}{\nu}$ (where $\overline{l}$ is the mean wetted surface length and ν is the kinematic viscosity of air)

S reference wing area, sq ft

SHP shaft horsepower

S_L total landing distance over 50 feet, ft

S_w total aircraft wetted area, sq ft

TED trailing edge down

TEU trailing edge up

T_c' thrust coefficient, $\frac{\text{thrust}}{qS}$

t time

V_{k_i} indicated airspeed, knots

V_{MC} minimum single-engine control speed, knots

$\frac{W}{S}$ wing loading, psf

α_i indicated angle of attack, deg

β sideslip angle, deg

γ_A approach descent angle, deg

δ_{e_t} elevator tab deflection, deg

δ_F flap deflection angle, deg

δ_{sp} spoiler deflection, deg

δ_{stab} stabilator deflection, deg

θ pitch attitude, deg

$\dot{\theta}$ pitch rate, deg/sec

$\ddot{\theta}$ pitch acceleration, rad/sec^2

φ roll angle, deg

$\ddot{\varphi}$ rolling acceleration, rad/sec^2

DESCRIPTION OF AIRCRAFT AND INSTRUMENTATION

Description of the Test Aircraft

The test aircraft (shown in fig. 1 in an STOL landing approach) had two 650 SHP engines driving opposite rotation, 9-foot-diameter propellers; the tips rotated upward in the center. Retractable Krueger flaps were used on the inboard leading edges of the wing which was largely immersed in the propeller slipstream. The 44-percent chord trailing-edge flap was single slotted and double hinged, and was deflected $60^\circ/30^\circ$ for the landing approach and $20^\circ/0^\circ$ for take-off. (The flap geometry is shown on the inset; the $40^\circ/11^\circ$ position is an intermediate one which was investigated only briefly.) The control system was entirely mechanical; lateral control was obtained with circular-arc spoilers only and longitudinal control with a free-floating, single-hinged (geared, camber-changing) horizontal tail (called a stabilator). The twin rudders were conventional. A three-view drawing of the test airplane is shown in figure 2. Table I lists the pertinent physical characteristics.

Design Considerations

The Charger was designed according to a Marine Corps specific operating requirement (SOR) that specified a take-off and landing distance of 500 feet over a 50-foot obstacle and included a requirement for "single-engine survivability." To meet this latter requirement, a "torque-equalizer" device was incorporated to reduce the power on one engine automatically in the event the other failed, thereby allowing the pilot to hold the wings near-level long enough to eject safely; this device was operable during all the NASA flight tests in the STOL regime (with the exception, of course, of the single-engine investigations).

Instrumentation

The flight test data were recorded with an on-board tape deck and photo panel. These data were correlated through voice contact with the pilot by a time-coding system. Measured quantities included: airspeed, altitude, angle of attack, angle of sideslip, rate of climb, and engine data on the photo panel; plus angular rates (about three axes), angular accelerations (about three axes), linear accelerations (in three directions), and primary control positions recorded on tape.

For the landing and take-off data, a "TOL" (Take-Off and Landing) camera (ref. 3) was installed in the bottom of the fuselage to provide accurate information on aircraft height (ground clearance), ground speed, and pitch attitude.

RESULTS AND DISCUSSION

The flight test data were obtained during nine flights encompassing approximately 10 hours of flying time. In two later flights, landing and take-off data were obtained with the "TOL" camera. The aft landing-gear doors were removed to allow the camera a full field of view. All of the take-offs and landings and most of the NASA flights were made in the STOL regime (i.e., at speeds below power-off stall and substantially below the minimum single-engine control speed). The discussion of the data is divided into four parts, each covering a particular category of flight: first, landing; second, take-off; third, cruise; and fourth, miscellaneous areas (engine-out, wave-off, etc.). Most of the parts have separate sections dealing with performance, handling qualities, and operational techniques and pilot's comments.

STOL Landing Regime

Most of the NASA flights were made in the landing configuration because the landing maneuver has proven to be the prime problem area for most STOL aircraft; also, the landing distance of this aircraft, as with most projected aircraft in the STOL category, is consistently greater than that for take-off.

Landing performance.- Figure 3 shows the flight-test-measured STOL landing distances over 50 feet for the test airplane (corrected for the small winds) as a function of descent angle; air distance is also indicated, and data are shown from both NASA and contractor flight tests. Representative Breguet 941 landing distances are also shown for comparison; frequent reference will be made to this aircraft, a four-propeller deflected-slipstream STOL transport which was flight tested by NASA in 1963 (ref. 4). The curves superimposed on the data show calculated distances for approaching over a 50-foot obstacle in a straight-line descent, touching down with no flare, and stopping with an average deceleration (a_G) of 1/2 g. These calculated distances will be used in subsequent plots to show the probable trend of landing distance variation as approach angle and speed are varied. The variation with descent angle of distance over 50 feet is noteworthy, since it points out the great importance of attaining good descent performance, with low speed, for short-field landings.

The permissible sink speed[1] of 16 fps for the prototype landing gear made possible no-flare landings with a great reduction in landing distance and an improvement in touchdown point consistency over the conventional full flare.

While investigating the landing performance, the NASA pilot was concerned primarily with different combinations of approach speed and sink rate and not with optimizing the ground roll (as evidenced by the increased ground distance at the higher descent angles caused by bouncing). During the earlier contractor flight testing, actual landing distances as low as 600 feet over 50 feet were achieved. (For reference, the contractor landing data are also shown in the figure.)

Descent characteristics.- The descent characteristics in the landing approach condition, derived (after cross-plotting and extrapolation) from the NASA flight test data, are presented in figure 4 as a function of speed, for constant throttle settings, with angle-of-attack values superimposed. The actual descent capability (ignoring the possibility of engine failure) was determined by a stall margin of approximately 10 knots and 10° angle of attack usually demanded by the pilot (the indicated angle of attack for the stall varied from approximately 20° to 35° as power was increased from idle to NRP). The nominal approach condition for a STOL landing was made at 55 to 60 knots with 600 to 800 fpm rate of descent (corresponding to slightly more than half the NRP); this was approximately 10 knots below the power-off stall speed of 67 knots. The weight ranged from 7100 to 7700 pounds (corresponding to a wing loading of 37-40 psf).

The nominal descent condition for the Breguet 941 (ref. 4) is also indicated and is approximately the same (in terms of speed, C_L, and $\overline{C}_D$) as that shown for the subject airplane. The similarity of the descent conditions for these two fairly dissimilar craft is interesting. The fact that the Breguet descends at the same angle as the test aircraft, despite its higher aspect ratio (6-1/2 vs. 4-1/2), is attributable to its superior flap effectiveness.

---

[1]The design sink speed for the gear was 20 fps, but since the prototype landing gear had not been drop-tested, a 16-fps placard was imposed.

Figure 5 shows the actual power-on, lift-drag polars of the airplane as derived from flight test data. Lines of constant thrust coefficient are plotted with angle-of-attack values superimposed. The nominal STOL approach condition is indicated, and the Breguet 941 condition is again shown for comparison. The figure points up the large disparity between the $C_{L_{max}}$ capability of the airplane and the actual C_L used in a landing approach, which is representative of most STOL designs. This disparity is due partly to the steep descent capability required for short landing distances over an obstacle and partly to the stall margin usually demanded by the pilot (see ref. 5 for further discussion of this subject).

Comparison between descent capabilities determined in wind-tunnel and flight tests.- Constant thrust coefficient ($T_c' = 1.0$) polars in the nominal STOL approach condition are plotted in figure 6. Data derived from the NASA flight tests are compared with data from tests in the Ames 40- by 80-Foot Wind Tunnel (ref. 6) with a full-scale COIN model (similar to the test airplane but with blunt wing tips). Data are also shown for a 1/4-scale model similar in configuration to the test airplane (and corrected to the same configuration as that tested in the 40- by 80-foot tunnel). Superimposed on the plot for reference are calculated no-flare landing distance lines for a wing loading of 40 psf.

The full-scale wind-tunnel data agree surprisingly well with the flight test data; the small-scale data, however, appear optimistic and might encourage the prediction of a nominal landing distance (even for $T_c' = 1.0$) of 500 to 600 feet, as opposed to the 700 to 800 feet which is actually feasible. This illustrates a common general weakness in small-scale STOL low-speed data, that is, an optimistic (rather than conservative, as might be expected, because of the low Reynolds number) indication of descent capability from small-scale wind-tunnel test data. It is beyond the scope of this paper to attempt to explain this discrepancy, but the significance is obvious when the effect on the preliminary design is considered.

Handling qualities.- Table II shows the most important stability, control, and handling qualities parameters, with some appropriate pilot ratings, for the test airplane in the nominal STOL approach condition.[2] These data were obtained from stabilized descents made in the landing configuration at altitudes of 2,000 to 10,000 feet. The handling qualities characteristics in this condition were generally acceptable, for flight test purposes at least. Some of the more noteworthy aspects will be discussed below.

Control System Characteristics

The problems encountered with the nonboosted control system were not precisely as might have been anticipated. The free-flying horizontal stabilizer-elevator system, controlled by a small trailing-edge tab connected directly to the stick, proved highly successful in producing adequate control moments with low stick forces. There was, however, a small lag between an

[2]The pilot ratings here and in subsequent portions of the report are based on the criteria of table III.

abrupt stick input and the onset of the resultant pitching acceleration. (See the time history of an elevator reversal in fig. 7.) The all-mechanical lateral control system, however, was deficient because of the high mass and resultant moments of inertia of the circular-arc spoilers used which, combined with the sensitive longitudinal system, produced a force disharmony and caused inadvertent pitch inputs from lateral control motions. Figure 8 shows a time history of an aileron reversal with full deflection; the severe bouncing of the system against the stops (due to its high inertia) can be noted.

Adverse sideslip in turn entry.- The problem of extreme adverse sideslip during a turn at high C_L, so often evidenced by the larger STOL aircraft, has not proven so serious with the smaller craft, such as the Charger and the Ryan VZ-3. The reason is evident from the data presented in reference 5. With directional periods of less than approximately 7 seconds, the pilot is able to adequately coordinate the turn with rudder and has not as much tendency to overcontrol or to produce out-of-phase inputs as with the larger aircraft. (The period of the Dutch roll of the test aircraft in the landing approach condition was approximately 5 sec.)

Operational technique and pilot's comments.- Transition to the landing configuration was generally performed in two steps. First, the flaps were lowered to the take-off setting and the airspeed was allowed to stabilize at some intermediate value, such as 80 knots. This arrangement allowed good maneuverability at a reasonable speed, yet did not require a large amount of power to maintain level flight. Landing flaps were lowered upon initiation of the final descent to a landing. The idea was to keep the amount of time in the STOL configuration to a minimum, but still allow the pilot to establish the desired flight-path angle, airspeed, etc., well before landing. The approaches were made at a relatively constant attitude, depending upon the desired approach speed and rate of descent. Generally, about 0° to 5° nose up seemed to be the best attitude for ground contact. Angle of attack was considered to be a poor reference during the approach because of its sensitiveness to gusts which rendered it difficult to interpret. There appeared to be very little change in flight path with changes in pitch attitude; however, response to power changes was considered good. The longitudinal trim change with power was also satisfactory. Most of the approaches were made between 55 and 60 knots at about 600 to 800 fpm sink rate. A minimum comfortable approach speed was considered to be 55 knots at 600 fpm, since it provided about a 13° angle of attack or an 8-knot margin from the stall.

Two shallow approaches (200 fpm) were made at less than 55 knots; however, the handling qualities deteriorated, lateral control became poor, and the landings were not so good. Much steeper approaches were well within the capabilities of the aircraft but were not attempted because of lack of sufficient pilot confidence and familiarity.

The object during landing was to maintain the approach attitude and drive the aircraft into the ground without flaring (a slight inadvertent flare, however, was natural near the ground; see fig. 9), initiating reverse pitch at or very slightly before ground contact. This method of approach and landing can provide very good performance and is easy to perform since it eliminates the requirement for the pilot to judge the flare. The biggest problem noted during the approaches was a lateral unsteadiness due to gusts. This was probably aggravated by the high lateral control inertia which prevented the pilot from applying rapid instinctive corrections. (The low roll damping ($1/\tau_r \cong 0.3$) may, in part, contribute to the poor lateral behavior noted in turbulence.)

Longitudinal control and sensitivity in the approach were good; however, there did appear to be a slight lag in the buildup of pitching velocity following a step input, and the pilot induced a slight oscillation in one approach when attempting very tight attitude control (P.R. = 3). Longitudinal short-period damping appeared to be dead beat and was considered good.

The phugoid oscillation had a fairly short period (13 sec) and consisted of an undamped oscillation of angle of attack, airspeed, attitude, etc.; however, it was easy to damp and no problem was noted in any approaches. Static longitudinal stability (C_{m_α}) was a little low as the pitch attitude tended to wander a bit during the approach (P.R. = 3-1/2).

Lateral control power and sensitivity were a little low but acceptable (P.R. = 3-1/2). Lateral damping was low as the airplane was easily disturbed by gusts and there was quite a tendency to overshoot a specified bank angle (P.R. = 3-1/2 to 4). The cross coupling on turn entry looked all adverse and was pretty high ($\beta/\varphi \cong 0.4$). The damping was satisfactory, however, and the period was not too long so it did not create much of a problem. Landing from a 200-foot offset required coordinating rudder but was not difficult. (P.R. of cross coupling = 4, P.R. of Dutch-roll damping = 3.) Spiral stability was neutral in this configuration also and was satisfactory.

Directional control was a little weak since only 16° of sideslip could be generated with full rudder. Other than that, control power, sensitivity, and damping were satisfactory (P.R. = 3). The aircraft could easily be stabilized at any value of sideslip up to the maximum attainable. Dihedral effect seemed moderate and was satisfactory. Figure 9 shows a time history of a typical STOL landing.

Take-Off Regime

Performance.- The take-off performance of the test aircraft, as flown during the NASA flights, is shown in figure 10 where data points indicate ground roll distance, from brake release to lift-off, and air distance to clear a 50-foot obstacle; total distance lines are superimposed.

The weight for these take-offs varied from 7100 to 7700 pounds; the indicated lift-off speed, from 52 to 58 knots; and the speed at 50 feet, from 58 to 65 knots. During the earlier contractor flight tests, take-off distances (over 50 ft) as short as 550 feet were achieved with a higher power setting (these data points are shown also for reference); all distances are corrected to zero wind conditions.

Figure 11 shows the rate-of-climb characteristics of the test airplane in the take-off configuration ($\delta_F = 20^o/0^o$, gear down) as a function of speed (for a constant throttle setting corresponding to approximately 1000 total SHP, as derived from flight tests at altitude). The rate of climb in this configuration is about 1200 fpm at 60 to 90 knots. (More power is available for take-offs at sea level, of course.) Also indicated on the figure are data for an intermediate flap setting ($\delta_F = 40^o/11^o$, gear down) which might be used for wave-off; this shows a rate of climb of 100 fpm for 800 SHP (the maximum available at this altitude). It is of interest here that when similar angles of attack and power settings are compared with the $\delta_F = 60^o/30^o$ data in figure 4, no speed decrement is apparent for the $\delta_F = 40^o/11^o$ setting but a rate-of-climb increment is achieved (i.e., changing the flap from $60^o/30^o$ to $40^o/11^o$ at constant angle of attack has very little effect on lift but a sizable effect in reducing drag; the significance of this will be discussed later in the section on wave-off capability).

Handling qualities.- The handling qualities in the take-off configuration were generally satisfactory except for some of the same inherent deficiencies noted for the landing configuration, namely, high inertia of the lateral control system with resultant force disharmony with the longitudinal system, poor Dutch-roll damping, and highly adverse sideslip in turn entries. A large nose-down trim change was evident in retracting the flaps from the take-off setting; this was responsible (in the earlier development program) for an arbitrary reduction in flap retraction rate to allow coordination with the longitudinal trim control.

Operational technique and pilot's comments.- Figure 12 is a time history of a typical STOL take-off. The take-off procedure recommended by Convair was considered simple to execute and capable of providing fairly consistent near-maximum performance. With the brakes on, the power was advanced to about 20 psi (approximately 550 SHP) on both engines, about the maximum the brakes would hold. The brakes were then released and take-off power was applied smartly. The engines did not always accelerate together and directional control by rudder alone is not adequate at the beginning of the take-off roll; consequently, some brake had to be used occasionally to maintain heading. The use of nose-wheel steering was not recommended nor attempted during take-off. At about 50 knots, aft stick was applied to rotate the airplane quickly to about 25^o pitch attitude. As soon as airspeed stabilized after lift-off, minor adjustments to pitch attitude were made in an attempt to hold 55 to 60 knots during the initial climb. When the simulated obstacle was cleared, the nose was lowered, the gear retracted, and the aircraft accelerated to a safe flap retraction speed.

In the take-off configuration, longitudinal control, sensitivity, and damping were considered good. The aircraft was quite responsive in pitch, and control forces were light (P.R. = 2). Static longitudinal stability was low but satisfactory (P.R. = 3). Lateral control power was felt to be a little low but satisfactory (P.R. = 3-1/2). The major problem with lateral control in all configurations was the high inertia of the system. It was impossible to put in a step input since considerable force was required to initiate the step and the system oscillated, even with chain stops, when the pilot tried to stop it. Lateral control forces were considered too high and resulted in poor control harmony with longitudinal control. The pilot inadvertently tended to control pitch while attempting to make lateral corrections (P.R. = 5). The final NASA flight was made with a different spoiler lip configuration which reduced lateral control forces. Lateral control forces and sensitivity and lateral damping in this configuration were considered satisfactory (P.R. = 3); however, the problem of high inertia was not alleviated. Adverse yaw in turn entries was high and was more noticeable with the lower lateral control forces (P.R. = 4 to 4-1/2). Spiral stability was essentially neutral and was satisfactory. Dutch-roll damping was somewhat low (P.R. = 4). Directional control, although inadequate at the beginning of the take-off roll was considered satisfactory above about 30 knots (P.R. = 3). No take-offs were made under strong cross-wind conditions, and no consideration was given for possible failure of one engine.

A rather strong nose-down trim change was experienced while flaps were being retracted from the take-off setting. Some effort was required by the pilot to prevent a loss of altitude when transitioning to the climb configuration.

Cruise Regime

Performance.- The cruise and high-speed performance of the test airplane fell somewhat below the earlier estimates of the manufacturer. Figure 13 is a plot of power and trim data for various stabilized speed conditions in the clean configuration at an altitude of 10,000 feet. The value of the net parasite drag, as calculated from the data measured in this condition (using the manufacturer's estimate of propeller efficiency), was approximately 60 percent higher than that originally estimated. It is felt, however, that careful attention to detailed improvements would probably net a reasonable cruise performance with no appreciable penalty in the low-speed regime.

Figure 14 (derived from ref. 7) shows a comparison of the equivalent mean skin-friction drag of various airplanes. (The points shown for the Electra, Boeing 707, and C-130 are gross approximations, based on simple computations, and are presented for reference only.) The approximate net parasite drag coefficient in cruise, $\overline{C}_F$, based on wetted area (which corresponds to an equivalent skin-friction drag coefficient), is plotted against the approximate average Reynolds number, $\overline{Re}$, for the airplane in the condition tested; lines of flat plate laminar and turbulent skin-friction coefficients are shown for comparison. It can be seen that high performance sailplanes reach a mean skin-friction drag coefficient approaching that of a turbulent flat plate, but that most powered airplanes have drag levels somewhat higher; the Breguet 941 falls in this category with $\overline{C}_F \approx 0.005$. According to the NASA flight test data in the "clean" configuration at normal rated power, and the manufacturer's estimate for propeller efficiency, $\overline{C}_F$ for the test airplane was 0.008, a relatively high value, as indicated on the plot. That good STOL performance and reasonable drag values in cruise need not be mutually exclusive is evident from the data shown for the Breguet 941; even though this airplane is by no means optimized for cruise, it has a reasonably low cruise drag as well as good low-speed performance.

Pilot's comments.- In the clean configuration, longitudinal control response was good and the short-period damping was essentially dead beat (P.R. = 2-1/2). A random high-frequency, low-amplitude pitching motion was noticeable, however, that was mildly objectionable. This motion would probably be detrimental in a tight control task such as target tracking. Static longitudinal stability was positive and satisfactory. Lateral control power was considered to be a little low (P.R. = 4-1/2). Turn entries produced quite a bit of sideslip, first favorable then adverse. This was not too objectionable in mild maneuvering, but turn reversals or "S" turns were impossible to coordinate with rudder, and excited a Dutch-roll oscillation that was poorly damped (P.R. of cross coupling = 5, P.R. of Dutch-roll damping = 4). Spiral stability was essentially neutral and satisfactory.

Miscellaneous Regimes

Engine out.- A major consideration in a noninterconnected twin-engined, twin-propellered, deflected slipstream aircraft, such as the one tested, is the engine-out landing performance (i.e., the question of whether or not the aircraft can be landed at all in a short field). Because of the deflected slipstream principle being utilized, the minimum speed with engine out is determined by the lateral control power available for decreasing the lift on the power-on side, an effect which dictates a compromise toward higher speed and lower flap deflections. Engine-out data (at altitude) were obtained with the test airplane for three different conditions to investigate this effect, to establish V_{MC} (minimum single-engine control speed), and to determine the applicability of cross-shafting to this configuration; these data are shown in figure 15. Two descent curves are shown for single-engine flight with the normal landing flap setting, $\delta_F = 60^\circ/30^\circ$, one at a low-power setting, the other at the maximum setting the pilot felt advisable; the minimum sink speed in this condition was 1900 fpm, beyond the landing gear limit. With the take-off flap setting, $\delta_F = 20^\circ/0^\circ$, and 460 SHP on the single engine, a sink rate of 500 to 600 fpm was established, indicating this to be a more desirable condition for a single-engine landing; the minimum control speed for this condition was 78 knots. Two successful single-engine landings were made earlier without incident during the contractor's flight test program, one with the take-off flap setting ($\delta_F = 20^\circ/0^\circ$), and one with the intermediate flap setting ($\delta_F = 40^\circ/11^\circ$). For a single-engine approach at 80 knots and 900 fpm descent rate (a probable V_{MC} approach condition) the calculated no-flare landing distance over 50 feet would be about 1200 feet. It is noteworthy that the test airplane, if equipped with cross-shafting, would be capable of descending at the nominal STOL approach condition with one engine at military power and would have a wave-off capability with flaps retracted to the take-off setting (provided a fast-retract mechanism were incorporated). See reference 8 for a more general commentary on these conclusions.

Pilot's comments on engine out.- Single-engine characteristics were looked at briefly in both take-off and power approach configurations. In take-off, V_{MC} for a static condition was 77 knots where full directional control and considerable lateral control were required. In powered approaches with 10 psi (230 SHP) on the good engine V_{MC} was 66 knots; with 15 psi (350 SHP) normal approach power V_{MC} increased to 71 knots (see fig. 15). Both were limited by full lateral control although nearly full directional control was also required. The descent rate at V_{MC} with one propeller feathered was so high that survival of the pilot was questionable (2000 fpm). The operation of the "Torque Equalizer" had not been completely demonstrated at the time of the tests.

Wave-off considerations.- Effective turning of the slipstream to allow good descent capability for landing a deflected slipstream STOL aircraft, such as the one tested, necessarily implies a negligible or nonexistent climbing capability when full power is applied for wave-off with landing flap deflection; this is evident from the data previously presented in figure 4. The most obvious solution to the wave-off problem, and one previously incorporated in some of the more advanced deflected slipstream STOL aircraft (see, e.g., ref. 4), is to incorporate an easily activated fast-retracting mechanism. The mechanism would allow the flaps to be retracted to some intermediate position that would preserve the high lift capability of the wing while reducing the drag substantially (such a position for the test aircraft might be the $40^\circ/11^\circ$ or the $20^\circ/0^\circ$ position; see fig. 11) at the same time as the engines are being brought to full power.

To document the wave-off maneuver, records were taken during several aborted landing approaches with subsequent wave-offs (including take-off power application and flap retraction). Data from one of these are shown in figure 16. As was noted previously, the flap retraction rate of the test aircraft was deliberately decreased because of the large longitudinal trim increments accompanying a change in flap deflection; consequently, wave-off performance was compromised. Incorporation of a fast-retract mechanism into an airplane similar to the one tested would probably necessitate a form of interconnection between the flap, throttle, and longitudinal trim to compensate for the large and rapid trim changes seemingly inherent.

Longitudinal trim effects.- The relative merits of a high or low horizontal-tail location for COIN aircraft have been discussed for various configurations. Initially, concern was expressed that a high horizontal-tail configuration would have unacceptable pitch-up characteristics as well as an undesirable pitching-moment response to thrust changes. The pilot's opinion was that the test airplane's small pitching response to throttle changes was good; very little longitudinal trim increment with power change was evident from the flight test data for the landing approach (as exhibited in fig. 17). (A similar result was obtained in the simulator studies of ref. 2.) Figure 18 illustrates the pitch-up situation. Stick deflection (corresponding to elevator tab position) and indicated angle of attack are plotted against speed for stalls with two power settings and $60^\circ/30^\circ$ landing flaps. The first stall is at normal rated power, corresponding approximately to a wave-off condition. An appreciable, but easily controllable, pitch-up tendency can be seen for this condition (corresponding to $\alpha_i = 34^\circ$) at the minimum speed. The second stall is with reduced power corresponding to the nominal approach condition; there was no pitch-up tendency at the minimum speed. These results are representative of all NASA flight tests with this aircraft; no uncontrollable pitch-ups were ever encountered, and the only pitch-up tendency occurred in the above wave-off condition. (During the NASA flights, the propellers rotated upward in the center, a possibly relevant factor which helped counteract the "roll-up" tendency of the wing-tip vortices.)

Pilot's comments on longitudinal trim.- Stall characteristics were satisfactory in all configurations except wave-off (P.A. with take-off power) where a slight pitch-up was noticed just prior to the stall. To recover from the pitch-up the pilot reduced power and applied full-forward stick. There was no stall warning in any configuration.

CONCLUDING REMARKS

A flight investigation showed that a current generation COIN-type STOL aircraft was capable of performing well at low speed and had acceptable handling qualities in the STOL regime, provided the possibility of engine failure is either ignored or a suitable safeguard, such as (perhaps) cross-shafting, is incorporated. Good performance was achieved despite the medium effectiveness of the flaps, because the aircraft had a low aspect ratio, a high power loading, and a no-flare landing gear design. However, when the aircraft was flown above the minimum single engine control speed, in compliance with the normal safety restrictions for twin-engined airplanes, major aspects of the performance were no better than those of many small "twins" in current production, and most of the original objectives of the COIN concept were compromised. It is also noted that the high-speed performance of the test airplane did not meet the original expectations, but comparison with other aircraft indicates that careful attention to detailed improvements would probably net a reasonable cruise performance with no appreciable penalty in the low-speed regime.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., 94035, June 15, 1967
721-04-00-02-00-21

REFERENCES

1. Margason, Richard J.; and Hammond, Alexander D.: Lateral Control Characteristics of a Powered Model of a Twin-Propeller Deflected Slipstream STOL Airplane Configuration. NASA TN D-1585, 1964.

2. Vomaske, Richard F.; and Drinkwater, Fred J., III: A Simulator Study to Determine Pilot Opinion of the Trim Changes With Power for Deflected Slipstream STOL Airplane. NASA TN D-3246, 1966.

3. Sullo, A. A.; Dick, R. E.; and Duke, J. O.: Lockheed Location Orientation Recording Instrument. Rep. 16256, Lockheed Aircraft Corp., 1962.

4. Quigley, Hervey C.; Innis, Robert C.; and Holzhauser, Curt A.: A Flight Investigation of the Performance, Handling Qualities, and Operational Characteristics of a Deflected Slipstream STOL Transport Airplane Having Four Interconnected Propellers. NASA TN D-2231, 1964.

5. Anderson, S. B.; Quigley, H. C.; and Innis, R. C.: Stability and Control Considerations for STOL Aircraft. AIAA Paper 65-715, 1965.

6. Deckert, Wallace H.; Koenig, David G.; and Weiberg, James A.: A Summary of Recent Large-Scale Research on High-Lift Devices. NASA SP-116, 1966.

7. Raspet, August: Application of Sailplane Performance Analysis to Airplanes. Aeron. Eng. Rev., vol. 13, no. 8, Aug. 1954, pp. 56-62.

8. Feistel, Terrell W.; Holzhauser, Curt A.; and Innis, Robert C.: Results of a Brief Flight Investigation of a COIN-Type STOL Aircraft. NASA SP-116, 1966.

TABLE I.- PHYSICAL AND GEOMETRIC CHARACTERISTICS

Aircraft (complete)	
Weight (as flown), lb	
Empty (less flight test equipment and pilot)	4,612
Zero fuel	6,409
Gross (full fuel)	7,730
Approximate c.g. position, percent $\bar{c}$	
Gear up	28
Gear down	24
Moments of inertia, slug-ft^2 (W = 7,070 lb)	
I_{xx} (rolling)	6,478
I_{yy} (pitching)	6,044
I_{zz} (yawing)	12,312
I_{xz} (cross product)	(not available)
Overall dimensions, ft	
Length	34.9
Height	13.8
Width	30.9
Total wetted area, sq ft	1,132
Propulsion system	
Engines	
Left: U.A.C. LT-74-CP-8 (counterclockwise rotation)	
Right: U.A.C. LT-74-CP-10 (clockwise rotation)	
Propellers	
3 blade, 9.0 ft diam, opposite rotation (up in center)	
Activity factor: 113, design C_L: 0.5	
Wing	
Area (total projected), sq ft	216
Reference area, S, sq ft	192.5
Span, b, ft	30.9
Aspect ratio	4.4
Mean aerodynamic chord, $\bar{c}$, ft	7.0
Airfoil section: NACA 63A-418 (a = 0.8 mod.)	
Incidence, deg	4.0
Trailing-edge flap area, sq ft	55.5
Leading-edge flap area, sq ft	9.7
Maximum projected area of spoilers, sq ft	3.3
Horizontal tail (stabilizer)	
Total area, sq ft	83.0
Span, ft	20.0
Aspect ratio	4.82
Chord, ft	4.15
Airfoil section: NACA 0014-214 (a = 0.6 mod.)	
Incidence, deg	4.0
Elevator area (including tab, 7.2), sq ft	33.2

TABLE I.- PHYSICAL AND GEOMETRIC CHARACTERISTICS - Concluded

Vertical tail	
Total area, sq ft	56.1
Span, ft	6.67
Aspect ratio	1.55
Mean aerodynamic chord, ft	4.26
Airfoil section: NACA 63A-017 (extended 15 percent)	
Sweepback at leading edge, deg	34.5
Rudder area (including tab, 3.0), sq ft	25.8
Landing gear	
Wheel size	
Main	24×7.7-10
Nose	9.00-6
Tread, ft	14.3
Wheel base, ft	12.4
Maximum vertical travel of axles	
Main, in.	22
Nose, in.	15
Design limit sink speed, 20 fps	

TABLE II.- STOL HANDLING QUALITIES

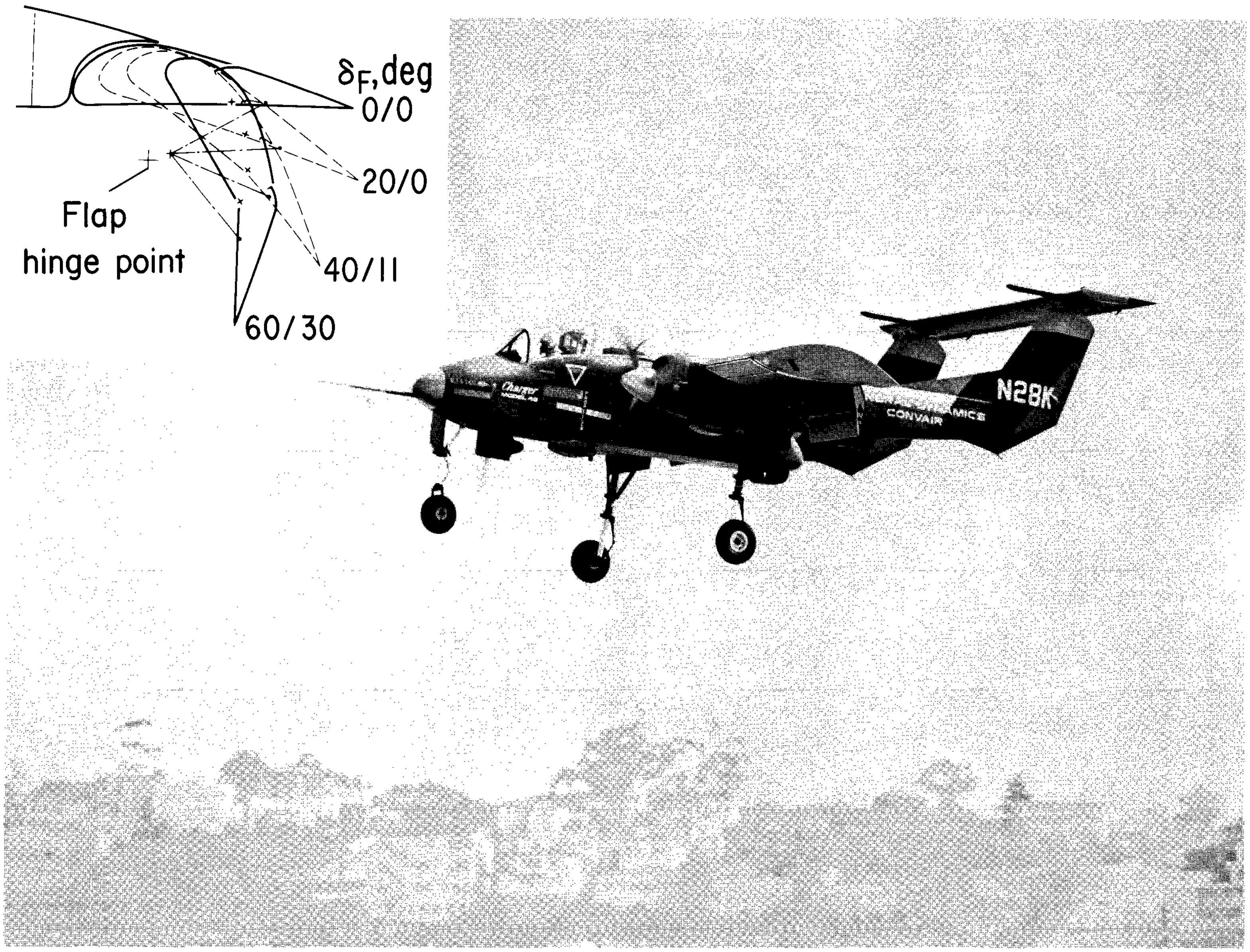
[NASA flights, landing approach condition ($\sim\delta_F = 60^\circ/30^\circ$, V_k = 55-60, 600-800 SHP, 600-800 fpm R/D)]

Axis and quantity	Flight test value
Lateral	
Control power ($\ddot{\varphi}_{max}$)	±0.7
Damping ($L_p/I_{xx} \equiv 1/\tau_r$)	≈0.3
Pilot rating (control)	3-1/2
Stability (L_β/I_{xx})	≈-1.2
Response (actual) after 1 second ($\Delta\varphi_1^\circ$), deg	≈10
Longitudinal	
Control power ($\ddot{\theta}_{max}$)	+1.4, -1.0
Damping ($M_q/I_{yy} \equiv 1/\tau_p$)	≈0.8
Pilot rating (control)	3
Stability (M_α/I_{yy})	≈-0.43
Response (actual) after 1 second ($\Delta\theta_1^\circ$), deg	≈14
Directional	
Control power ($\ddot{\psi}_{max}$)	±0.33
Damping ($N_r/I_{zz} \equiv 1/\tau_y$)	≈0.7
Pilot rating (control)	3
Stability (N_β/I_{zz})	≈1.2
Response (actual) after 1 second ($\Delta\psi_1^\circ$), deg	≈7
Maximum steady-state sideslip angle ($\beta^\circ_{ss_{max}}$), deg	≈16

TABLE III.- PILOT OPINION RATING SYSTEM

	Adjective rating	Numerical rating	Description	Primary mission accomplished?	Can be landed?
Normal operation	Satisfactory	1	Excellent, includes optimum	Yes	Yes
		2	Good, pleasant to fly	Yes	Yes
		3	Satisfactory, but with some mildly unpleasant characteristics	Yes	Yes
Emergency operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes	Yes
		5	Unacceptable for normal operation	Doubtful	Yes
		6	Acceptable for emergency condition only*	Doubtful	Yes
No operation	Unacceptable	7	Unacceptable even for emergency condition*	No	Doubtful
		8	Unacceptable - dangerous	No	No
		9	Unacceptable - uncontrollable	No	No

*Failure of stability augmenter.



AAA036-1.1

Figure 1.- The test aircraft in an STOL landing approach.

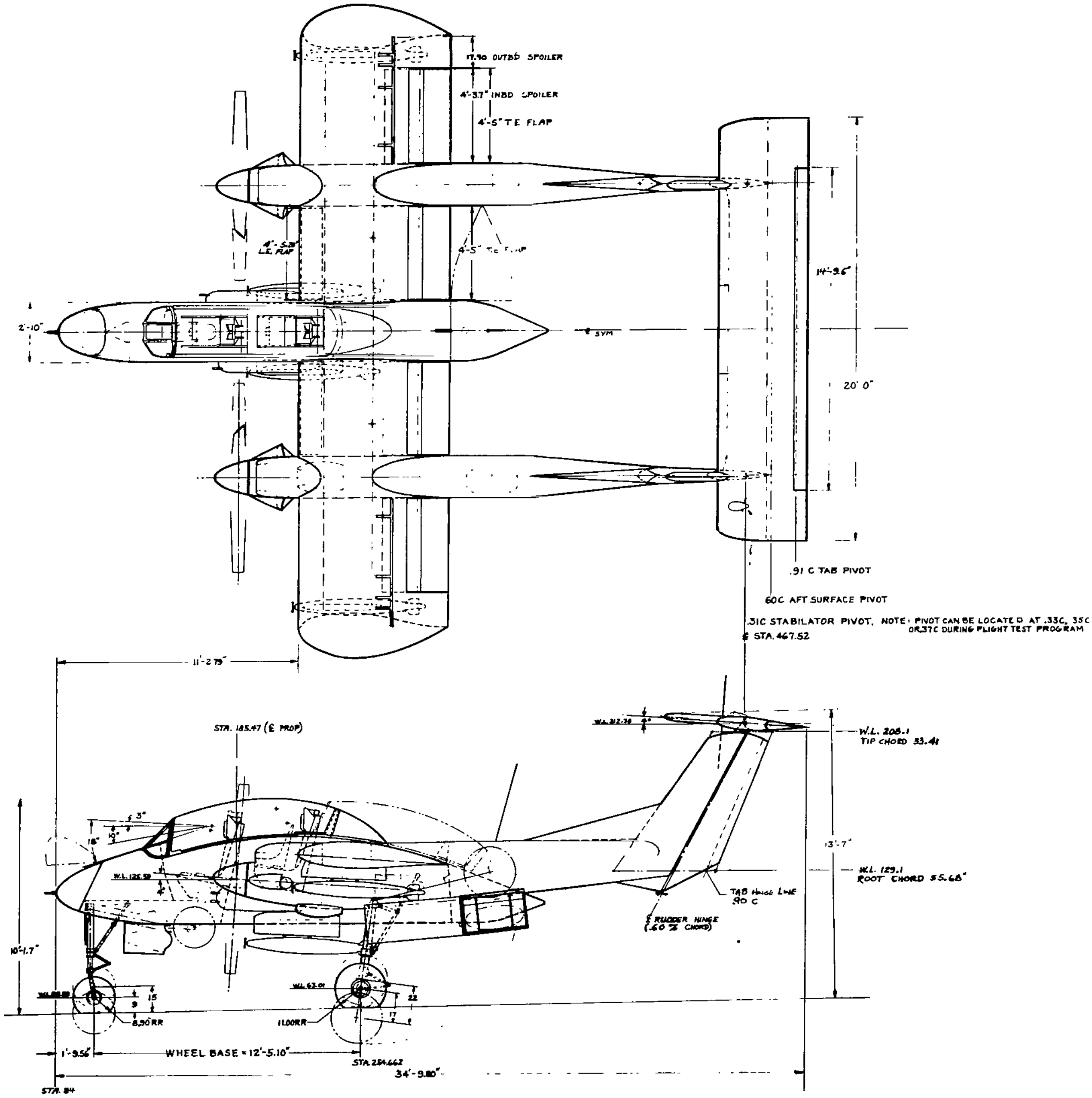


Figure 2.- Three-view drawing of test aircraft.

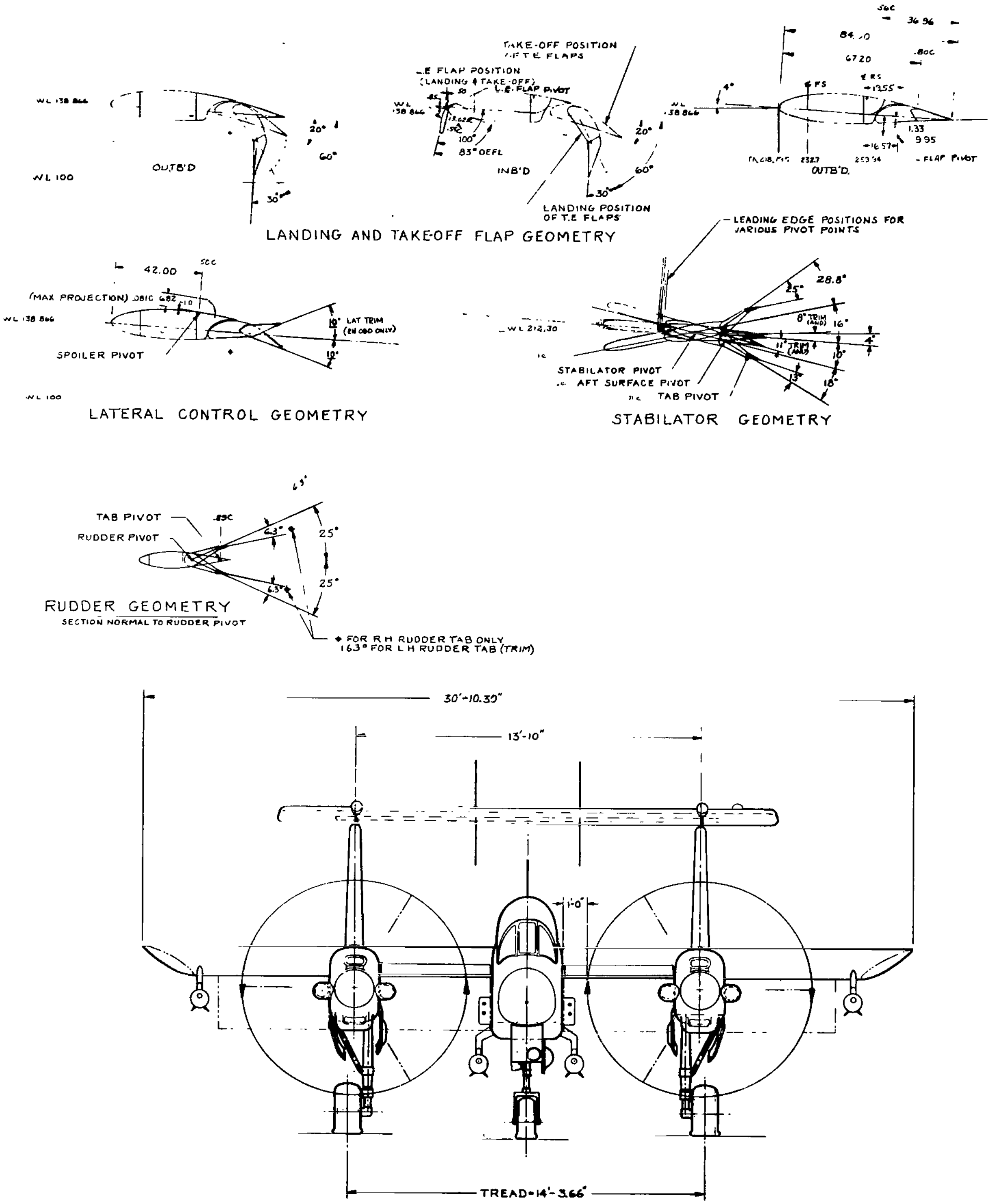


Figure 2.- Concluded.

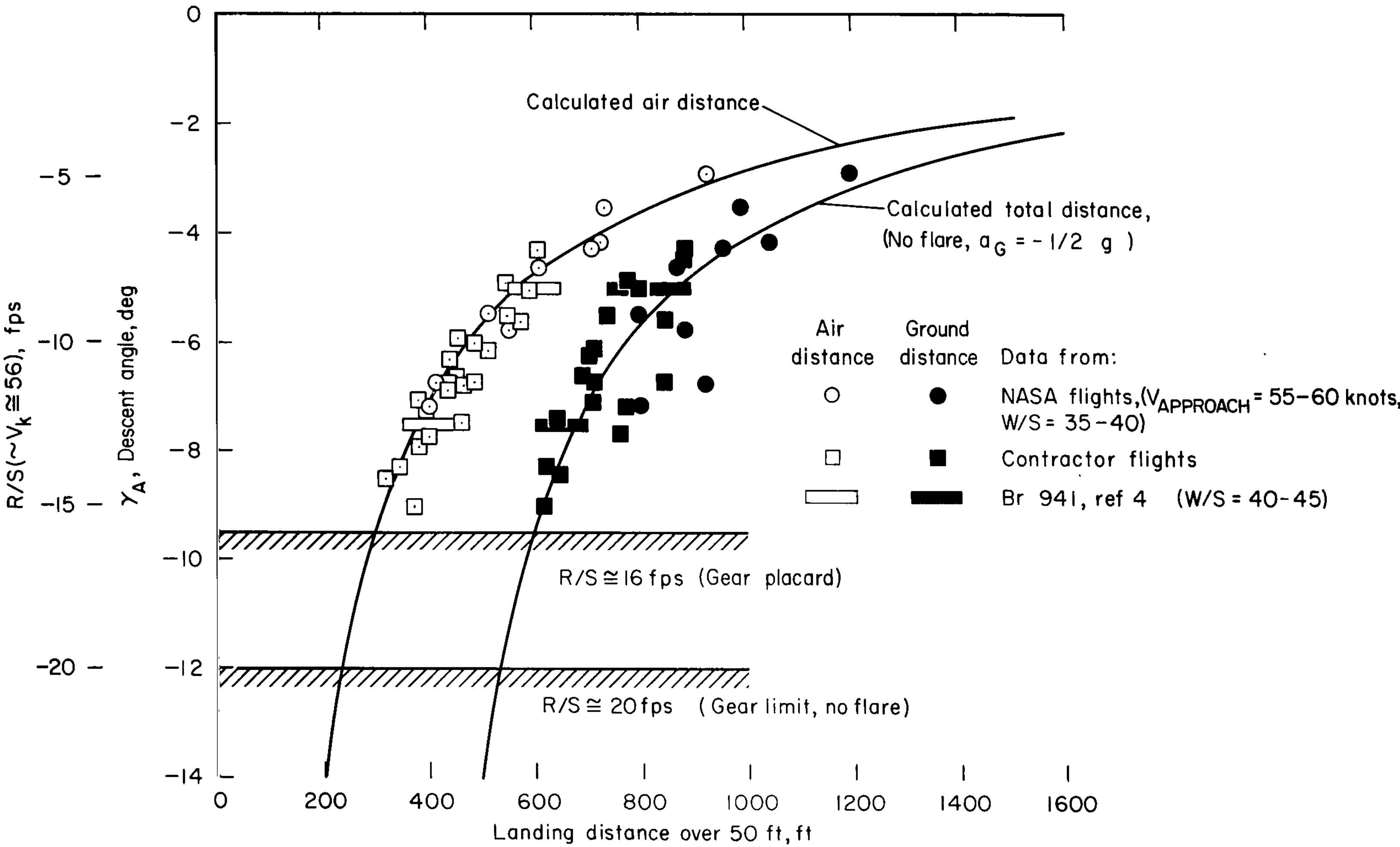


Figure 3.- STOL landing performance; zero wind.

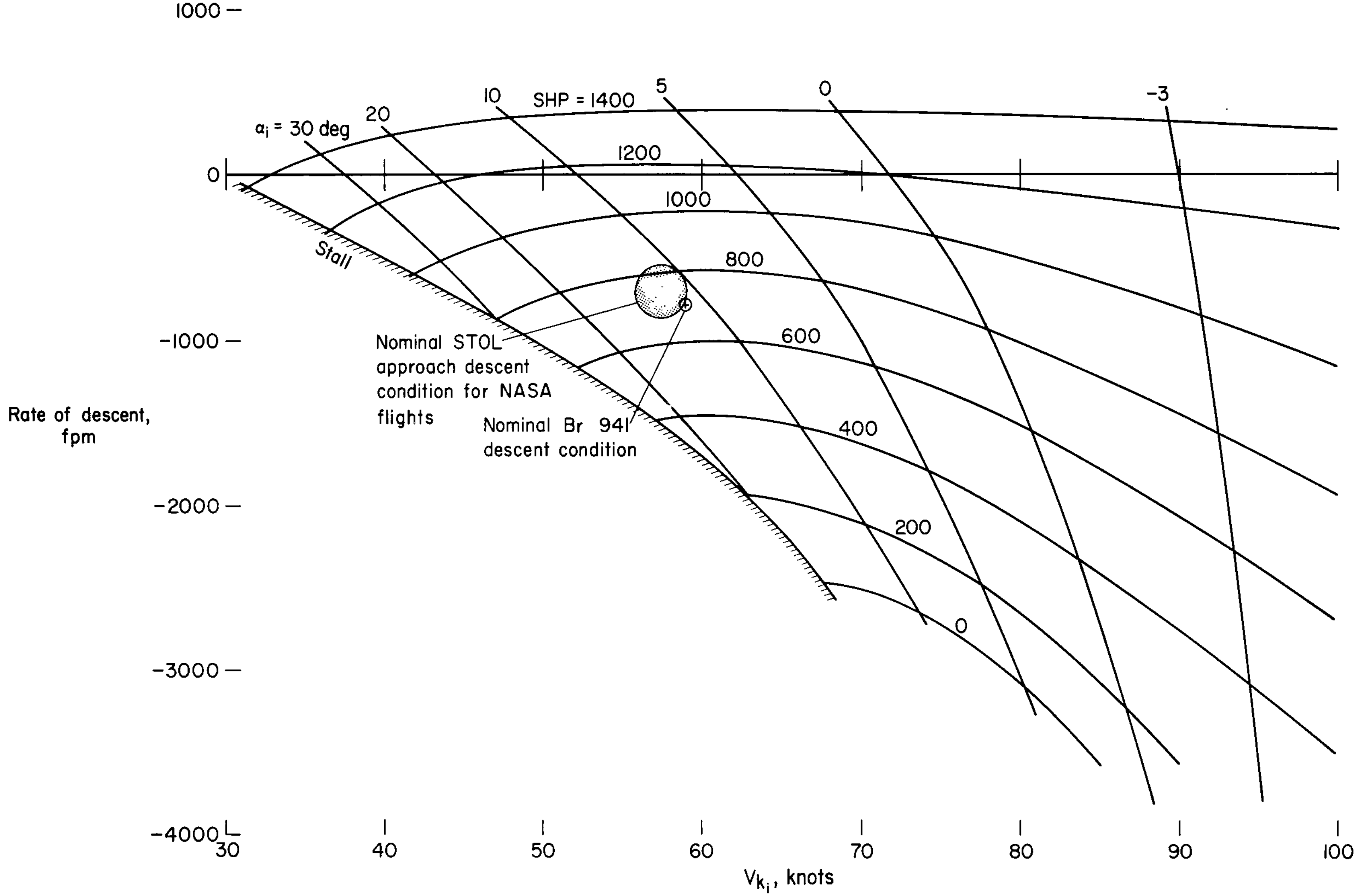


Figure 4.- Descent characteristics; STOL landing approach condition.

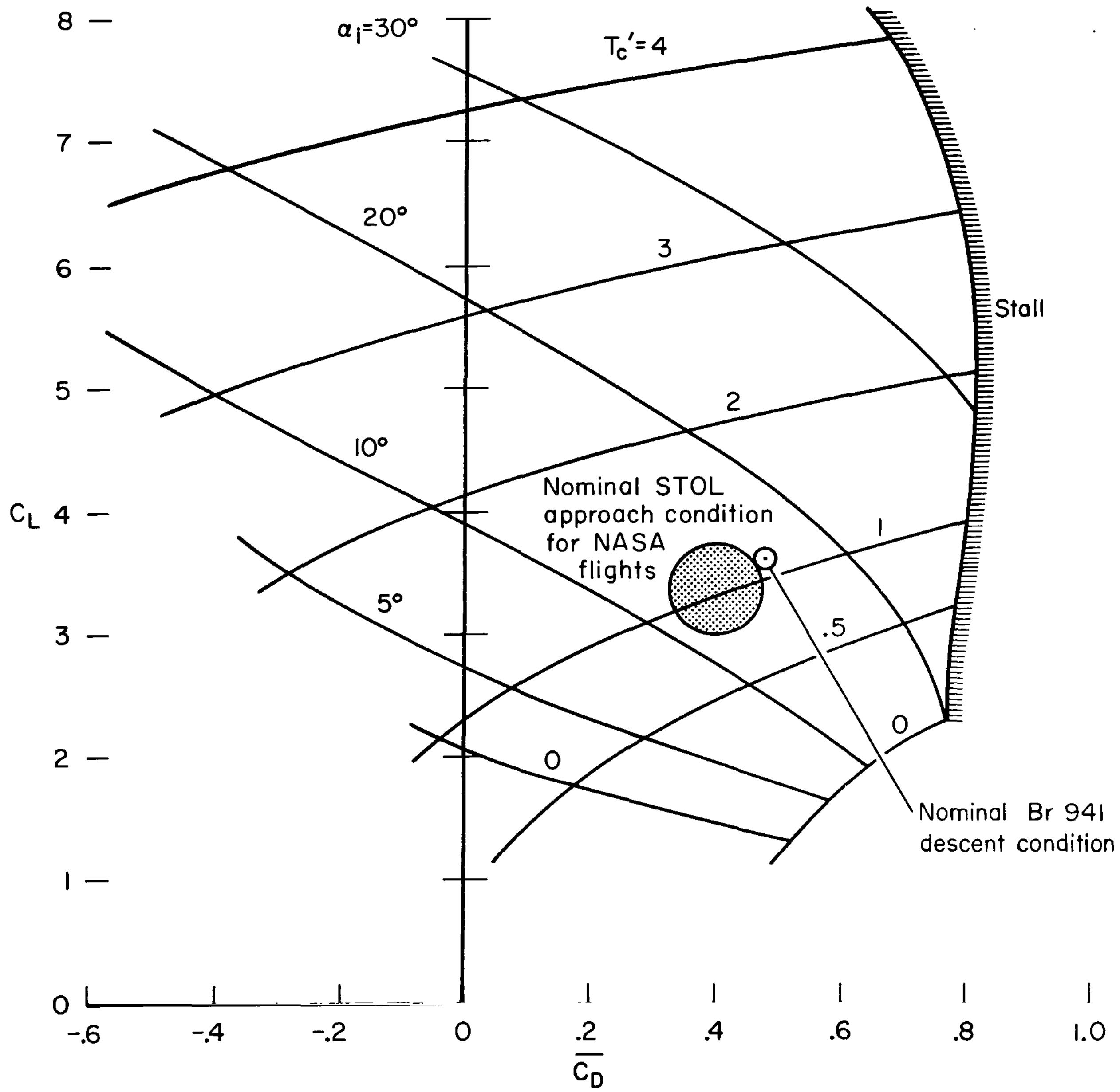


Figure 5.- Power-on lift-drag characteristics; STOL landing approach condition.

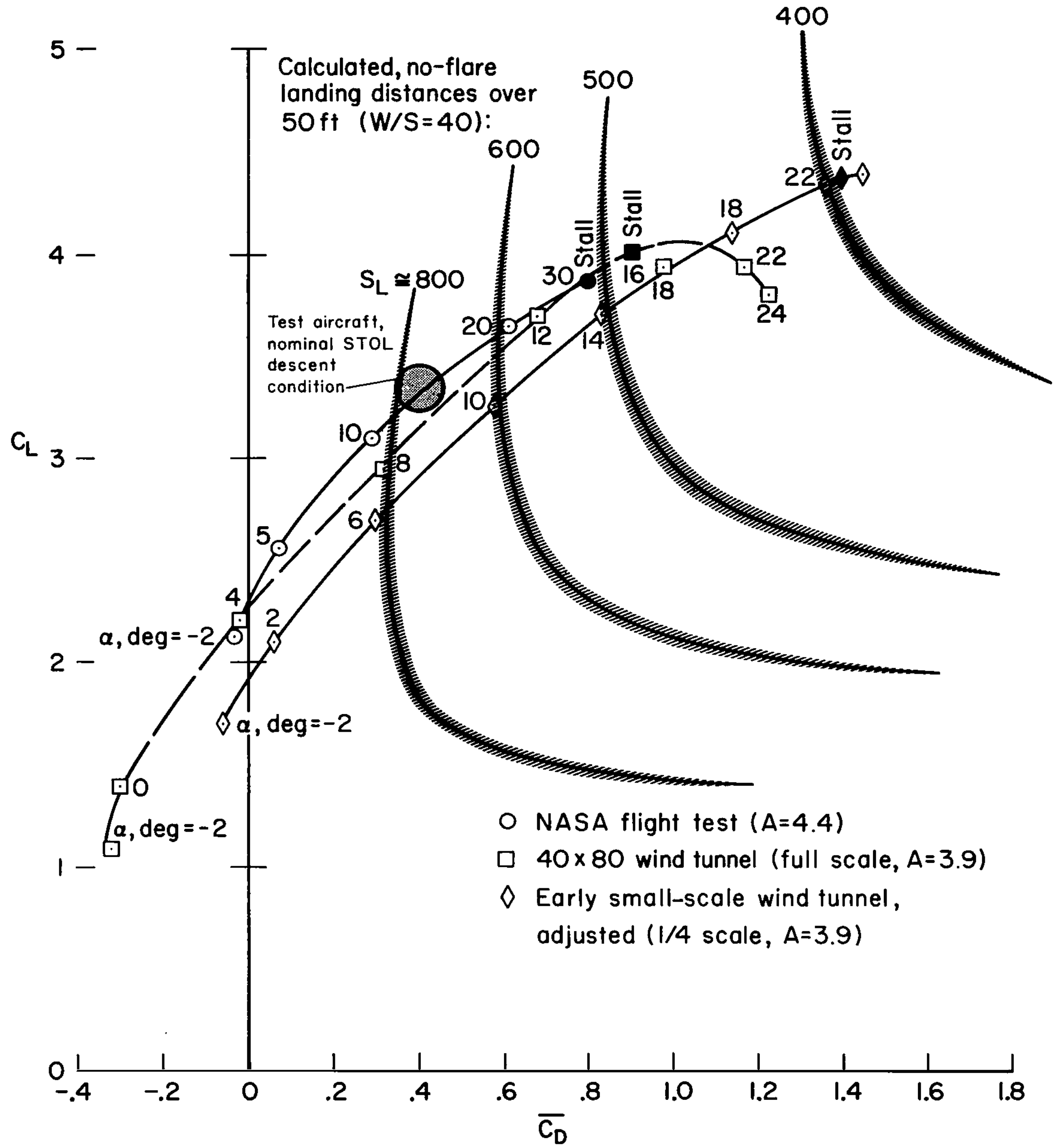


Figure 6.- Comparative COIN polars, wind tunnel, and flight test (flight test STOL landing approach condition, $T_c' = 1.0$).

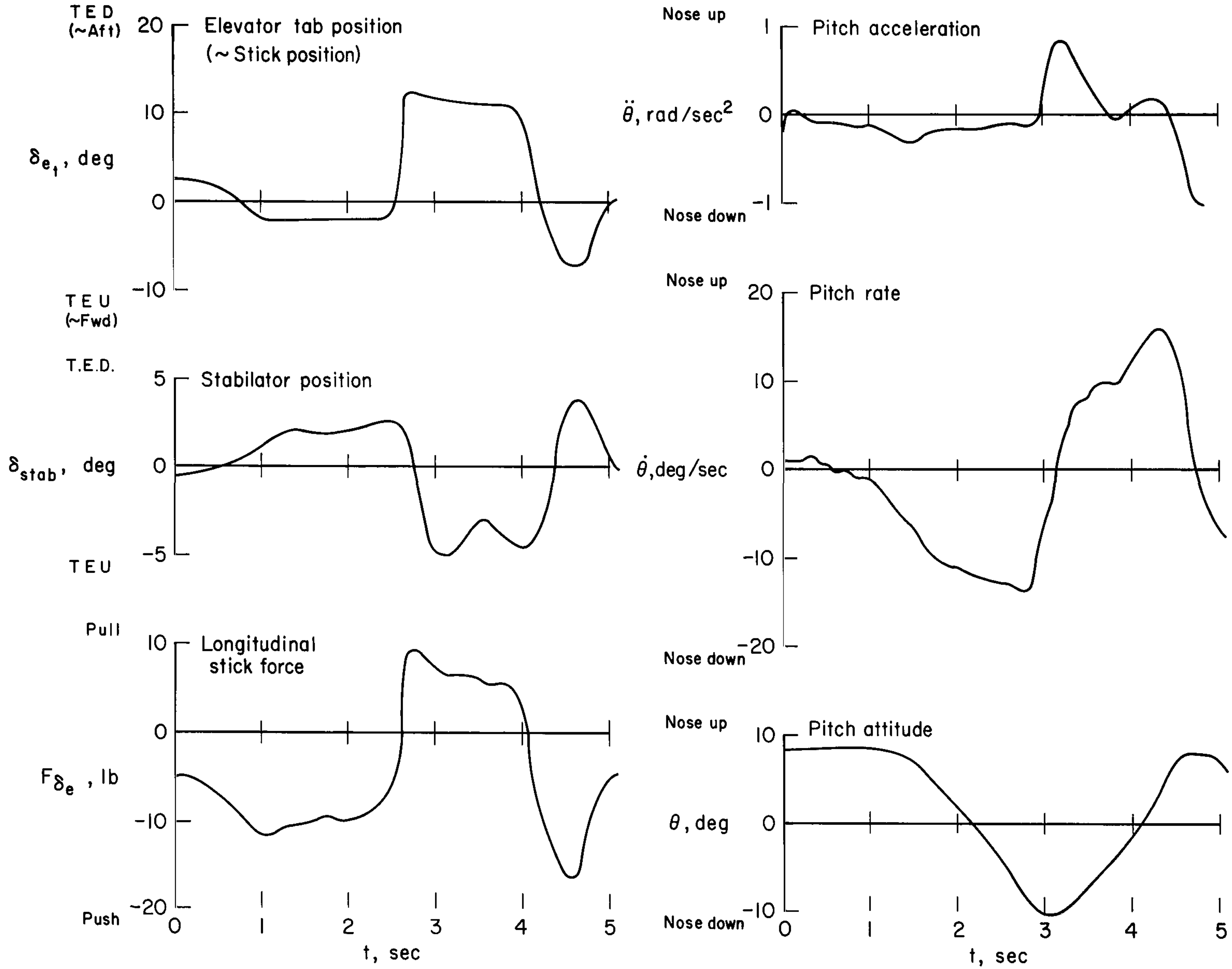


Figure 7.- Time history of elevator reversal; STOL landing approach condition.

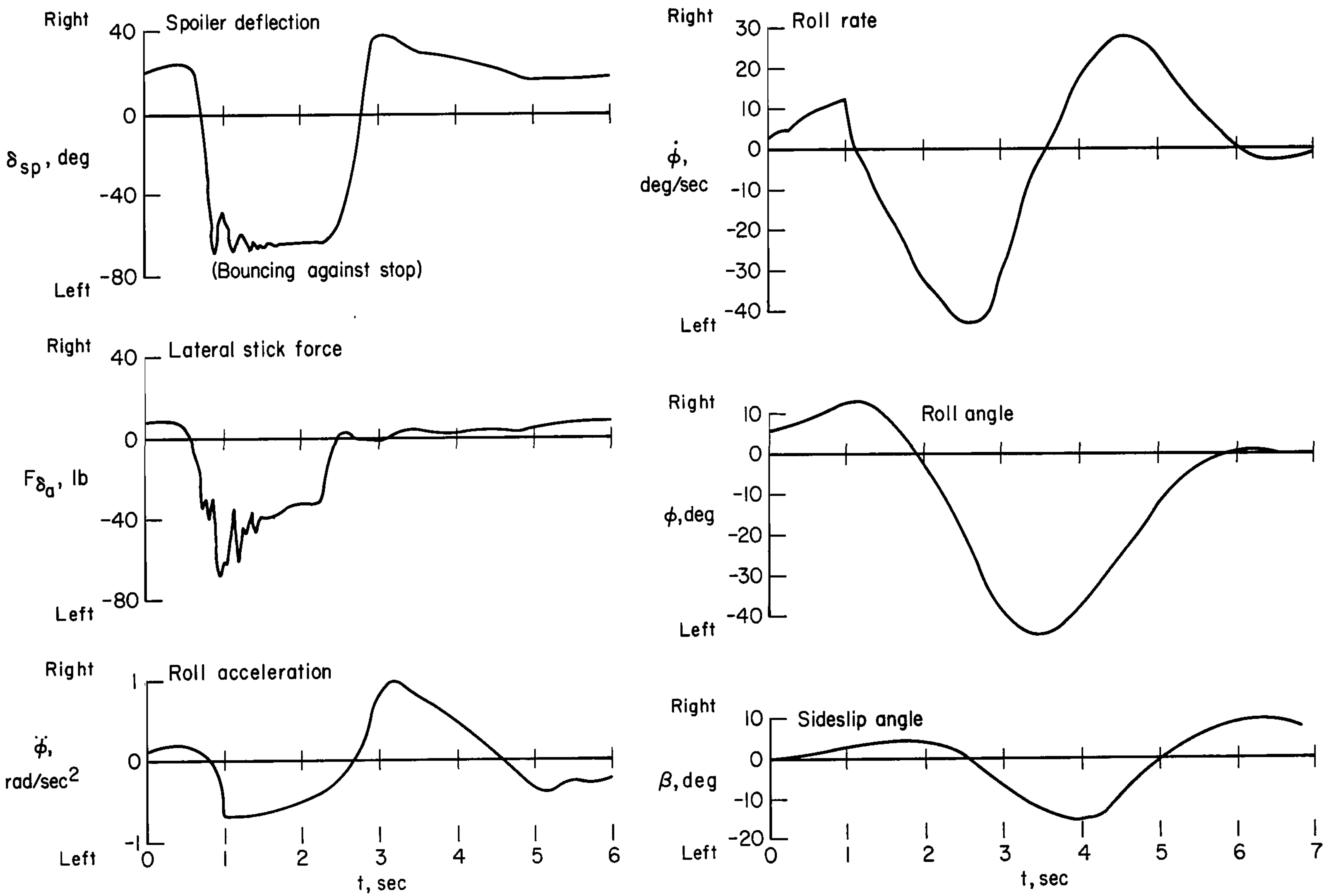


Figure 8.- Time history of aileron reversal; STOL landing approach condition.

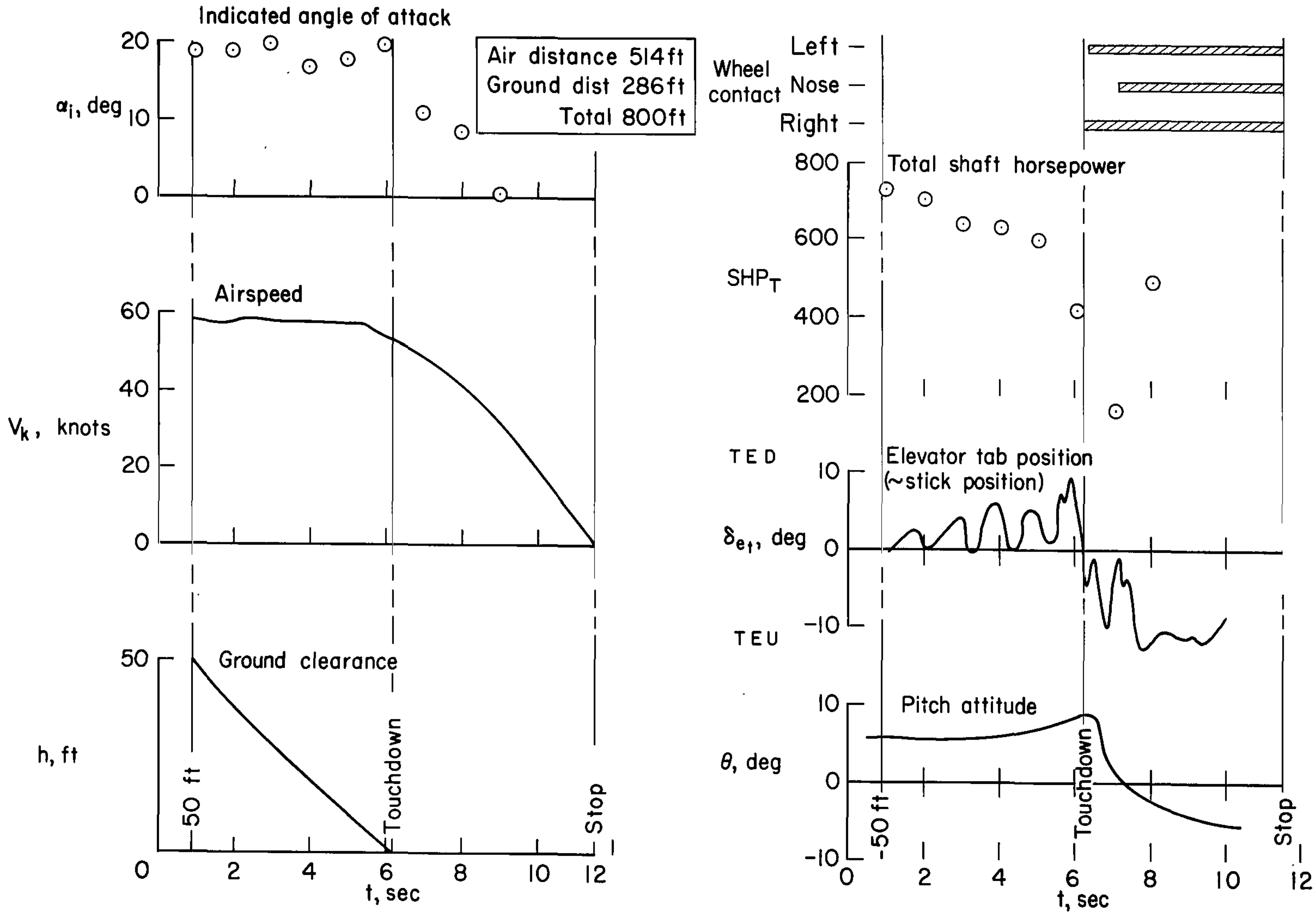


Figure 9.- Time history of STOL landing.

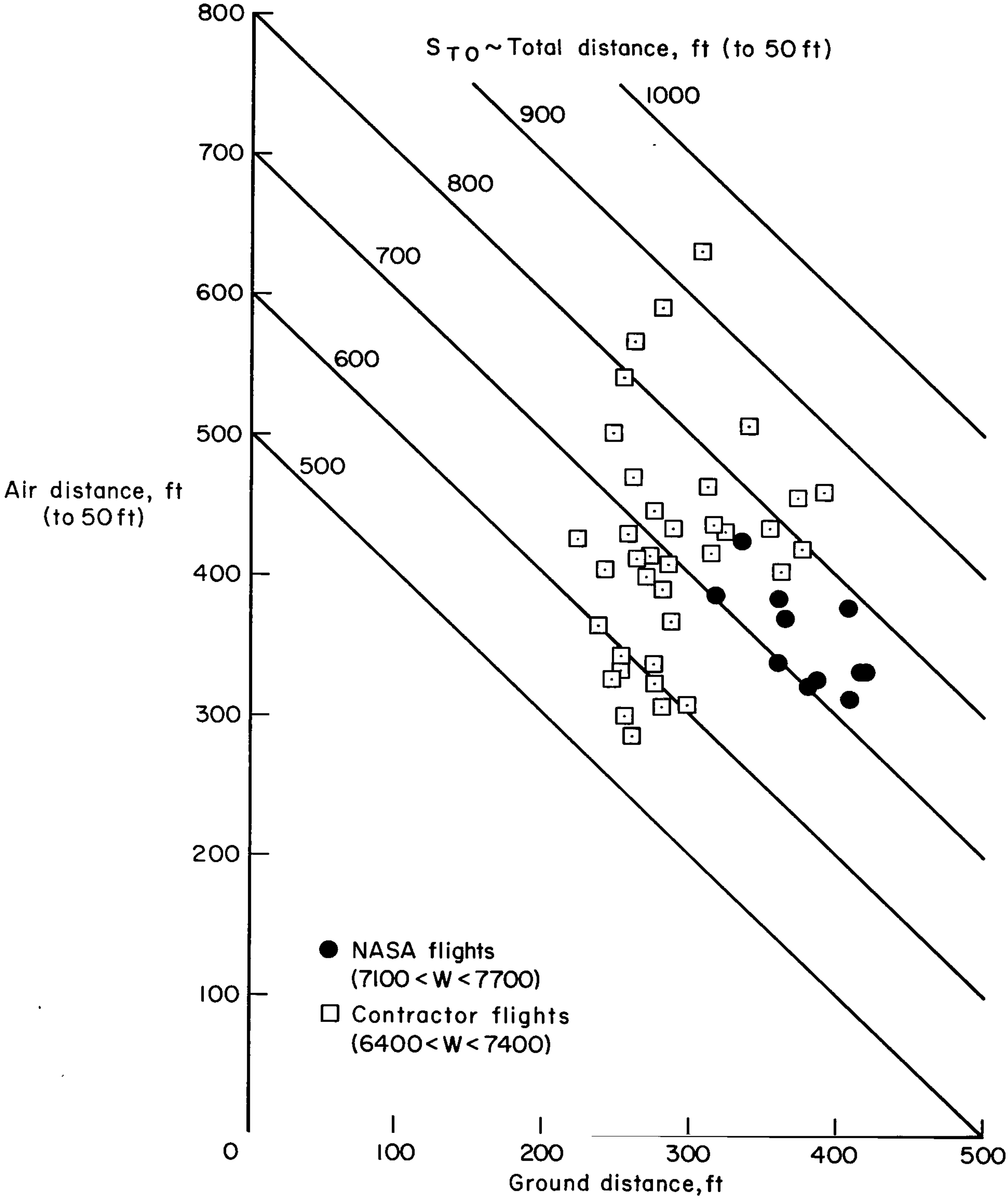


Figure 10.- STOL take-off performance; zero wind.

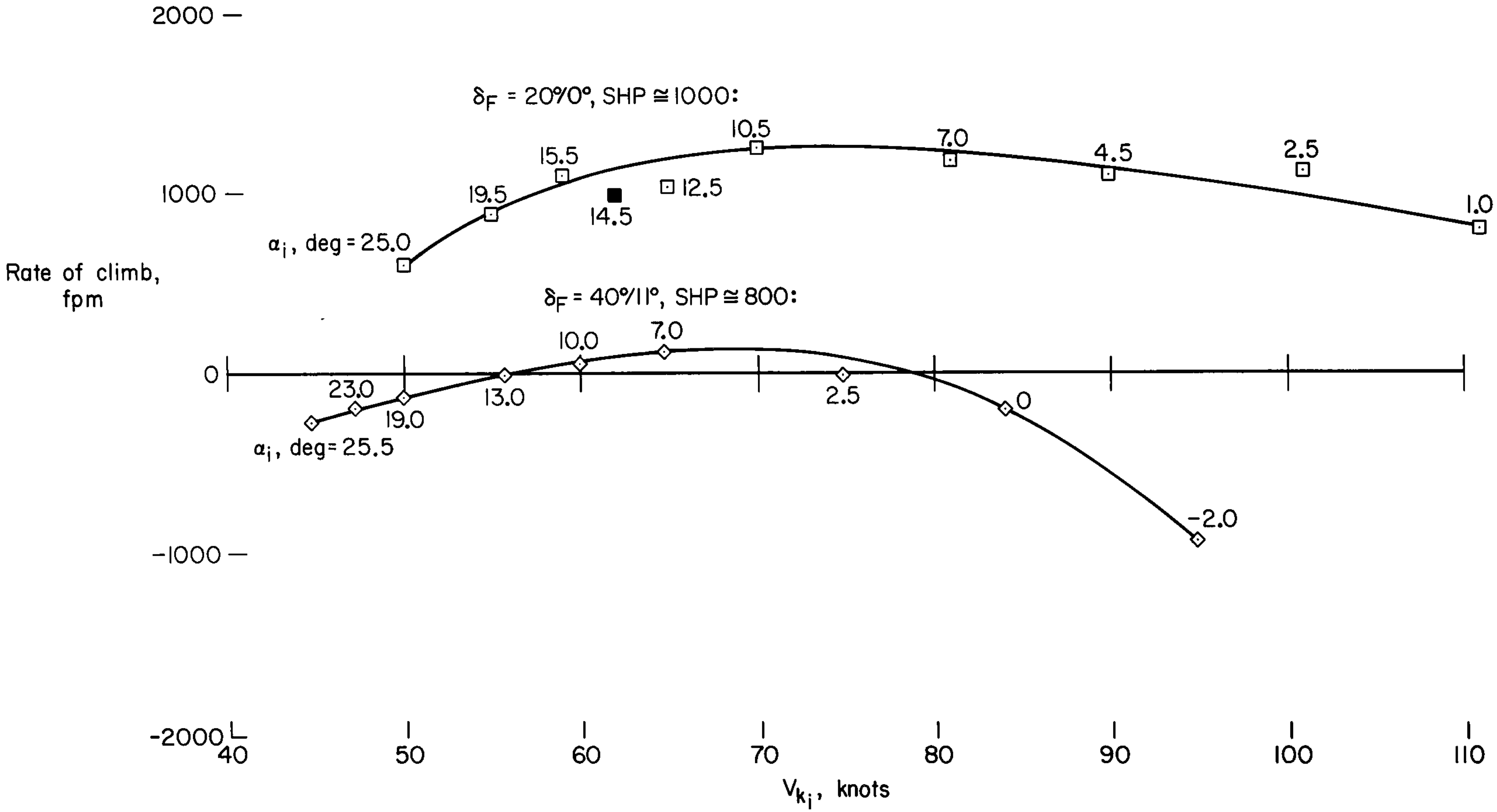


Figure 11.- Climb and descent characteristics at altitude; STOL take-off condition; and wave-off condition.

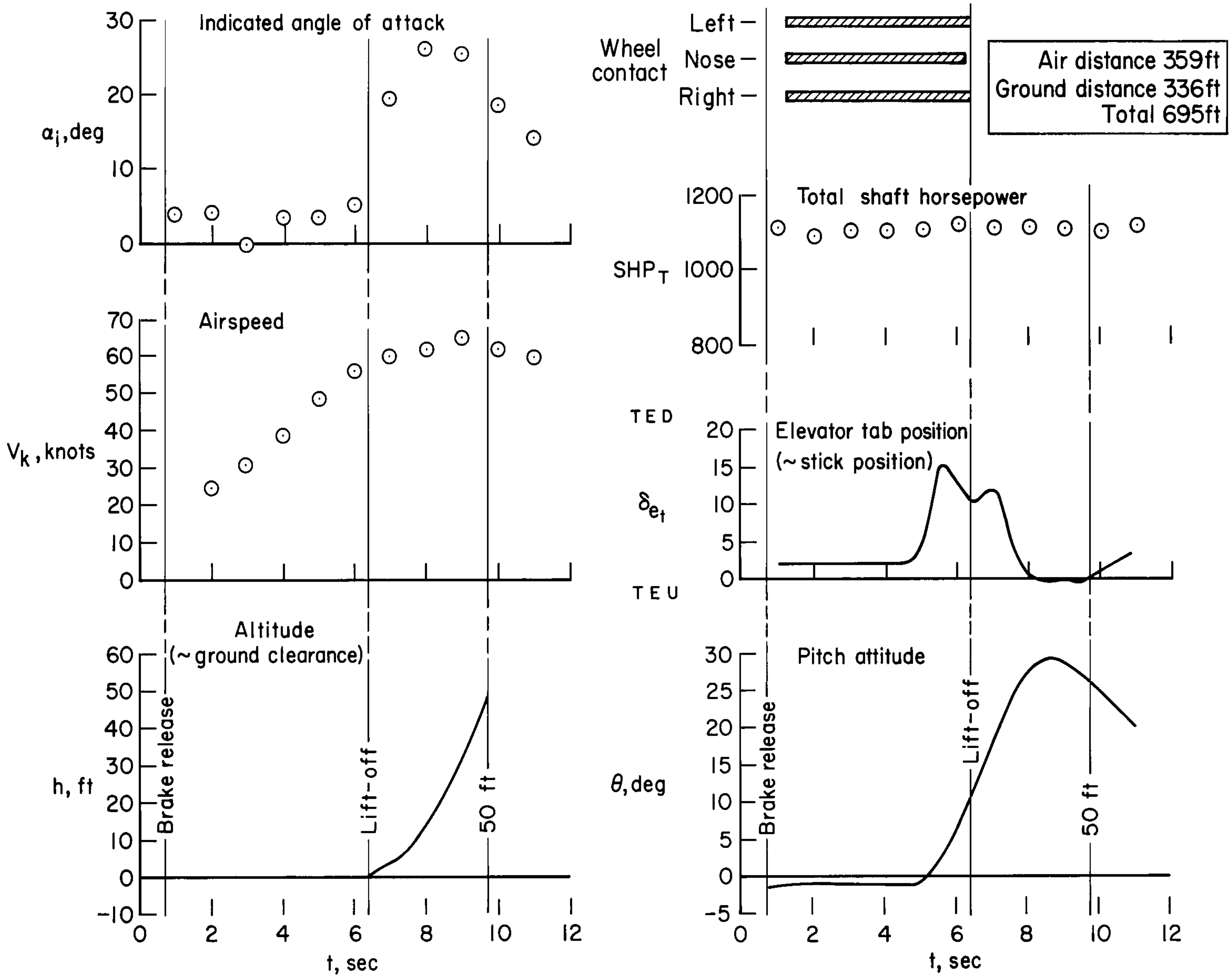


Figure 12.- Time history of STOL take-off.

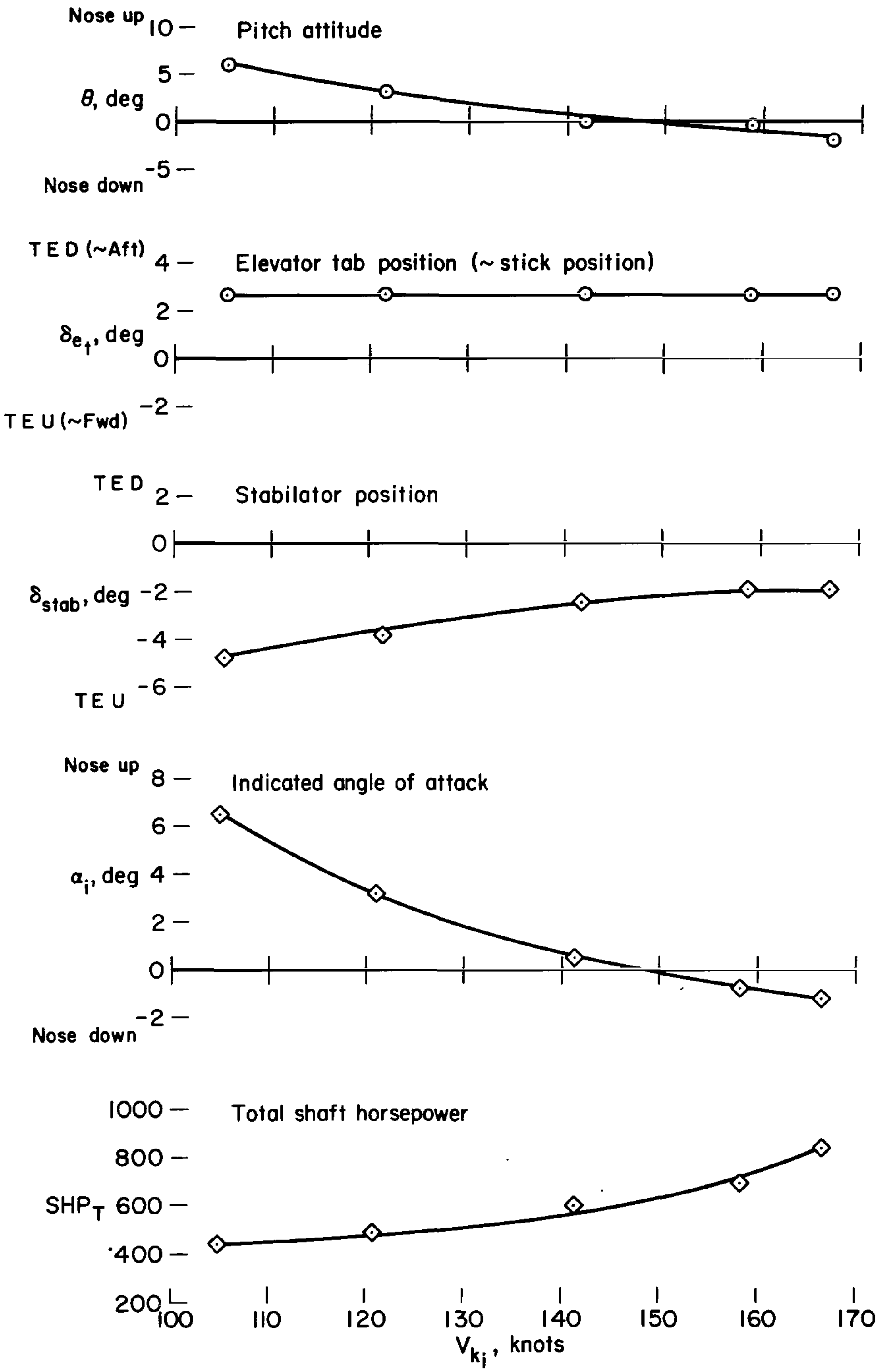


Figure 13.- Speed performance capability; cruise configuration; h = 10,000.

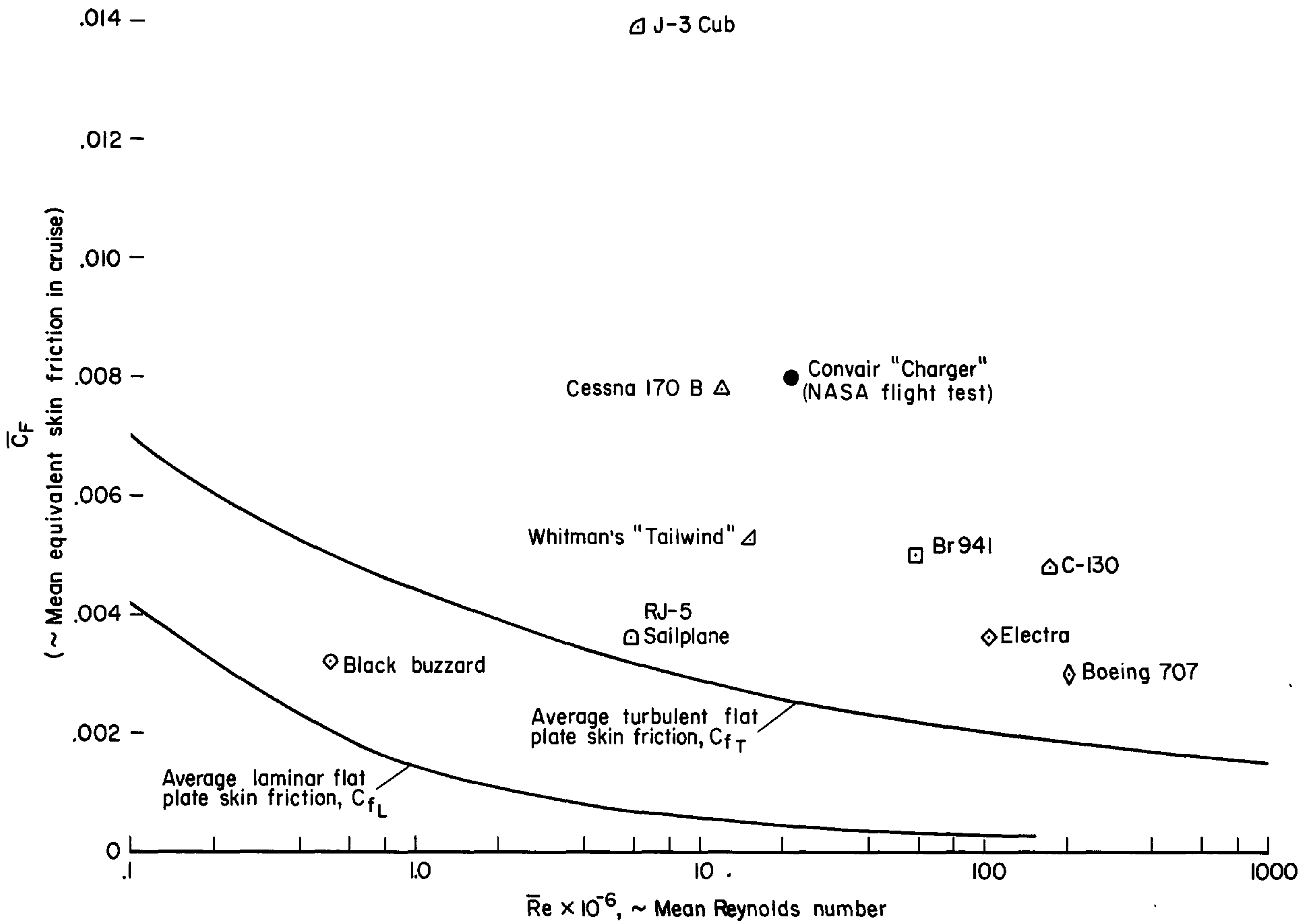


Figure 14.- Cruise drag comparison.

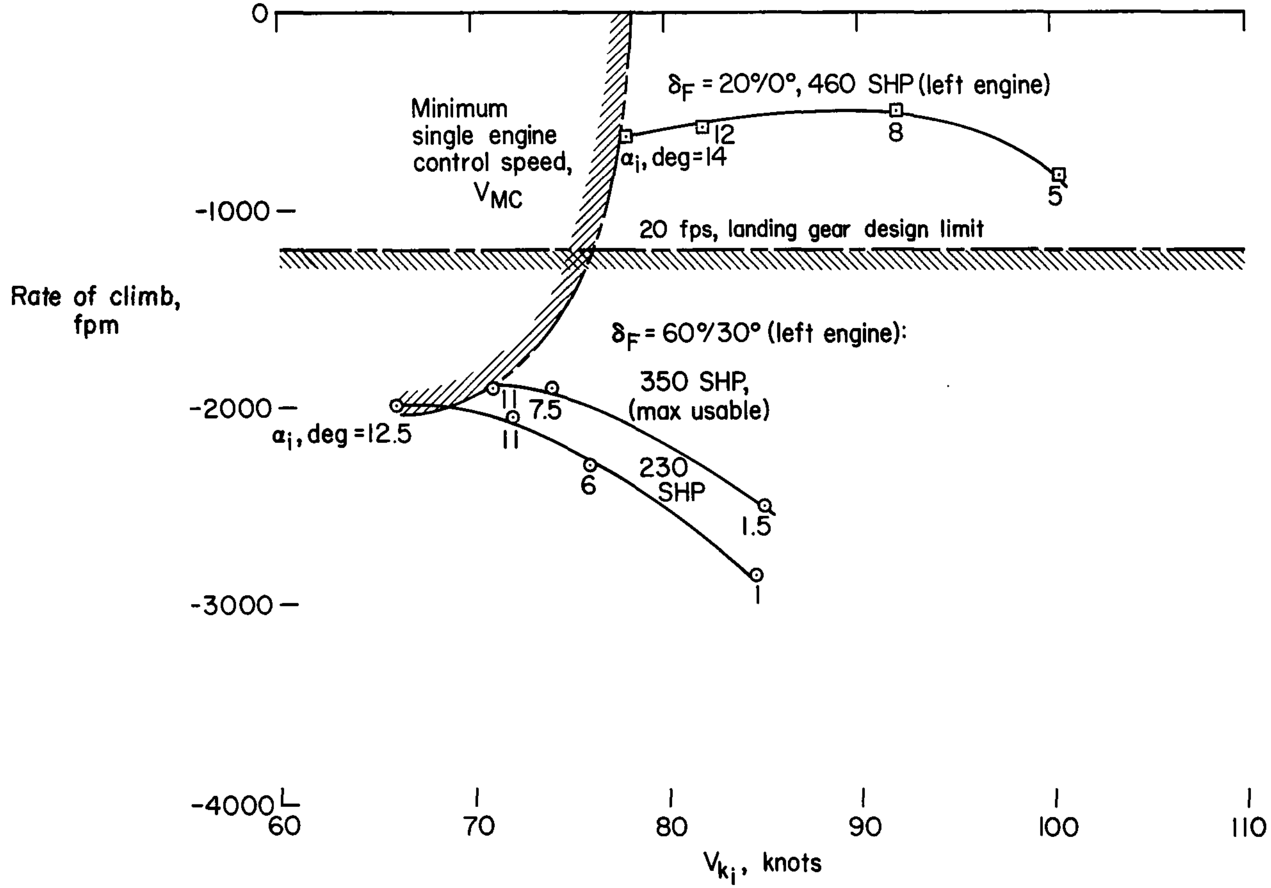


Figure 15.- Engine-out descent characteristics.

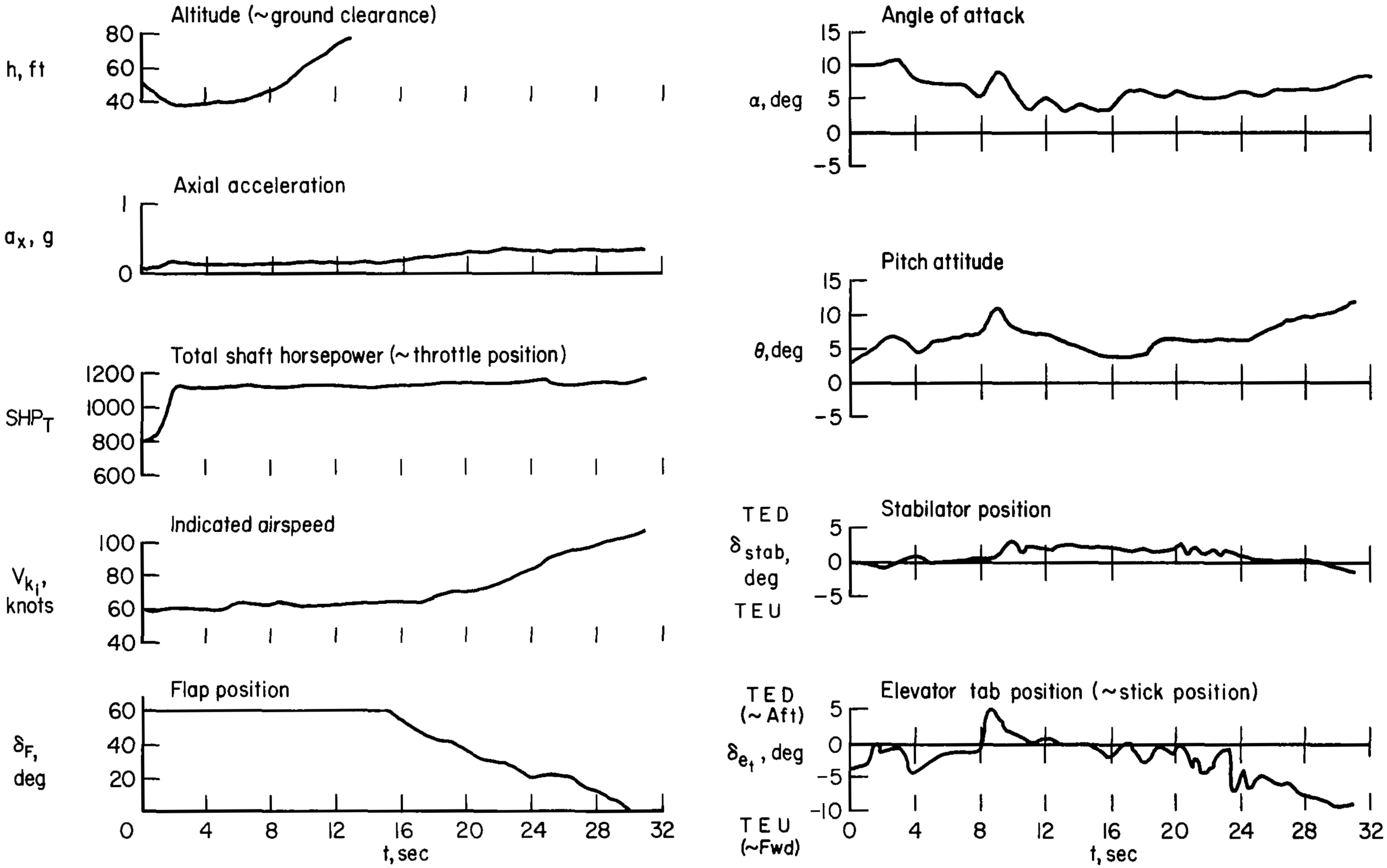


Figure 16.- Time history of wave-off maneuver.

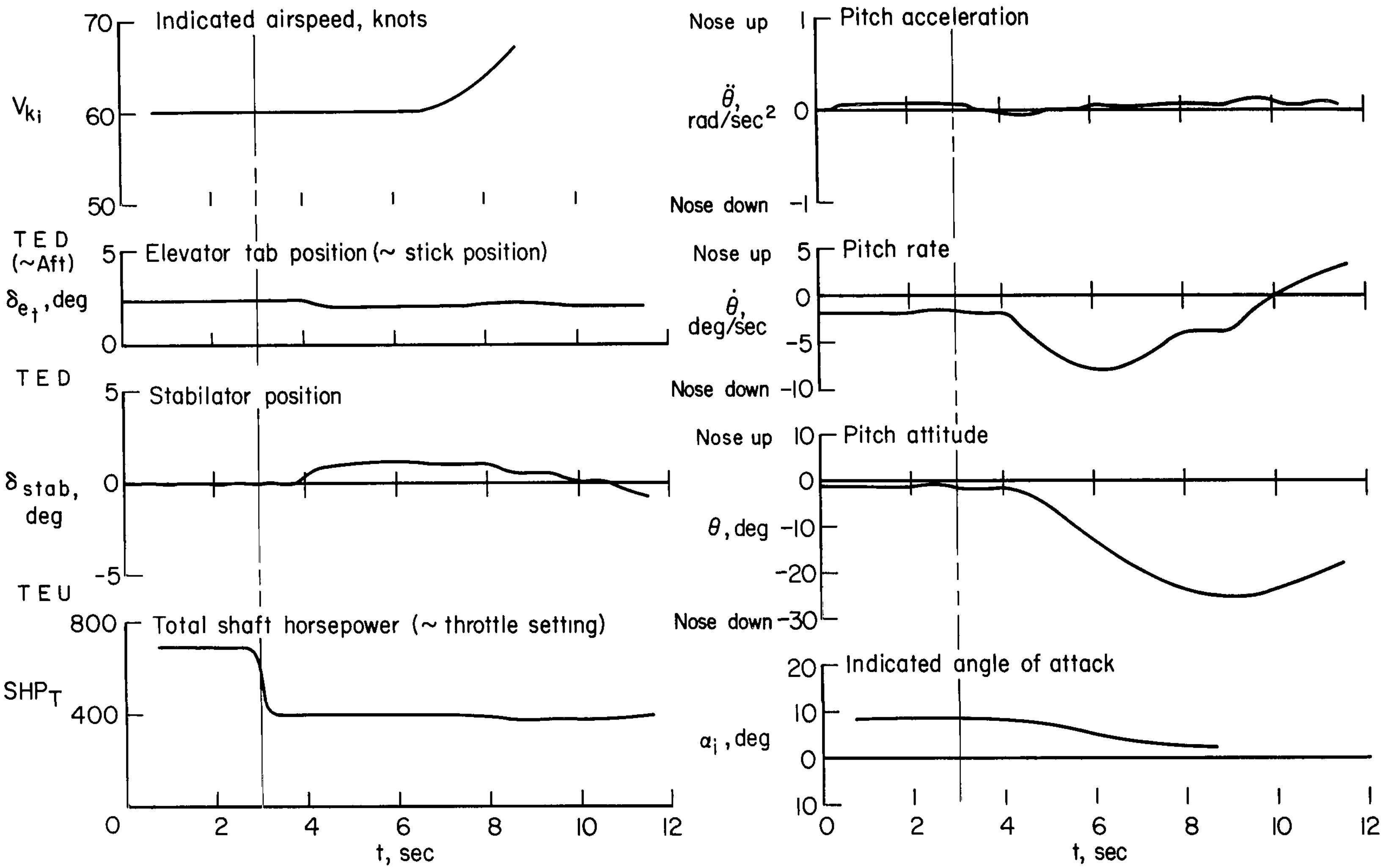


Figure 17.- Response to throttle step; STOL landing approach condition.

NASA-Langley, 1967 — 2 A-2407

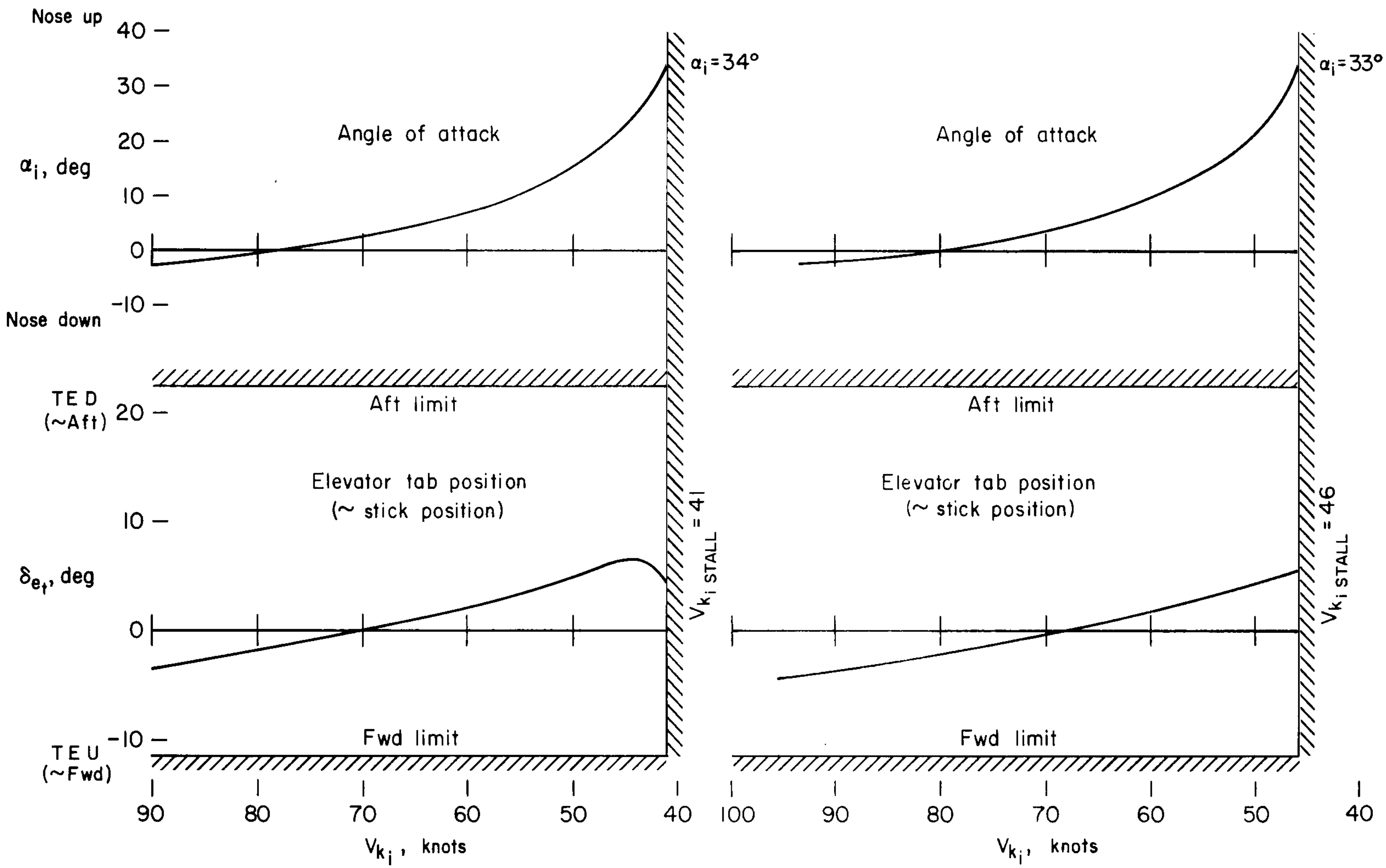


Figure 18.- Illustration of controllable pitch-up characteristic.

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

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

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

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

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

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

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

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

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

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

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546