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Piloted Simulation Study of the Effect of High-Lift Aerodynamics on the Takeoff Noise of a Representative High-Speed Civil Transport

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Summary

As part of an effort between NASA and private industry to reduce airport-community noise for a high-speed civil transport (HSCT), a piloted simulation study was initiated to determine the noise reduction benefits that could result from improved low-speed high-lift aerodynamic performance for a typical HSCT configuration during takeoff and initial climb. In addition to determining potential noise reduction benefits associated with improved high-lift performance, an initial assessment of the impact of pilot performance on noise reduction benefits was done.

To accomplish the aforementioned objective, simulation results for flight profile and engine parameters were coupled with the NASA Langley Aircraft Noise Prediction Program (ANOPP) to estimate jet engine noise and to propagate the resulting source noise to ground measuring stations. A representative HSCT configuration, which incorporated different levels of projected improvements in low-speed high-lift aerodynamic performance, was simulated to investigate effects of increased lift and lift-drag ratio on takeoff noise levels. Simulated flights from brake release through initial climb were performed with a specified thrust management procedure in which a single thrust cutback was performed at selected altitudes ranging from 400 to 2000 ft, or a multiple-cutback procedure was performed where thrust was reduced in a two-step process. Results show that improved low-speed high-lift aerodynamic performance provides at least a 4- to 6-dB reduction in effective perceived noise level at the FAA downrange centerline measurement station for either cutback procedure. However, improved low-speed high-lift aerodynamic performance reduced maximum sideline noise levels only for the multiple-cutback procedure.

Introduction

The advantage of commercial transpacific flight with block times of 4 to 6 hr has generated renewed interest in developing a viable supersonic commercial transport. Recent research sponsored by NASA (refs. 1 and 2) has identified the potential economic benefit of the high-speed civil transport (HSCT) resulting from continued population growth and economic expansion of the Pacific-rim countries. As a result, NASA has initiated a national program to address environmental issues which must be resolved before the HSCT can become a reality. One such issue is the anticipated high level of airport-community noise generated by an operational HSCT during takeoff. An approach under consideration for reducing noise levels is to increase the low-speed lift-drag ratio of the configuration, thereby reducing the engine thrust required during takeoff and initial climb. A number of investigations are underway to explore various means of providing such improvements in low-speed aerodynamic performance.

The purpose of this simulation study was to evaluate the reduction in jet engine noise associated with improved high-lift performance of a typical HSCT configuration during takeoff and initial climb. A secondary objective was to assess the impact of pilot performance on noise reduction benefits associated with improved high-lift performance and to obtain pilot evaluations of the acceptability of the noise-reduction flight procedures. The configuration simulated in the present study was developed during the Supersonic Cruise Aircraft Research (SCAR) program of the 1970's. The configuration was used because of its representative character, the existence of a large wind-tunnel database, and also because of the availability of the full six-degree-of-freedom piloted simulation program of reference 3. It is anticipated that upon the successful resolution of the environmental issues, the present simulation capability can function as a flight dynamics research simulation for the study of HSCT flying qualities.

To accomplish near-term objectives, aerodynamic increments were incorporated into the database to represent improved low-speed high-lift performance. Takeoff flights, using the Langley Visual/Motion Simulator (VMS), were performed for the baseline configuration and for the configuration reflecting advanced high-lift capability. The resulting noise levels were calculated using ANOPP (ref. 4), and comparisons of the results are presented and discussed.

Symbols

C_μ	BLC blowing coefficient, $\dfrac{\text{Thrust produced by BLC system}}{qS}$
I_x, I_y, I_z	moments of inertia about body axes, slug-ft^2
I_{xz}	product of inertia, slug-ft^2
L/D	lift-drag ratio
M	Mach number
q	dynamic pressure, lb/ft^2
S	wing reference area, ft^2
T	total aircraft thrust, lb
T/W	thrust-to-weight ratio
t_f	final time for EPNL integration
t_i	initial time for EPNL integration

V_c	climb speed, knots
$V_{j,\mathrm{eq}}$	equivalent exhaust jet velocity, ft/sec
V_r	rotation speed, knots
W	airplane weight, lb
W/S	aircraft wing loading
α	angle of attack, deg
ΔC_L	aerodynamic lift coefficient increment
ΔC_M	aerodynamic pitching-moment coefficient increment
δ_a	aileron deflection, deg
$\delta_{a,fi}$	inboard flaperon deflection, deg
$\delta_{a,fo}$	outboard flaperon deflection, deg
δ_f	trailing-edge flap deflection, deg
δ_{LE}	leading-edge flap deflection for apex and outboard flaps, deg
δ_r	rudder deflection, deg
δ_t	horizontal tail deflection, deg
δ_{TE}	trailing-edge flap deflection for control surfaces 6 and 7 (see fig. 2)

Abbreviations:

ANOPP	Aircraft Noise Prediction Program
BLC	boundary-layer control
CBA	cutback altitude, ft
c.g.	center of gravity
CGI	computer-generated imaging
DAC	digital-analog converter
dof	degrees of freedom
EADI	electronic attitude director indicator
EPNdB	effective perceived noise level, dB
EPNL	effective perceived noise level, $10 \log_{10} \int_{t_i}^{t_f} \langle \mathrm{pnlt}^2 \rangle \, dt$, dB
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
HSCT	high-speed civil transport
HSI	horizontal situation indicator
IAS	indicated airspeed, knots
mac	mean aerodynamic chord
PNLT	tone-corrected perceived noise level, dB
$\langle \mathrm{pnlt}^2 \rangle$	mean-square equivalent of PNLT
SCAR	Supersonic Cruise Aircraft Research
VMS	visual motion simulator
VSCE	variable-stream-control engine

Description of Airplane

The configuration simulated in this study is designated the AST-105-1 and was previously utilized in the piloted simulation study addressing airport-community noise for supersonic transport configurations (ref. 3). The AST-105-1 was designed to transport 273 passengers in 5-abreast seating at a Mach number of 2.62 for a distance of 4500 n.mi. A detailed description of the vehicle, including a summary of the aerodynamic database, is given in reference 5, and additional details are provided in reference 3. A three-view sketch of the configuration is given in figure 1. The weight and wing loading were 686 000 lb and 82 psf, respectively, for the takeoff configuration and 392 250 lb and 47 psf for the landing configuration. Vehicle weight, inertias, and geometric characteristics are given in table 1.

The aircraft design employs a double-cranked arrow wing that incorporates an inboard leading-edge sweep of 74°, a midspan sweep 70.84°, and an outboard sweep of 60°. The low-speed configuration (see fig. 2) has two inboard leading-edge apex flaps deflected to 30° and an outboard leading-edge flap deflected to 45°. The trailing-edge ailerons and outboard flaperons were biased down 5°, the inboard flaperon was biased down 20°, and the flap was set to 20°. An all-movable vertical tail provided directional control, and an all-movable horizontal tail with a geared elevator provided pitch control. For this study, the center of gravity (c.g.) of the vehicle was located in the plane of symmetry and positioned longitudinally at 60.1 percent of the mean aerodynamic chord. This c.g. location was also used in the study of reference 3 and was the most aft location for this design. For this c.g. position, the vehicle was statically unstable longitudinally, with a static margin of −3.7 percent, which required an up-load on the horizontal tail for trim. The aircraft incorporates a "visor" nose concept which, for improved visibility during the low-speed operational phases of flight, is deflected 12° downward. The landing gear consisted of left and right main bogies and nose wheels. The math model used in the simulation of the landing gear involved strut deflections and strut dynamics for each unit in order to provide vehicle motion response to runway crown and surface roughness.

To evaluate the impact of improved low-speed high-lift aerodynamic performance on airport-community noise, aerodynamic increments were added to the baseline AST-105-1 data. The condition of primary interest is intended to represent the level of high-lift performance considered achievable for an advanced HSCT configuration. This level of performance reflects the current goal of NASA/industry HSCT high-lift research and was simulated by adding a lift increment, $\Delta C_L = 0.10$, to the database with no change in drag or pitching moment.

To aid in the interpretation and analysis of results, a second condition of improved high-lift performance was also considered. This second condition is representative of the performance thought to be achievable for an advanced SCAR configuration in 1980. The advanced SCAR configuration achieves improved high-lift performance through the incorporation of wing trailing-edge flap boundary-layer control (BLC). Data pertaining to the application of BLC for a representative SCAR configuration are presented in reference 6. For the condition represented herein it is assumed that a blowing coefficient, $C_\mu = 0.02$, is used. Figure 3 presents data from reference 6 showing the effect of the application of trailing-edge flap BLC on longitudinal aerodynamic characteristics. Based on these data, the simulation database was incremented as follows: $\Delta C_L = 0.0687$, $\Delta C_M = -0.0142$, and $\Delta C_D = 0.0$. Although supplying this level of BLC could place a significant burden on the jet engines, the impact on engine performance was not evaluated in this study. Also, the noise produced due to the operation of the BLC system was not accounted for in the noise calculations. These issues may have a significant impact on aircraft noise results and should be considered when performing a detailed system design study. Figure 4 shows the resulting values of L/D as a function of C_L and indicated airspeed for the baseline AST-105-1 configuration, the projected advanced HSCT high-lift aerodynamics, and the assumed 1980 high-lift technology SCAR aerodynamics.

The AST-105-1 simulated aircraft was powered by four Pratt & Whitney VSCE-516 engines, which are dual-stream duct-burning turbofan engines that incorporate an inverted exhaust velocity profile for noise suppression. Information describing inverted exhaust velocity profile engines is available in reference 7. The engines were scaled to produce 43 485 lb at 100-percent thrust with 557.6 lb/sec of airflow per engine. This thrust scaling results in a thrust-to-weight ratio of 0.254. For the present study, the VSCE-516 engines were operated at 116.4 percent of rated thrust levels, which gave an actual maximum sea level static thrust-to-weight ratio of 0.295 with 563.5 lb/sec of airflow.

The VSCE-516 engine is assumed to have an articulated nozzle which has the effect of producing fully expanded jet streams at all operating conditions, and thereby eliminates exhaust shock noise. The engines feature independently controlled, dual-stream, inverted velocity profiles aimed at reducing jet mixing noise. Engine response times are 4.8 sec from flight idle to maximum thrust and 3.4 sec from maximum thrust to flight idle. It was noted in reference 3 that the coannular noise benefit was reduced at low power settings. In cooperation with industry, the engine cycle was slightly modified to alleviate this condition. Figure 5 presents the coannular noise benefit as a function of percent net thrust for both the initial VSCE-516 engine cycle and the modified VSCE-516 engine cycle. For purposes of the present study, the modified VSCE-516 engine cycle was used. However, in some instances the original cycle was used to develop comparisons of present results with results from reference 3.

Cockpit Simulator

The investigation was performed in the Langley Visual/Motion Simulator (VMS), which is a hydraulically operated, six-legged synergistic motion base cockpit simulator (fig. 6). Six computed leg positions were used to drive the motion base. The transformation equations used to compute the leg extensions, the filter characteristics used to smooth the computed drive signals from the DAC outputs, and the performance limits of the VMS are given in references 8 and 9. The washout system used to present the motion-cue commands to the motion base was the coordinated adaptive washout of references 10 and 11 with some adjustment of the parameter values to improve base response for this study. The interior of the simulator was configured to be that of a transport with the usual pilot information displays found in current transport aircraft (fig. 7). A CGI system generated the out-of-the-window visual scenes which were displayed to the pilots with color monitors viewed through beam splitters and infinity optics mirrors. Forward and side window views were generated with this system. The pilot and the copilot were provided duplicate sets of pilot information displays, which included an EADI, an HSI, and engine data displays. The EADI was the primary instrument used for the takeoff procedure. It provided the pilot with the necessary data to facilitate the precise flying of the takeoff procedures. The pilot's controls consisted of a side-stick controller, rudder pedals, speed brake, and engine throttle levers. For this study, the copilot manipulated the throttles during the single thrust cutback maneuvers. The control system used for this study was the rate command/attitude hold system of reference 3. This system provided the precise control needed for the takeoff trajectories of this study.

The VMS was driven by a real-time digital simulation system using a Control Data CYBER 175 series computer. The dynamics of the simulated airplane were calculated by using six-degree-of-freedom nonlinear equations of motion and were computed at an iteration rate of 32 frames per second.

Evaluation Methods

One aspect of aircraft certification is to demonstrate that noise levels produced by the aircraft do not exceed the requirements specified by Federal Aviation Regulation (FAR) Part 36. At the time of the simulation study of reference 3, subsonic aircraft were required to certify to the stage 2 noise levels. These requirements specified EPNL values not exceed 108 EPNdB at the three measurement stations (centerline, sideline, and approach) after trade reductions were made (if necessary). The simulation results of reference 3 indicate that the stage 2 noise levels could be met, but only through the use of advanced takeoff procedures. The current goal of the High-Speed Research (HSR) program is to design an HSCT that meets the stage 3 noise regulations for subsonic aircraft. Currently, FAR Part 36 does not require supersonic aircraft to certify to the stage 2 or stage 3 regulations but rather requires the operator to demonstrate that the noise levels of the aircraft have been reduced to the lowest levels that are economically reasonable and technologically practicable. In May 1990, the FAA issued a Notice of Proposed Rulemaking (Notice no. 86-16) for civil supersonic aircraft noise certification standards and operating rules. The Government/industry responses are currently under review, but by the time the HSCT concepts become operational (current projections are for the years 2005 to 2010) more stringent noise regulations may be in place. Table 2 lists the FAR maximum stage 2 and stage 3 noise levels permitted for the vehicle weight considered herein, and figure 8 shows the noise measurement locations.

The reduction in ENPL mandated for stage 3 sideline noise is considerably more difficult to achieve than is indicated by the values of table 2. Not only are the stage 3 values significantly lower than stage 2, but the location of the sideline noise measuring station for stage 3 is closer to the runway centerline than for stage 2 (fig. 8). The lateral displacement specified by the FAA for stage 3 noise measurements is the same as that specified by the International Civil Aviation Organization (ICAO).

Recent analytical investigations, such as that reported in reference 12, have illustrated the potential noise benefits obtainable during takeoff if increased lift can be developed for HSCT configurations. These results show that centerline noise can be substantially reduced and that a large part of this reduction occurs because of the lower thrust levels required. The present study extends these analytical efforts to incorporate operational considerations.

Noise Prediction System

Noise results for this study were generated using the NASA Langley Aircraft Noise Prediction Program (ANOPP) in conjunction with flight trajectories established from the AST-105-1 piloted simulation. The overall flow of data for this analysis routine is presented in figure 9. The AST-105-1 piloted simulation trajectories are combined with the appropriate engine data and form the input for ANOPP. ANOPP, which is fully described in references 4, 13, and 14, calculates the total aircraft noise and propagates it to specified observer locations. For the present study, source noise levels were estimated for jet mixing only. Source noise calculations and takeoff flight trajectory calculations were performed for a "hot day," which is defined as +10°C above standard atmospheric conditions. Resulting noise levels in units of EPNdB were calculated for an array of ground observer positions as well as for the FAA stage 3 noise certification test positions shown in figure 8. The sideline noise level is defined as the maximum value of EPNL measured after aircraft liftoff, along a line parallel to the extended runway centerline and displaced 1476 ft to the side. An alternate method for the measurement of the sideline noise for turbojet engines is allowed under the current regulation (ref. 15, sec. A36.1, para. 7, p. 711). This paragraph stipulates that "For turbojet powered aircraft, when approved by the FAA, the maximum sideline noise at takeoff thrust may be assumed to occur at the point (or its approved equivalent) along the extended centerline of the runway where the aircraft reaches 1000 feet (305 meters) altitude above ground level." The analytical investigations contained in reference 12 used this as a basis to obtain quick results for the potential noise reduction of increased lift during takeoff. This study incorporates the above methodology and, additionally, extends the analytical effort by incorporating operational considerations. All microphones used in this study were placed at a height of 4 ft above the runway surface.

Pilot Task

A predetermined takeoff task was flown by three evaluation pilots for each of the baseline and advanced high-lift concepts considered. One was a NASA research pilot with extensive transport flight experience and presently serving as principal pilot for the NASA Boeing 737 research aircraft. One was an instrument-rated instructor with multiengine flight experience, and the other was an instrument-rated pilot. All three subjects had extensive simulator flight experience. Prior to each simulated takeoff, the pilot was briefed on the particular procedure to be flown. The particular takeoff procedure followed by the pilots was defined by target values for rotation speed, climb speed, and cutback altitude. Two sets of rotation and climb speed were used in this study to permit the largest possible difference in aircraft airspeed. These airspeeds, corresponding to $V_r = 172$ knots, $V_c = 211$ knots and $V_r = 200$ knots, $V_c = 250$ knots, were selected based on balanced field length criteria, tire rotation speed limitations, and maximum allowable indicated airspeed (specified by FAR's) as discussed in reference 3. Climb speed, V_c, was required to remain within ±4 knots. If IAS at any time after climb speed was reached exceeded the tolerance for IAS, the run was terminated. Although the condition of $V_r = 200$, $V_c = 250$ is not allowed according to FAR Part 36 noise certification tests, it would be permitted under FAR Part 25 airworthiness standards. Balanced field length for the baseline configuration was approximately 9200 ft.

Takeoffs were initially performed with the thrust maintained at its maximum value for the entire takeoff procedure. Thrust cutbacks were then initiated at altitudes from 400 ft up to 2000 ft in 100-ft increments to establish the effect of cutback altitude. Although the lower limit of cutback altitude is below the minimum allowable altitude (specified in FAR Part 36 as 689 ft), it was used to indicate the possible noise benefits arising from low-altitude thrust cutbacks. In addition to single thrust cutbacks, multiple-cutback procedures were tested.

The pilot task for this study was to first set the takeoff configuration, which consisted of setting the trailing-edge flaps to 20° and takeoff thrust to 116 percent. Following brake release, the aircraft was then accelerated on the runway until V_r (172 or 200 knots) was reached, at which point the pilot would rotate the aircraft, lift off, and acquire a 4-percent climb gradient. Immediately after liftoff, the landing gear was retracted and the aircraft was accelerated on the 4-percent climb gradient to intercept V_c (211 or 250 knots). When the climb speed was reached, the aircraft was pitched to an attitude that would maintain this speed (resulting in a climb gradient of approximately 20 percent), until the cutback altitude was reached. Upon reaching the cutback altitude, the thrust was reduced and simultaneously the aircraft was pitched down to reacquire a 4-percent climb gradient while maintaining constant airspeed. The time required for thrust- and pitch-attitude reduction was approximately 3 sec. The 4-percent gradient would then be flown until the aircraft reached 8 n.mi. from brake release, at which time the procedure would be terminated. Pitch rates for liftoff rotation, and cutback pitch-down were approximately 3°/sec; and the length of time for thrust reduction, at the thrust cutback point, was approximately 4 sec. Thrust manipulations during the takeoff and climb were performed by the copilot. Coordination was required between the pilot and copilot during thrust and pitch reductions. Figure 10 presents indicated airspeed, thrust, and altitude for a typical takeoff procedure.

An alternate takeoff maneuver was also incorporated in order to provide a direct comparison with noise results from reference 3. This procedure was very similar to the foregoing one except that the pilot would pitch the aircraft to maintain a prescribed angle of attack until intercepting V_c, and the length of time required for thrust reduction at the single cutback point was approximately 7 sec.

A multiple-cutback takeoff procedure was also studied. For this procedure the pilot would follow the same routine as with the single thrust cutback procedures up to the point of rotation, at which time the thrust was automatically reduced to a mid-cutback level followed by a final cutback just prior to passing over the centerline microphone station. During these maneuvers the pilots were required to keep the aircraft on the 4-percent climb gradient. The intermediate level of thrust was the minimum level of thrust that would result in the aircraft stabilizing at 250 knots after the final cutback was completed.

Results and Discussion

Effect of Updated ANOPP Code

The ANOPP system was originally used during the SCAR studies of the mid-1970's. Since then, various elements of ANOPP have been refined and updated to reflect improved methods of noise estimation. Because of these ANOPP upgrades, it is impossible to match noise results previously generated in reference 3. However, results from this study are compared with those from reference 3 to provide the reader with a relative framework for further interpretation of the results of reference 3.

Figure 11 presents altitude, percent net thrust, and indicated airspeed as a function of distance from brake release for a typical standard takeoff. Also presented in figure 11 are data for corresponding conditions from reference 3. As can be seen from this figure, the data agree well and the current VMS piloted trajectories are representative of those from the prior study. Figure 12 presents the ANOPP-generated noise results at the centerline microphone station. The updated version of the code generally predicts a higher level of noise than the older version used in reference 3. Reference 14 describes in detail various evaluations of the ANOPP code as it existed at the time of the reference 3 study and concludes that ANOPP generally underpredicted the actual measured noise levels. In particular, reference 14 states that the earlier version of ANOPP predicted source noise levels that were as much as 4 EPNdB below values measured for the Concorde aircraft.

Effect of Improved High-Lift Aerodynamic Performance on Centerline Noise Levels During Standard Procedures

The incorporation of improved high-lift aerodynamic performance into the AST-105-1 aerodynamic database allowed the simulated aircraft to accelerate faster during full-thrust, constant climb gradient accelerations; provided a greater rate of climb during full-thrust constant airspeed climb; and reduced the thrust required to maintain constant airspeed, constant climb gradient segments. All these results have a beneficial impact on airport-community noise; however, thrust reduction is the most important effect due to the strong dependence of source noise on jet velocity.

To determine the effect of acceleration and rate of climb, takeoff maneuvers were performed with constant thrust for both the $V_r = 172$ knots, $V_c = 211$ knots and the $V_r = 200$ knots, $V_c = 250$ knots takeoff procedures. The procedures were studied for the baseline configuration and for the configurations reflecting high-lift capability.

Figures 13(a) and 13(b) show the effect of improved high-lift performance on the trajectory for conditions with constant thrust and no cutback. Table 3 presents ANOPP-predicted values of centerline noise for these trajectories. As can be seen from the data of figures 13(a) and 13(b) and from table 3, with improved high-lift performance, the aircraft was able to climb higher and consequently is further from the centerline microphone, with a correspondingly reduced noise level. This effect is, as expected, due primarily to the increased altitude. The rate of noise decrease per 1000 ft of altitude over the centerline microphone is approximately the same for both the fast and the slow procedures, with 3.4 EPNdB/1000 ft for the slow trajectories and approximately 3.7 EPNdB/1000 ft for the fast trajectories.

The effect of improved high-lift aerodynamics for standard single thrust cutback maneuvers are now considered. As mentioned earlier, the most significant benefit resulting from improved low-speed high-lift performance is the reduction of the thrust required to maintain constant velocity and constant climb gradient segments. Figure 14(a) presents trimmed L/D as a function of indicated airspeed, and figure 14(b) presents the equivalent jet velocity (the mass-averaged velocity of the inner and outer streams of the VSCE-516 coannular jet) as a function of thrust required to maintain the constant velocity, 4-percent climb gradient. As shown in figure 14, improved high-lift aerodynamics greatly reduced the equivalent jet velocity required to maintain the constant velocity, 4-percent climb gradient. This results in a substantial reduction in the level of source noise generated from jet mixing. It should be noted that source noise represents the noise at the source, and not at the FAA measurement locations. In this study, source noise is assumed to be dominated by jet mixing noise, and therefore a reduction of jet mixing noise results in a corresponding reduction in total far-field noise. Incremental source noise values, for thrust settings represented in figure 14 are presented in table 4. These results were calculated based on the percent net thrust required to maintain the post-cutback, constant airspeed, 4-percent climb gradient.

Thrust cutback altitude also influenced the resulting trajectories and the levels of centerline noise. These effects were evaluated for a series of trajectories, where thrust cutback altitude was varied from 400 to 2000 ft in 100-ft increments. Figures 15(a) and 15(b) present centerline noise as a function of cutback altitude for the baseline and advanced high-lift conditions previously discussed. From these figures, it can be seen that centerline noise is significantly affected by cutback altitude. As cutback altitude is increased from 400 ft, the centerline noise decreases to a minimum and then rapidly increases. As an example, consider the data of figure 15(b) for the 1980 SCAR aerodynamics. These data show that minimum centerline noise occurs for a cutback altitude of approximately 1200 ft. Detailed study of the results shows that the noise increases when the thrust cutback altitude is reduced below 1200 ft, because the early cutback results in lower aircraft altitudes at the centerline microphone location. Thus, the noise source is closer to the measurement location. The aforementioned data also show the noise increases when the thrust cutback altitude is increased above 1200 ft. This result is attributed to the increased time the noise measurement location is exposed to the full-power source noise as the cutback is delayed. Obviously the cutback altitude for minimum centerline noise depends on the flight profile selected, and the preceding example explains the observed trends.

The data of figures 15(a) and 15(b) are represented in figures 16(a) and 16(b) in the form of centerline noise versus the distance from brake release at which cutback is effected. Since the centerline point is specified as 21 325 ft from brake release, examination of the data of figures 16(a) and 16(b) shows that (for the conditions considered) minimum centerline noise is achieved by thrust cutback at distances of approximately 4800 to 2300 ft ahead of the microphone location.

Percent net thrust and altitude for the minimum centerline noise trajectories are shown as a function of distance from brake release in figures 17(a) and 17(b). Improved high-lift aerodynamics allowed the aircraft to reach climb velocity sooner while accelerating on the 4-percent gradient after liftoff; climb steeper during the constant airspeed, precutback climb segment; and reduce thrust further on the postcutback, constant climb, constant airspeed segments. The preceding minimum centerline noise values are summarized in table 5. Based on these data, it can be seen that for the single thrust cutback procedure, improved high-lift aerodynamics results in a reduction of about 5 to 7 EPNdB in centerline noise.

Comparison of the source noise suppression resulting from reduced levels of thrust (table 4) with the results presented in table 5 indicates that between 72 percent and 90 percent of the overall noise reduction is, as expected, simply due to the capability of the aircraft to operate at a lower level of thrust during the postcutback segment.

Effect of Improved High-Lift Aerodynamic Performance on Sideline Noise Levels During Standard Procedures

As noted in a previous section, the sideline noise level is defined by FAR Part 36 as the maximum value of EPNL measured after aircraft liftoff, along a line parallel to the extended runway centerline and displaced 1476 ft to the side. For purposes of the present study, sideline noise is calculated for both the FAR Part 36 method and the alternate method.

Figures 18(a) and 18(b) present the calculated sideline noise as a function of thrust cutback altitude for the baseline and the advanced high-lift aerodynamics previously discussed. To aid in the understanding of these results, figure 19 presents the sideline noise calculated along the FAA stage 3 noise evaluation line (see fig. 8) for conditions where the thrust cutback altitude is approximately 600 ft. As can be seen from figure 19, for either the baseline or the advanced aerodynamics configurations, the maximum value of noise occurs shortly after liftoff and well before the thrust cutback point. Based on the preceding result, it is not surprising that the FAR Part 36 sideline noise values are not influenced by the improvements in low-speed high-lift performance or by the thrust cutback altitude for the single thrust cutback trajectories employed in this study (as shown by the data of fig. 18). By contrast, the dashed line of figure 19 indicates the noise values calculated when the aircraft passes through an altitude of 1000 ft, and therefore represents values which would correspond to the alternate measurement method. As can be seen, improved high-lift aerodynamics can provide significant noise reductions if this method of measurement is used. Furthermore, as shown in figure 18, the alternate method of measuring sideline noise (i.e., when the aircraft passes through an altitude of 1000 ft) is, as expected, very sensitive to cutback altitude.

Effect of Improved High-Lift Aerodynamics on Centerline and Sideline Noise Levels for Multiple Thrust Cutback Procedures

As noted previously, the maximum sideline noise occurs just after liftoff and is not affected by thrust cutbacks performed at altitudes of 400 ft or greater. Accordingly, multiple-cutback procedures are being considered wherein an initial thrust cutback is performed on liftoff. For these procedures, thrust was initially reduced to an intermediate level, which was the minimum level that would result in the aircraft accelerating to and stabilizing at 250 knots after a second thrust cutback was completed. The final thrust level was equal to the level of thrust used during the postcutback segments of the single thrust cutback trajectories. The point at which the second thrust cutback occurred was defined by using results for minimum centerline noise during single thrust cutback trajectories.

Figure 20 presents percent net thrust, altitude, and L/D as functions of distance from brake release for the baseline and advanced aerodynamics conditions considered. From figure 20, it can be seen that all the resulting flight profiles were similar and that improved aerodynamic performance was used solely to reduce the level of thrust required to accomplish these flight profiles. Table 6 shows the resulting noise levels for the respective high-lift conditions. Relative to the single-cutback procedure, where FAR Part 36 sideline noise levels were 117.4 EPNdB, improved aerodynamic performance in conjunction with multiple-cutback procedures can provide reductions of 4.7 EPNdB for the baseline AST-105-1 and up to 8.6 EPNdB for the advanced HSCT. However, as a result of the lower altitude associated with this trajectory, there is a corresponding increase in centerline noise.

Figure 21 provides a simultaneous assessment of centerline and sideline noise reductions associated with high-lift and thrust cutback procedures. Maximum sideline noise after liftoff is plotted against centerline noise for six different trajectories. The results for the single-cutback procedure are for the trajectories presented in figure 17(b) and correspond to minimum centerline noise for the three aerodynamic configurations. Also, the results for the multiple-cutback procedure are presented for the trajectories from figure 20. The clipped-corner regions represent the further noise reduction required to meet the FAA stage 3 traded noise levels, which are based on the assumption that, on approach, the aircraft will be at least 3 EPNdB below the level mandated for approach noise. From this figure it can seen that although the level of centerline noise is higher for the multiple-cutback procedure, the reduction in sideline noise greatly lowers the level of noise reduction required for this aircraft to satisfy the FAA stage 3 noise requirement. Specifically, the level of further noise reduction required to meet FAA stage 3 noise requirement drops from approximately 13 EPNdB to less than 5 EPNdB for the advanced HSCT aerodynamics from the use of the multiple-cutback procedure.

Effect of Improved Aerodynamics on Ground Noise Contours

In addition to considering noise certification measurements at specified locations, NASA and industry are seeking to minimize the potential noise impact HSCT aircraft may have on the community surrounding the airport. For purposes of the present study, the takeoff profiles were extended such that the aircraft continued climbing on a 4-percent gradient at an IAS of 250 knots to an altitude of 10 000 ft, at which point the flights were terminated. Recognizing that below an altitude of 10 000 ft Federal Aviation Regulations prohibit speeds above 250 knots, it is assumed that at 10 000 ft the aircraft would increase thrust, accelerate, and climb.

A total of 560 ground noise measurement stations, at distances from −12 000 to 200 000 ft from brake release and from the runway centerline to a lateral distance of 16 000 ft, were used to calculate ground noise contours corresponding to 120, 110, and 100 EPNdB levels. Figure 22 presents these calculated noise contours for the baseline and advanced aerodynamics configurations undergoing the single ($V_r = 200$ knots, $V_c = 250$ knots) and multiple-cutback procedures indicated in figures 17(b) and 20. In this figure, the left half of the ground plane represents results for the baseline AST-105-1, and the right half represents results for the advanced HSCT high-lift system, for both single-cutback (fig. 22(a)) and multiple-cutback (fig. 22(b)) trajectories. From this figure, it can be seen that the effect of improved low-speed high-lift aerodynamic performance was to greatly reduce ground noise. However, this effect was only for regions overflown by the aircraft after the level of thrust had been reduced from full power. For the single-cutback trajectories, the 120 and 110 EPNdB contours were virtually unaffected by the incorporation of improved low-speed high-lift aerodynamics, which was a result of the aircraft operating at maximum power when flying over these areas. Tables 7(a), (b), and (c) present the enclosed areas for the 120, 110, and 100 EPNdB contour lines for the baseline AST-105-1 and advanced HSCT low-speed high-lift systems. The effect of improved low-speed high-lift is demonstrated in table 7(c), where the 100 EPNdB contour area was reduced from 19.79 to 6.6 n.mi^2 for the multiple-cutback trajectories, which is a reduction of 66.6 percent of the baseline 100 EPNdB contour area. This result highlights the impact of advanced high-lift aerodynamics and the resulting thrust reduction as a primary mechanism for ground noise reductions.

Pilot Performance

When HSCT takeoff procedures are to be performed by a pilot (as opposed to an automated takeoff), some effects on noise levels are expected to occur from differences in piloting performance. For the single-cutback procedure examined herein, thrust cutback altitude has been shown to greatly influence centerline noise levels. This effect varied depending on where the thrust cutback occurred in relation to the centerline microphone. With reference to the discussion of figure 15(b), the sensitivity of centerline noise to cutback altitude can be estimated by using three linear regions. The first region is defined for altitudes between 400 and 900 ft, where the centerline noise decreases with increasing cutback altitude. The second region is for altitudes between 900 and 1200 ft, where changes in cutback altitude have no effect on centerline noise. Finally, the third region covers altitudes between 1200 and 1900 ft, where centerline noise increases with increasing cutback altitude. For the 1980 Advanced SCAR configuration, the sensitivities for these three regions are −0.00415, 0.0, and +0.0145 EPNdB/ft, respectively. Similar sensitivities have been determined for the configuration having differing levels of high-lift performance.

An indication of how accurately the thrust was manipulated was estimated through analysis of the 111 simulated takeoff flights of this report. This analysis assumes errors in thrust cutback altitude to be independent of climb speed or aerodynamic configuration. Figure 23 presents the cumulative frequency distribution for errors in cutback altitude obtained for all aerodynamic configurations investigated. Examination of this figure reveals that for approximately 50 percent of the simulated takeoffs, the thrust cutback was performed within about ±15 ft of the target cutback altitude and for 90 percent the thrust cutback was performed within ±40 ft. The maximum cutback altitude error for all the simulated flights in this study was less than ±60 ft. Combining these results with the sensitivities for the 1980 Advanced SCAR configuration produces a maximum centerline noise increment, due to cutback altitude error, of less than 0.87 EPNdB.

As stated previously, IAS was required to remain within ±4 knots after V_c had been reached. If IAS exceeded this limit, the run was terminated. However, exceeding this arbitrary airspeed limit may occasionally occur in actual airline operations. In order to determine the impact this piloting error would have on centerline noise, takeoffs were performed that intentionally produced airspeed errors of greater than ±5 knots. This error was introduced through a simulated lack of coordination between the pilot and the copilot during the thrust cutback portion of the single-cutback procedures.

Figure 24 presents altitude, IAS, and thrust as functions of distance from brake release for three takeoffs during which the timing of the pitch attitude reduction was slightly altered (with respect to thrust cutback) to produce an airspeed variance. To recover from an above-target IAS condition, the pilot increased pitch attitude by 5° in order to decrease IAS, then reacquired the 4-percent climb gradient pitch attitude when IAS approached the target value. To recover from a below-target IAS condition, the copilot increased thrust 10-percent above that required to maintain a 4-percent climb gradient, then reduced thrust again to the required level to maintain a 4-percent climb gradient when IAS approached the target value. For the above-target-airspeed and below-target-airspeed conditions, centerline noise was respectively increased 1.1 and 3.0 EPNdB above the noise level with no airspeed variance. This result indicates that a substantial percentage of the centerline noise reduction, available from improved low-speed high-lift aerodynamic performance, could be lost due to poor pilot-copilot coordination for the single-cutback procedure.

Crew coordination was less of a factor for multiple cutback takeoffs, for which thrust was automatically controlled. However, pilot performance was a factor in performing the rotation at the specified speed. The sensitivity of sideline noise to rotation speed was estimated by executing takeoffs at rotation speeds of ±5 knots and ±10 knots from the target value. Figure 25 presents the cumulative frequency distribution for rotation speed error, and sideline noise sensitivity to rotation speed error. As shown in figure 25, for approximately 50 percent of the simulated flights rotation speeds were within ±2 knots, and for over 90 percent of the simulated flights rotation speeds were within ±5 knots. For all flights, rotations speeds were within ±7 knots. From figure 25, sideline noise sensitivity can be approximated as

$$\frac{-0.2\text{ EPNdB}}{\text{Rotation speed error in knots}}$$

Therefore sideline noise increments due to rotation speed error were less than ±1.4 EPNdB for all flights, and for 90 percent of the simulated flights the increment was less than ±1.0 EPNdB. Obviously liftoff distances change somewhat with changes in rotation speed. The sensitivity of liftoff distance to rotation speed was approximately

$$\frac{-67\text{ ft}}{\text{Rotation speed error in knots}}$$

Pilot Comments

The NASA research pilot commented that the airplane response to pilot inputs and the pilot-out-of-the-loop stability for the takeoff maneuver were good and gave a Cooper-Harper pilot rating of 2 for longitudinal handling qualities. See figure 26 for a detailed description of the Cooper-Harper rating system. The amount of thrust reduction performed at altitudes as low as 400 ft was not a safety of flight issue for this research pilot, provided that the thrust was reduced gradually by the copilot and that no aircraft heading changes were required. The piloting technique preferred by this pilot involved flying three different pitch attitudes corresponding to the three takeoff segments. Takeoffs using multiple thrust cutbacks with the programmed auto-throttle engaged provided no concern for this pilot, and he indicated they were easy to perform and appeared acceptable as a normal commercial aircraft operating procedure. In addition, simulator flights involving a critical engine-out condition posed no piloting or safety difficulties, since more than adequate thrust remained available to complete the takeoff in an acceptable fashion. Finally, this research pilot commented that the motion cues provided by the cockpit motion base during the takeoff ground roll were representative of those experienced by actual transport aircraft.

Concluding Remarks

A piloted simulation study, using the Langley Visual/Motion Simulator, was undertaken to examine the effect of improved low-speed high-lift aerodynamics on airport-community noise levels during takeoff of a representative high-speed civil transport (HSCT) configuration. The simulated airplane was developed during a previous NASA supersonic transport program and was designated the AST-105-1 and was powered by scaled versions of a Pratt & Whitney-developed variable-stream-control engine cycle designated as the VSCE-516. In addition to the baseline configuration, advanced low-speed high-lift configurations, having low-speed high-lift performance consistent with present HSCT programmatic goals, were considered. The effect of improved low-speed high-lift performance was quantified through analysis of resulting noise data for a series of simulated takeoffs, in which thrust cutback altitude, rotation, and climb speed were varied.

The incorporation of improved low-speed high-lift performance produced significant results. It allowed for faster acceleration during full-thrust constant climb gradient accelerations, greater rate of climb during full-thrust constant airspeed climb, and reduced thrust required to maintain constant airspeed constant climb gradient segments. All these results had a beneficial impact on airport-community noise, with reduced thrust being the most important due to its influence on jet velocity.

Results indicate that centerline noise was reduced primarily due to the aircraft being capable of operating at reduced levels of thrust while maintaining constant airspeed and constant climb gradient flight. The level of centerline noise reduction ranged from 3.2 to 7.3 EPNdB, based on minimum centerline noise trajectories.

The maximum level of sideline noise was not reduced by the incorporation of improved low-speed high-lift performance for single-cutback trajectories studied herein. However, an alternate sideline noise level (sideline noise level when aircraft reaches an altitude of 1000 ft) was affected by the incorporation of improved low-speed high-lift performance, but only for takeoff trajectories where thrust cutback occurred below approximately 800 ft. The level of alternate sideline noise reductions were similar to the centerline noise reductions for trajectories where thrust was cutback at altitudes below approximately 700 ft.

For multiple-cutback procedures, improved low-speed high-lift performance reduced noise for centerline, maximum sideline, and alternate sideline microphone stations to between 2.6 and 4 EPNdB. However, because of the lower trajectory associated with the multiple-cutback procedure, the level of centerline noise was increased above the minimum value for the standard single-cutback procedure.

The takeoff procedures employed for this study were found to be acceptable from a piloting standpoint if no heading changes were required at low altitudes and thrust was reduced in a gradual process either manually by the copilot or automatically by computer control. Computer controlled thrust management was found to be required for the multiple-cutback procedures. Both procedures involved only moderate levels of pilot workload. The flying qualities of the simulated aircraft, with a rate-command, attitude-hold control system, were adequate to perform these takeoff procedures.

The effect of piloting performance errors on noise reduction benefits associated with improved high-lift performance has been evaluated for both the single- and multiple-cutback procedures. Piloting errors affected centerline noise only for single thrust cutback trajectories. Crew coordination could be a potential problem when performing the simultaneous thrust-cutback and reduction of pitch attitude associated with the single-cutback procedures, and result in a significant increase in centerline noise. Other sources of piloting error studied were rotation speed error and cutback altitude error. Of these, only cutback altitude error affected centerline noise and was less than 0.87 EPNdB for all 111 takeoffs performed. For the multiple-cutback procedure, only rotation speed error was found to significantly affect noise results, which were less than ±1.4 EPNdB for sideline noise only.

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15. Noise Standards: Aircraft Type and Airworthiness Certification. FAA, Code of Federal Regulations, Part 36, Title 14 (Parts 1 to 59), 1993, pp. 700–772.

Table 1. Dimensional and Mass Characteristics

Geometric dimensions:	
Reference wing area, ft^2	8366
Wingspan, ft	126.22
Wing leading-edge sweep, deg	74.00/70.84/60.00
Reference mean aerodynamic chord (mac), ft	88.16
Center of gravity, percent mac	60.10
Static margin, percent	−3.7
Wing fin area, ft^2	196
Horizontal fin area, ft^2	620
Vertical tail area, ft^2	358
Mass properties:	
Takeoff weight, lb	686 000
I_x, slug-ft^2	7 540 000
I_y, slug-ft^2	54 910 000
I_z, slug-ft^2	60 730 000
I_{xz}, slug-ft^2	−1 540 000
Control surface deflections:	
δ_t, deg	±20
δ_f, deg	0 to 30
δ_a, deg	±35
$\delta_{a,fo}$, deg	±30
$\delta_{a,fi}$, deg	±10
δ_r, deg	±25

Table 2. FAR Part 36 Maximum Noise Levels

FAA requirements	Sideline noise, EPNdB	Centerline noise, EPNdB	Approach noise, EPNdB
Stage 2	108.0	108.0	108.0
Stage 3	101.9	104.5	105.0

Table 3. Effect of Improved Low-Speed, High-Lift Performance on Centerline Noise (Full-Thrust Takeoffs)

[$V_r = 172$ knots; $V_c = 211$ knots]

High-lift system	Centerline noise, EPNdB	Altitude at centerline point, ft
Baseline AST-105-1	117.6	1912
1980 Advanced SCAR	116.5	2241
Advanced HSCT	115.7	2470

[$V_r = 200$ knots; $V_c = 250$ knots]

High-lift system	Centerline noise, EPNdB	Altitude at centerline point, ft
Baseline AST-105-1	117.9	1561
1980 Advanced SCAR	116.7	1847
Advanced HSCT	116.2	2021

Table 4. Noise Increment Due to Thrust Reduction for Conditions Presented in Figure 14

High-lift system	Noise increment, EPNdB, at—	
	$V_c = 211$ knots	$V_c = 250$ knots
Baseline AST-105-1	0.0	0.0
1980 Advanced SCAR	−3.8	−2.3
Advanced HSCT	−6.6	−4.0

Table 5. Effect of Low-Speed High-Lift Performance on Centerline Noise Levels (Single Thrust Cutback Procedure)

[$V_r = 172$ knots; $V_c = 211$ knots]

High-lift system	EPNdB	Cutback altitude, ft	Net thrust, percent
Baseline AST-105-1	111.5	1481	71
1980 Advanced SCAR	107.3	1522	60
Advanced HSCT	104.2	1472	55

[$V_r = 200$ knots; $V_c = 250$ knots]

High-lift system	EPNdB	Cutback altitude, ft	Net thrust, percent
Baseline AST-105-1	107.6	1101	59
1980 Advanced SCAR	104.4	970	52
Advanced HSCT	103.0	932	48

Table 6. Effect of Improved Low-Speed High-Lift Performance on Noise

[Multiple-cutback procedure; $V_r = 200$ knots; $V_c = 250$ knots]

High-lift system	Centerline noise, EPNdB	Maximum sideline noise, EPNdB	Alternate sideline noise, EPNdB
Baseline AST-105-1	113.4	112.7	104.9
1980 Advanced SCAR	110.8	110.0	102.3
Advanced HSCT	109.3	108.8	101.2

Table 7. Enclosed Area

[V_r = 200 knots; V_c = 250 knots]

(a) 120 EPNdB contour

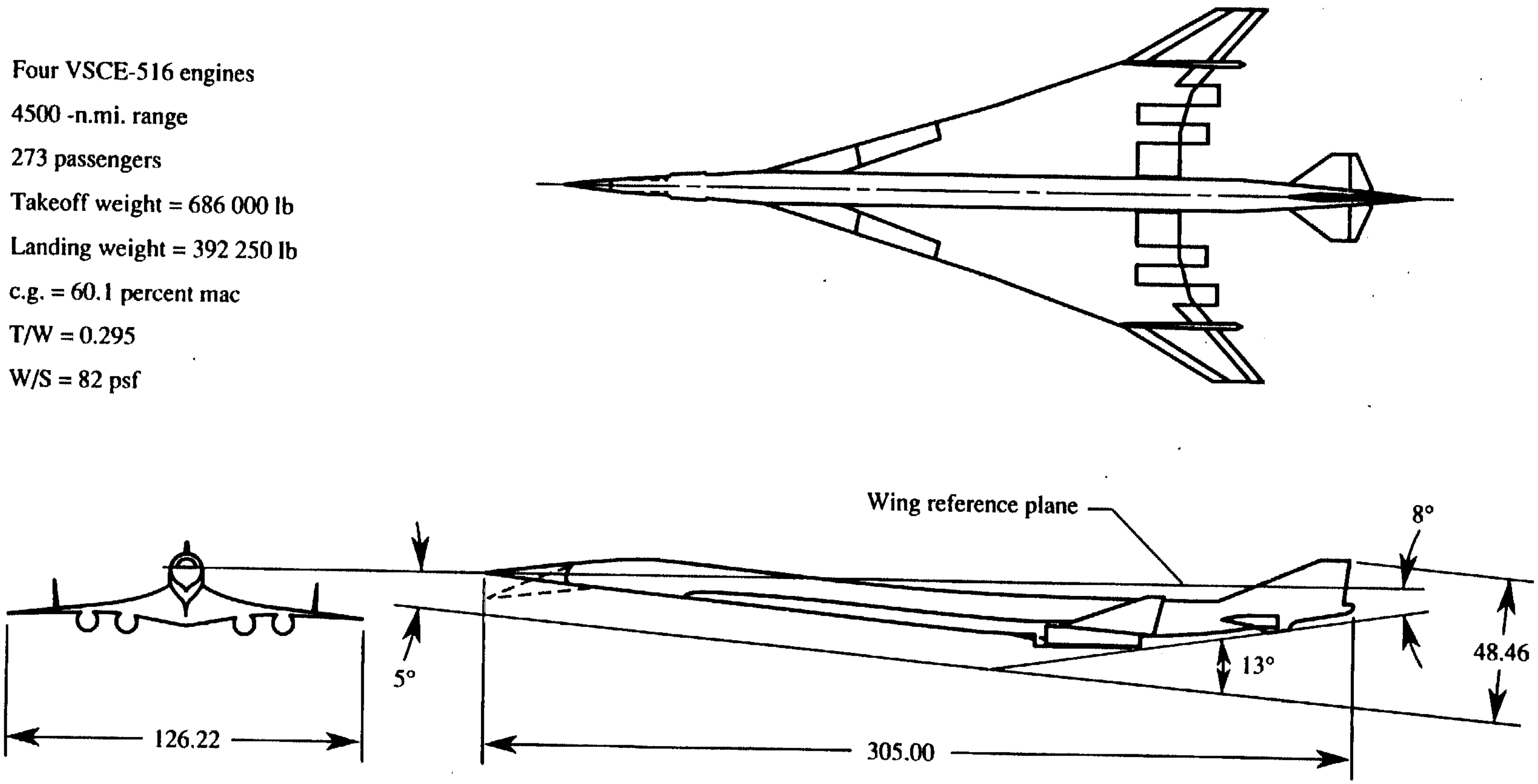
High-lift system	Area, n.mi.^{2}, for—	
	Single cutback	Multiple cutback
Baseline AST-105-1	1.28	1.17
1980 Advanced SCAR	1.27	.96
Advanced HSCT	1.25	.84

(b) 110 EPNdB contour

High-lift system	Area, n.mi.^{2}, for—	
	Single cutback	Multiple cutback
Baseline AST-105-1	2.65	2.66
1980 Advanced SCAR	2.76	2.19
Advanced HSCT	2.72	1.93

(c) 100 EPNdB contour

High-lift system	Area, n.mi.^{2}, for—	
	Single cutback	Multiple cutback
Baseline AST-105-1	19.21	19.79
1980 Advanced SCAR	8.68	8.76
Advanced HSCT	7.76	6.60



Four VSCE-516 engines
4500 -n.mi. range
273 passengers
Takeoff weight = 686 000 lb
Landing weight = 392 250 lb
c.g. = 60.1 percent mac
T/W = 0.295
W/S = 82 psf

Figure 1. AST-105-1 configuration. All linear dimensions are in feet.

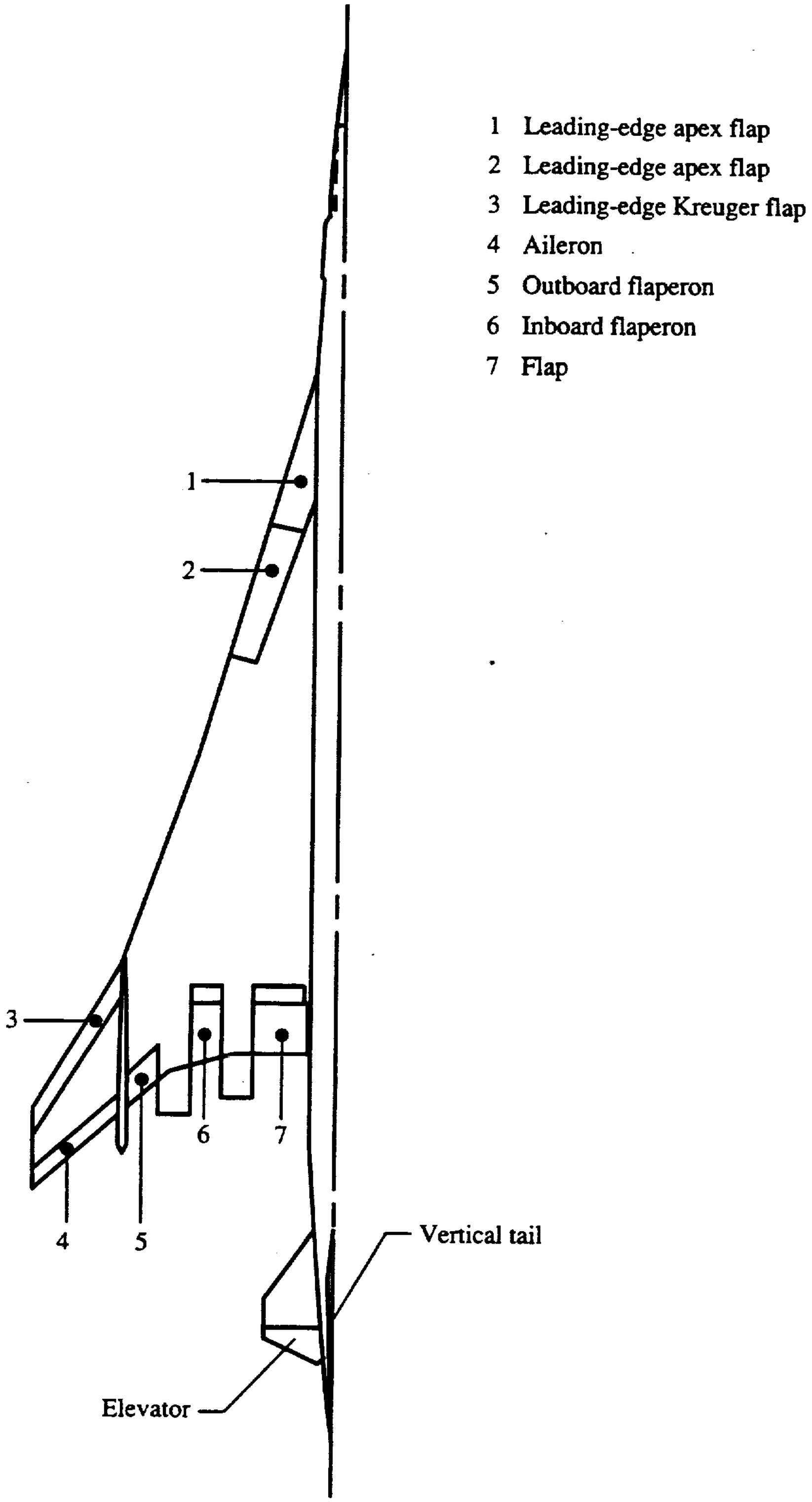


Figure 2. Control surface layout.

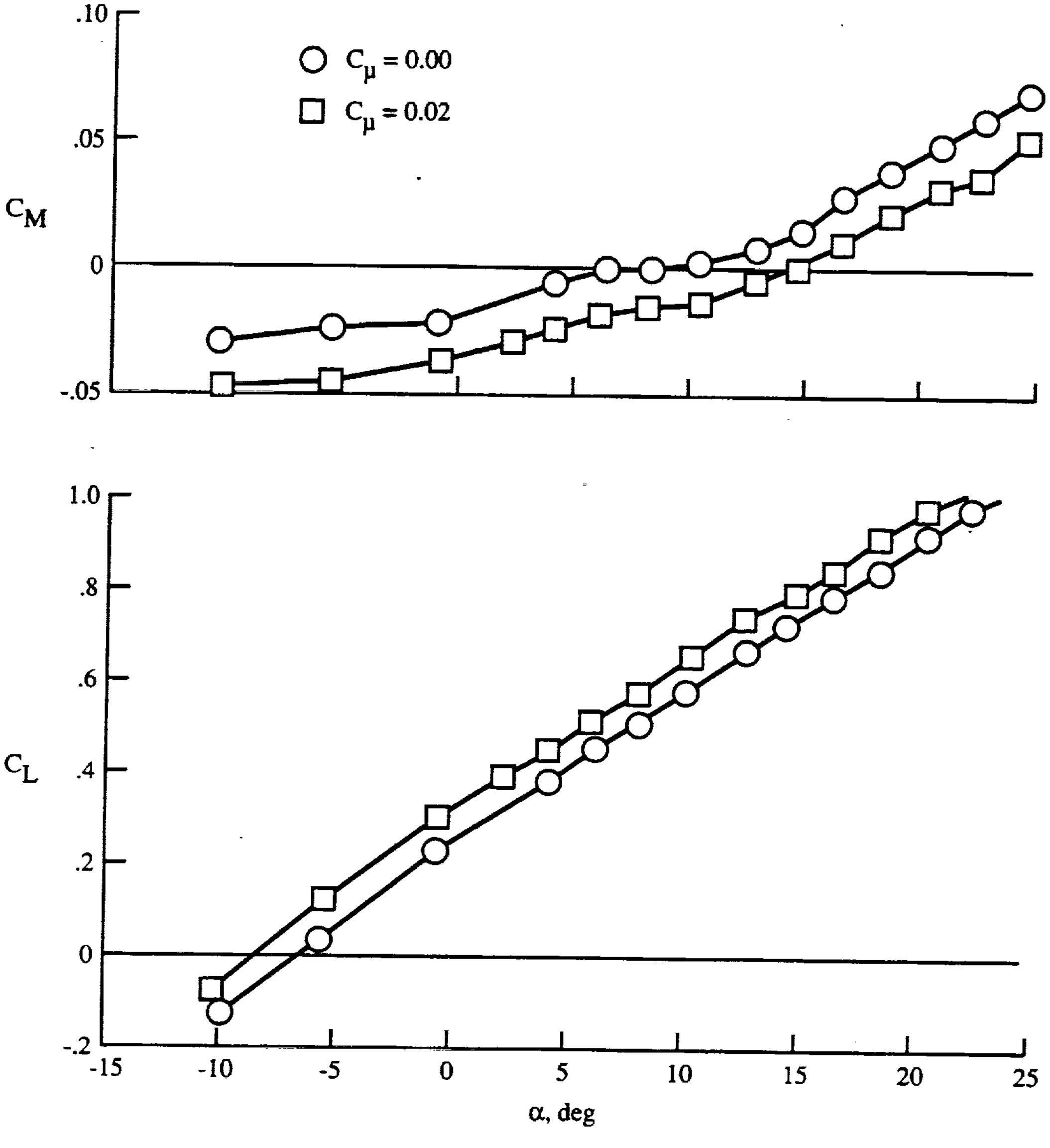


Figure 3. Effect of wing trailing-edge BLC on longitudinal aerodynamic characteristics. Data from reference 6 for conditions with $\delta_{LE} = 30°$, $\delta_{TE} = 20°$. Wing-body configuration.

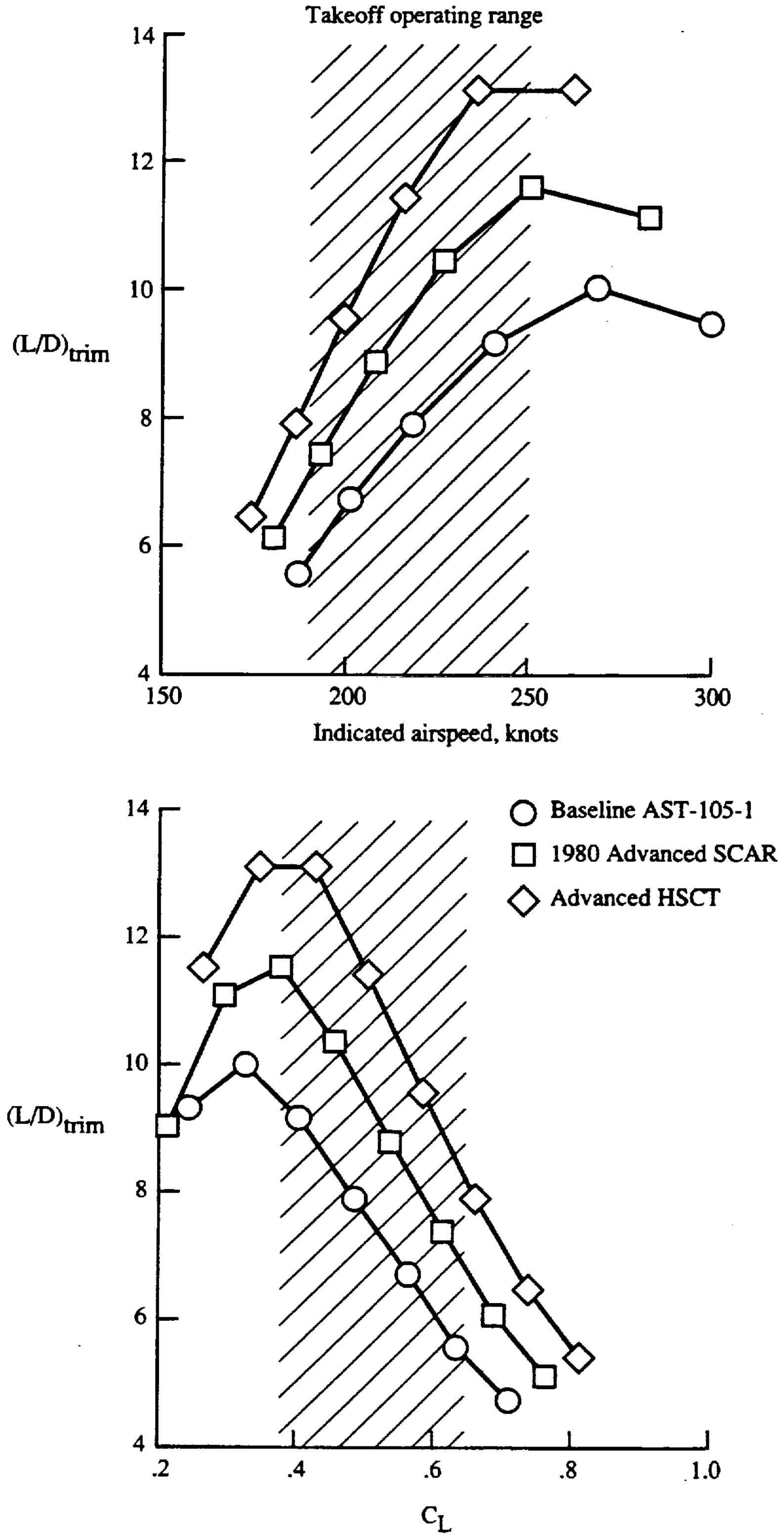


Figure 4. Variation of L/D with airspeed and lift coefficient. Aircraft positioned out of ground effect.

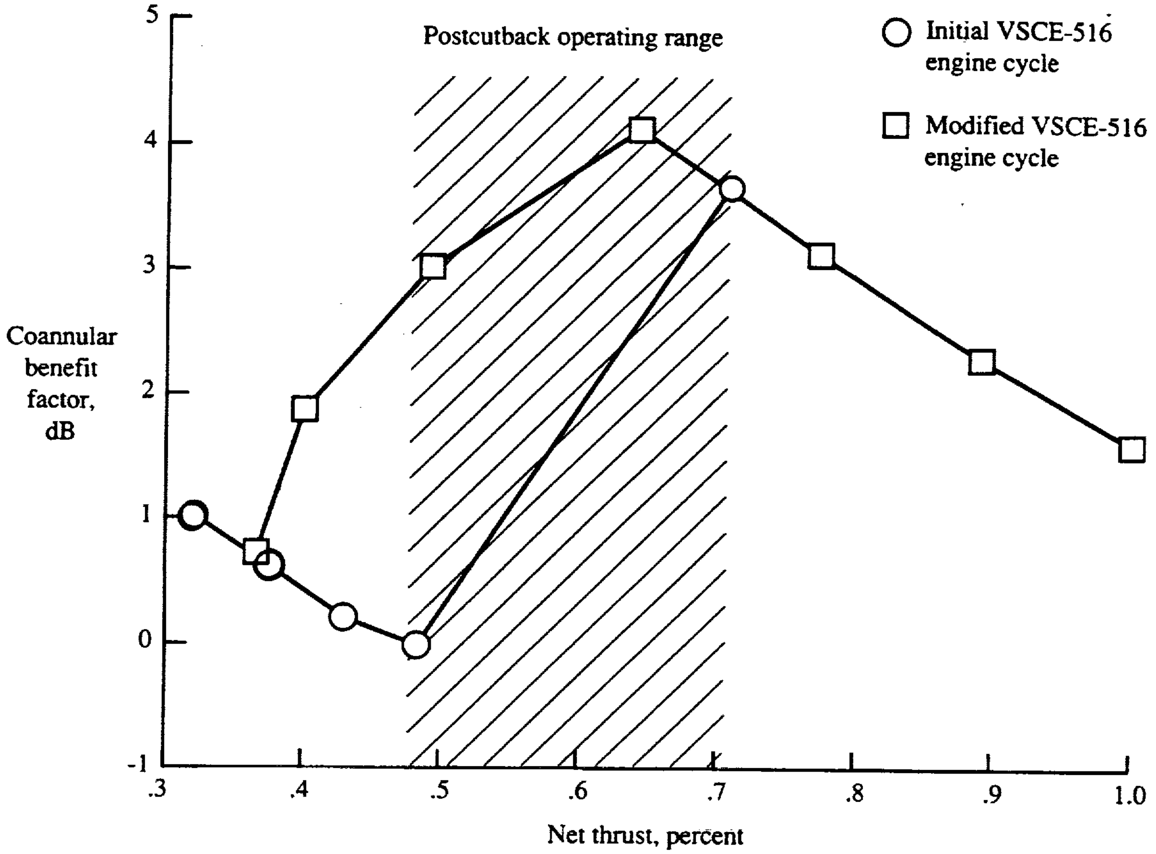
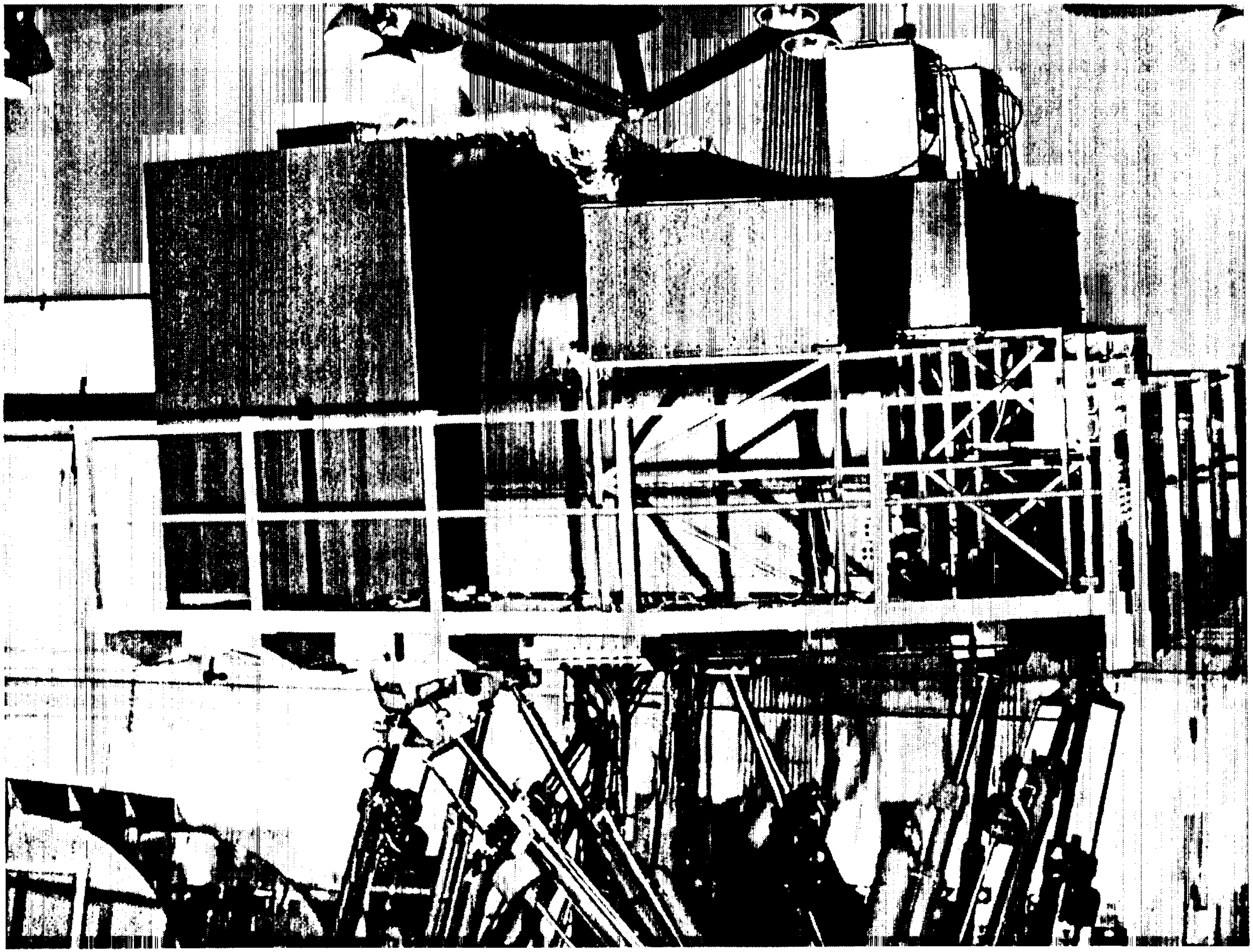


Figure 5. Coannular noise suppression for baseline and optional engines of reference 3. $M = 0.40$; Altitude = 4000 ft.



L-90-13717

Figure 6. Langley six-degree-of-freedom Visual/Motion Simulator.

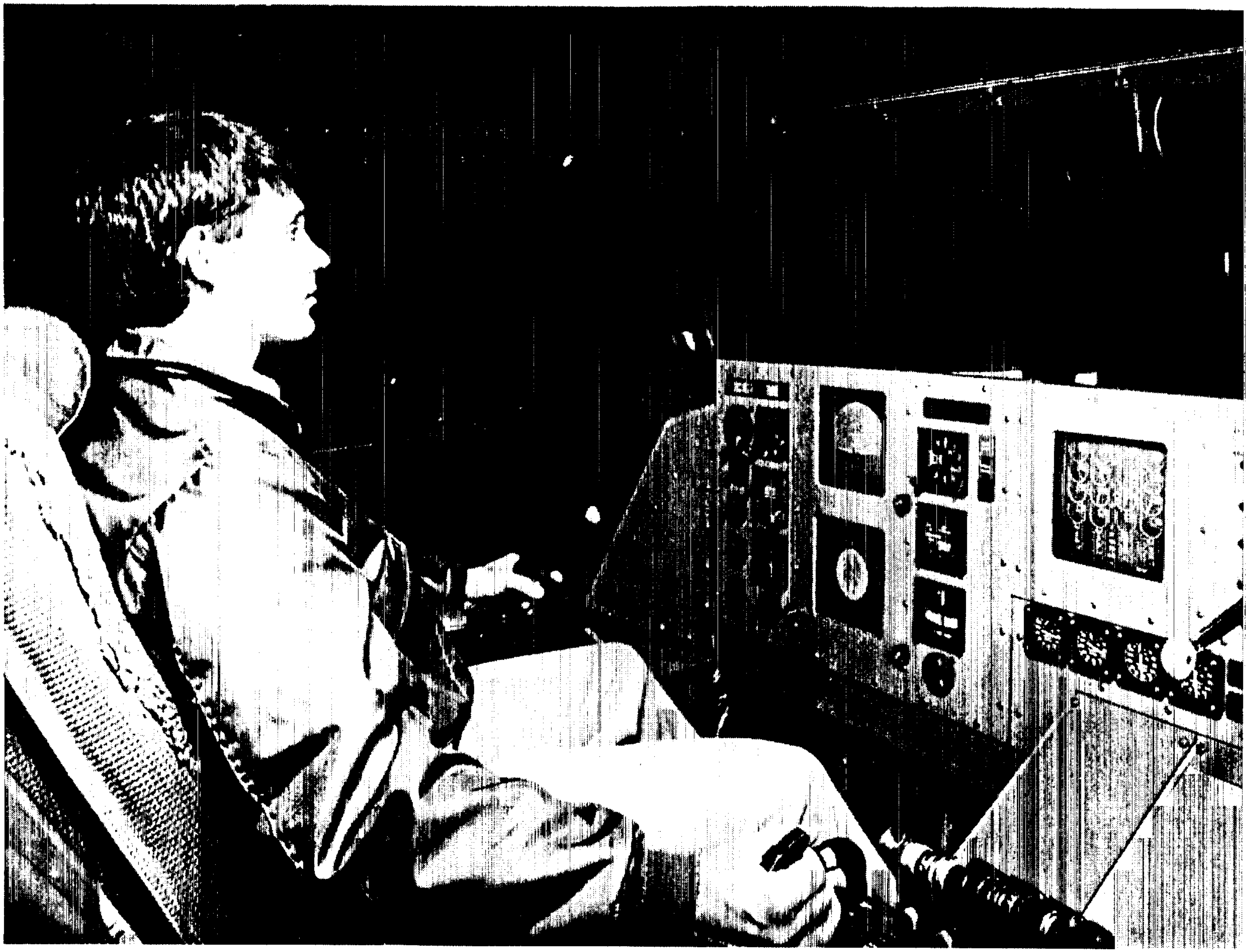


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Figure 7. Interior view of VMS cockpit simulator.

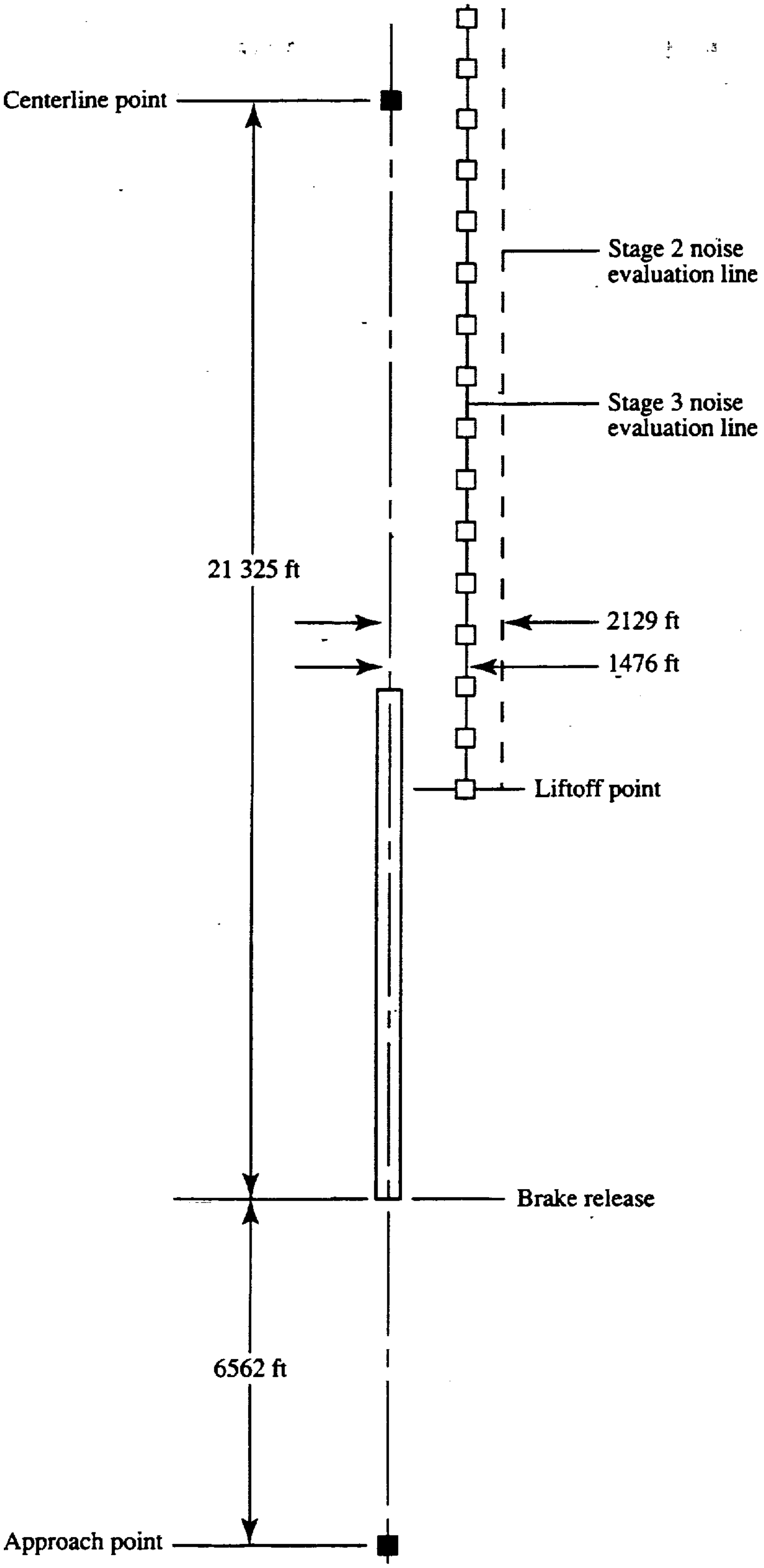

Figure 8. FAR Part 36 noise measurement system layout.

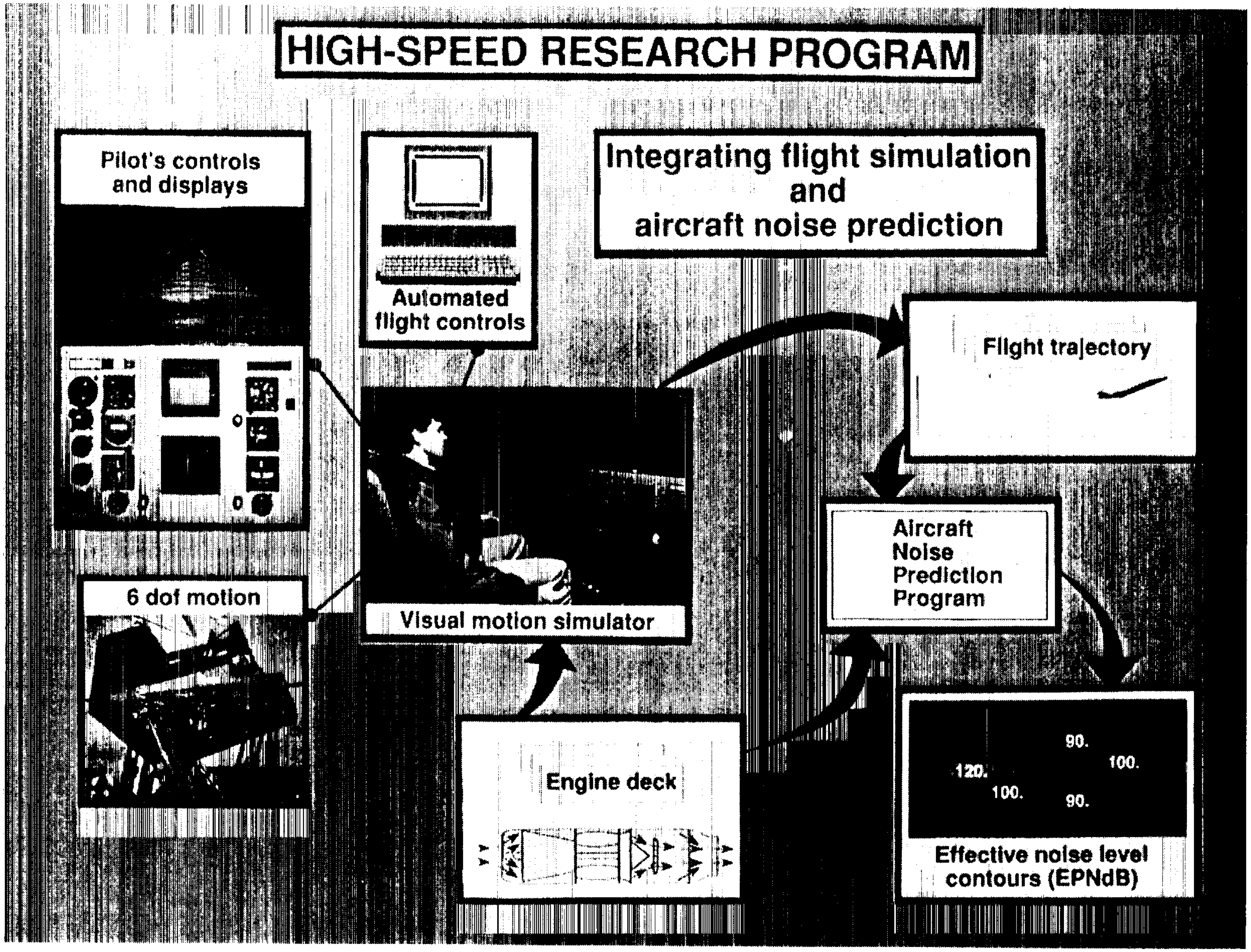

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Figure 9. Data flow pattern of VMS/ANOPP simulation.

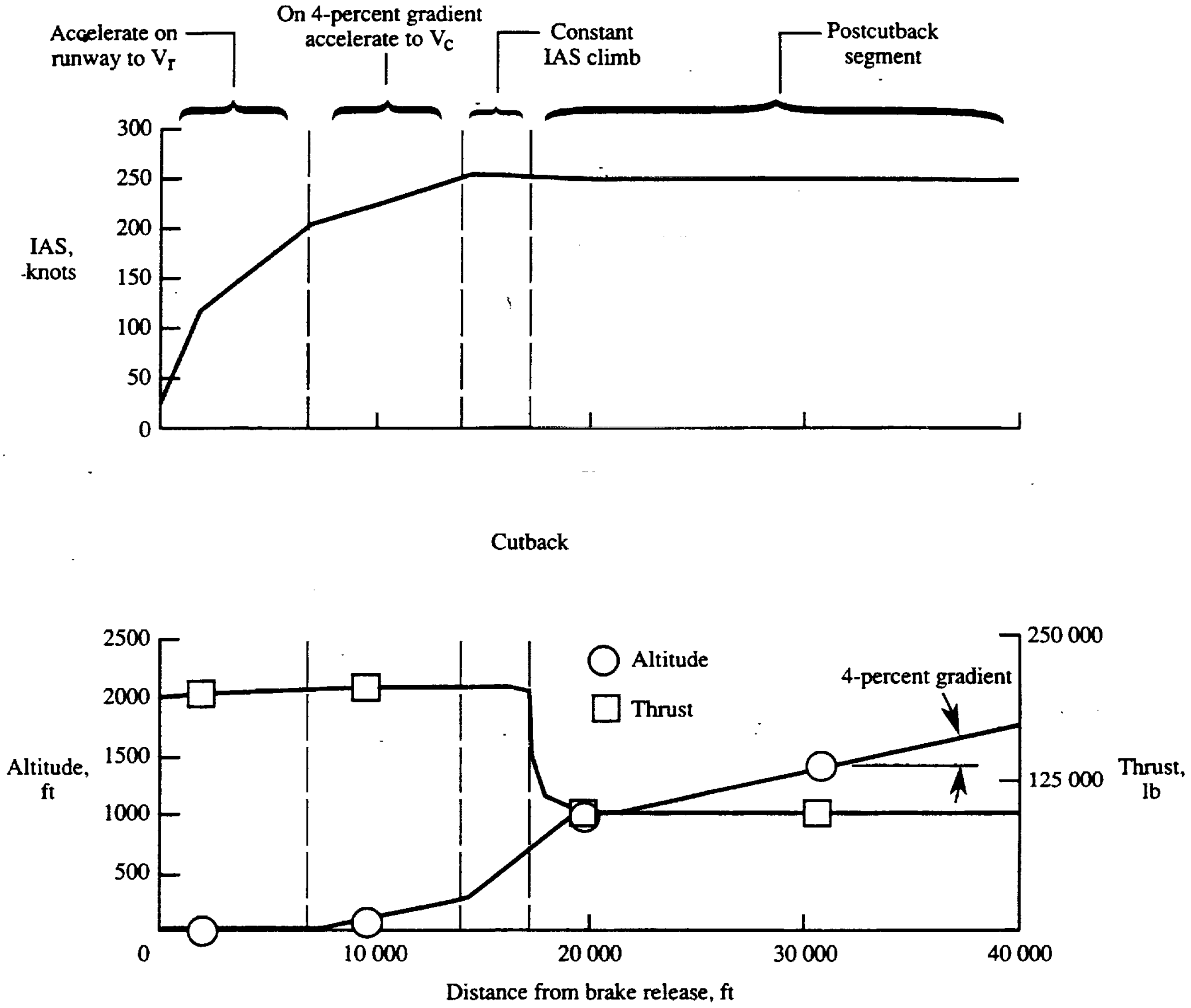


Figure 10. HSCT standard takeoff procedure.

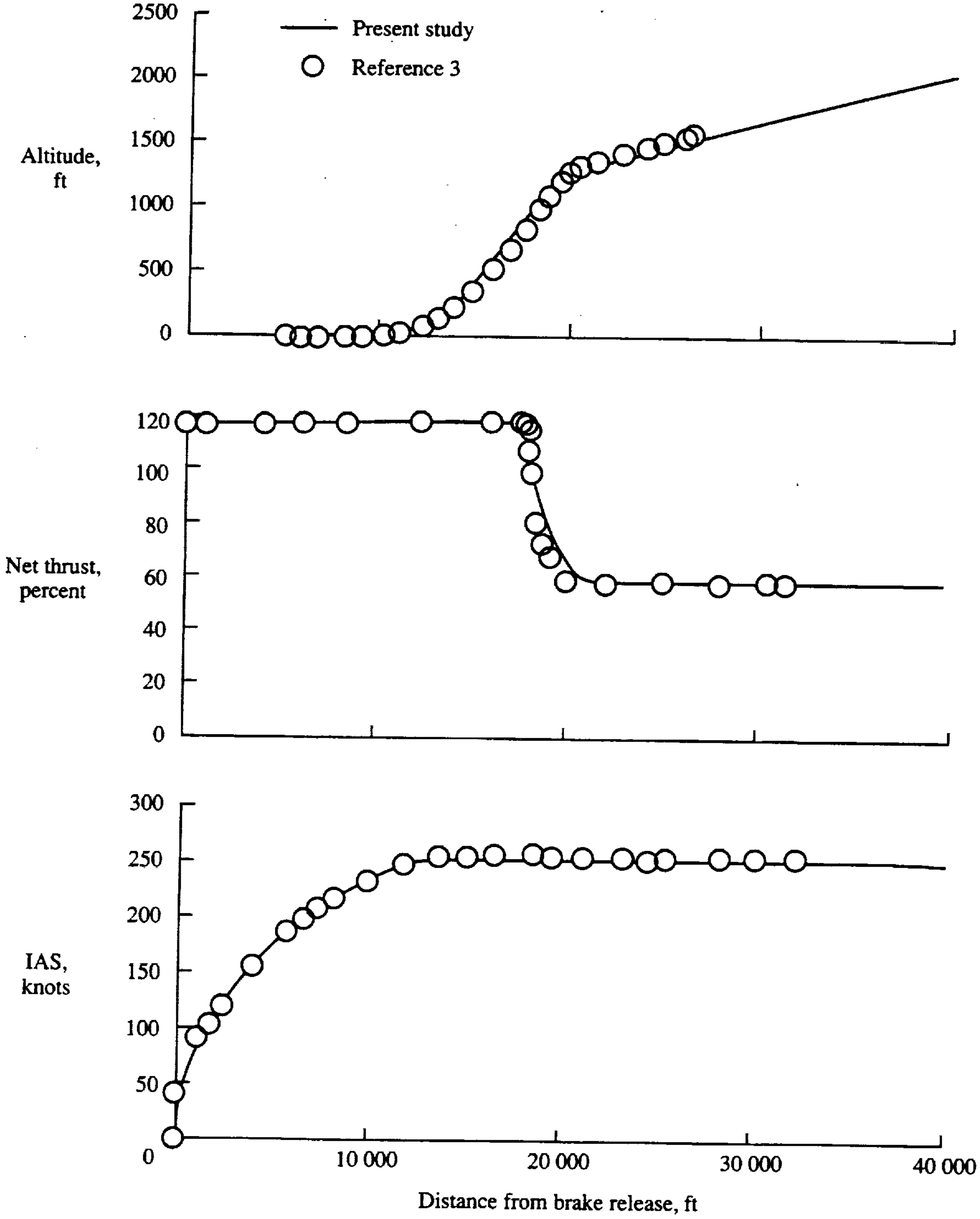
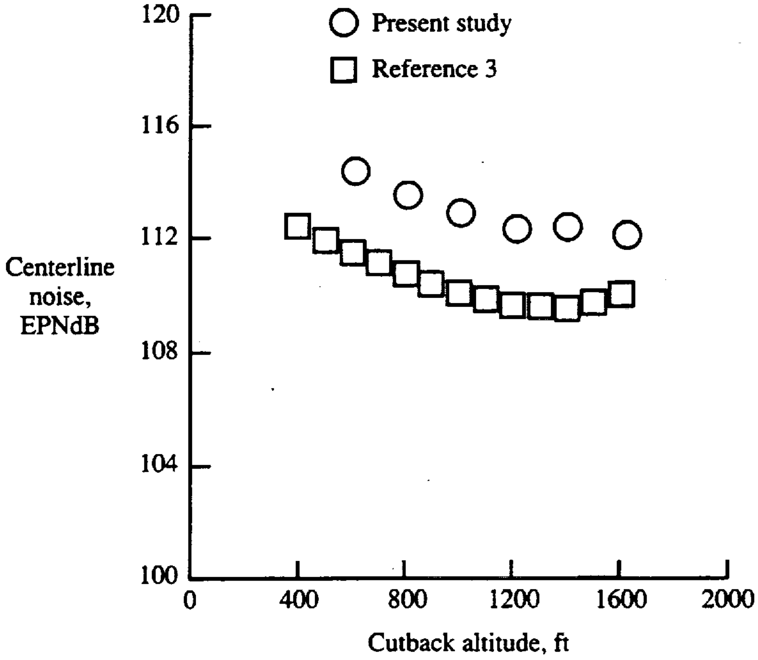
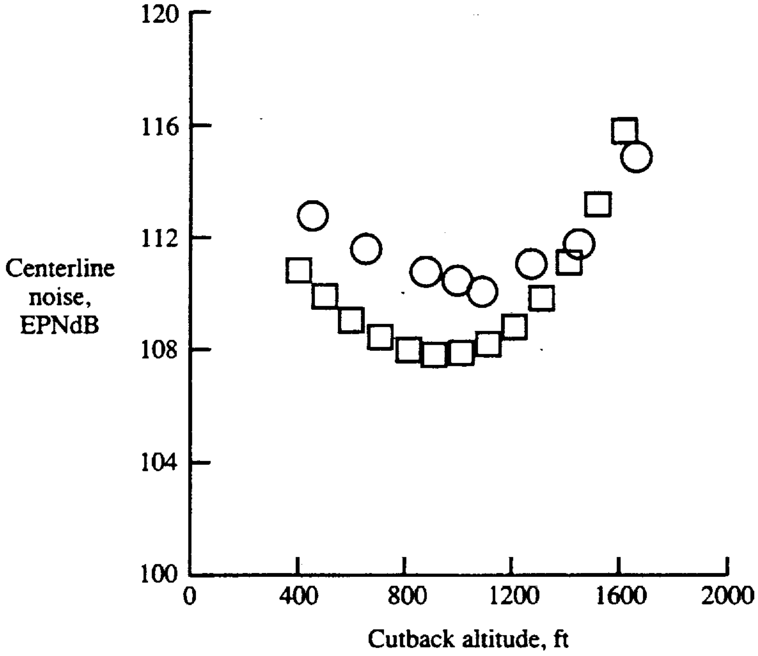


Figure 11. Evaluation of current trajectory results with reference 3 results.

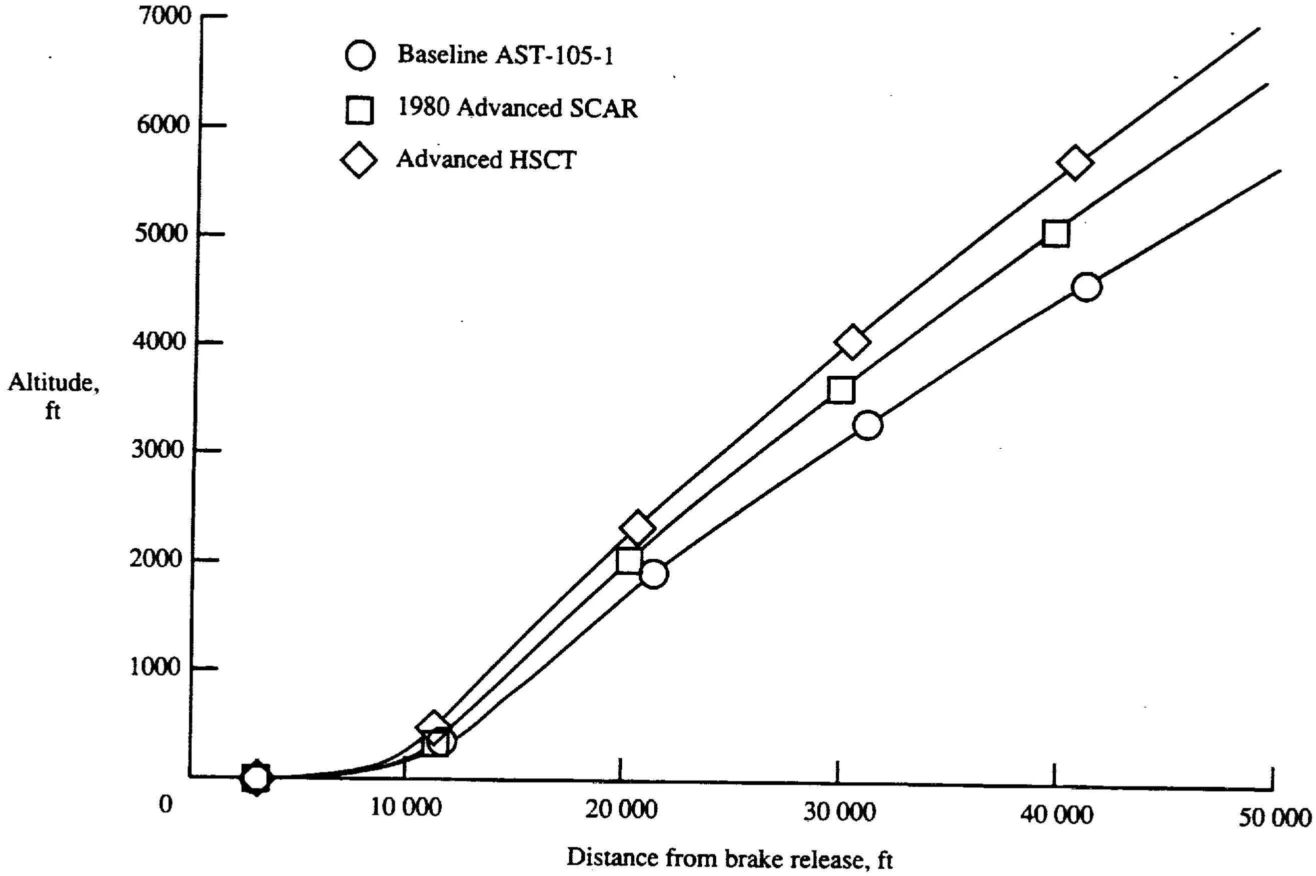


(a) $V_r = 172$ knots; $V_c = 211$ knots.



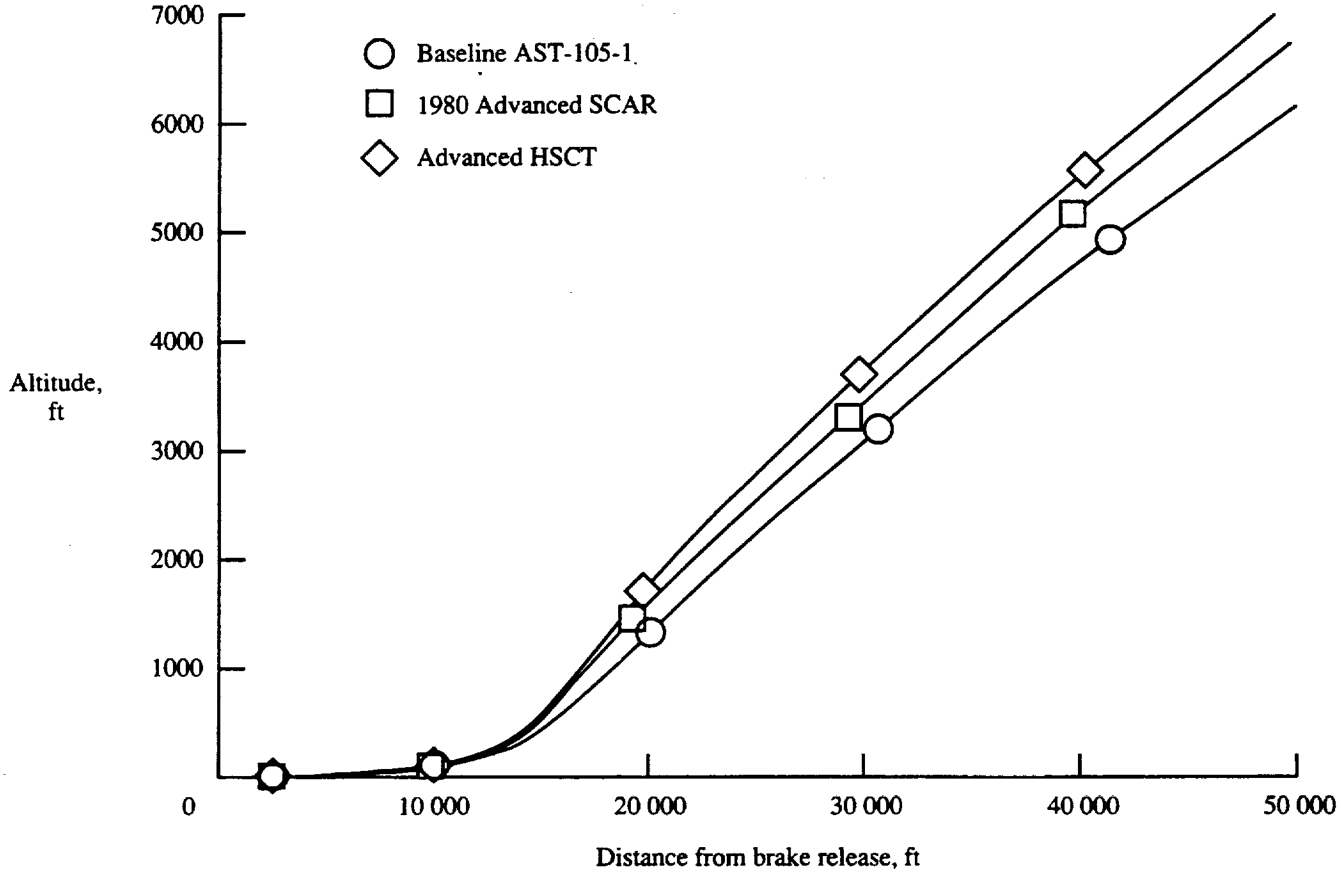
(b) $V_r = 200$ knots; $V_c = 250$ knots.

Figure 12. Evaluation of current ANOPP results with reference 3 results.



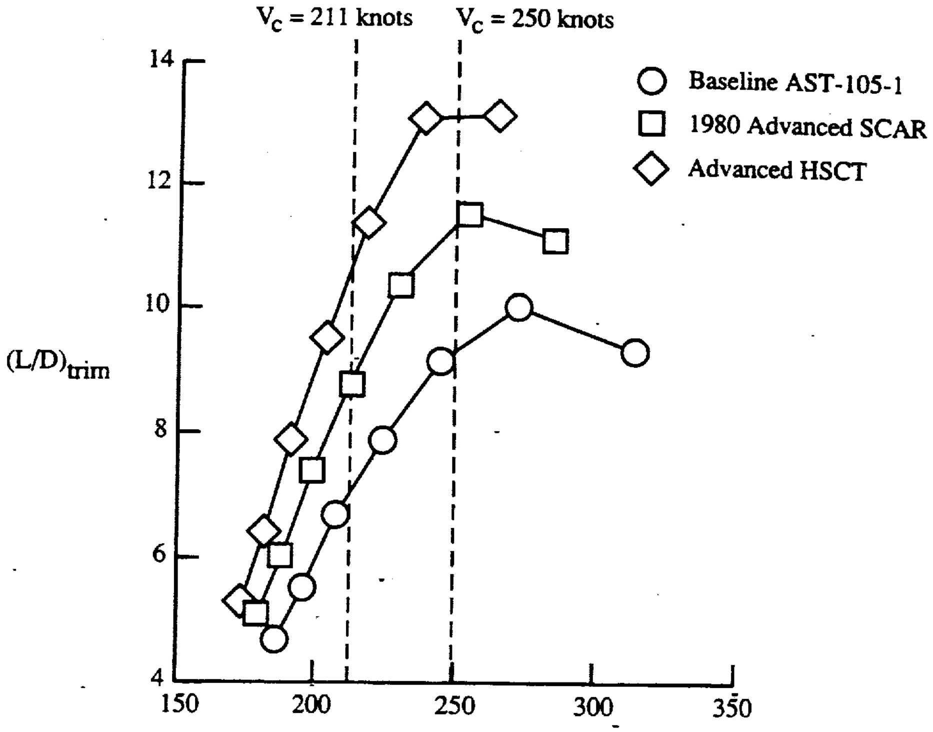
(a) $V_r = 172$ knots; $V_c = 211$ knots.

Figure 13. Effect of improved high-lift aerodynamic performance on constant thrust trajectories.

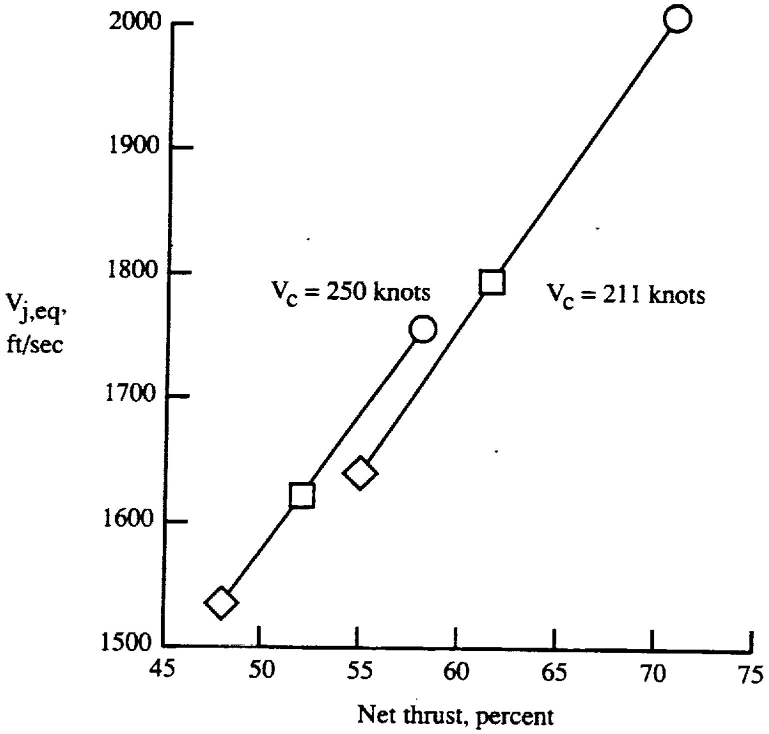


(b) $V_r = 200$ knots; $V_c = 250$ knots.

Figure 13. Concluded.

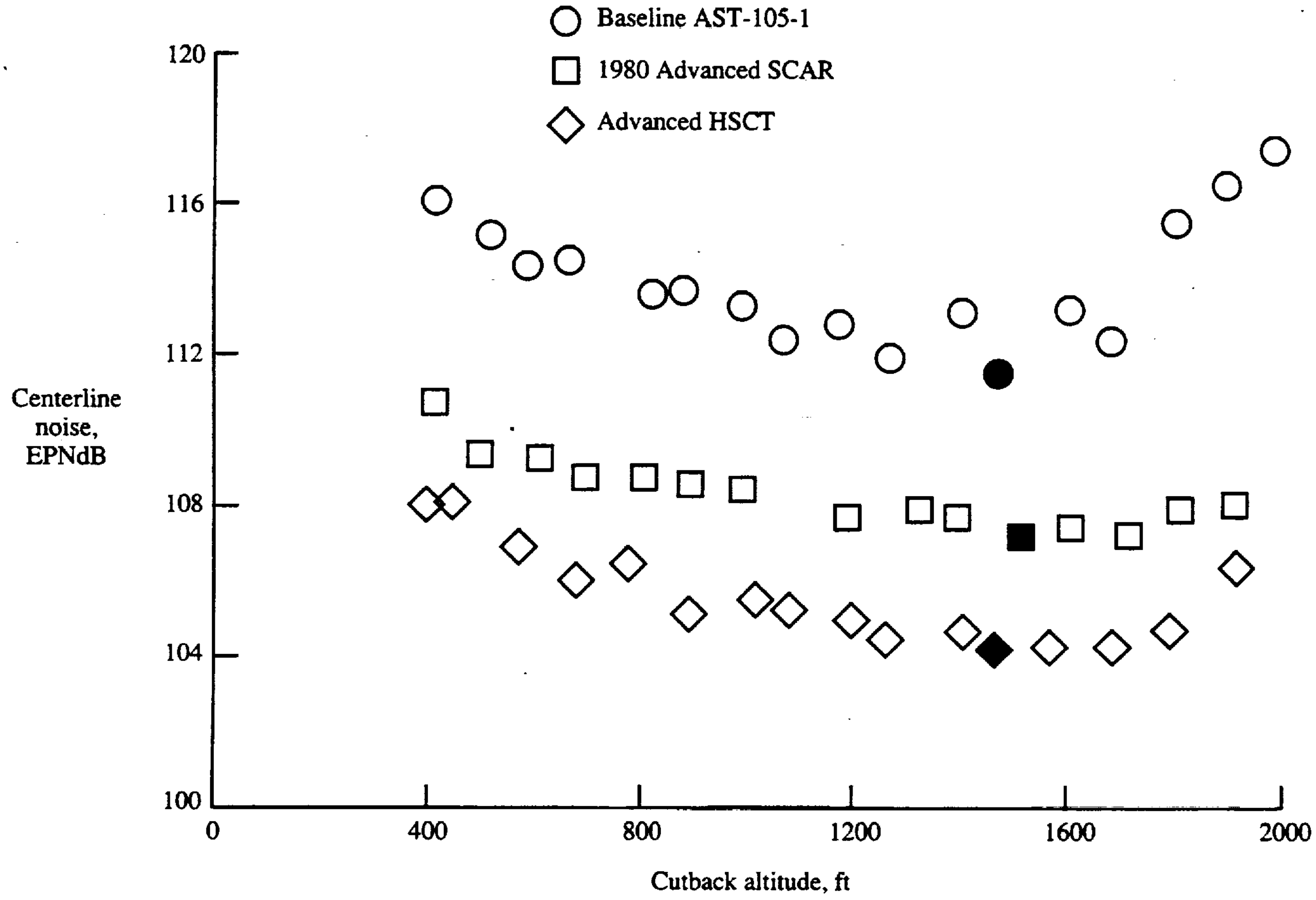


(a) L/D versus IAS.



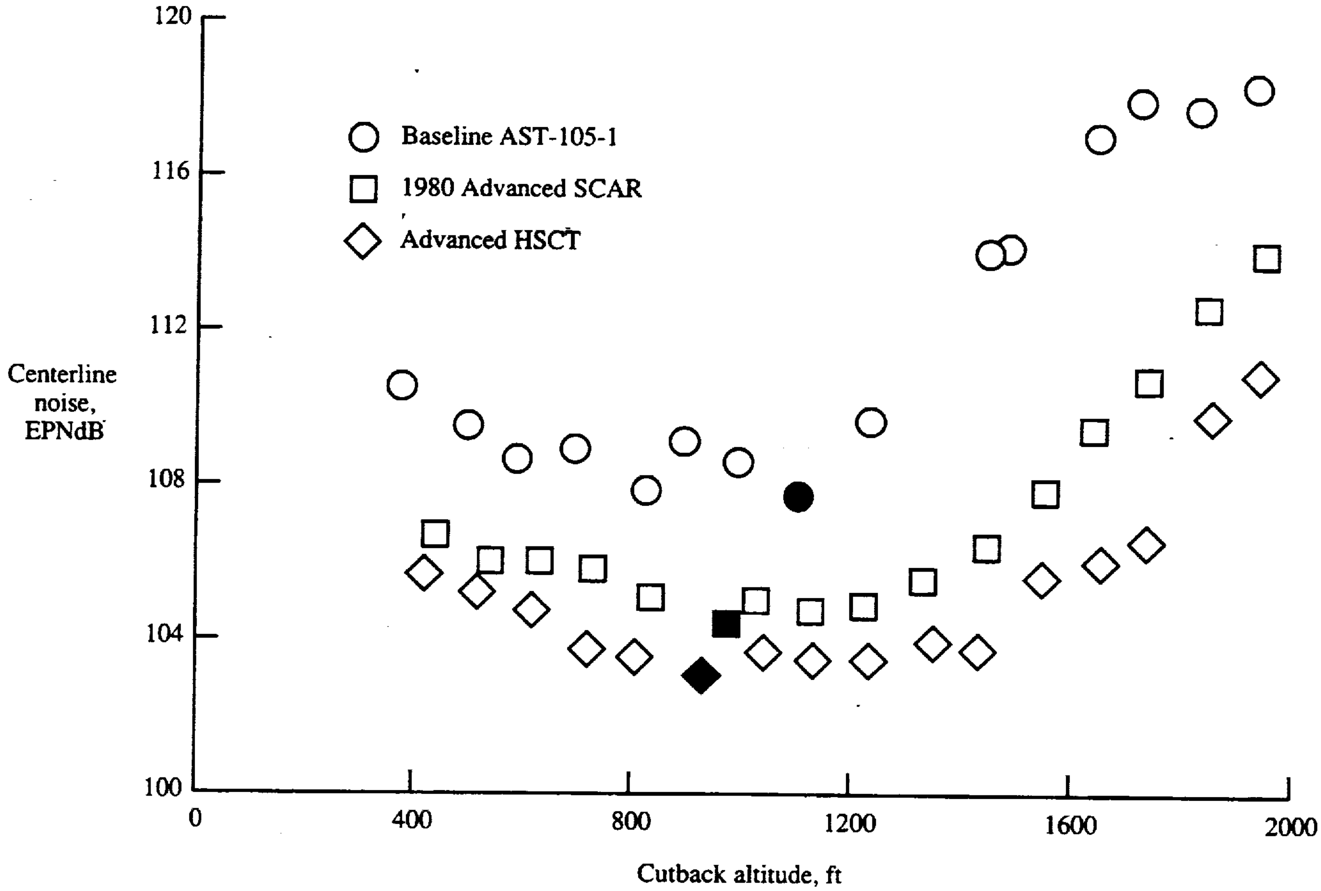
(b) Thrust required to maintain 4-percent climb gradient.

Figure 14. Effect of improved high-lift aerodynamic performance on equivalent exhaust jet velocity. Aircraft positioned out of ground effect.



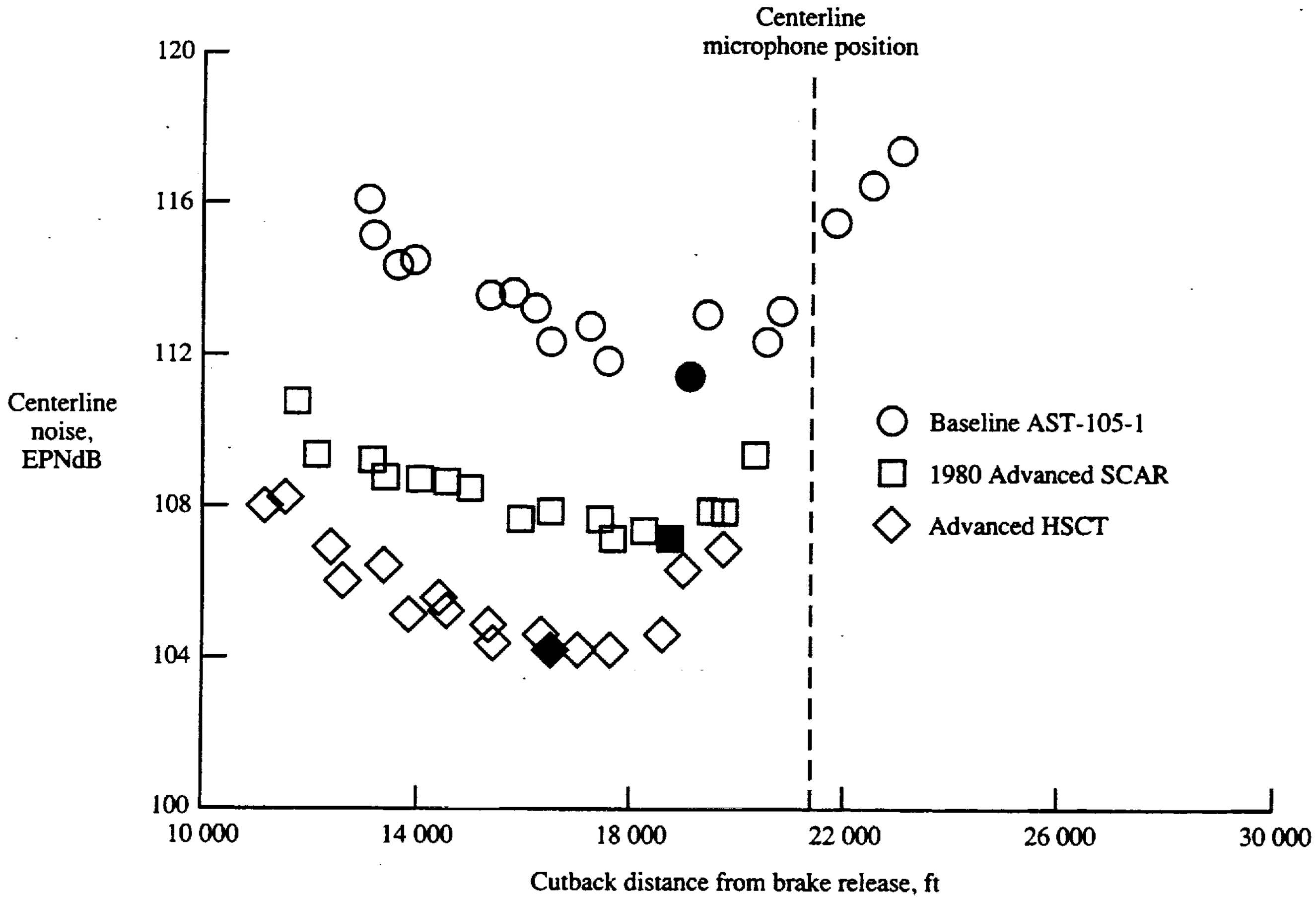
(a) $V_r = 172$ knots; $V_c = 211$ knots.

Figure 15. Effect of improved high-lift aerodynamic performance and cutback altitude on centerline noise during single thrust cutback procedures. Solid symbols indicate minimum centerline noise.



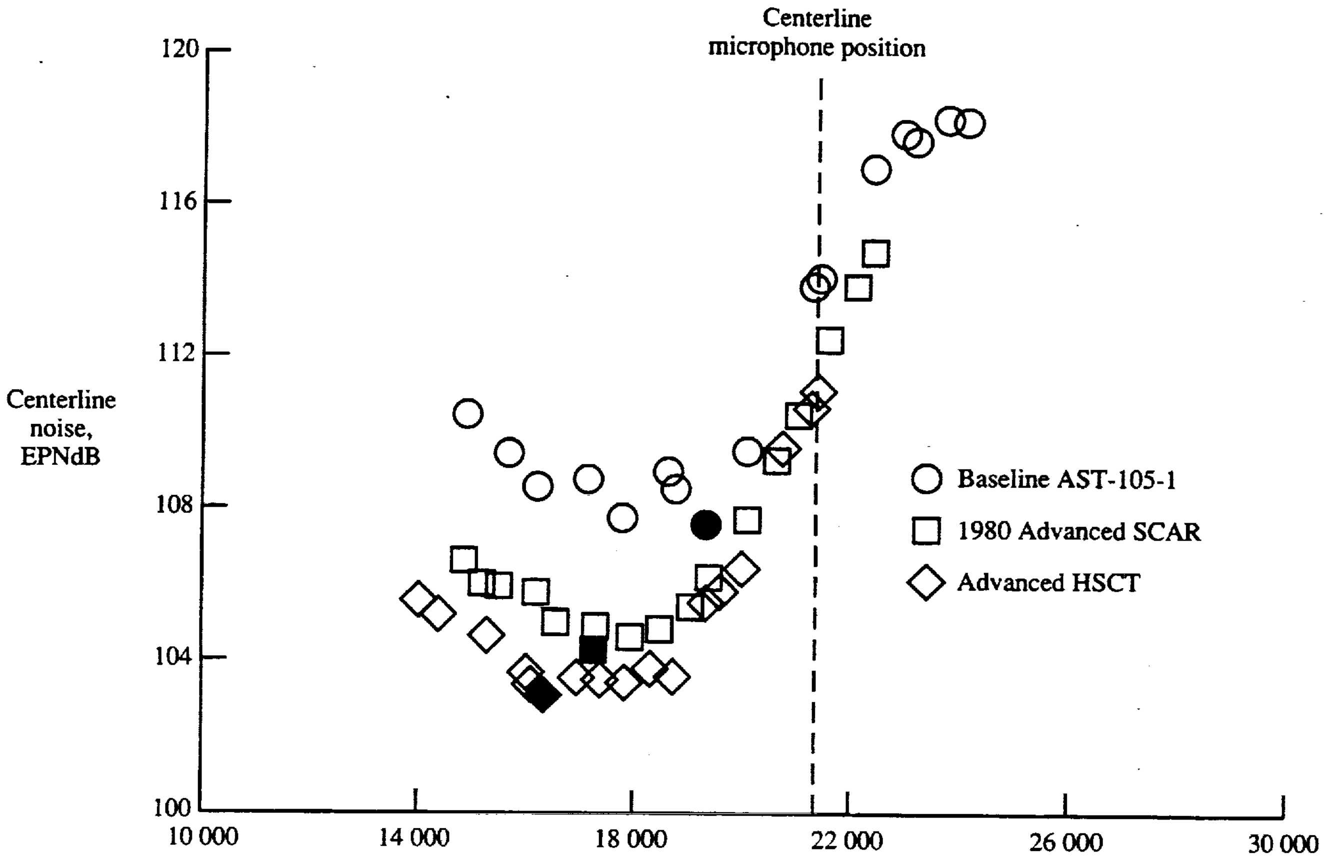
(b) $V_r = 200$ knots; $V_c = 250$ knots.

Figure 15. Concluded.



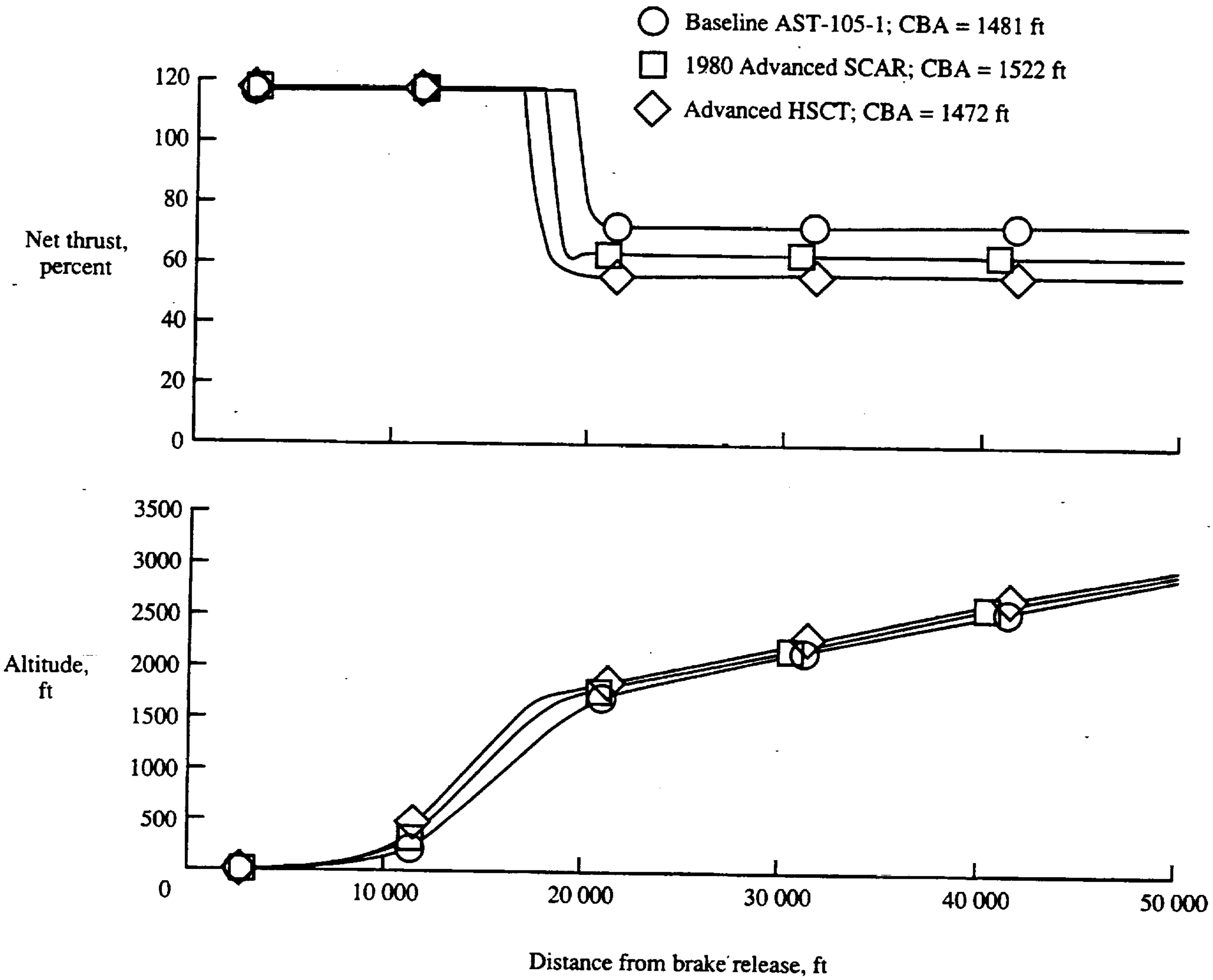
(a) $V_r = 172$ knots; $V_c = 211$ knots.

Figure 16. Effect of improved aerodynamic performance and cutback distance on centerline noise during single thrust cutback procedures. Solid symbols indicate minimum centerline noise.



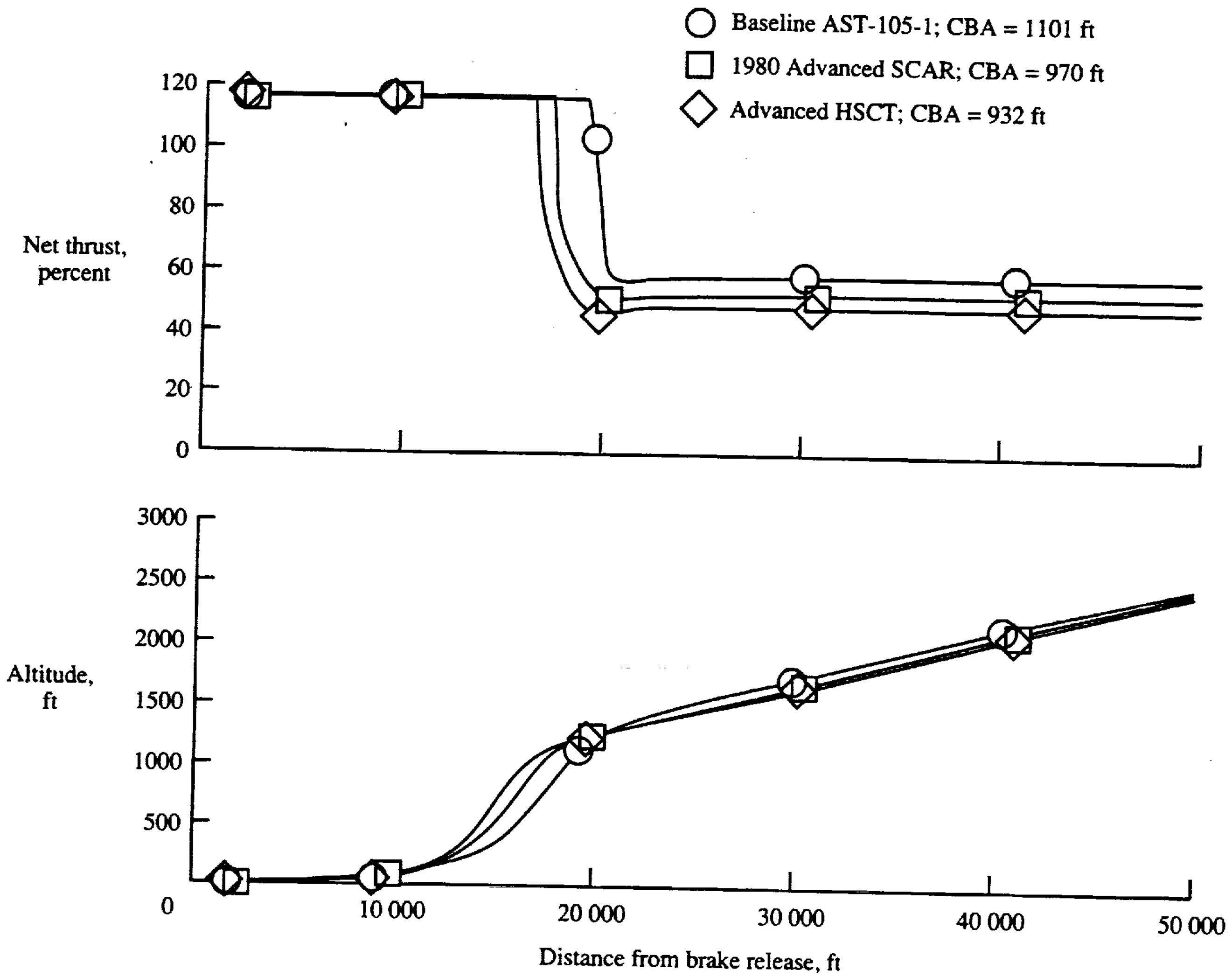
(b) V_r = 200 knots; V_c = 250 knots.

Figure 16. Concluded.



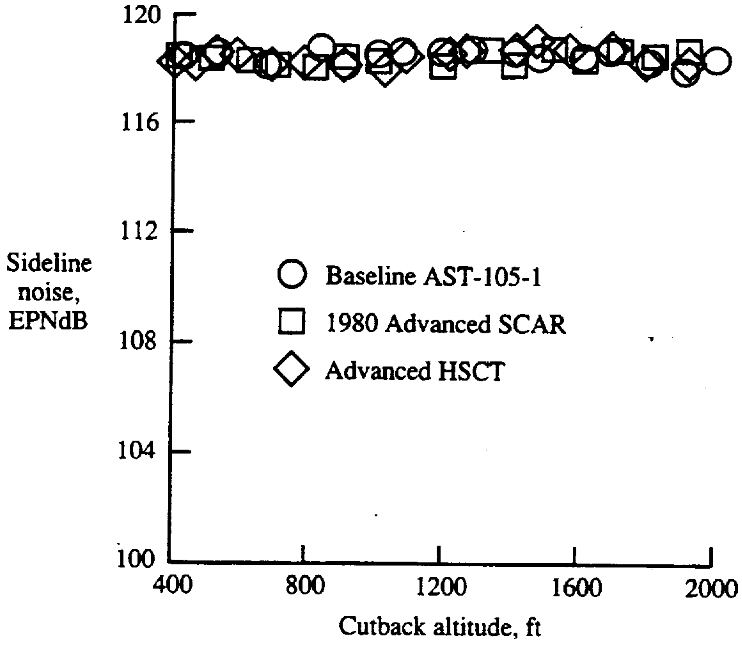
(a) V_r = 172 knots; V_c = 211 knots.

Figure 17. Effect of improved high-lift aerodynamic performance for single-cutback flight procedures. Minimum centerline noise trajectories.

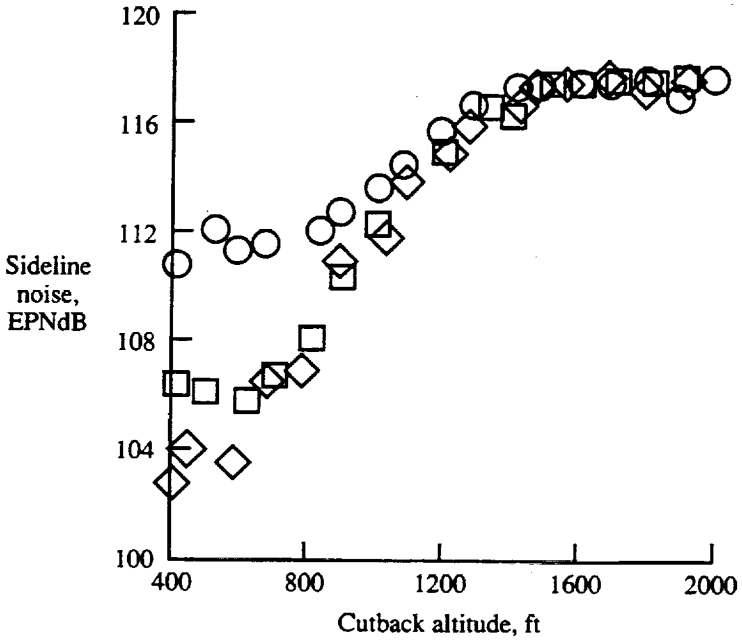


(b) V_r = 200 knots; V_c = 250 knots.

Figure 17. Concluded.



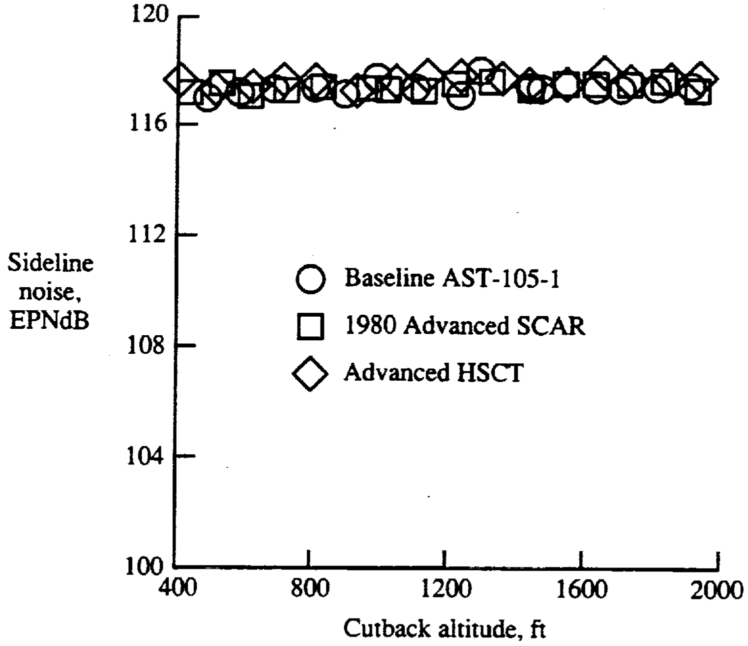
FAR Part 36 method



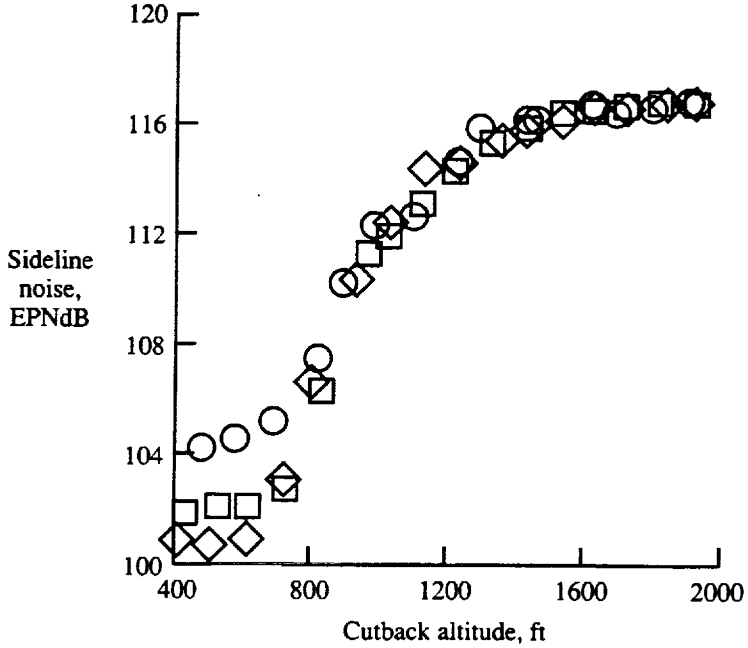
Alternate method

(a) $V_r = 172$ knots; $V_c = 211$ knots.

Figure 18. Effect of improved high-lift aerodynamic performance and cutback altitude on sideline noise during single thrust cutback procedures.



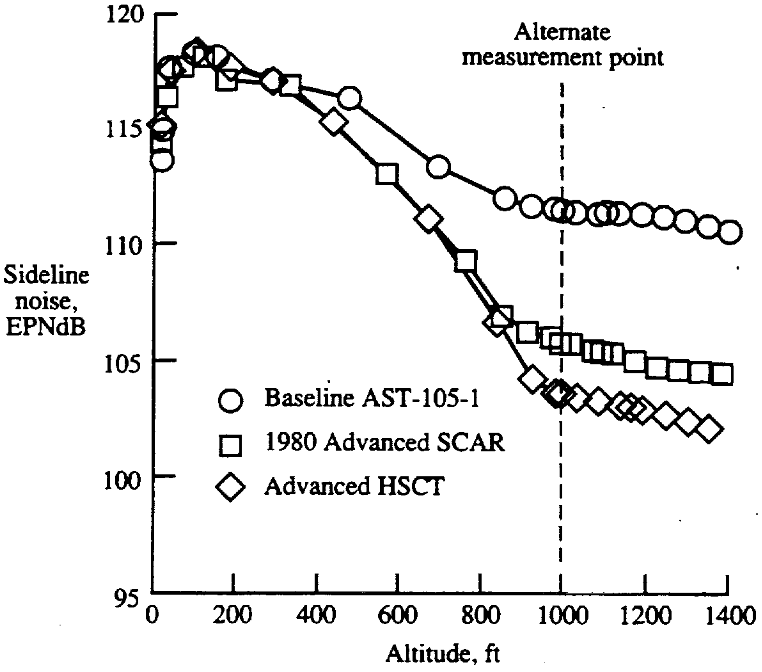
FAR Part 36 method



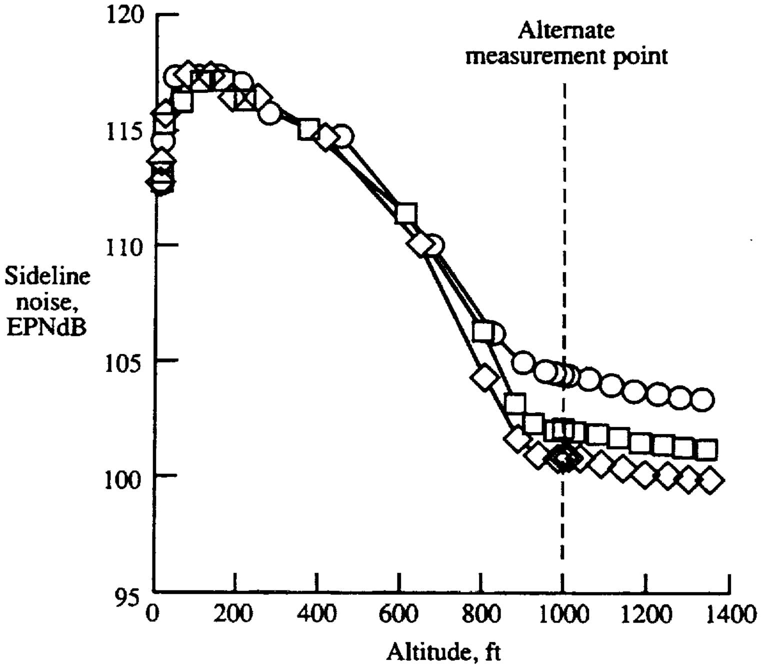
Alternate method

(b) $V_r = 200$ knots; $V_c = 250$ knots.

Figure 18. Concluded.



(a) $V_r = 172$ knots; $V_c = 211$ knots.



(b) $V_r = 200$ knots; $V_c = 250$ knots.

Figure 19. Effect of improved high-lift aerodynamic performance on sideline noise during single thrust cutback procedures. Cutback altitude ≈ 600 ft.

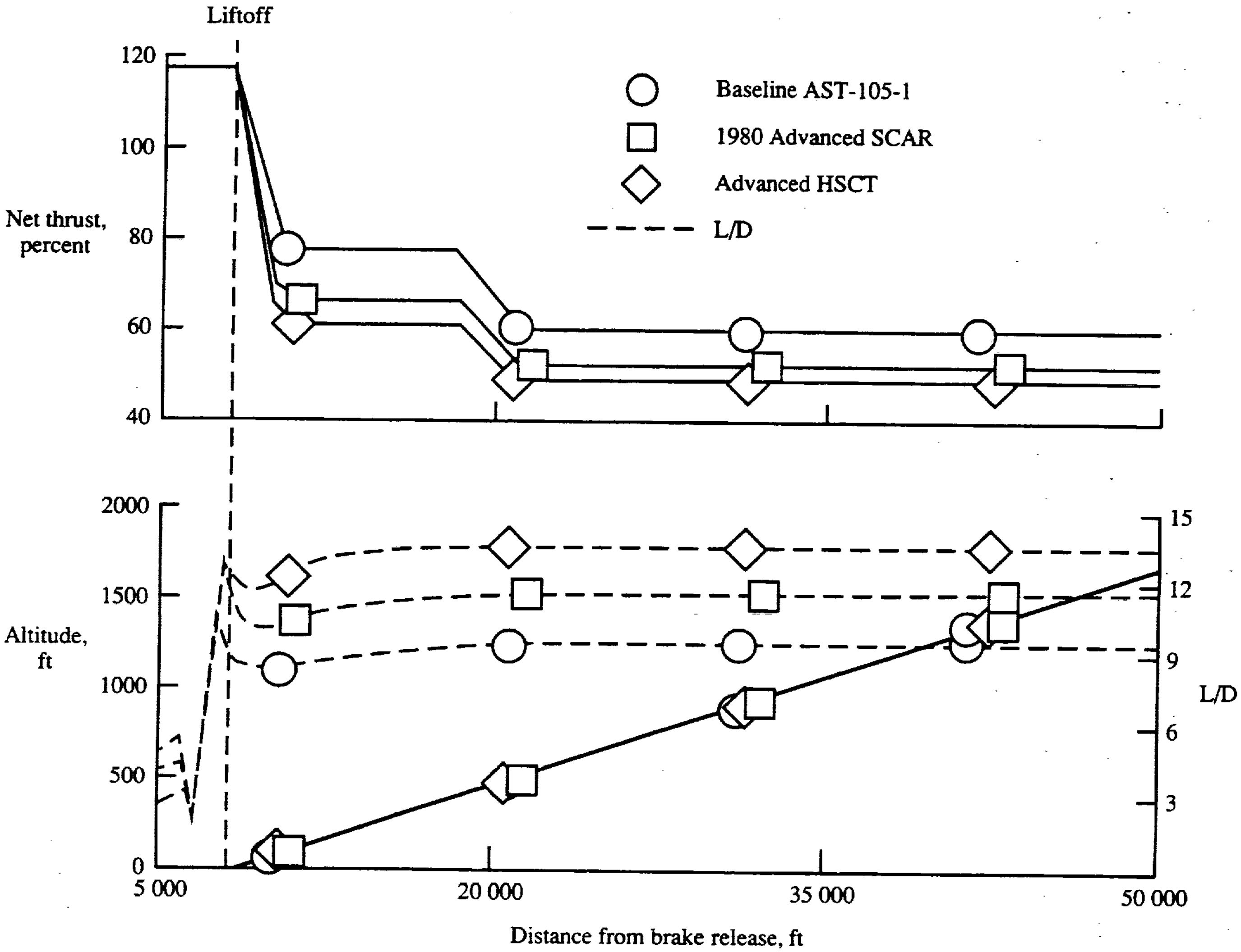


Figure 20. Effect of improved high-lift aerodynamic performance on multiple thrust cutback flight trajectories.

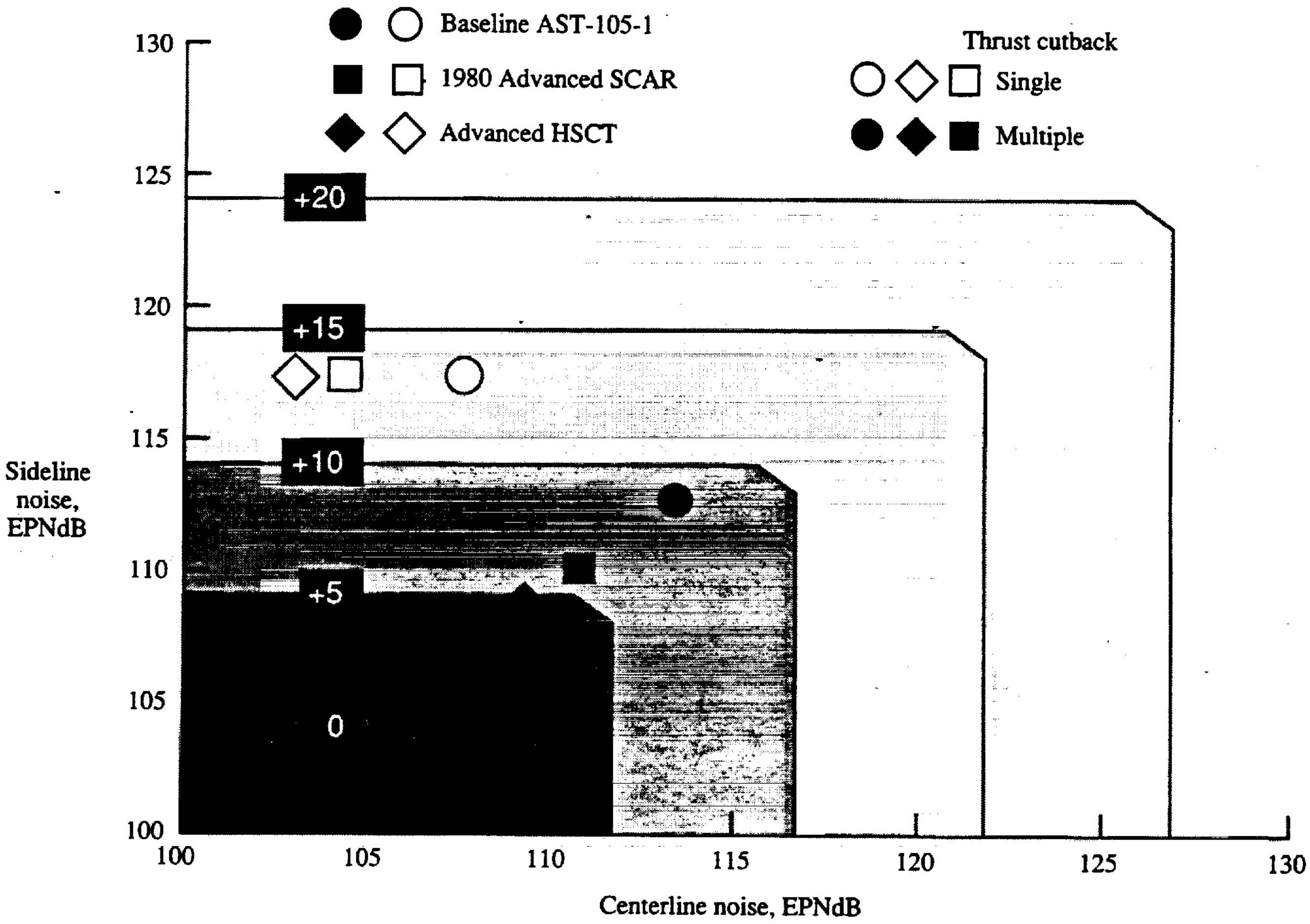
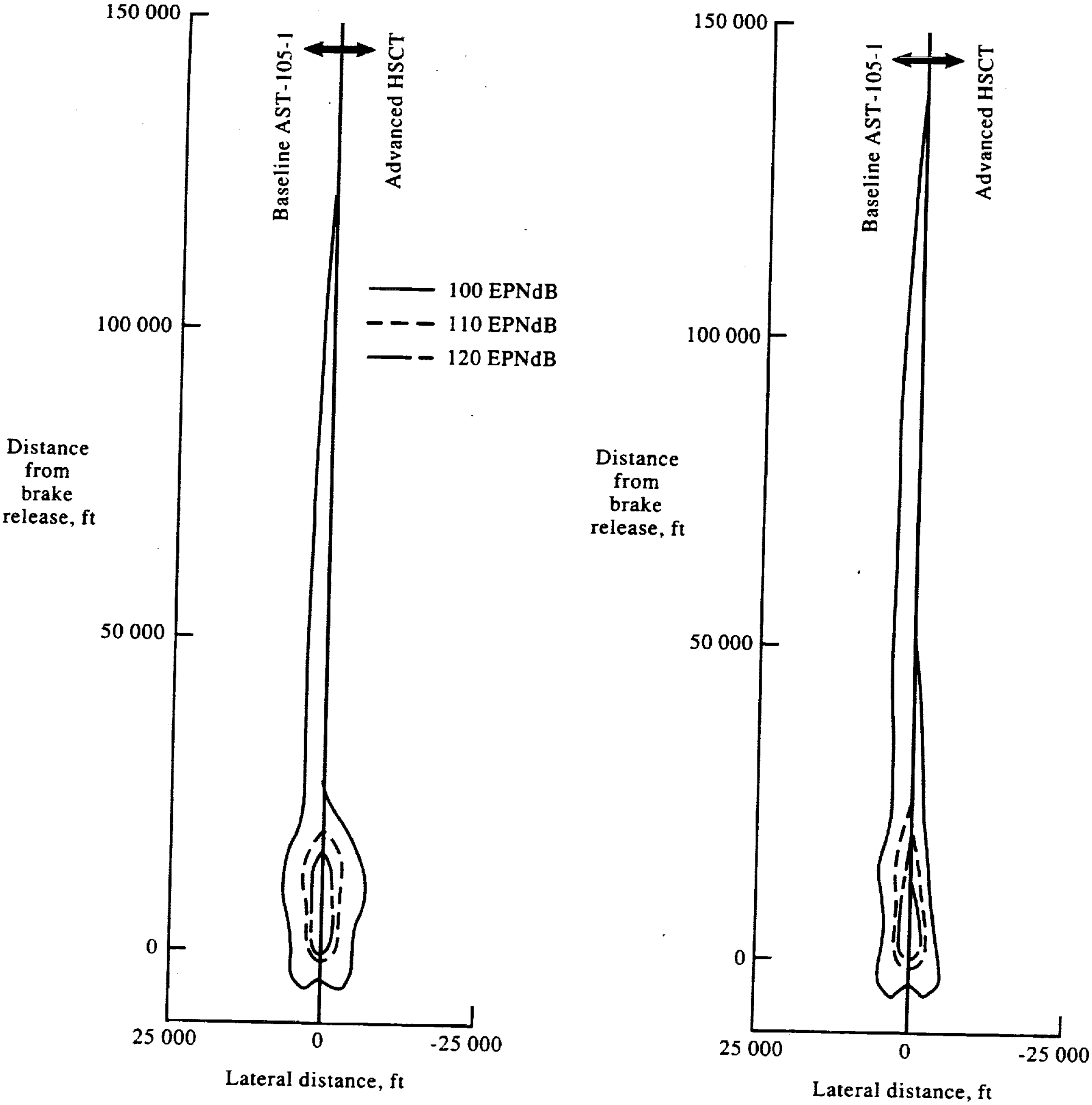


Figure 21. Effect of improved high-lift performance and thrust reduction scheme on the level of noise reduction required to meet FAA stage 3 requirements.



(a) Single thrust cutback.

(b) Multiple thrust cutback.

Figure 22. Effect of improved low-speed high-lift aerodynamic performance on ground noise contours.

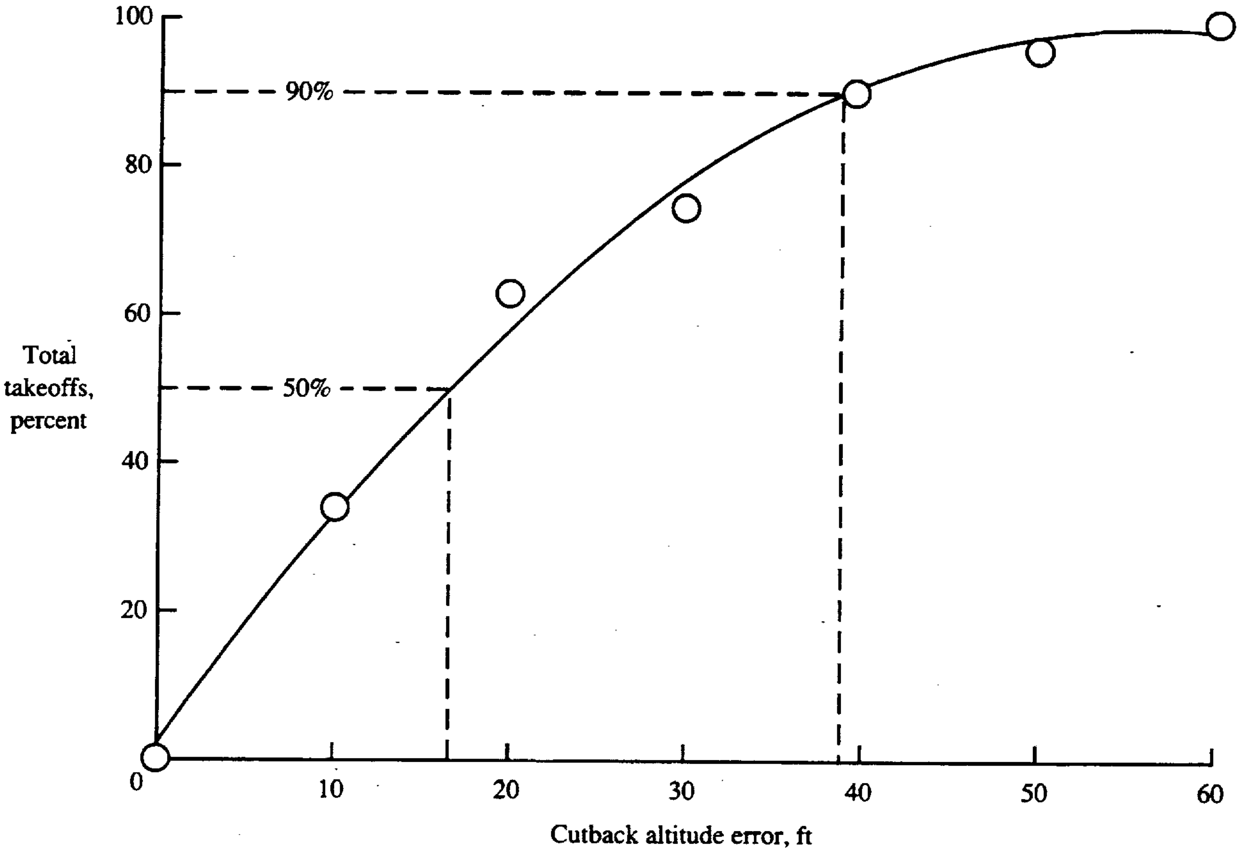


Figure 23. Cumulative frequency distribution for cutback altitude error for all single-cutback flights.

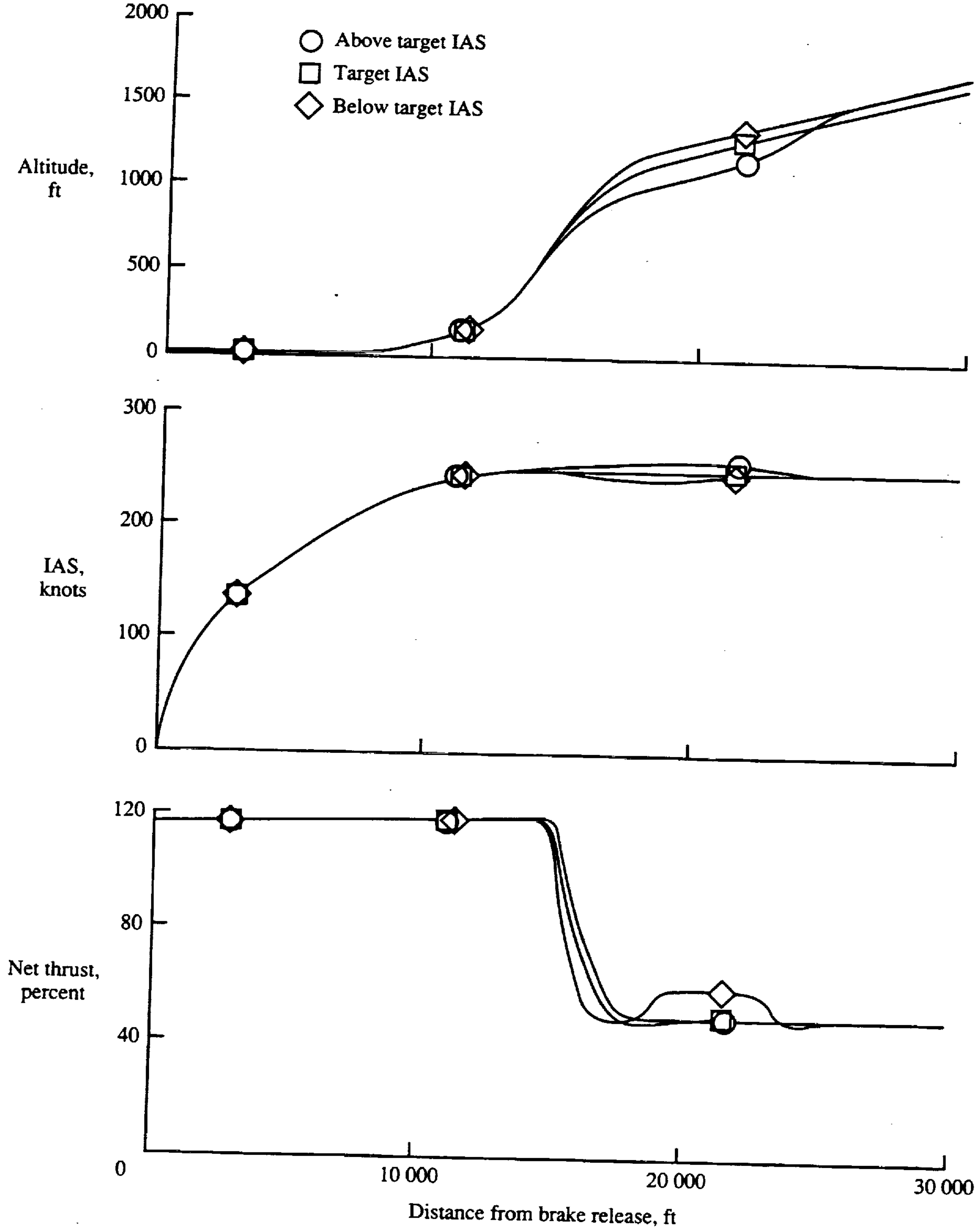


Figure 24. Effect of simulated miscoordination between pilot and copilot on trajectory, airspeed, and percent net thrust.

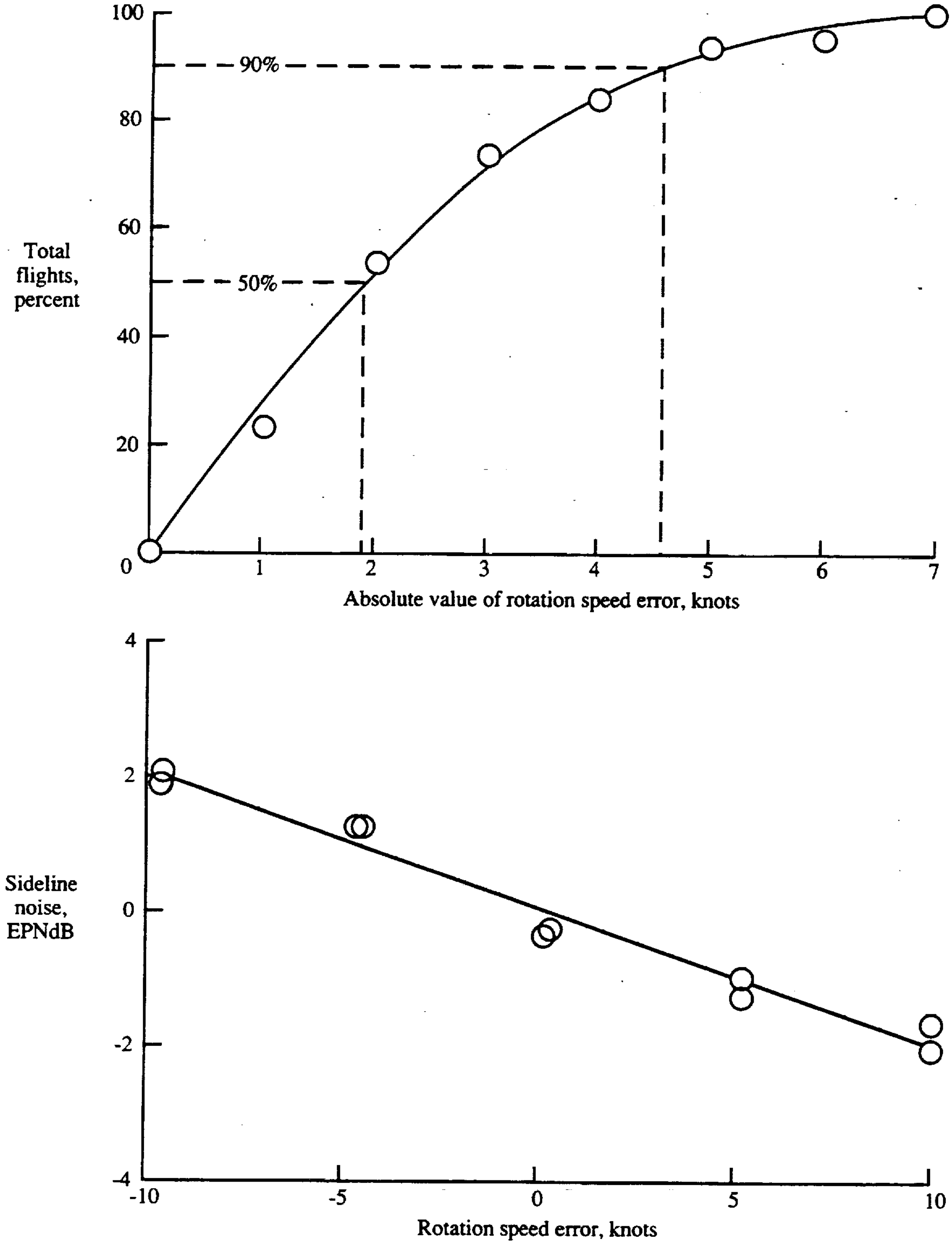
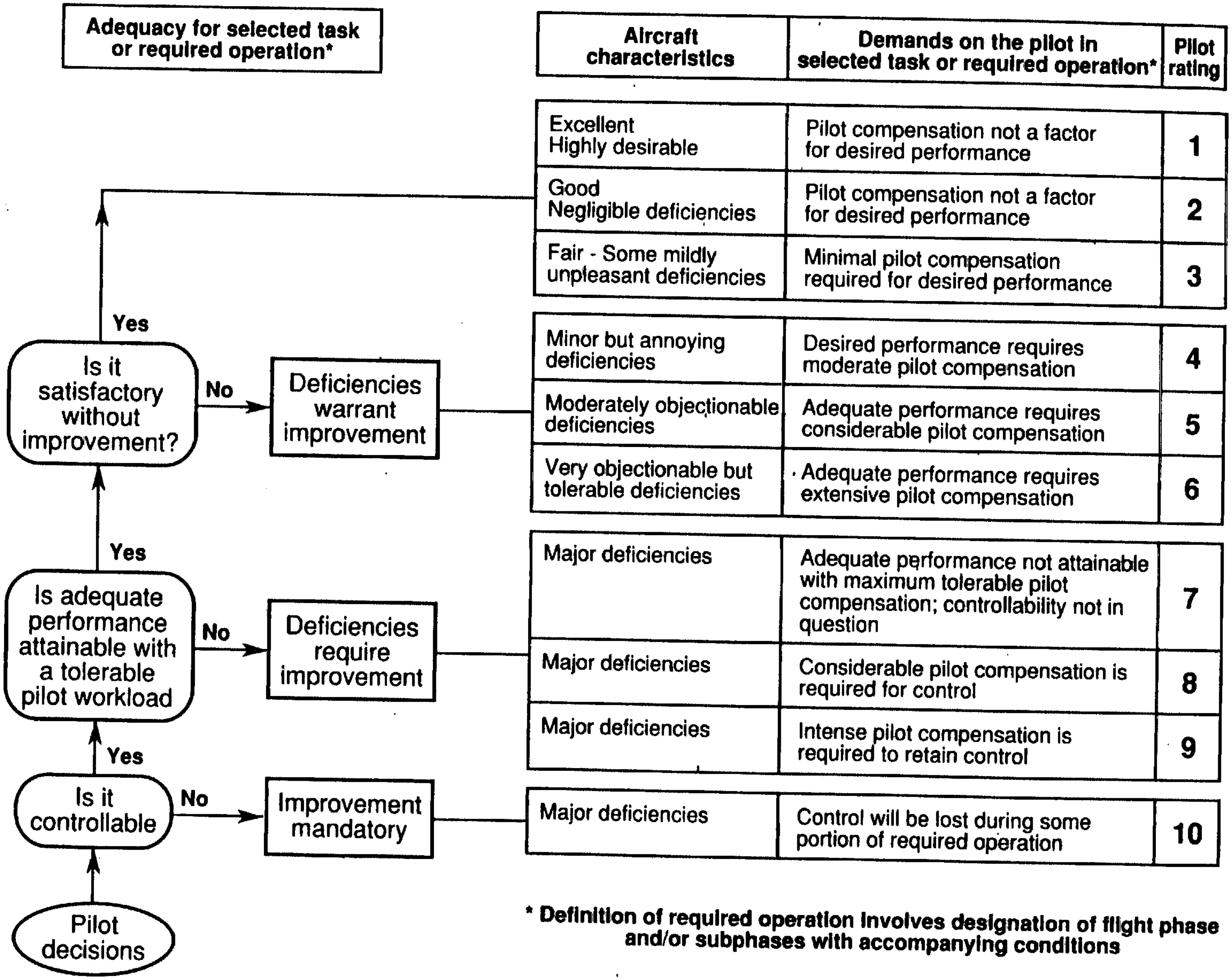


Figure 25. Cumulative frequency distribution for rotation speed error and sideline noise sensitivity to rotation speed error for advanced HSCT low-speed high-lift aerodynamics.



Aircraft characteristics	Demands on the pilot in selected task or required operation*	Pilot rating
Excellent Highly desirable	Pilot compensation not a factor for desired performance	1
Good Negligible deficiencies	Pilot compensation not a factor for desired performance	2
Fair - Some mildly unpleasant deficiencies	Minimal pilot compensation required for desired performance	3
Minor but annoying deficiencies	Desired performance requires moderate pilot compensation	4
Moderately objectionable deficiencies	Adequate performance requires considerable pilot compensation	5
Very objectionable but tolerable deficiencies	Adequate performance requires extensive pilot compensation	6
Major deficiencies	Adequate performance not attainable with maximum tolerable pilot compensation; controllability not in question	7
Major deficiencies	Considerable pilot compensation is required for control	8
Major deficiencies	Intense pilot compensation is required to retain control	9
Major deficiencies	Control will be lost during some portion of required operation	10

*** Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions**

Figure 26. Handling qualities rating scale.

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13. ABSTRACT *(Maximum 200 words)*

As part of an effort between NASA and private industry to reduce airport-community noise for high-speed civil transport (HSCT) concepts, a piloted simulation study was initiated for the purpose of predicting the noise reduction benefits that could result from improved low-speed high-lift aerodynamic performance for a typical HSCT configuration during takeoff and initial climb. Flight profile and engine information from the piloted simulation were coupled with the NASA Langley Aircraft Noise Prediction Program (ANOPP) to estimate jet engine noise and to propagate the resulting source noise to ground observer stations. A baseline aircraft configuration, which also incorporated different levels of projected improvements in low-speed high-lift aerodynamic performance, was simulated to investigate effects of increased lift and lift-to-drag ratio on takeoff noise levels. Simulated takeoff flights were performed with the pilots following a specified procedure in which either a single thrust cutback was performed at selected altitudes ranging from 400 to 2000 ft, or a multiple-cutback procedure was performed where thrust was reduced by a two-step process. Results show that improved low-speed high-lift aerodynamic performance provides at least a 4 to 6 dB reduction in effective perceived noise level at the FAA downrange flyover measurement station for either cutback procedure. However, improved low-speed high-lift aerodynamic performance reduced maximum sideline noise levels only when using the multiple-cutback procedures.

14. SUBJECT TERMS
HSCT; Airport-community noise; High lift; ANOPP; Piloted simulation

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