DEVELOPMENT OF SCR AIRCRAFT TAKEOFF AND LANDING PROCEDURES FOR COMMUNITY NOISE ABATEMENT AND THEIR IMPACT ON FLIGHT SAFETY

William D. Grantham
NASA Langley Research Center

Paul M. Smith
Kentron International Incorporated
Hampton Technical Center

SUMMARY

Piloted simulator studies have been conducted to determine takeoff and landing procedures for a supersonic cruise transport concept that result in predicted community noise levels which meet current Federal Aviation Administration (FAA) standards.

The results of the study indicate that with the use of advanced procedures, the subject simulated aircraft meets the FAA traded noise levels during takeoff and landing utilizing average flight crew skills. The advanced takeoff procedures developed involved violating three (3) of the current Federal Aviation Regulations (FAR) noise test conditions. These were: (a) thrust cutbacks at altitudes below 214 meters (700 ft); (b) thrust cutback level below those presently allowed; and (c) configuration change, other than raising the landing gear. It was not necessary to violate any FAR noise test conditions during landing approach.

It was determined that the advanced procedures developed in this study do not compromise flight safety.

Automation of some of the aircraft functions reduced pilot workload, and the development of a simple head-up display to assist in the takeoff flight mode proved to be adequate.

INTRODUCTION

Since 1972, the Langley Research Center of the NASA has been working in advanced supersonic technology for potential application to future U. S. transport aircraft. Among the significant advances which have been made during this period is the development of a new engine concept that is a duct burning turbofan variable stream control engine (VSCE) which has the potential to be operated in such a manner as to create less jet noise than conventional turbojets during takeoff and landing — the improvement being attributed to coannular nozzle jet noise relief.

Current Federal Aviation Regulations (FAR's) for subsonic transport aircraft specify takeoff and landing "piloting" procedures for noise measurement, requiring constant flight speed and no configuration changes (except the landing gear may be retracted after liftoff). It should be considered, however, that a supersonic transport with VSCE engines will have airframe-engine characteristics that are different from the present-day subsonic jet transports, and if utilized properly, could significantly reduce community noise during takeoff and landing. Under the NASA Supersonic Cruise Research program, advanced noise abatement procedures have been identified requiring modifications to the current FAR's for use with future supersonic transports.

Noise characteristics of a typical supersonic cruise research (SCR) concept, designated the AST-105-1, during takeoff and landing were calculated at the three measuring stations prescribed in Ref. 1, and the results are reported in Ref. 2. Although the results of Ref. 2 indicated that the use of advanced operating procedures could be an important additional method for noise reduction, the preliminary procedures reported therein were insufficient to meet the noise requirements of Ref. 1 for takeoff noise (both flyover and sideline), and it was therefore suggested that more detailed studies were required to identify the "optimum" procedures.

The preceived noise level limits dictated by Ref. 1 for an airplane of the class of the subject SCR concept is 108 EPNdB for flyover, sideline, and approach. Although the approach noise for the AST-105-1 was calculated to be 106.6 EPNdB using standard procedures and therefore met the 108 EPNdB requirement, Ref. 2 showed that by using advanced procedures for flying the landing approach, such as steep-decelerating approaches, the calculated approach noise could be reduced below 100 EPNdB. The advanced procedure used in Ref. 2 in an attempt to reduce the flyover and sideline noise during takeoff resulted in a decrease in flyover noise from 115.8 to 113.2 EPNdB, and resulted in an increase in the sideline noise from 113.8 to 115.3 EPNdB — both obviously still much too high to meet the 108 EPNdB requirements even if the noise level "tradeoffs" of Ref. 1 were exercised. [The noise standards, Ref. 1, allow tradeoffs between the measured approach, sideline, and flyover noise levels if: (1) the sum of exceedance is not greater than 3 EPNdB; (2) no exceedance is greater than

2 EPNdB; and (3) the exceedances are completely offset by reductions at other required measuring points.]

This piloted simulation study was therefore conducted using the AST-105-1 SCR concept in an attempt to determine:

1. Advanced takeoff and landing procedures for which the noise level requirements of Ref. 1 could be met.

2. If a pilot with average skills could perform the task of flying the suggested profiles without compromising flight safety.

3. The degree of automation required.

4. The pilot information displays required.

SYMBOLS AND DEFINITIONS

Values are given in both the International System of Units (SI) and U. S. Customary Units. The measurements and calculations were made in U. S. Customary Units. Dots over symbols denote differentiation with respect to time.

AK_V	gain on airspeed error
GK_I	integrator gain
$G_{(ENG)}$	acceleration and deceleration engine inverse time constants, per second
h	altitude, m (ft)
K	gain
M	Mach number
s	Laplace operator
t_1	deceleration time, sec
T	thrust, N (lbf)
T_G	gross thrust
V	airspeed, knots (ft/sec)
V_1	decision speed (engine failure speed + ΔV for a 2-sec reaction time), knots

V_2	airspeed of aircraft at obstacle, knots
V_C	climb speed, knots
V_R	rotate airspeed, knots
V'_R	reference airspeed, knots
V_{RI}	desired airspeed upon completion of deceleration, knots
W	airplane weight, N (lbf)
X	distance from brake release, m (ft)
α	angle of attack, deg
δ_f	trailing-edge flap deflection, deg
δ_{SB}	speed brake deflection, deg
ε	error
γ	flight-path angle, deg
ϕ	angle of roll, deg
ψ	heading angle, deg
τ	time constant, sec
τ_B	pitch attitude bias time constant, sec
Θ	pitch attitude, deg

Subscripts:

C	commanded
FI	flight idle
IAS	indicated airspeed
IC	initial condition
INT	initial
LG	landing gear
LO	lift off

max	maximum
min	minimum
N	net
PFD	pitch command sensitivity to flight director
PIL	pilot
sb	speed brake
VFD	velocity flight director

Abbreviations:

ADI	attitude director indicator
ADV	advanced
AST	advanced supersonic technology
dB	decibel
EF	engine failure
ENG	engine
EPNdB	effective perceived noise decibels
EPNL	effective perceived noise level
FAR	Federal Aviation Regulations
KIAS	knots of indicated airspeed
MOD	modified
PLA	power lever angle
PNL	perceived noise level
PNLT	tone-corrected perceived noise level
PROC	procedure
SCR	supersonic cruise research

STD	standard
TH	track/hold
VMS	visual motion simulator
VSCE	variable stream control engine

DESCRIPTION OF SIMULATED AIRPLANE

The supersonic cruise transport concept simulated in this study was a resized version of the configuration of Ref. 3 and is described in detail in Ref. 2. Reference 2 also presents the mass and dimensional characteristics, control-surface deflections and deflection rate limits, and most of the aerodynamic data used in this study. A three-view sketch of the simulated airplane is presented in Fig. 1.

To facilitate steep-decelerating approaches, a speed brake was designed which incorporated bifurcated "rudders" on the two wing fins. To minimize ground roll following touchdown, the speed brakes and wing spoilers were utilized. The aerodynamic effects of ground proximity were obtained from the test data of Ref. 4. The dynamic aerodynamic derivatives were estimated by using a combination of the forced oscillation test data of Ref. 5 and the estimation techniques of Ref. 6.

The variable stream control engine concept, designated VSCE-516, was selected for this study. The engine was scaled to meet the takeoff design thrust-to-weight ratio of 0.254 for the simulated SCR airplane. The engine performance data generated by the manufacturer was provided in the form of an unpublished data package which included the performance for a standard day plus 10°C. The engine performance for a standard day plus 10°C was used for the takeoff and landing analyses as well as the subsequent noise analyses made during this study.

DESCRIPTION OF SIMULATION EQUIPMENT

Studies of advanced takeoff and landing procedures for a typical SCR transport concept were made using the general-purpose cockpit of the Visual Motion Simulator (VMS) at the Langley Research Center. This ground-based six-degree-of-freedom motion simulator had a transport-type cockpit which was equipped with conventional flight and engine-thrust controls and with a flight-instrument display representative of those found in current transport airplanes (see Fig. 2). Instruments indicating angle of attack, sideslip, pitch rate, and flap angle were also provided. A conventional cross-pointer-type flight director instrument was used, and the command bars (cross pointers) were driven by the main computer program. The horizontal bar of the ADI was used for flight path control command during landing approaches, and was also used as a simplified airspeed control command during takeoffs. This "takeoff" director was programmed with two options: (1) to command the pilot to climb at an airspeed of $(V_2 + \Delta V)$; or (2) to command the pilot to climb at an airspeed of 250 KIAS. See Fig. 3 for block diagram of takeoff director.

The control forces on wheel, column, and rudder pedals were provided by a hydraulic system coupled with an analog computer. The system allows for the usual variable feel characteristics of stiffness, damping, coulomb friction, breakout forces, detents, and inertia.

The visual display of an airport scene used was an "out-the-window" virtual image system of the beam splitter, reflective mirror type (see Fig. 4). In addition to the airport scene presented on the out-the-window virtual image system, a "head-up" display was superimposed on the same system. The head-up portion of the display consisted of angle of attack, pitch rate, and climb gradient presentations that were used only for the takeoff and climb maneuvers — the head-up display was not used for landing approaches (see Fig. 5).

The motion performance characteristics of the VMS system possess time lags of less than 50 milliseconds. The washout system used to present the motion-cue commands to the motion base was nonstandard (see Ref. 7).

A runway "model" was programmed that was considered to have certain roughness characteristics and a slope from the center to the edge representing a runway crown. Only a dry runway was considered in this study.

TESTS AND PROCEDURES

The tests consisted of both simulated takeoffs and landings using "advanced" procedures. A NASA test pilot participated in the simulation program,and his comments dictated the type of pilot information displays and the degree of automation that was developed for performing the task of "flying" the advanced takeoff and landing procedures used in this study.

The pilot information displays (in addition to the normal-type displays used in present day subsonic jet transports) consisted of a takeoff director and a head-up display — both previously described in this paper and used only during takeoff and climb. The automated features consisted of an autothrottle for controlling airspeed and an auto-decel control. The auto-decel control was programmed as a part of the autothrottle and was used only when the decel switch was activated by the pilot. The autothrottle portion of the system was sometimes used for both takeoffs and landings, whereas the auto-decel mode was only used during landing approaches (see Fig. 6 for block diagram of autothrottle).

By operating the VSCE engines used in this study at maximum allowable turbine inlet temperature, the maximum thrust is increased approximately

16 percent over that for the "normal" operation procedure (T_{max} = 100%). The higher values of thrust allow the achievement of higher speeds, increased lift-drag ratio, better climb performance, and permitted larger power cut-backs — resulting in lower community noise. Therefore, the initial thrust used for takeoffs in this study was 116.4 percent unless otherwise noted.

All computations were made for a standard day plus 10°C. Also, constant weights were used for takeoff, W = 3051.48 kilonewtons (686000 lbf), as well as approach and landing, W = 1744.81 kilonewtons (392250 lbf) — no weight changes due to fuel burn were considered. Current Federal Aviation Regulations (FAR's) were adhered to at all times throughout this simulation study, with the exception of some of those presented in FAR-36. Some of the procedures presented in FAR-36, Ref. 1, were not followed at all times in order to determine the benefits (noise savings) that may be realized should these "rules" be changed. Specifically, the rules listed in Ref. 1 that were not always followed during the present study were:

(1) A constant takeoff configuration must be maintained throughout the takeoff noise test, except that the landing gear may be retracted.

(2) Takeoff power or thrust must be used from the start of takeoff roll to at least an altitude above the runway of 214 meters (700 ft).

(3) Upon reaching an altitude of 214 meters (700 ft), or greater, the power or thrust may not be reduced below that needed to maintain level flight with one engine inoperative, or to maintain a four percent climb gradient, whichever power or thrust is greater.

(4) A steady approach speed must be established and maintained over the approach measuring point.

(5) The approaches must be conducted with a steady glide angle of 3° ±0.5°.

Noise characteristics of the simulated SCR concept at the three measuring stations prescribed in Ref. 1 and indicated in Fig. 7 were calculated for both takeoffs and landing approaches using the NASA Aircraft Noise Prediction Program (ANOPP) described in Ref. 8.

Takeoffs were performed using rotation speeds from 172 KIAS to 200 KIAS, and the climb speeds varied from 211 KIAS to 250 KIAS. During these takeoffs, thrust reductions (cut-backs) were made as a function of distance from brake release and/or altitude. Also, these thrust reductions were made manually as well as automatically. It should be mentioned that after the "final" thrust reduction was made (always made prior to reaching the flyover measuring point), the climb gradient was reduced to 0.04 ($\gamma \approx 2.3°$).

Landing approaches were made at: (1) constant speed for various constant glideslope angles; and (2) decelerating speeds for various constant glideslope angles. The glideslope angles varied from 3° to 5°, and the approach speeds varied from 250 KIAS to 158 KIAS.

The results of this study, using the aforementioned evaluation procedures, will primarily be presented in the form of effective perceived noise level (EPNL) savings as a function of piloting techniques used to perform takeoffs and landings on the subject SCR transport concept. The more significant results are reviewed in the following sections.

RESULTS AND DISCUSSION

The results of this study are discussed in terms of the previously stated objectives and primarily presented in the form of effective perceived noise level (EPNL) as the piloting technique varied while performing takeoffs and landings on the simulated SCR transport concept. The noise levels discussed pertain to jet noise only.

Takeoff

Takeoffs were performed using rotation speeds (V_R) from 172 KIAS to 200 KIAS, an angular rotation rate ($\dot{\theta}$) of 3°/second, and "initial" rotation angles of attack (α_{int}) from 4° to 8° (depending on the desired climb speed (V_C)). The α_{int} as used here is the angle of attack to which the pilot rotates and maintains until V_2 is achieved.

Determination of rotation speed.- The procedures used to determine the minimum and maximum rotation speeds to be used in this simulation study were those prescribed in FAR-Part 25, (Ref. 9). In general, the range of V_R's used were selected from the V_1 information determined on the simulator and presented in Fig. 8. The V_1 concept was developed for civil air transport certification, and its intent is to provide the pilot sufficient information to decide whether to refuse or to continue the takeoff. If the pilot elects to refuse the takeoff, the total distance required for the maneuver (from brake release, to V_1, to full stop) is called the accelerate-stop distance. If the pilot elects to continue the takeoff, the total distance required from brake release, to V_1, to an altitude of 10.7 meters (35 ft) is called the takeoff distance. (As can be seen from Fig. 8, the intersection of the two curves (balanced field length) occurs at approximately 172 KIAS.) In addition, Ref. 9 states that the critical engine-inoperative takeoff distance, using a rotation speed of 5 knots less than V_R, must not exceed the corresponding critical engine-inoperative takeoff distance using the established V_R. Therefore, it can be seen from the "takeoff distance" curve of Fig. 8 that the minimum "established" V_R should be no less than approximately 185 KIAS. However, during the present simulation program, a minimum $V_R = V_1 = 172$ KIAS was chosen in order to get the maximum possible variable range for V_R and the corresponding V_C. From the "accelerate-stop-distance" curve, in combination with the "takeoff distance" curve of Fig. 8, the maximum V_R chosen to be used in this simulation program was 200 KIAS, due to tire speed limitations. Thus, the range of rotation speeds used in this study was from 172 KIAS to 200 KIAS, resulting in lift-off speeds from 193 KIAS to 215 KIAS, respectively. It should also be mentioned that the range of V_R's used does not exceed the limits dictated by the Tentative Airworthiness Standards for Supersonic Transports (unpublished).

Angular rotation rate.- An angular rotation rate $(\dot{\theta})$ of approximately 3°/sec was used for all takeoffs in the present study. This value was selected from considering tail-scrape as well as pilot-passenger comfort. It was also noted that the nominal angular rotation rate used by the pilots when flying the Concorde simulation, Ref. 10, was approximately 2.8°/second.

Initial rotation angle of attack.- The initial α selected for each takeoff varied depending upon the selected rotate speed and climb speed. For example, for a selected V_R of 172 KIAS and a climb speed of V_2 + 10 KIAS, the initial α used for the best performance was determined to be approximately 8°, whereas for a selected V_R of 200 KIAS and a V_C of 250 KIAS, the initial α used for the best performance was determined to be approximately 4°.

Minimum flyover noise during takeoff.- Using simulated takeoff procedures with no power cut-backs, the flyover noise was calculated to be approximately 118 EPNdB, regardless of the selected rotate speed or the selected climb speed, and the sideline noise was calculated to be greater than 116 EPNdB for all takeoffs.

The scheme used to determine a piloting technique that would result in acceptable noise levels for both flyover and sideline was to first define the minimum flyover noise procedure — with no consideration for the sideline noise generated.

Reference 1 states, in part, that: (1) takeoff power or thrust must be used from the start of takeoff roll to an altitude of at least 214 meters (700 ft) for airplanes with more than three engines; (2) upon reaching an altitude of 214 meters, the power or thrust may not be reduced below that needed to maintain level flight with one engine inoperative, or to maintain a four percent climb gradient, whichever power or thrust is greater; and (3) a speed of at least V_2 + 10 knots must be maintained throughout the takeoff noise test. Therefore, the first task was to determine the amount of allowable thrust cutback and this is indicated in Fig. 9. As can be seen, for airspeeds greater than approximately 240 KIAS the four-engine, four percent climb gradient criterion should be used, whereas the three-engine, zero climb gradient criterion should be used for airspeeds below 240 KIAS. For the present study, the four-engine, four percent climb gradient criterion was arbitrarily used for all climb speeds considered since it was more beneficial at the lower climb speeds (V_C < 240 KIAS) and was almost as beneficial at the higher climb speeds (V_C > 240 KIAS). Therefore, the net thrust was reduced to 71 percent, at the cutback point, when the slowest climb speed was flown (V_R = 172 KIAS and $V_C = V_2 + 10 = 211$ KIAS) and was reduced to 58 percent, at the cutback point, when a climb speed of 250 KIAS was flown. (It should be noted that the maximum airspeed allowed below an altitude of 3048 meters (10000 ft) is 250 KIAS due to Air Traffic Control considerations.

The "ideal" cutback altitudes were then determined using the lowest V_R and V_C investigated (V_R = 172 KIAS and V_C = 211 KIAS), as well as the highest V_R and V_C investigated (V_R = 200 KIAS and V_C = 250 KIAS), and the results are presented in Fig. 10. Indications are that for V_R = 172 KIAS and V_C = 211 KIAS the ideal cutback altitude, from an effective perceived noise level standpoint, was approximately 400 meters (1312 ft), and for V_R = 200 KIAS and V_C = 250 KIAS, the ideal cutback altitude was approximately 290 meters (951 ft). Figure 10 also indicates that the faster climb speed, which allowed more thrust cutback, was approximately 2 EPNdB less noisy than the slower climb speed (107.7 EPNdB compared to 109.6 EPNdB) even though the cutback altitude was approximately 110 meters (361 ft) lower. It should also be noted that the minimum flyover EPNL for the V_R = 200 KIAS, V_C = 250 KIAS technique was slightly lower than the maximum level allowed (108 EPNdB; Ref. 1).

These two takeoff profiles are presented in Fig. 11. The piloting procedures used were to: (a) accelerate from brake release to V_R (172 KIAS and 200 KIAS); (b) at V_R, rotate the airplane at an angular rotation rate of 3°/sec to an angle of attack of 8° and 4°, respectively, and maintain those α's until V_2 was achieved; (c) after attaining V_2, the pilot merely "flew" the takeoff director commands, which in these cases commanded climb speeds of V_2 + 10 = 211 KIAS and 250 KIAS, respectively; and (c) upon attaining the designated "ideal" cutback altitudes (400 meters (1312 ft), and 290 meters (951 ft), respectively) the co-pilot reduced the net thrust to 71 percent and 58 percent, respectively, and the pilot simultaneously reduced the climb gradient to 0.04 in each instance. The results indicate that the airplane was at an altitude of 492 meters (1614 ft) when it flew over the noise measuring station (a distance of 6500 meters (21325 ft) from brake release) for the slower V_R and V_C compared to an altitude of 420 meters (1378 ft) for the faster V_R and V_C. The calculated flyover perceived noise levels (PNL) and effective perceived noise levels (EPNL) are also presented in Fig. 11, and indicate that the maximum calculated PNL's for the slower and faster takeoffs were 110.8 dB and 109.6 dB, respectively, resulting in EPNL's of 109.6 dB and 107.7 dB, respectively. Therefore, it was concluded that the faster climb speed was more beneficial from a noise standpoint, and thus the majority of the takeoffs made and discussed throughout the remainder of the present study pertain to rotate speeds of 200 KIAS and climb speeds of 250 KIAS.

Figure 12 indicates that for climb speeds greater than approximately 233 KIAS, less thrust is required to trim on a 0.04 climb gradient for δ_f = 10° than for δ_f = 20°. For example, at V_C = 250 KIAS, two percent less thrust is required to trim for the δ_f = 10° configuration (T_N = 56 percent compared to 58 percent). Figure 13 presents the flyover EPNL savings due to raising the flaps to 10° (after V_C > 233 KIAS) and indicates that since the ΔdB was less than one for any cutback altitude, the configuration change would probably not be justified. (It should be noted that Ref. 1 requires a constant configuration throughout the takeoff noise test - with the exception of landing gear retraction.)

During the generation of the flight profiles necessary to calculate the corresponding EPNL's shown in Figs. 10 and 13, it was found that the rate of thrust cutback and the rate of climb gradient change were very important as to whether the climb speed was maintained. Therefore, instead of manually reducing the thrust to the specified level (depending upon the V_c and δ_f), the autothrottle was activated at various altitudes and, again, the climb gradient was reduced to 0.04. These results are presented in Fig. 14 and compared to the manual throttle cutbacks. The results indicate that the use of the autothrottle makes for approximately one EPNdB savings for the "ideal" cutback altitude. Figure 15 presents the flight profiles comparing the manual cutback and autothrottle activation at an altitude of approximately 290 meters (951 ft). Note that although the same approximate altitude (417 meters (1368 ft)) was achieved at the flyover measuring station (6500 meters from brake release), the calculated values for PNL and EPNL were somewhat different, even though both takeoffs were for the same configuration and the same takeoff procedures were used — with the exception of the method used to reduce the thrust at the designated altitude. The differences in the EPNL's were attributed to the differences in the thrust management. Note from the net thrust trace that for the manual cutback procedure, the co-pilot gradually reduced the thrust from T_{max} to 58 percent with no overshoot. However, when the thrust was reduced by the autothrottle, an overshoot in thrust resulted (T_N became as low as approximately 44 percent at one instance) and therefore the EPNL was lower at the measuring station due to the lower values of net thrust. It should be noted that the climb speed was maintained relatively constant at approximately 250 KIAS during both flights.

Obviously, it will be necessary to use the minimum amount of thrust during takeoff in order to keep the sideline noise at a minimum. However, sufficient thrust must be used to keep the takeoff flyover noise at 110 EPNdB or less in order to even consider the possibility of using the present FAR tradeoff capabilities. Therefore, takeoffs were performed for which only 100 percent of the maximum available thrust was used. Figure 16 presents the calculated flyover EPNL's against various cutback altitudes for initial values of thrust of 100 percent and 116.4 percent, and as can be seen, the minimum flyover effective perceived noise level that was experienced was greater than 111 dB when 100 percent thrust was used for takeoff, regardless of the cutback altitude, compared to a minimum EPNL of less than 108 dB when maximum available thrust (116.4 percent) was used for takeoff.

It was therefore concluded that an initial value of thrust greater than 100 percent must be used in order to achieve a flyover EPNL equal to or less than 110 dB. Furthermore, these results indicated that at some point during the early stages of the takeoff, the thrust must be reduced below 100 percent in order to reduce the sideline noise being generated -- the sideline noise was greater than 110 EPNdB even when only 100 percent thrust was used for takeoff. (As mentioned previously, the sideline noise was greater than 116 EPNdB for the maximum thrust takeoff.)

Summary of results pertaining to minimum flyover noise during takeoff.- With no consideration given to the sideline noise being generated, various takeoff procedures were used in an attempt to define the "best" piloting procedure that could be used in order to create the minimum effective perceived noise level at the flyover noise measuring station (6500 meters from brake release). The more significant results were as follows:

- With no power cutbacks the flyover EPNL was approximately 118 dB, regardless of the rotate speed and/or climb speed.

- Using the noise abatement takeoff procedures presently allowed by the Federal Aviation Regulations of Ref. 1, the maximum allowed rotation speed and climb speed (V_R = 200 KIAS and V_C = 250 KIAS) were the most beneficial for creating the minimum noise at the designated flyover noise measuring station. This takeoff procedure resulted in a flyover EPNL of 107.7 dB, which met the 108 EPNdB requirement of Ref. 1.

- Minor additional noise benefits could be realized by reducing the flap deflections from 20° to 10° for airspeeds greater than approximately 233 KIAS.

- Additional noise benefits were gained by activating the autothrottle (as opposed to manual throttle manipulations) at the "ideal" cutback altitude.

The best advanced piloting procedure used during this study for minimum flyover noise, disregarding the sideline noise being generated, was as follows:

(a) with maximum available thrust (116.4 percent), accelerate the airplane from brake release to 200 KIAS;

(b) at V = 200 KIAS, rotate the airplane at an angular rotation rate of 3°/sec to an angle of attack of 4°. Retract the landing gear after liftoff;

(c) maintain α = 4° until V_2 is achieved; V_2 is defined as the aircraft velocity at the hypothetical obstacle ($h_{L.G.}$ = 10.67 m (35 ft));

(d) accelerate the airplane from V_2 to a climb speed of 250 KIAS (V_C = 250 KIAS is the maximum speed allowed below an altitude of 3048 m (10000 ft));

(e) prior to achieving V_C = 250 KIAS, reduce the flap deflections from 20° to 10°; and

(f) at an altitude of 290 m (951 ft), activate the autothrottle and reduce the climb gradient to 0.04.

This takeoff procedure resulted in a flyover noise level of 106.7 EPNdB, which is 1.3 dB less than the maximum allowed EPNdB of 108 (Ref. 1).

Sideline noise considerations during takeoffs.- In an attempt to determine a takeoff procedure that would allow the use of the aforementioned noise tradeoffs between the flyover noise, sideline noise, and approach noise and thus meet the 108 EPNdB requirements of Ref. 1, various piloting procedures were used during simulated takeoffs. Since it was determined earlier that the most advantageous procedure for flyover noise was to rotate as late as possible and climb as fast as possible, the majority of the "sideline noise" takeoffs were made for which V_R was 200 KIAS and V_c was 250 KIAS.

Figure 17 indicates the sideline effective perceived noise levels calculated for a standard procedure (no FAR rules were broken) takeoff. Note that the sideline EPNL approaches 108 dB approximately 1800 meters (5906 ft) after brake release and has exceeded 110 dB prior to liftoff (X = 2496 m (8189 ft)). Therefore, it was obvious that some degree of power cutback would be required prior to liftoff in order to keep the sideline noise equal to or less than 110 EPNdB, the maximum level that would allow the use of the previously discussed noise tradeoff criterion.

Various piloting techniques were then used in an attempt to determine the optimum takeoff procedure insofar as the minimum sideline and flyover jet noise were concerned. Power cutbacks were made at various distances from brake release as well as at various altitudes in an attempt to keep the sideline noise to a minimum. Then — a "final" power cutback was made (sometimes autothrottle was used) and the climb gradient reduced to 0.04, prior to reaching the flyover noise measuring station, in order to keep the flyover EPNL to a minimum. The objective was to keep the sideline EPNL equal to or less than 110 dB and at the same time keep the flyover EPNL equal to or less than 109 dB.

A typical takeoff using "advanced" procedures is presented in Fig. 18. The piloting procedures used were as follows:

(a) with the flaps set at 20°, and using maximum available thrust, accelerate the airplane from brake release to $V = 200$ KIAS;

(b) at $V = 200$ KIAS, rotate at a $\dot{\theta} \approx 3°/sec$ to an initial angle of attack of approximately 4°. At $X \approx 2225$ meters (7300 ft) and $V \approx 208$ KIAS, reduce the net thrust to 110 percent;

(c) after liftoff ($X \approx 2500$ meters (8202 ft) and $V \approx 217$ KIAS), raise the landing gear and accelerate to V_2 while maintaining $\alpha \approx 4°$;

(d) at V_2, which was approximately 235 KIAS, reduce the net thrust to 90 percent and, by following the commands of the takeoff director, accelerate to 250 KIAS. Prior to attaining $V_c =$ 250 KIAS, raise the flaps from 20° to 10°; and

(e) continue the climb-out at V_C = 250 KIAS. At an altitude of approximately 185 meters (607 ft), activate the autothrottle and reduce the climb gradient to 0.04.

Figure 18 indicates that the sideline EPNL exceeds 108 dB at $X \approx 2700$ meters (8858 ft) from brake release and that the maximum sideline EPNL was 109.8 dB, occurring at $X \approx 3350$ meters (10991 ft). Note that an altitude of 254 meters (833 ft) was attained at the flyover noise measuring station and that the calculated flyover EPNL was 108.1 dB. It should also be mentioned that the autothrottle caused the net thrust to overshoot the allowed level of 56 percent. (T_N actually became as low as 38 percent at one point and was less than 56 percent for approximately 5 seconds, which corresponded to the time just prior to, and immediately after, flying over the flyover noise measuring station.) It is believed that although this large, temporary, thrust reduction exceeded the limit allowed (Fig. 12), flight safety would not be jeopardized in that, for example, should an engine fail during the time the autothrottle had driven the thrust to this "unacceptably" low value, the autothrottle would very quickly command sufficient thrust on the remaining three (3) engines to maintain an airspeed of 250 KIAS. It is therefore concluded that this piloting procedure is a realistic and safe takeoff procedure if autothrottle is used, and that by utilizing the aforementioned tradeoff criterion, the traded noise can be kept below 108 EPNdB at the designated measuring stations, again assuming that the approach noise is no more than 105 EPNdB.

Effects of modifying the VSCE engine for maximum coannular acoustic benefit.- As mentioned previously, the noise levels discussed in this paper are those due to jet noise only. For example, the effects of engine shielding on the sideline noise levels have not been included in the noise calculations, and, therefore, the sideline noise levels discussed previously for takeoffs would have been somewhat lower if the engine-shielding effects were included. It was also determined during the simulation program that very large cutbacks in thrust were possible in order to reduce the flyover noise during takeoff. It was realized at that time that the design of the simulated VSCE engine was such that the coannular nozzle acoustic benefit was lost for thrust settings below approximately 60 percent. Therefore, in general, the flyover jet-noise levels discussed previously would be somewhat lower if the coannular benefit could be maintained for thrust settings lower than 60 percent.

The engine designers were therefore asked to investigate the impact of retaining the coannular nozzle acoustic benefit at cutback thrust settings approaching 40 percent of maximum thrust. These data were supplied for use in the present simulation study with the warning that design changes to the "current" VSCE engine might be required, with potential impact on weight and performance. Nevertheless, these "modified" engine data were used to repeat some of the advanced procedure takeoffs, and the results indicated that although the engine modification did not improve the sideline EPNL, the flyover EPNL was reduced approximately 2 dB. (Repeating the takeoff procedure indicated in Fig. 18, but using the modified VSCE engine, reduced the flyover jet noise from 108.1 EPNdB to 106.0 EPNdB.)

Landing Approaches

Reference 1 states that a constant airspeed and configuration must be maintained on a constant glide angle of 3° ±0.5° throughout the landing approach noise test. However, for the purposes of this study, all of these were varied in an attempt to determine the noise benefits that could be realized should these "rules" be changed. During the present simulation study, landing approaches were made at constant speed for various constant glideslope angles, as well as for decelerating speeds for various constant glideslope angles. (Segmented approaches were not performed.) The glideslope angles varied from 3° to 5°, and the approach speeds varied from 250 KIAS to 158 KIAS during the decelerating approaches.

Reference 1 (FAR-36) landing approach test procedure.- The approach noise calculated using a constant airspeed of 158 KIAS, a constant configuration, and a constant glide angle of 3° was 101.5 EPNdB. Note that this approach noise was well below the allowed 108 EPNdB, and in fact was sufficiently low to allow the use of the tradeoff rules previously discussed.

Constant speed for various constant glide angles.- Landing approaches were made using a constant configuration and a constant airspeed of 158 KIAS for various constant glideslopes. In addition to the standard 3° glideslope discussed above, glide angles of 4° and 5° were used, and the resulting calculated effective perceived noise levels were 96.8 EPNdB and 92.3 EPNdB, respectively.

Decelerating speeds for various constant glide angles.- During the decelerating approaches, an initial airspeed of 250 KIAS was used and the final airspeed used was 158 KIAS. (It should be noted that speed brakes were sometimes used during the decelerating approaches.) The results indicated that only minor noise reduction benefits were gained by flying decelerating approaches. For example, the approach noise for a glideslope of 4° and a constant airspeed of 158 KIAS was 96.8 EPNdB; whereas for the same glideslope (4°) and decelerating from an initial airspeed of 250 KIAS to V = 158 KIAS, the calculated approach noise was 95.4 EPNdB, a reduction of only 1.4 EPNdB.

Summary of results pertaining to landing approach noise tests.- It was determined that the calculated landing approach effective perceived noise level for the simulated SCR transport concept, using present-day FAR-36 test procedures, was 101.5 EPNdB, which was well below the allowed 108 EPNdB. It was also found that substantial noise reduction benefits could be gained by increasing the glide angle and flying a constant airspeed, but that only minor additional noise reduction benefits were realized by flying decelerating approaches. It should be noted, however, that although the decelerating approach produced minor noise benefits insofar as the noise at the approach noise measuring station of Ref. 1 (2000 meters short of the runway threshold, Fig. 7), decelerating approaches should be very beneficial for reducing the approach noise contours (footprints). It is also concluded from these results that these "low" noise levels underscore the need for examining other noise sources such as engine fan noise, turbomachinery noise, and airframe noise.

Noise Tradeoffs

The Federal Aviation Regulations Noise Standards, Ref. 1, dictate a maximum noise limit of 108 EPNdB at the approach, sideline, and flyover noise measuring stations. (See Fig. 7 for location of noise measuring stations.) However, Ref. 1 allows tradeoffs between the approach, sideline, and flyover noise levels if: (1) the sum of the exceedance is not greater than 3 EPNdB; (2) no exceedance is greater than 2 EPNdB; and (3) the exceedances are completely offset by reductions at other required measuring points. Therefore, these noise tradeoff rules were applied to the noise levels calculated during the previously discussed takeoffs and landings performed using various piloting procedures.

Takeoff and landing using standard procedures.- The term "standard procedure," as used in this paper, applies to the piloting procedure used that abides by all present-day Federal Air Regulations, and in particular, the noise standards certification regulations of Ref. 1. The minimum flyover noise obtained, using standard procedure, was 107.7 EPNdB (Fig. 11), and the sideline noise produced was 114.8 EPNdB (Fig. 17). Therefore, since the approach noise was 101.5 EPNdB, the traded noise was 112.8 EPNdB. It should be mentioned that this traded noise could be reduced by using less initial thrust for takeoff, thereby reducing the sideline noise to some extent and allowing the flyover noise to become greater. For example, if 100 percent of thrust (as opposed to 116.4 percent) was used for takeoff, the flyover noise would increase to 111.7 EPNdB, and the sideline noise would decrease to 112.3 EPNdB, producing a traded noise level of 110.5 EPNdB. However, the traded noise for either procedure was well above the allowed 108 EPNdB.

Advanced procedure used for takeoff.- The term "advanced procedure," as used within this paper, applies to the piloting procedure used that did not abide by the recommended FAR-36 noise test procedures for airplane certification (Ref. 1). Advanced piloting procedures were developed in an attempt to decrease the sideline noise generated during takeoff. These procedures were discussed previously and presented in Fig. 18. The takeoff noise levels, using these procedures, were calculated to be 108.1 EPNdB for flyover and 109.8 EPNdB for sideline, resulting in a traded noise level of 107.8 EPNdB. Therefore, by using these advanced procedures, the traded noise level was reduced by 5 EPNdB. It should also be noted that this traded noise level (107.8 EPNdB) meets the noise limit requirements of 108 EPNdB, Ref. 1.

Advanced procedure and modified VSCE engine used for takeoff.- As discussed previously, the simulated VSCE engine was modified in order to retain the coannular nozzle acoustic benefit at much lower thrust settings than the basic engine design. Also, the use of this modified engine reduced the flyover noise from 108.1 EPNdB to 106.0 EPNdB when the same procedures were used for takeoff. (The modified engine did not affect the sideline noise generated.) Therefore, a new takeoff procedure was developed for use with the modified engine in an attempt to further reduce the sideline noise level (allowing the flyover noise to increase above 106.0 EPNdB) and thus reduce the traded noise level below 107.8 EPNdB. The piloting procedure used is presented in Fig. 19 and was as follows:

(a) with the flaps set at 20°, and using maximum available thrust, accelerate the airplane from brake release to $V = 200$ KIAS;

(b) at $V = 200$ KIAS, rotate at a $\dot{\theta} \approx 3°/sec$ to an initial angle of attack of approximately 4°;

(c) after liftoff ($X \approx 2496$ meters (8188 ft) and $V \approx 218$ KIAS), raise the landing gear and accelerate to V_2 while maintaining $\alpha \approx 4°$;

(d) at V_2, which was approximately 235 KIAS, reduce the net thrust to 75 percent and, by following the commands of the takeoff director, accelerate to 250 KIAS. Prior to attaining $V_c =$ 250 KIAS, raise the flaps from 20° to 10°; and

(e) continue the climb-out at $V_c = 250$ KIAS. At an altitude of approximately 152 meters (500 ft), activate the autothrottle and reduce the climb gradient to 0.04.

Figure 19 indicates that the flyover noise was 106.8 EPNdB and the maximum sideline noise was 108.2 EPNdB, occurring at $X \approx 2743$ meters (9000 ft); thus the traded noise would be 106.2 EPNdB. An interesting point to be noted here is that the maximum sideline noise occurred prior to reaching the end of the runway.

It is concluded from these results that by using advanced takeoff procedures, the simulated SCR transport concept, with the modified VSCE engines, readily meets the noise certification standards of Ref. 1.

The histogram presented in Fig. 20 summarizes the traded noise levels calculated for the various conditions and test procedures flown during the present study. It can be seen that by using "advanced" takeoff procedures, the traded noise level for the subject SCR transport concept can be reduced by approximately 4.5 EPNdB.

Impact of Advanced Procedures on Flight Safety As Determined by Recovery From Critical Engine Failure

The advanced takeoff procedures developed for the subject SCR transport involved violating some of the current FAA noise certification test conditions, Ref. 1, in order to meet the required noise levels. (No rule violations were required to meet the required noise levels during landing approach.) The three rule violations were as follows:

(1) Reference 1 required that takeoff power or thrust be used from the start of takeoff roll to at least an altitude of 214 meters (700 ft) for airplanes with more than three turbojet engines.

[During the present SCR simulation program, thrust reductions were required at altitudes below 214 meters in order to meet the takeoff sideline noise requirement.]

(2) Reference 1 states that upon reaching an altitude of 214 meters (700 ft), the power or thrust may not be reduced below that needed to maintain level flight with one engine inoperative, or to maintain a four percent climb gradient, whichever power or thrust is greater.

[During the SCR simulation program, it was determined that larger temporary thrust reductions reduced the flyover noise at the flyover noise measuring station — and the climb speed could still be maintained.]

(3) Reference 1 states that a constant takeoff configuration must be maintained throughout the takeoff noise test, except that the landing gear may be retracted.

[It was determined during the SCR simulation program that additional noise reduction could be achieved by raising the flaps from 20° to 10° for climb speeds greater than 233 KIAS.]

Of these three (3) rule violations, the number (1) rule listed above is of primary importance. That is, only minor noise reduction benefits were realized by violating the rules listed above as numbers (2) and (3).

Obviously, it must be shown that violating these current FAA rules does not jeopardize flight safety. To demonstrate this, the advanced-procedure takeoffs were repeatedly performed,and an outboard engine was failed at various locations during the takeoff. The test pilot felt that the most critical stage of the takeoff was immediately after liftoff. Therefore, one location included during the engine-failure takeoffs was the point immediately following the thrust cutback made upon attaining V_2 (altitude of 10.67 meters (35 ft)),and this time history is presented in Fig. 21. After the number 4 engine (outboard engine on right wing) was failed, the pilot advanced the thrust on the remaining three engines, attempted to maintain wings-level and heading, and continued to accelerate to a V_C of 250 KIAS. As indicated in Fig. 21, the wings were kept within ±1° of being level and the heading was maintained within approximately 2°.

The pilot commmented that the aforementioned advanced takeoff procedures posed no safety problems. He stated that, due to the excess thrust available on the simulated airplane, after attaining approximately 230 KIAS, instead of declaring an engine-failure an emergency situation, the pilot could safely choose to continue to follow the noise abatement procedure.

CONCLUDING REMARKS

The subject piloted simulation study was conducted using the AST-105-1 Supersonic Cruise Research (SCR) transport concept to determine: (a) advanced takeoff and landing procedures for which the Federal Aviation Regulations (FAR) noise level requirements could be met; (b) if a pilot with average skills could perform the task of flying the suggested profiles without compromising flight safety; (c) the degree of automation required; and (d) the pilot information displays required. This paper has attempted to summarize the results of this study which support the following major conclusions.

Utilizing the current Federal Aviation Regulations test procedures for aircraft noise certification produced the following results: (a) the landing approach effective perceived noise level (EPNL) was 101.5 dB; (b) the flyover EPNL was 107.7 dB; and (c) the sideline EPNL was 114.8 dB.

Advanced takeoff procedures were developed that involved violating three of the current FAR noise test conditions. These were: (a) thrust cutbacks at altitudes below 214 meters (700 ft); (b) thrust cutbacks below those presently allowed; and (c) configuration change, other than raising the landing gear. Utilizing the current FAR noise test conditions, with these three exceptions, the calculated effective perceived noise levels for flyover and sideline were 108.1 dB and 109.8 dB, respectively.

The basic variable stream control engine (VSCE) used in this study was modified in order to retain the coannular nozzle acoustic benefit at thrust levels below 50 percent. With this engine modification, the advanced takeoff procedure was also modified in an attempt to reduce the takeoff noise levels below the presently allowed 108 EPNdB. With this "up-dated" takeoff procedure and modified engine, the flyover noise was calculated to be 106.8 EPNdB and the sideline noise was 108.2 EPNdB.

Utilizing the current FAR noise tradeoff rules, it was determined that the traded noise level was 110.5 EPNdB, when using current FAR noise certification test conditions, compared to a traded noise level of 106.2 EPNdB when advanced takeoff procedures were used — a traded noise reduction of approximately 4.5 EPNdB.

It was determined that the advanced takeoff procedures developed and evaluated during this study did not compromise flight safety.

It is concluded that the subject SCR transport concept, with the augmented variable stream control engines modified to maintain its coannular nozzle acoustic benefit at thrust settings below 50 percent, can meet the current FAA noise standards if the current noise certification test conditions are modified in such a manner to allow maximum performance utilization of the aircraft — as long as it does not jeopardize flight safety.

It is further concluded that the automation of some of the aircraft functions reduced the pilot workload when performing the advanced procedure takeoffs, and that very simple piloting displays seemed to be adequate for the task.

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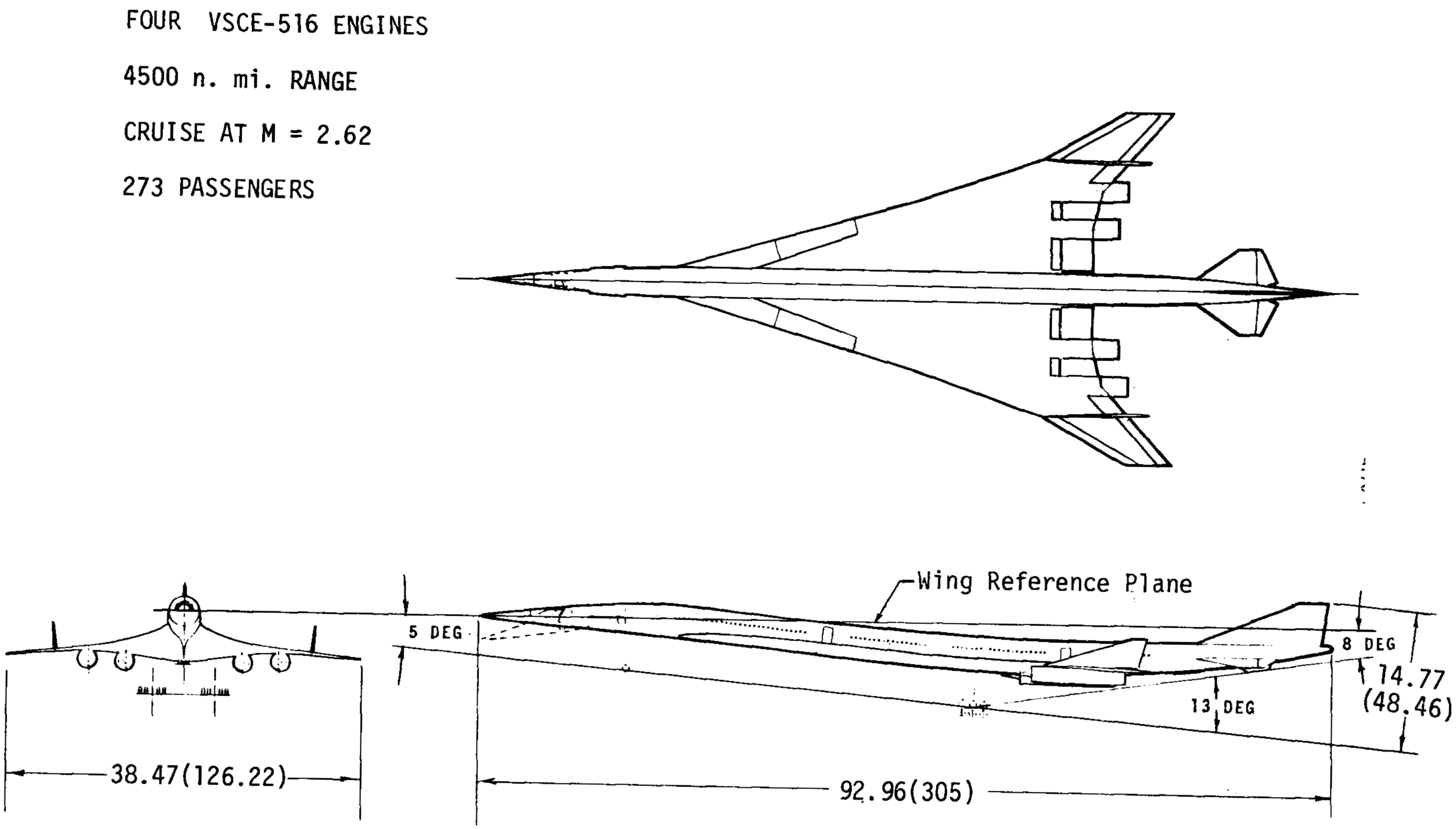
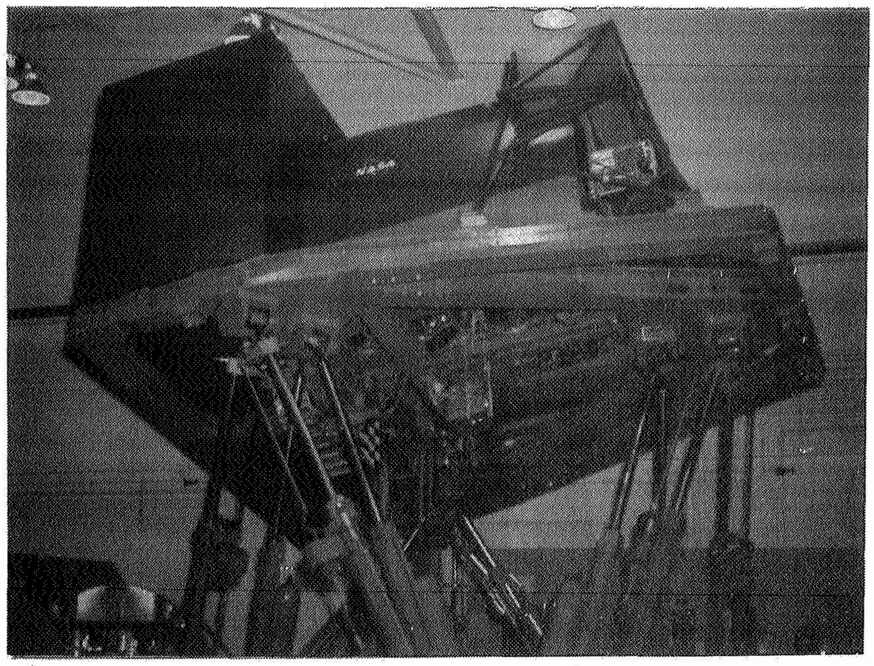
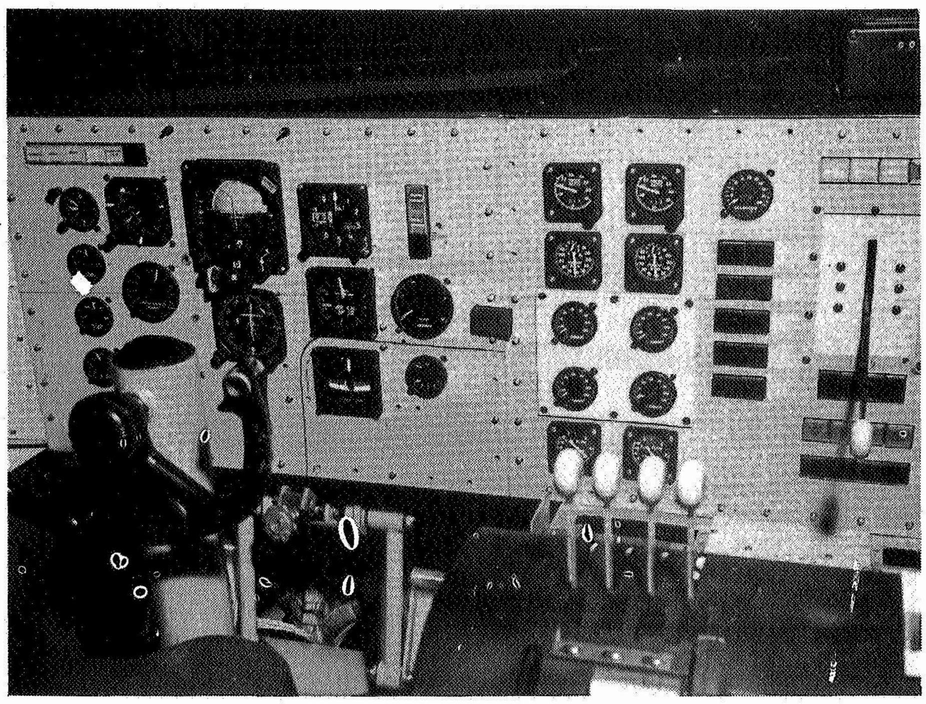


Figure 1.- Three-view sketch of simulated SCR concept (AST-105-1). All linear dimensions are in meters (feet).



(a) Visual Motion Simulator (VMS).



(b) Instrument panel.

Figure 2.- VMS and instrument display.

* SWITCHES ACTIVATED AT PREDETERMINED CAPTURE VELOCITY

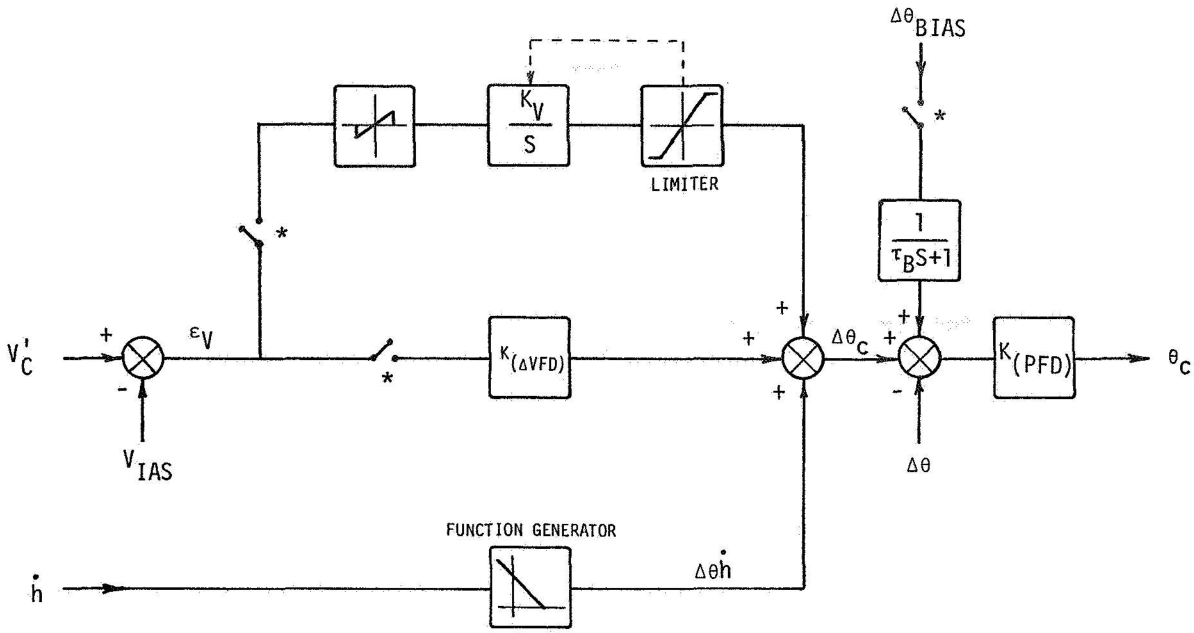
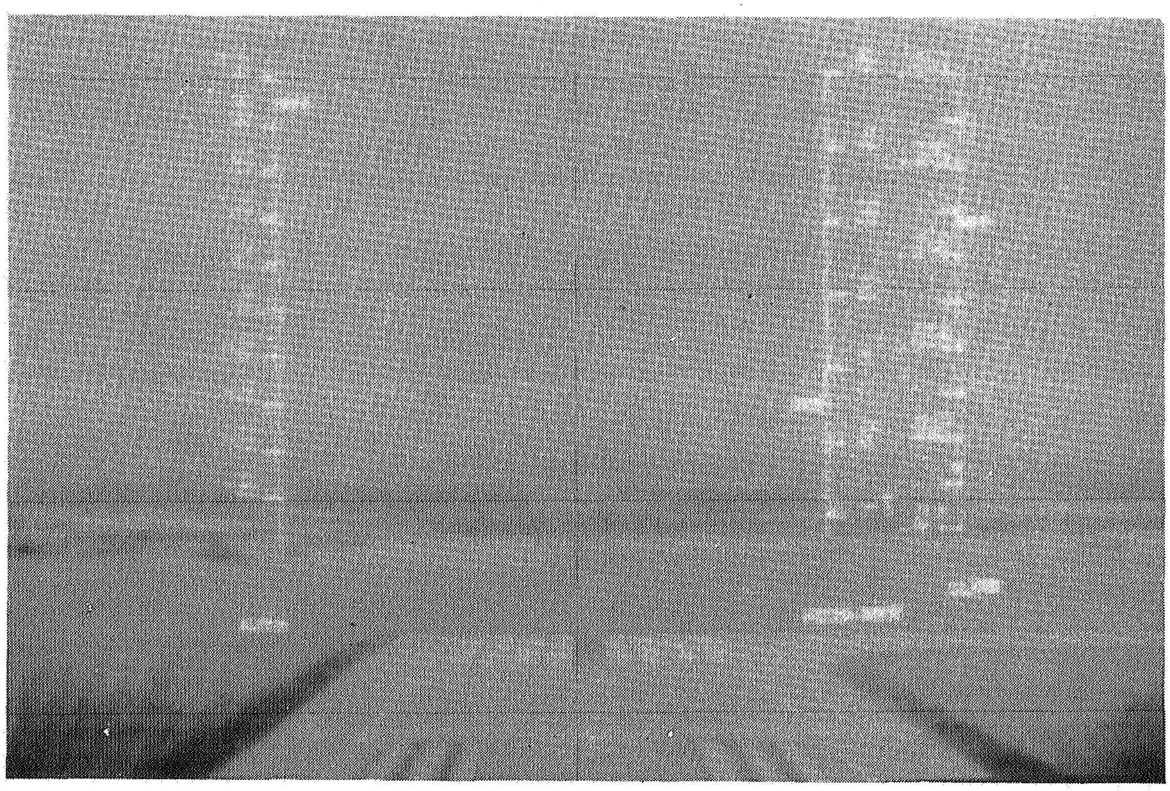


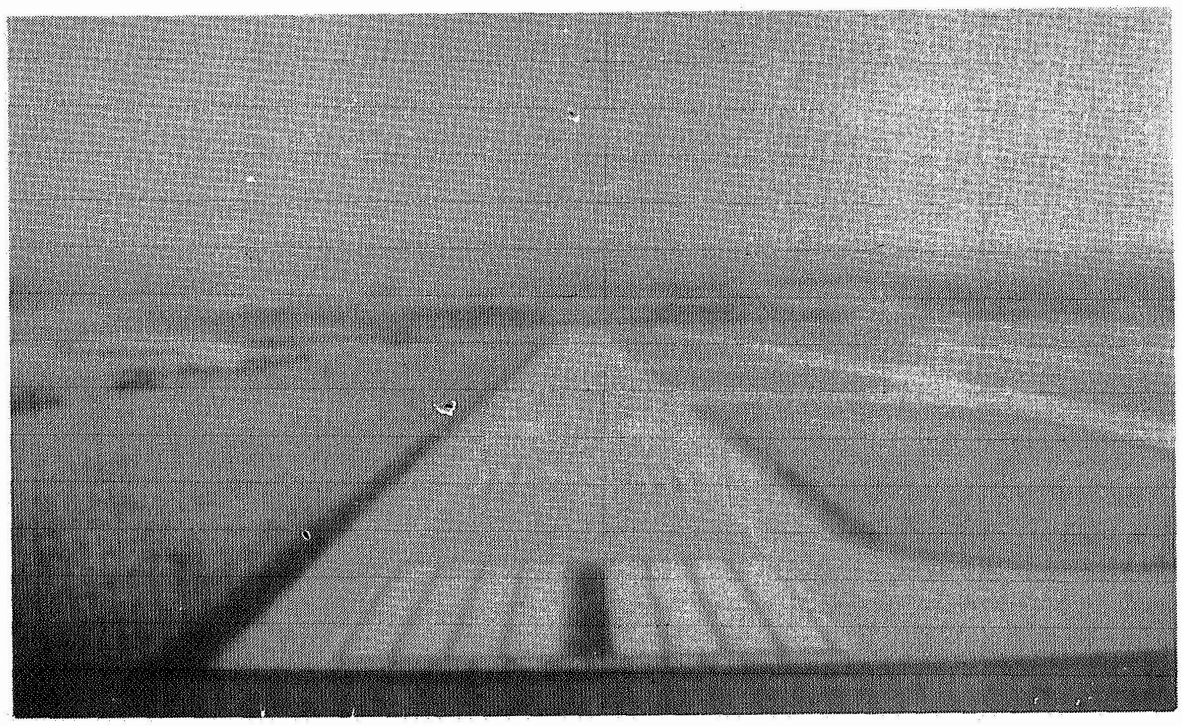
Figure 3.- Block diagram of takeoff director.



(a) Head-up display superimposed on airport scene.

Figure 4.- View of airport scene as seen by pilot.

(b) Approach scene.



(c) Landing scene.

Figure 4.- Concluded.

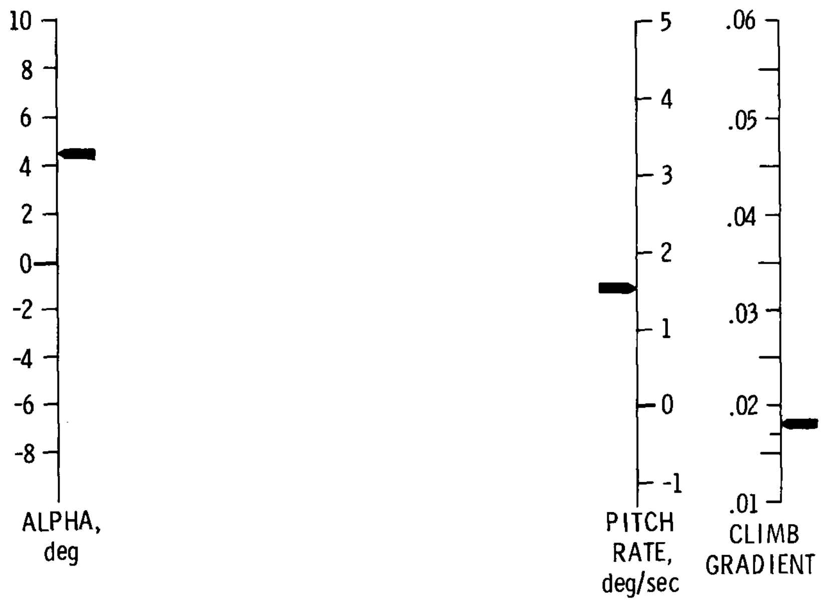


Figure 5.- Sketch of head-up display.

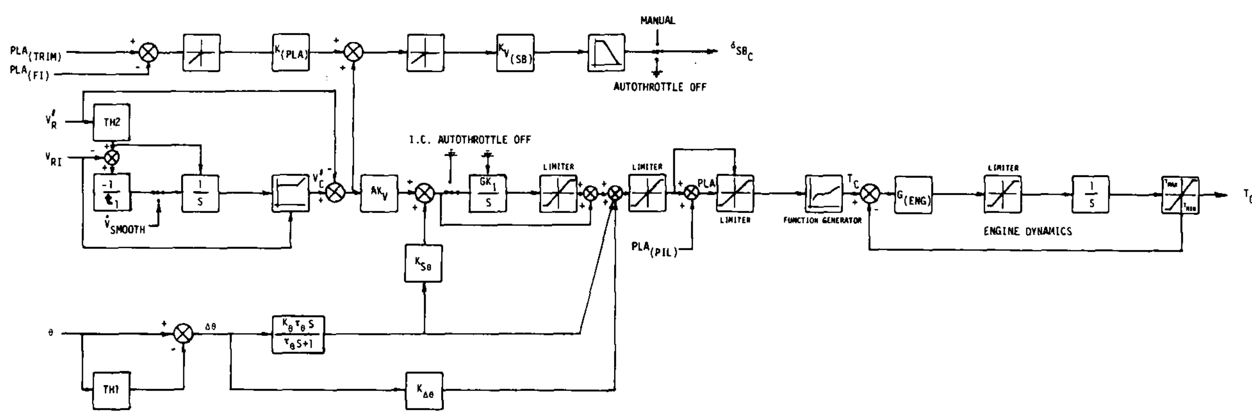


Figure 6.- Block diagram of autothrottle.

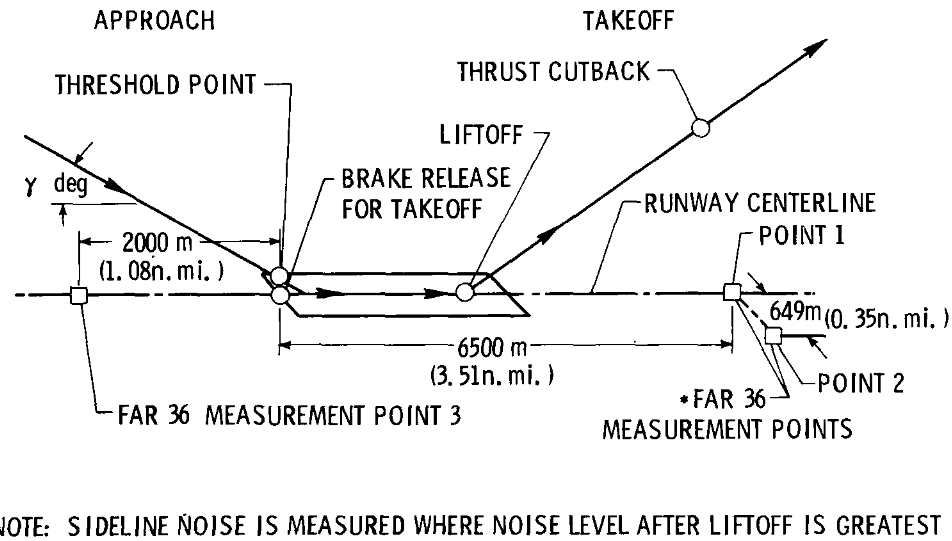


Figure 7.- Noise measurement locations for takeoff and landing.

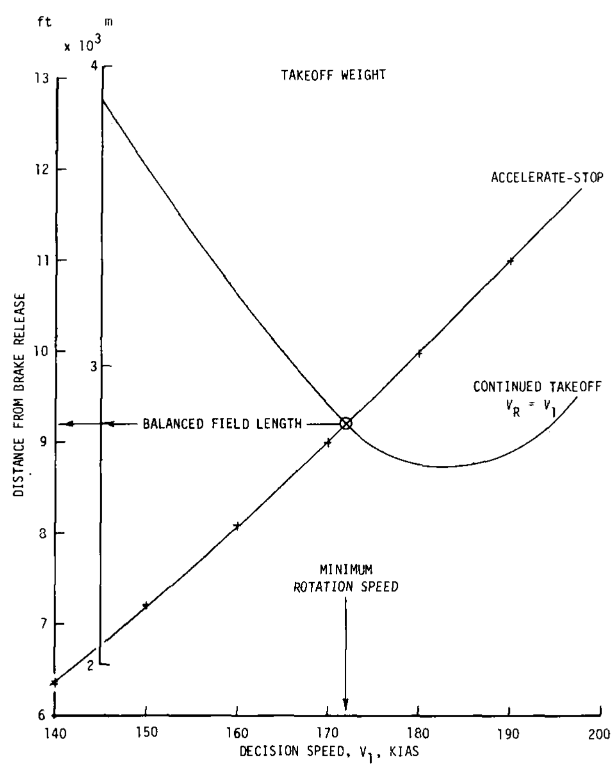


Figure 8.- Indication of three-engine balanced field length.

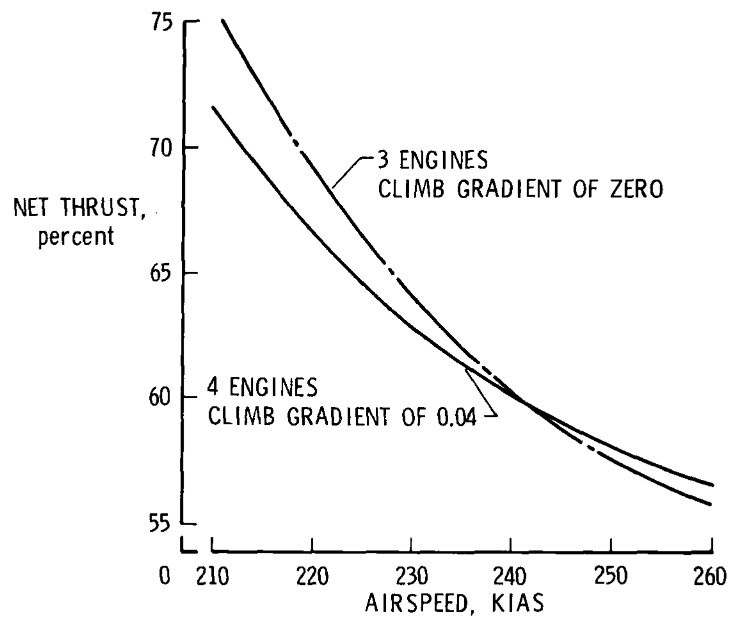


Figure 9.- Net thrust and airspeed used in establishment of allowable thrust cutback.

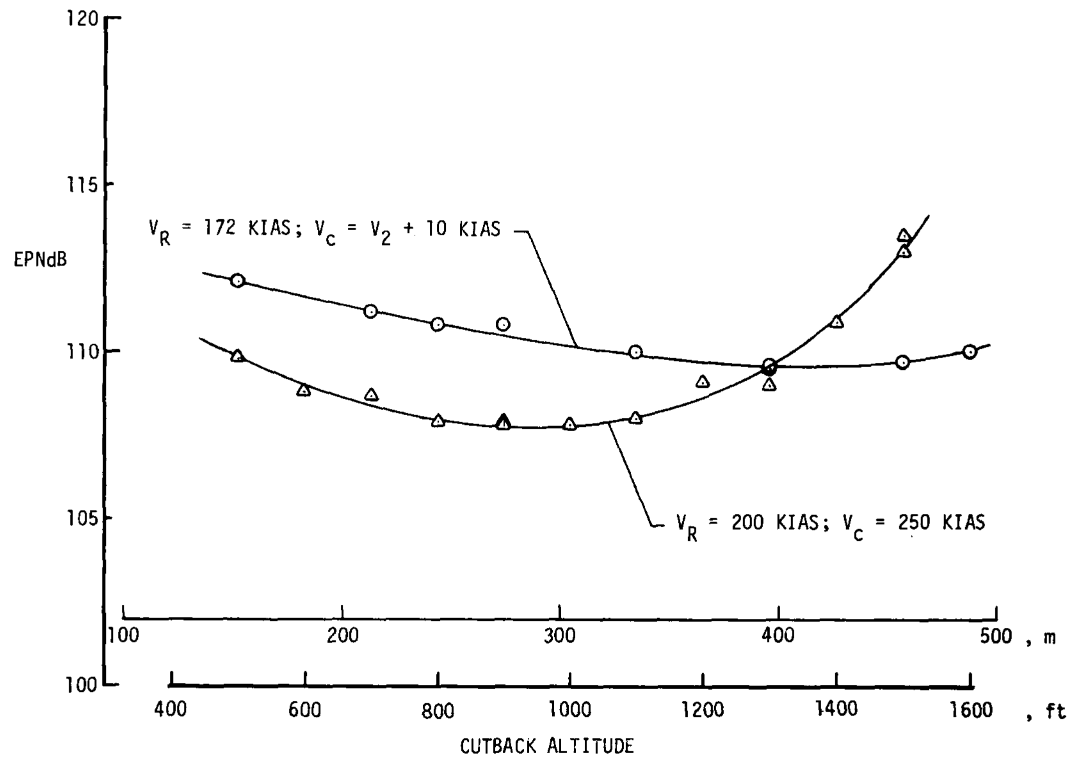


Figure 10.- Flyover effective perceived noise level as function of thrust cutback altitude for two takeoff conditions.

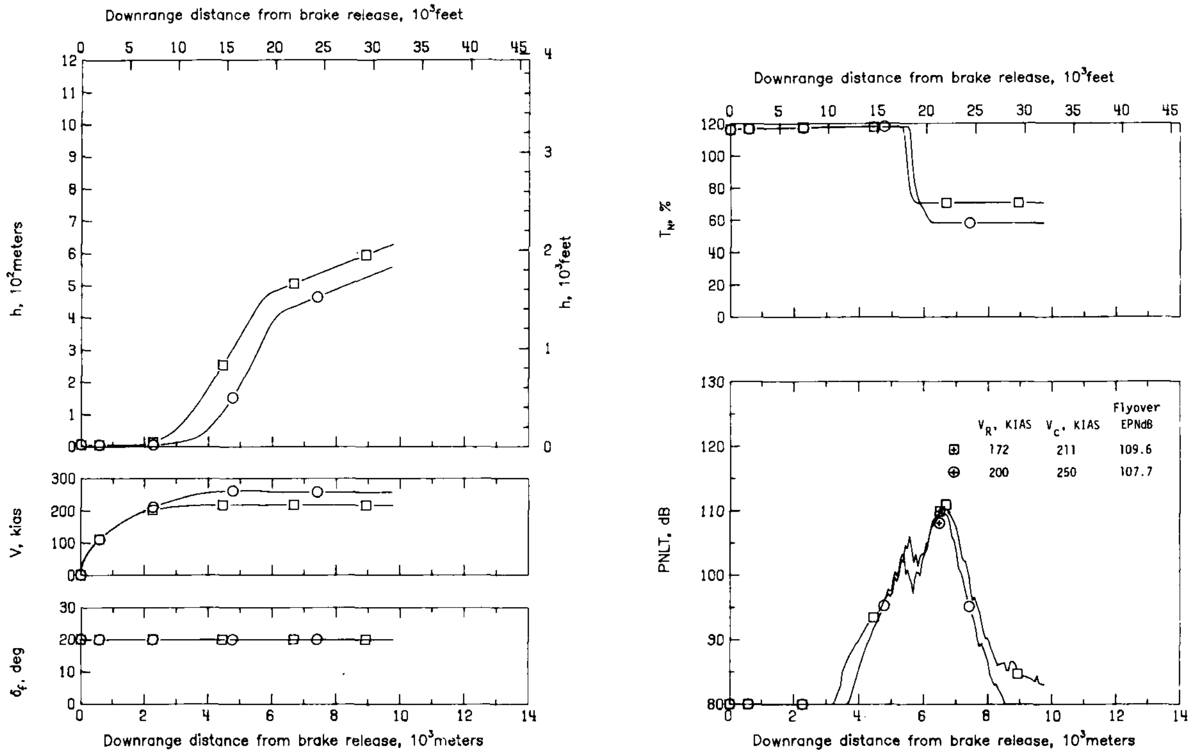


Figure 11.- Takeoff profiles and flyover noise generated for minimum and maximum simulated rotate and climb speeds.

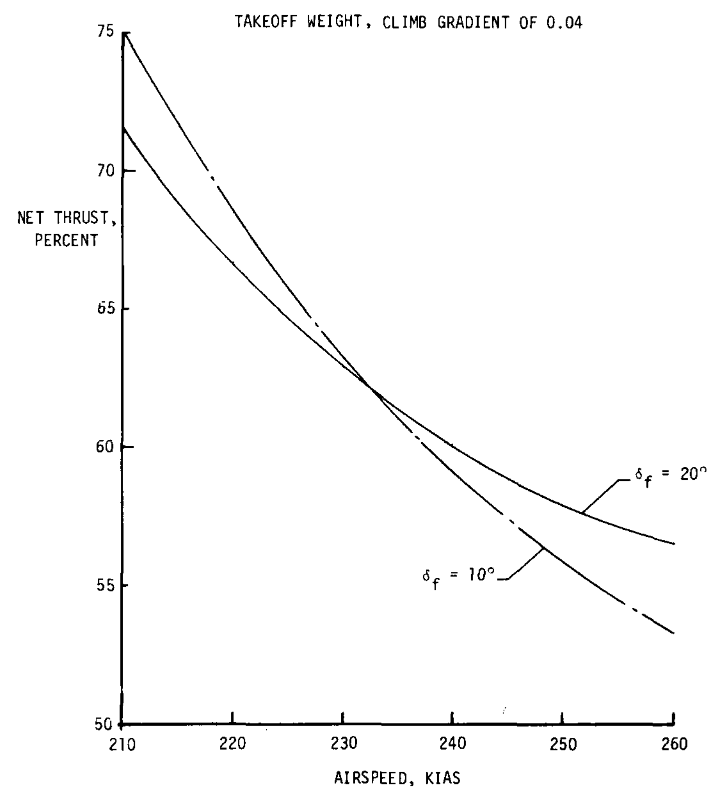


Figure 12.- Effect of airspeed on net thrust required for two trailing edge flap deflections.

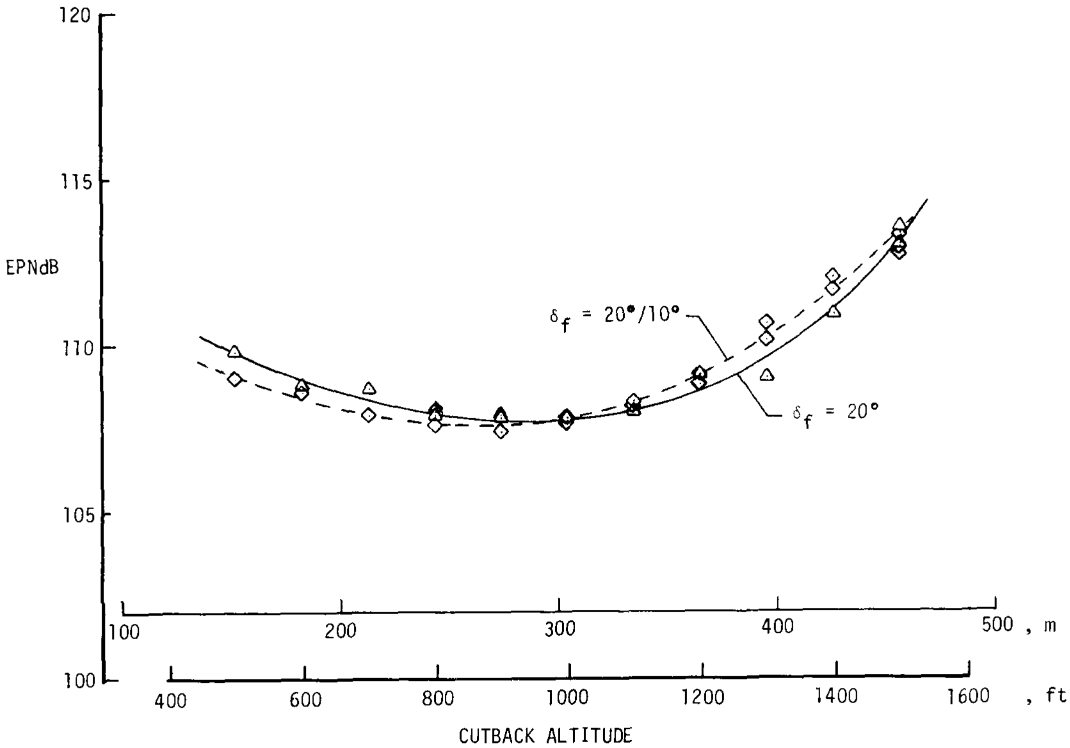


Figure 13.- Flyover effective perceived noise level as a function of cutback for two trailing edge flap schedules.

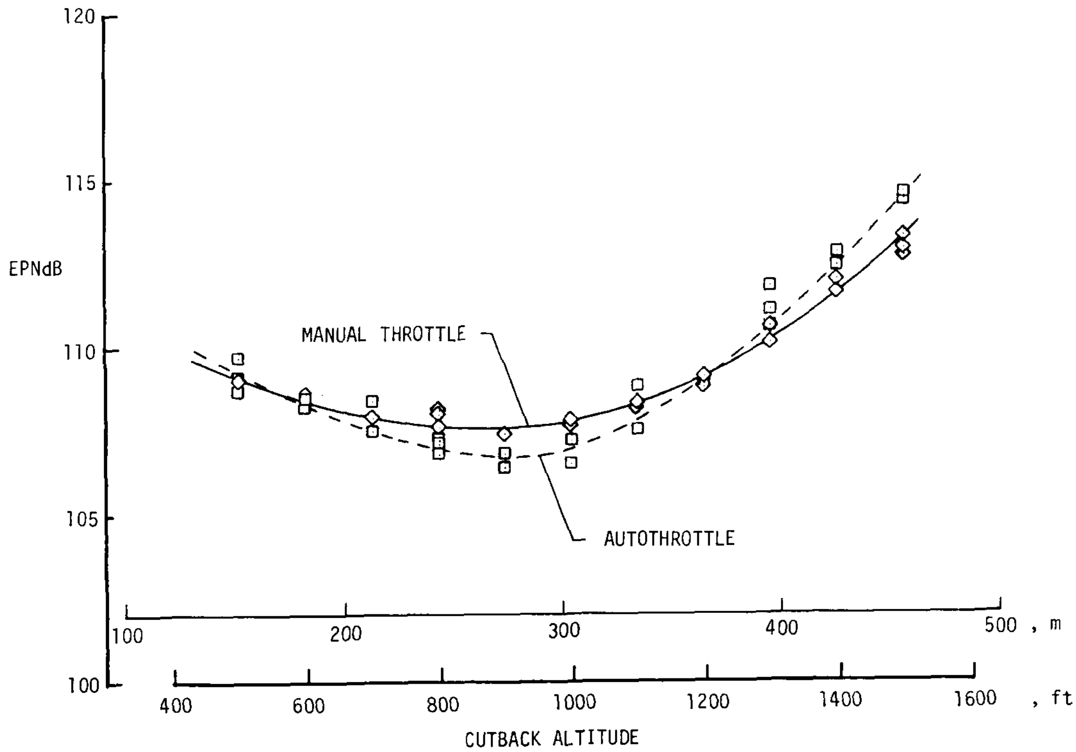


Figure 14.- Flyover effective perceived noise level as a function of cutback altitude for manual and automatic throttle operation.

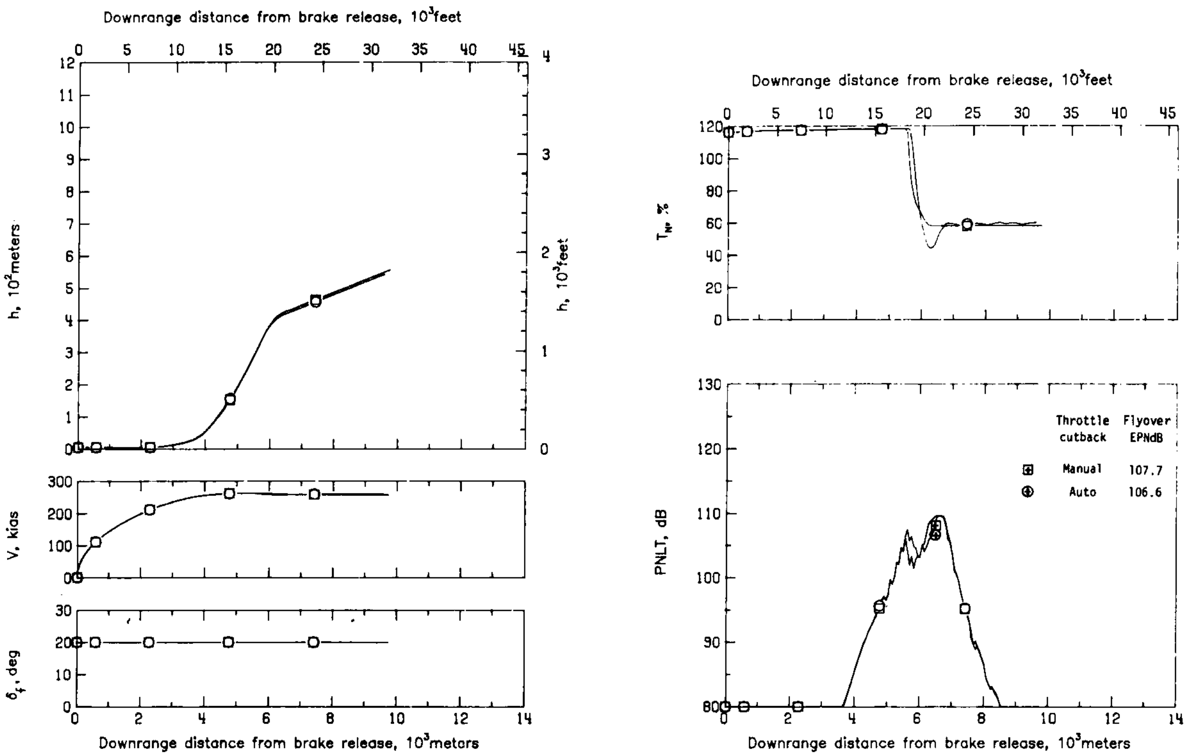


Figure 15.- Takeoff profiles and flyover noise for different cutback procedures.

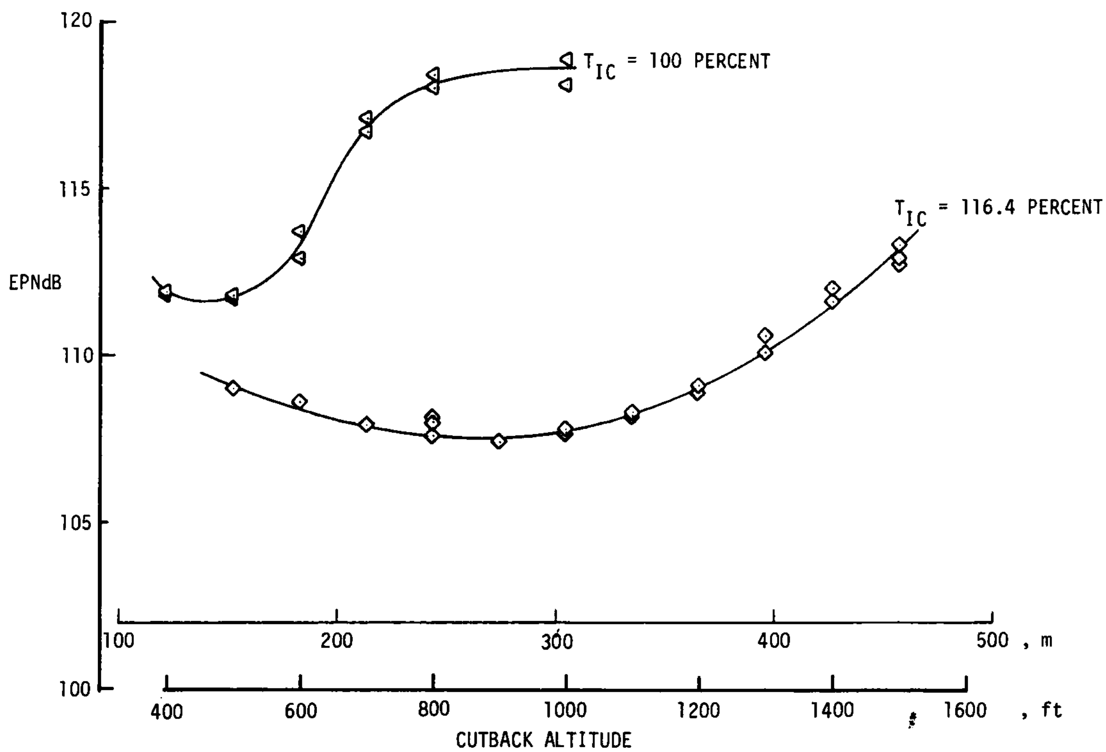


Figure 16.- Effect of cutback altitude on flyover effective perceived noise level for two initial thrust settings.

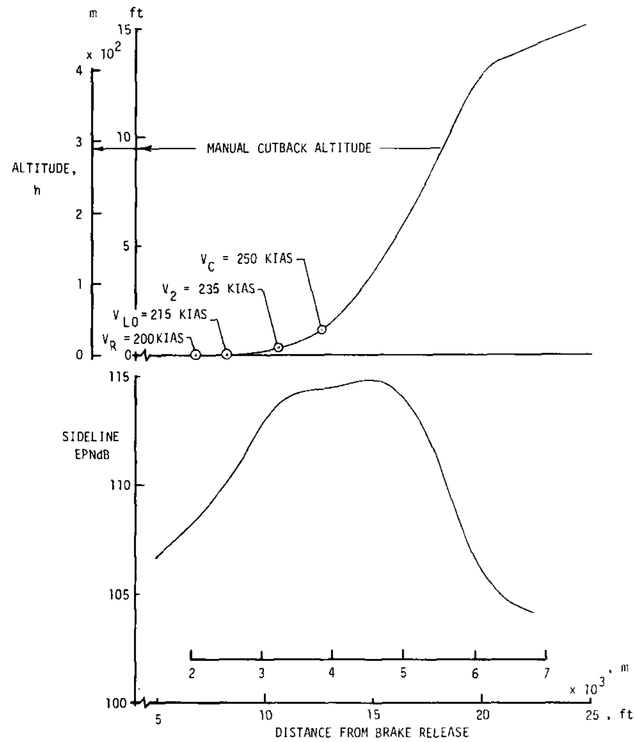


Figure 17.- Indication of altitude profile and sideline effective perceived noise level buildup during standard procedure takeoff (Flyover EPNL = 107.7 dB).

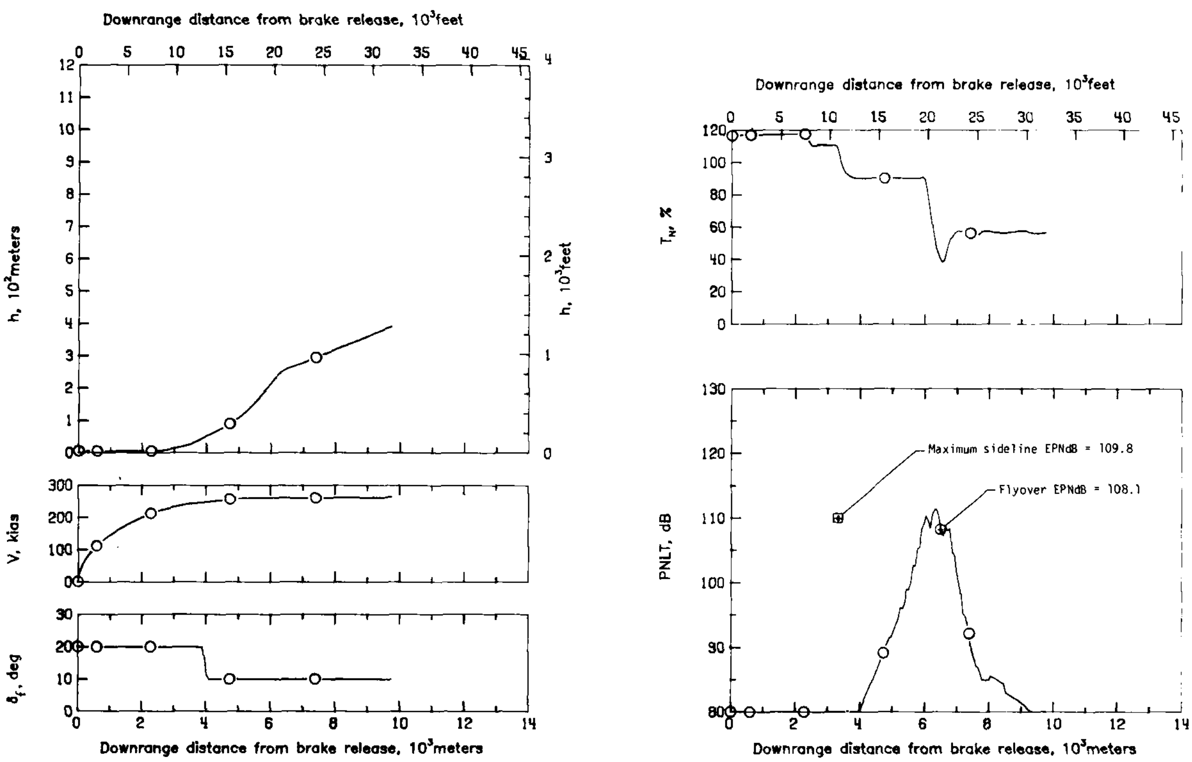


Figure 18.- Advanced procedure I takeoff and corresponding calculated sideline and flyover noise.

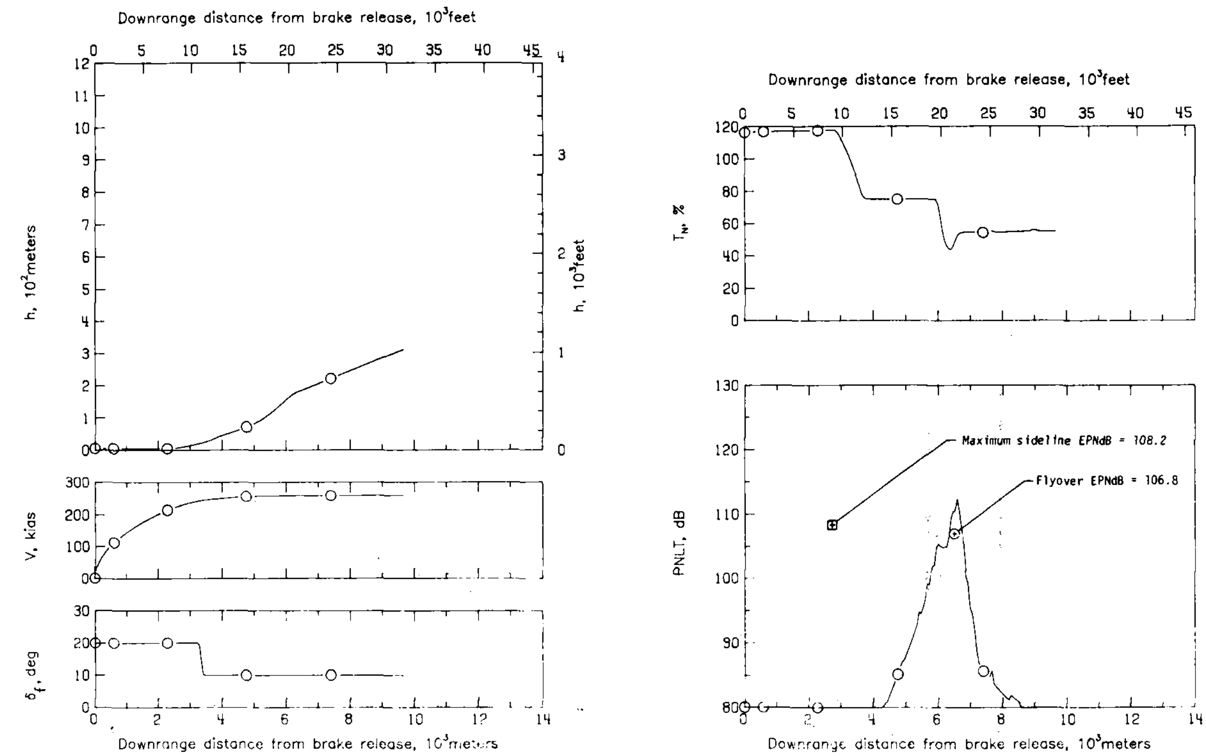


Figure 19.- Advanced procedure II takeoff and corresponding calculated sideline and flyover noise.

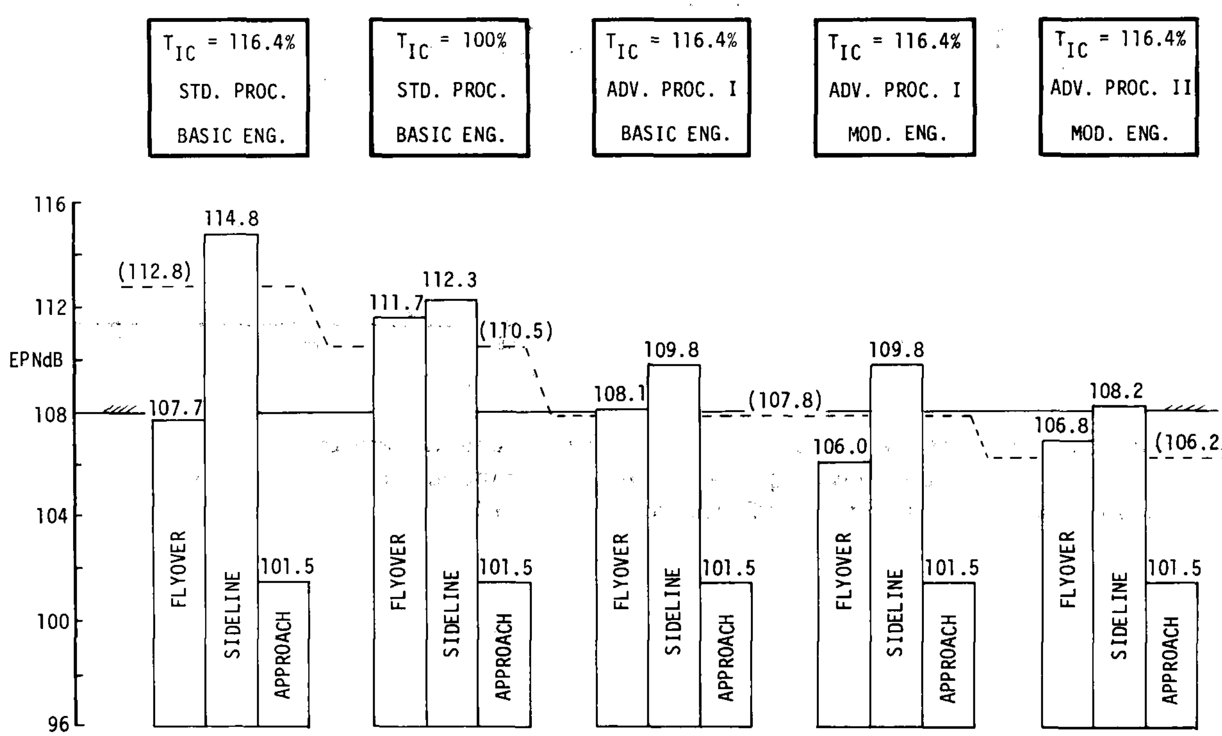


Figure 20.- Histogram of the traded noise levels calculated for the various conditions and test procedures flown. (Number in parentheses indicates traded noise levels.)

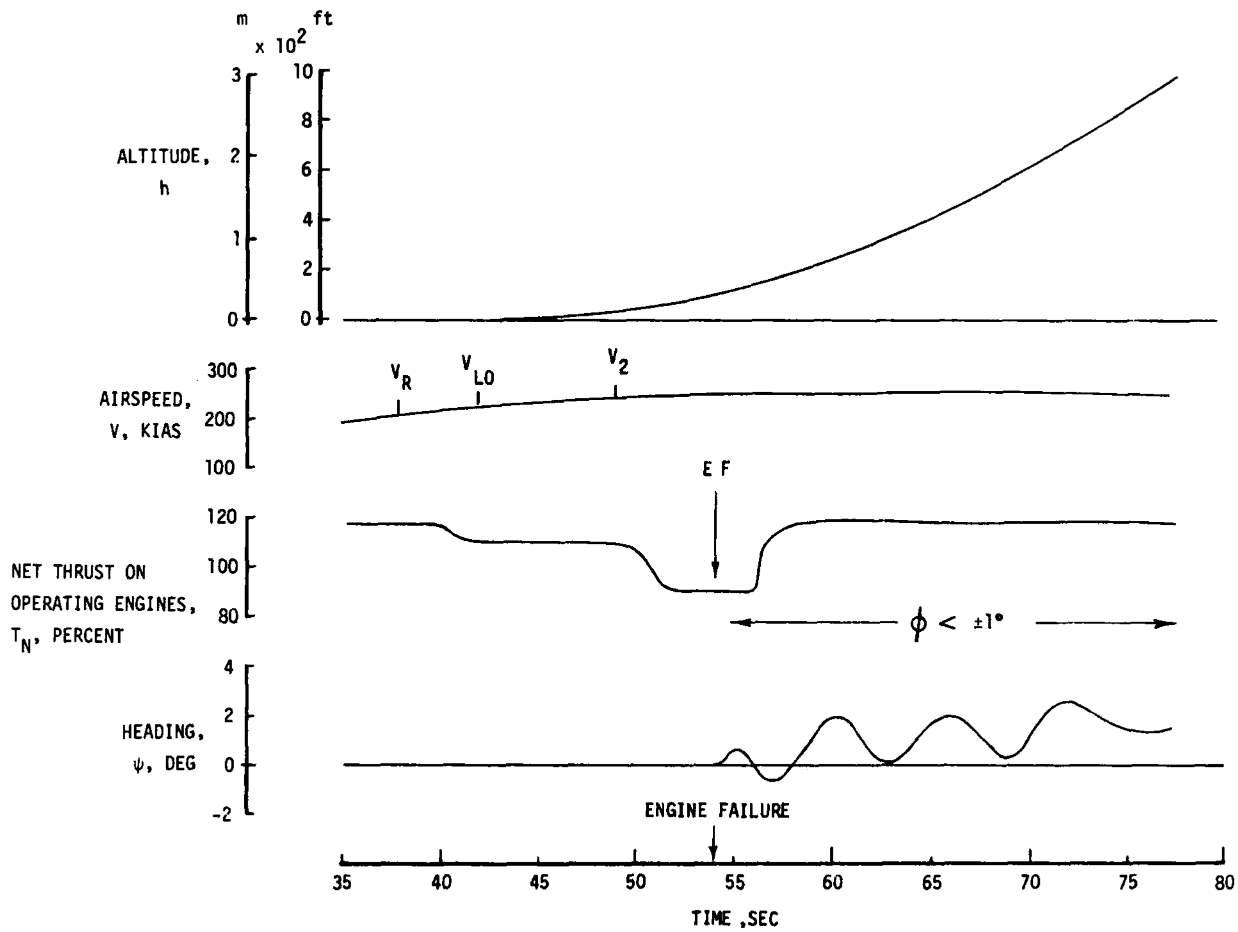


Figure 21.- Indication of bank angle and heading excursion following failure of number 4 engine while performing an advanced procedure takeoff. (Advanced procedure takeoff shown in fig. 18.)