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SUMMARY

A computer program to determine the takeoff and approach performance of an aircraft has been developed. The performance is calculated in accordance with the airworthiness standards of the Federal Aviation Regulations. The aircraft and flight constraints are represented in sufficient detail to permit realistic sensitivity studies in terms of either configuration modifications or changes in operational procedures.

Advanced operational procedures for noise alleviation such as programmed throttle and flap controls may be investigated. Extensive profile time history data is generated and is placed on an interface file which can be input directly to the NASA Aircraft Noise Prediction Program (ANOPP).

Examples of advanced takeoff procedures are presented, which indicate that throttle scheduling is effective in tailoring the flight profile and can result in noise reductions in the terminal area. Examples of advanced approach procedures indicate that significant reductions in noise level are possible.

The use of the program for in-house studies of supersonic cruise aircraft technology has afforded the opportunity to compare detailed results with those of two major aircraft manufacturers. Flight paths calculated with the present program, and using the manufacturer aircraft inputs, are in very good agreement with the flight paths computed by the individual manufacturers.

INTRODUCTION

One of the most important considerations in the design of a commercial transport aircraft is the performance during takeoff and approach operations. The aircraft must be designed to meet field length constraints in accordance with airworthiness standards specified in the Federal Aviation Regulations. In addition, the noise levels generated during these operations must be within acceptable limits.

A computer program has been developed to permit detailed performance analysis of the takeoff and approach capability of specific aircraft designs. The aircraft characteristics and flight constraints are represented in sufficient detail to permit realistic sensitivity studies in terms of changes in either configuration modifications or operational procedures. The takeoff and climbout flight-path is generated by a stepwise integration of the equations of motion. Special features include options for: nonstandard-day operation; balanced field length; derated throttle to meet a given field length for off-loaded aircraft; and throttle cutback during climbout for community noise alleviation. Advanced takeoff procedures such as programmed throttle and flap controls may be investigated to determine the effect on noise in the terminal area and over the community. Approach profiles may incorporate advanced procedures such as two segment approaches and decelerating approaches.

The program has been used for in-house studies of advanced aircraft by the Vehicle Integration Branch of the Aeronautical Systems Division at the Langley Research Center. Results of the most recent studies are reported in references 1 and 2. The advanced supersonic transport concept defined in reference 1 is the updated reference configuration for Langley studies of supersonic cruise aircraft technology. This concept, designated AST 105-1, will be used as an example throughout the description of the program features.

The noise sensitivity studies reported in references 3 and 4 were concerned with contractor aircraft concepts. An early phase of each of these studies required the calculation of takeoff and approach profiles using the present program, for the contractors' aircraft configurations. Results of these calculations indicated very close agreement with the contractor-generated flight paths even through the climbout-acceleration control-logic is different in all three programs.

Extensive profile time history data is generated, and, if noise predictions are desired, the data can be placed on an interface file which can be used directly as input data for the NASA Aircraft Noise Prediction Program (ANOPP (ref. 5)) for calculation of the preceived noise level at selected monitoring stations.

The main text of this paper describes the features and assumptions of the computer program. As each operational mode is described, examples are included to illustrate typical performance results. The Appendix contains a description of the input data required to define the aircraft as well as the input data concerned with flight-control logic and profile constraints. The Appendix also describes input data which may be used to select optional modes of calculation; (i.e., automatic determination of balanced field length and the associated V_1 speed). Input data to control both the amount and form of the output results are described. Sample output listings are included to illustrate the effect of these options.

The program core size requires $110{,}000_8$ words on a CDC CYBER 175 computer. The run time for a single takeoff profile is about 2 seconds; for a series of four balanced field-length calculations, about 10 seconds are required.

SYMBOLS

D	aircraft drag
D_R	engine ram drag
F_W	vertical landing gear force

g	gravitational acceleration
h	altitude
L	aircraft lift
L/D	aircraft lift-drag ratio
T_G	engine gross thrust
T/T_{nor}	throttle setting, thrust/thrust at normal power
T/W	thrust-weight ratio, installed sea level static thrust/gross weight
V	true velocity
V_{LO}	aircraft velocity at liftoff
V_R	aircraft velocity at rotation
V_{mc}	aircraft minimum control velocity
V_1	aircraft velocity at engine failure for balanced field length
V_2	aircraft velocity at obstacle
W	weight
W_F	engine fuel weight
W/S	wing loading, gross weight/reference area
X	horizontal distance
α	angle of attack
α_G	angle of attack during ground roll
α_R	angle of attack for rotation
γ	flight path angle
δ	thrust inclination angle
μ	coefficient of friction
ΔC_D	incremental drag coefficient

a dot over a symbol denotes its time derivative

RESULTS AND DISCUSSION

The features and assumptions of the takeoff program will be described and sample computed results will be presented for an advanced supersonic transport concept. The concept, designated AST 105-1, is defined in detail in reference 1. It is the updated reference configuration for Langley Research Center in-house studies of supersonic cruise aircraft technology. With a design takeoff gross weight of 3051 kN (686000 lb), this aircraft can transport 273 passengers over a range of 8234 km (4446 nmi) at a cruise Mach number of 2.62. The cruise Mach number is for a mission "hot day" of ISA + 8C; however, takeoff performance is calculated on the basis of a different "hot day" of ISA + 10C.

The initial emphasis will be on the description of all calculations necessary to determine the takeoff performance capability of a transport aircraft in accordance with the airworthiness standards of the Federal Aviation Regulations, Part 25 (ref. 6). Climb procedures beyond the obstacle will be described next, including the effects of aircraft acceleration and of configuration (flap) changes. The procedure for, as well as the regulations regarding, cutback of the throttle for the purpose of alleviating the noise level over the community will be discussed. Finally, certain advanced procedures will be described which indicate that noise levels during takeoff and over the community may be reduced.

Approach calculations which are conducted primarily to obtain flight-path data for noise level predictions are described in terms of the standard approach profile with both velocity and glide slope held constant, and in terms of advanced procedures involving velocity and glide slope changes.

NORMAL TAKEOFF TO OBSTACLE, ALL ENGINES OPERATING

The equations of motion and the program control logic applicable to all profile calculations will be described first. During all segments of the takeoff, the flight profile is determined by a numerical integration of the following equations of motion:

$$\dot{V} = \frac{g}{W}\left[T_G \cos(\alpha + \delta) - D - D_R - W \sin\gamma\right]$$

$$\dot{\gamma} = \frac{g}{VW}\left[T_G \sin(\alpha + \delta) + L - W \cos\gamma\right]$$

$$\dot{H} = V \sin\gamma$$

$$\dot{X} = V \cos\gamma$$

$$\dot{W} = -\dot{W}_F$$

For ground roll conditions (where $\gamma = 0$), the tangential acceleration equation includes the ground friction term and becomes

$$\dot{V} = \frac{g}{W}\left[T_G \cos(\alpha + \delta) - D - D_R - \mu F_W\right]$$

where: $F_W = W - L - T_G \sin(\alpha + \delta)$

and μ = Rolling coefficient of friction during takeoff

or μ = Braking coefficient of friction during refused takeoff

A stepwise technique is employed, wherein the step control parameter is tailored to the particular mode of flight; for example, during ground roll acceleration, the step parameter is a velocity increment; during the climbout, the step parameter is an altitude increment. The equations of motion are balanced at each flight point using an iterative technique and all specific flight events are calculated exactly. If, during the iteration for an altitude step interval, the desired value of any flight parameter is exceeded, (for example, both climbout velocity and the distance from brake release) the step control parameter interval is automatically modified to just meet the desired velocity or distance (whichever occurs first). The control parameter for the step following the occurence of a specific event is determined automatically by internal control logic.

The takeoff distance for a turbine engine powered transport airplane is defined in section 25.113 of reference 6. The distance is the greater of: the horizontal distance along the runway required to reach the 10.7 m (35 ft) obstacle, after experiencing a failure of the most critical engine at a specified velocity V_1; or, 115 percent of the horizontal distance to the obstacle with all engines operating. The engine failure speed V_1 is selected such that the takeoff distance to the obstacle is equal to the distance required to bring the aircraft to a complete stop on the ground. The distance obtained under this rule is referred to as the balanced field length. It should be noted that the above definition is not directly applicable to aircraft powered by reciprocating engines. The performance standards for that type of aircraft are defined in sections 25.45 through 25.75 of reference 6, and these sections should be reviewed before attempting to calculate takeoff performance with the present procedure.

The takeoff procedure to the obstacle with all engines operating can best be described by referring to the sample results presented in figure 1. The figure shows the variation of flight altitude, flight velocity and aircraft angle of attack with the distance from brake release. Symbols are used to indicate the major events as they occur along the path. After brake release, the aircraft accelerates along the ground, at the ground-roll angle of attack α_G and the takeoff flap setting, until the velocity to begin rotation V_R is reached. At V_R, the aircraft begins to rotate at a given rate toward the limiting rotation angle of attack α_R. The selection of α_R is generally based on a "tail-scrape" restriction, but it also must not exceed the angle associated with the minimum control speed of the aircraft. As the aircraft accelerates with the angle of attack increasing, a point will be reached where the combination of dynamic pressure and lift coefficient is sufficient to lift the aircraft from the surface. This point is determined exactly by iteration for the velocity where the normal acceleration is equal to zero. From brake release to this velocity, the normal acceleration has been at a negative but increasing level. The velocity at this point is referred to as the liftoff velocity V_{LO}. For minimum takeoff distance, liftoff usually occurs before the aircraft attitude reaches α_R. As the aircraft leaves the ground and begins the transition climb to the obstacle, the landing gear is retracted and the ground effect decreases with increasing altitude. The drag coefficient representing the gear drag may be decreased linearly with time or held at the fully extended gear-drag level for the entire time interval required to retract the gear. Although the second option is perhaps more representative of actual operation, the examples presented herein utilize the first option. The ground effect on the aerodynamic characteristics is reduced linearly with altitude until the altitude at which ground effect becomes negligible is reached. At intermediate altitudes, this procedure results in ground effect which is too great, but it is believed to have only a small effect on the calculated takeoff performance. An alternate method of treating the ground effect is discussed in the input section.

When the aircraft completes the acceleration and climb to the obstable, its velocity is termed V_2, and the corresponding distance from brake release is the takeoff distance. The performance data shown in figure 1 are for a full power takeoff of the AST 105-1 configuration at the design takeoff weight of 3051 kN (686000 lb). For an assumed V_R of 94.7 m/s (184 kt), the resulting V_2 is 104.9 m/s (204 kt) with a takeoff distance of 3000 m (9842 ft). In this paper, the takeoff distance increased by 115 percent is referred to as the takeoff field length. The takeoff field length for the full-power example of figure 1 is 3450 m (11318 ft).

Takeoff field length as a function of the velocity at rotation V_R is shown in figure 2 for two values of the rotation angle α_R. The minimum field length with the limiting α_R of 8° occurs at V_R of about 92.6 m/s (180 kt). The variation of field length with V_R is discussed in detail by Hall in reference 7. In general, if the aircraft rotates too soon, the dynamic pressure is insufficient for the aircraft to lift off, and it must accelerate in a high-drag condition to reach liftoff speed. This consumes a greater amount of runway during the ground roll and results in a long takeoff field length. Late rotations (at higher velocities) improve the climbout capability from liftoff to the obstacle, but consume more runway during the acceleration to the higher speeds. The trend with V_R is the same for the lower value of α_R, which may be considered as representing an inadequate rotation. At low rotation velocities, the increased field lengths for reduced α_R are the result of greater acceleration distances to the higher liftoff velocities required because of the lower lift coefficients. At high velocities for rotation, the increased field lengths are caused by greater climbout distances resulting from the reduced lift coefficient. The regulations of reference 6 specify that V_R may not be less than: the engine failure speed V_1 which establishes the balanced field length; or 105 percent of V_{mc}, the minimum control speed of the aircraft. The limitation with respect to V_1 is contained in the program, and it is discussed in the description of balanced field calculations. The V_{mc} limitation is not considered in the program and must be controlled by the user. The limitation on V_{mc} is required because of concern over the adequacy of control in yaw in the event of an engine failure (section 25.149 of ref. 6).

FIRST AND SECOND SEGMENT CLIMB GRADIENTS

For each rotational velocity, after calculations of takeoff field length are completed, the first and second segment gradients are computed. These are minimum climb gradients, depending on the number of engines on the aircraft, which must be available to satisfy the regulations of reference 6. The first segment gradient is computed at V_{LO}, with one engine out, gear extended, and out of ground effect. The second segment gradient is computed at V_2, with one engine out, gear up, and out of ground effect. The required gradients (see Table I) are built into the program logic, and, if appropriate levels are not met, the output will so indicate. For the results shown in figure 2, with $\alpha_R = 8^0$, values of V_R less than 92 m/s (175 kt) do not meet the first segment climb gradient requirements.

BALANCED FIELD LENGTH

The balanced field length is the actual takeoff distance in the event of an engine failure at velocity V_1, where V_1 must be determined so that the engine-out takeoff distance to the obstacle is equal to the engine-out refused takeoff distance. First, the procedure for calculating both the engine-out takeoff distance and the refused-takeoff distance will be described for an arbitrary value of the engine failure velocity V_1. Then the technique employed to determine the value of V_1 that balances the two distances will be described.

The engine-out takeoff distance to the obstacle is calculated in the same manner as the normal takeoff. The only differences are the loss in total engine thrust and the drag of the failed engine. Figure 3 shows the variation of total engine thrust for a four engine aircraft with time and defines the events as they occur during engine-out operations. The figure is schematic in that the variation of engine thrust with both speed and altitude is not depicted. Beginning at the time of engine failure, the thrust of the failing engine is assumed to decrease linearly to zero in a given interval of time. During this time interval, an engine-out drag coefficient is added to the basic aircraft operating drag coefficient. The engine-out drag increases linearly from zero to the full engine-out level. At the end of the engine-failure interval, the calculations are continued to the obstacle with the total available thrust at the reduced level indicated by the circular symbols and including the full engine-out drag. The resulting distance to the obstacle is referred to as the engine-out takeoff distance.

The engine-out refused-takeoff distance is calculated considering several additional events. From the time of the engine failure, there is a time interval referred to as the pilot recognition time before any action is taken by the aircraft crew. After this time interval, the thrust level of the operating engines is reduced to the ground-idle thrust condition. The thrust is reduced linearly with time over a specified time interval. The resulting thrust variation with time is indicated by the square symbols in figure 3. The remainder of the refused takeoff is calculated at this reduced thrust level. No thrust reversal or other external drag effects due to engine operation are considered. The application of wheel brakes and of spoilers to decrease lift and increase drag is controlled by separate time intervals, each measured from the time of pilot recognition. The distance required for the aircraft to come to a complete stop is called the refused-takeoff distance.

The engine-out takeoff distance and the refused-takeoff distance have been calculated as a function of engine-failure speed and the results are shown in figure 4. In this case V_R was assumed to be 94.7 m/s (184 kt); thus, the highest assumed engine-failure speed is less than V_R. The takeoff distance decreases as the failure speed is increased because a shorter amount of time is spent at reduced thrust levels; however, the refused-takeoff distance increases because greater momentum must be absorbed in decelerating to a stop. For the example of figure 4, the pilot knows in advance of the takeoff that, if an engine fails at a velocity lower than 92.1 m/s (179 kt), he must abort the takeoff and stop the aircraft on the ground. If an engine fails at a velocity greater than V_1, he must continue the takeoff with the reduced thrust capability. By following these procedures, he will never exceed the balanced field length.

Options are available in the program to compute the engine-out distances for a single value of engine-failure speed or to automatically search for the particular failure speed V_1 that results in a balanced field length, for a given V_R. In addition, the program will repeat this search procedure for a given series of velocities at rotation. The variation of balanced field length with V_R is shown in figure 5. This figure also shows the effect of V_R on the takeoff field length (115 percent of all-engine distance). The FAR field length must be the greater of these two distances at each value of V_R. The minimum FAR field length of 3432 (11260 ft) occurs where the two curves cross at $V_R = 93.7$ m/s (182.2 kt). The FAR field length of 3450 m (11320 ft) quoted for this aircraft in reference 1 was obtained with an arbitrarily selected V_R of 94.7 m/s (184 kt) and it is consistent with the results shown in figure 5.

DERATED THROTTLE TAKEOFF

This aircraft configuration can be operated with a reduced or derated throttle setting, selected such that the all-engine takeoff-field length just meets a desired field length. Such reduced-thrust operation could be advantageous from the standpoint of either increased engine life or reduced noise in the terminal area. An option is available in the program to search for the derated throttle level and the appropriate V_R for any specified field length. For the example aircraft, a field length of 3810 m (12500 ft) can be met with the throttle set at 92 percent of the normal full-throttle level. The calculations with derated throttle do not consider engine-out field-length requirements. It is assumed that, in the event of an engine failure, the operating engines would be returned to the full-power thrust level so as to attain an engine-out takeoff field length less than the available field length. Under current operational rules, the initial throttle setting on a four engine aircraft cannot be changed during takeoff and climbout until an altitude of 213 m (700 ft) is attained. (For an aircraft with less than four engines, this altitude restriction is 305 m (1000 ft)). The effect of this rule on both climbout performance and noise level at the flyover point will be discussed in a later section of this paper entitled "Throttle Cutback Above the Community".

CLIMBOUT BEYOND THE OBSTACLE

Climbout beyond the obstacle includes acceleration to a climbout velocity which may be specified either in terms of an increment above V_2 or as a specific velocity. Current Air Traffic Control (ATC) practice is to accelerate to at least V_2 + 5.15 m/s (10 kt). The maximum climbout speed is 128.7 m/s (250 kt), which cannot be exceeded below an altitude of 3048 m (10000 ft).

Two control options are available within the program during the acceleration; one option is to hold the aircraft angle of attack constant, and the other is to hold the aircraft floor-angle constant. The latter option permits the aircraft angle of attack to be reduced as the flight path angle increases during the climb and acceleration. For the supersonic cruise design used herein as an example, the reduction in angle of attack allows the aircraft to operate at higher levels of lift/drag ratio L/D, thus improving the climbout performance. For an aircraft design which lifts off at an angle of attack close to the maximum L/D, the constant angle of attack control option would provide better climbout performance.

Once the climbout velocity is attained, the remainder of the climbout is conducted at constant velocity. During this portion of the climb, both angle of attack and flight path angle are adjusted to maintain zero tangential acceleration. Within the program, the iteration technique is designed to attain the highest possible altitude consistent with the available excess power. The climb may be terminated at any desired altitude or distance from brake release.

Figure 6 presents climbout profiles for the example aircraft with climbout velocities varying from V_2 plus 5.1 m/s (10 kt) to the maximum value of 128.7 m/s (250 kt). All profiles are for V_R = 94.7 m/s (184 kt) with a resulting V_2 of 105 m/s (204 kt), 2998 m (9836 ft) from brake release.

As the aircraft reaches a desired velocity, the portion of the excess power that had been used to accelerate is available to climb. Beyond this point, indicated for each velocity by tic marks in figure 6, the increase in slope is a direct result of the increased rate of climb. As the specified climbout velocity is increased, a greater amount of the available energy must be expended to accelerate rather than to climb, and, as a result, the flight altitudes are lower. Along the lowest profile, the aircraft is accelerating toward the maximum velocity of 128.7 m/s (250 kt). The velocity above a point 6482 m (3.5 nmi) from brake release is 120 m/s (234 kt). The height of the aircraft above this point is of interest in that it is one of the stations (often referred to as the flyover station) specified in FAR 36 (ref. 8) for monitoring noise. The effect of accelerating to the highest velocity shown is to reduce the altitude above the flyover station by about 70 m (230 ft). The primary advantage of accelerating to higher velocities is that, for this aircraft, the lift-drag ratio is improved by operating at the low lift coefficients required at the higher speeds. The selection of climb velocity is configuration dependent; for the example aircraft, L/D increased from 7.3 to 8.5 as climbout velocity increased.

Above an altitude of 122 m (400 ft), the regulations permit a change in aircraft configuration for purpose of improving the aerodynamic efficiency L/D during climbout. The example aircraft was already at the best flap setting for climbout during the takeoff so that no change was desired; however, an aircraft that requires a high flap setting to develop sufficient takeoff lift would benefit from a flap reduction at altitude to improve climbout L/D.

THROTTLE CUTBACK ABOVE COMMUNITY

The regulations of references 6 and 8 permit engine cutback for the purpose of noise alleviation over the community. The engine throttle setting used during the takeoff must be maintained until the aircraft reaches an altitude of 213 m (700 ft). (For aircraft with less than four engines, this altitude restriction is 305 m (1000 ft).) Above this altitude, throttle reductions are limited by the required minimum climb gradients. With all engines operating, a climb gradient of at least four percent must be maintained. In the event of an engine failure, the gradient must be equal to or greater than zero (level flight). The allowable cutback is limited so that the engines will provide sufficient thrust to meet the most critical requirement.

Within the program, throttle cutback is initiated when the aircraft reaches either a desired altitude or a desired distance from brake release. If the desired distance is reached before the limiting altitude of 213 m (700 ft) is attained, climbout continues until that altitude is reached before cutback is initiated. At cutback, the throttle setting, as limited by the gradients described above, is calculated, and climbout is continued with the reduced level of thrust. The high and low altitude profiles of figure 6 have been calculated with throttle cutback initiated at a distance of 5944 m (19500 ft) beyond brake release. The resulting profiles are shown in figure 7. The high profile with no cutback is shown for comparison. The aircraft climbing at a velocity of 110 m/s (214 kt) has an L/D of 7.3 at the cutback point, and the throttle can be reduced to 77 percent of the normal climb thrust. The aircraft achieves an altitude of 311 m (1020 ft) above the flyover monitor station. The accelerating aircraft has a velocity of 118 m/s (230 kt) and L/D of 8.3 at the cutback point. It can be throtttled to 67 percent thrust (primarily because of the better L/D), but arrives at an altitude of only 250 m (820 ft) above the flyover monitor. The effect of the higher velocity climbout technique is to reduce the altitude above the flyover monitor by 61 m (200 ft) but to permit the throttles to be cutback an additional 10 percent. The overall effect on the noise at the flyover station will be shown later to be beneficial.

The control logic within the program for continued climbout is to maintain the cutback-throttle-setting climb-gradient. Due to the normal thrust decay with increasing altitude, the forward velocity will decrease slightly (about 2.5 percent per 305 m (1000 ft) of altitude for the sample aircraft). If the calculation must be extended to greater distances, the program logic could be modified to allow the throttle setting to be increased with altitude so that both climb gradient and velocity could be maintained.

The noise sensitivity studies reported in references 3 and 4 were concerned with contractor aircraft concepts. An early phase of each of those studies included the calculation of takeoff and approach performance using the present program for the aircraft configuration inputs of the contractor. A comparison of the results of these calculations with those of each contractor permitted a calibration of the accuracy of the present program. The calculated performance for the approach and for the takeoff to the obstacle were in excellent agreement with results of each contractor. A direct comparison of the climbout flight-paths was not possible because each of the three programs employs a different flight-control logic to accelerate and climb beyond the obstacle. With the climb velocity schedule of each contractor matched as closely as possible, the flight path altitudes were in good agreement with the contractor profiles.

For the three takeoff profiles of figure 7, calculations have been made of the predicted noise levels in accordance with the procedures specified in FAR Part 36 (ref. 8). These regulations define three measurement stations for the noise certification of four-engine turbojet-powered aircraft. The stations are located on the centerline of the runway at a distance from brake release of 6.5 km (3.5 nmi); at a sideline distance of 648 m (0.35 nmi) at the point where the noise is the greatest; and under the approach profile at a distance of 2 km (1 nmi) from touchdown. These monitoring stations are referred to as the flyover, sideline, and approach points, respectively. For aircraft with less than four engines, the specified sideline distance is 463 m (0.25 nmi).

The noise calculations were made using the NASA Aircraft Noise Prediction Program (ANOPP)(ref. 5). The present program generates a data file which contains selected vehicle descriptive data, and the variation with time of 29 flight profile and propulsion parameters. The profile parameters define the aircraft weight, position, orientation, and velocity at each flight point. Sufficient propulsion parameters are available to define the engine airflow, jet areas, jet velocities, pressure ratios and jet temperatures for an advanced dual-stream engine. A listing of the time-dependent parameters is given in Table II. This data is stored at two-to-three-second intervals along the flight profile to provide a detailed time-history of each parameter. The time-history files are used as input data to the ANOPP program, in order to generate time-dependent one-third-octave-band spectra at a series of noise observer positions. The spectra are then integrated to obtain perceived noise and effective perceived noise at each observer station. ANOPP includes prediction modules for the major noise sources (i.e., jet noise, shock noise, fan noise, and airframe noise). Only jet noise will be used herein to indicate noise levels and potential reductions as a result of operating procedures. During takeoff, the most significant source is the jet noise. During approach, the fan noise would be the predominant source of noise if it were not suppressed. The results presented herein assume that the fan noise will be suppressed to a negligible level by use of inlet shielding and suitable duct liners. The airframe noise during takeoff and approach operations was sufficiently lower than other sources that it was neglected.

For the upper-most profile of figure 7 (climbing at a velocity of 110 m/s (214 kt) with no cutback), the maximum sideline noise level in EPNdB is 114.8 db and the flyover noise is 119.8 db. When the throttle is cutback at a distance of 5944 (19500 ft), the corresponding noise levels decreased to 113.6 dB and 115.8 dB. The maximum sideline noise occurs at a distance of 6096 m (20000 ft) for the first profile, and at 4572 (15000 ft) for the profile with cutback. The noise reduction at the sideline station indicates the relatively distant influence of the throttle cutback. The reduction of 4 EPNdB at the flyover station is a result of the reduced throttle setting after cutback, and it indicates that the reduced throttle setting has a greater influence than the lower altitude. For the lowest profile (accelerating to 118 m/s (230 kt) at the cutback point), the maximum sideline noise level is 112.6 EPNdB occuring at a distance of 3810 m (12500 ft) from brake release. The flyover noise is 113.4 EPNdB, a reduction of 2.4 dB with respect to the lower velocity profile with cutback, and a reduction of 6.4 dB with respect to the profile with no cutback. These significant noise reductions emphasize the advantages of accelerating climb profiles incorporating throttle cutback. For a given aircraft, there are limits to this procedure in that further throttle reductions or aircraft accelerations result in lower altitudes. In some cases, the aircraft will be below the minimum cutback-altitude of 213 m (700 ft) when it is over the flyover station. An example of this effect is the takeoff, mentioned earlier, incorporating reduced throttle (92 percent) to just meet the design field length. When the aircraft accelerates to 115 m/s (223 kt) during climb, the altitude above the flyover station is only 195 m (639 ft); however, the engines cannot be cutback until the aircraft is 254 m (834 ft) beyond the flyover station. Although the sideline noise level for this procedure is 111.5 EPNdB, the flyover noise increases to 121.7 dB because of the combination of the late cutback and the lower altitude.

ADVANCED TAKEOFF PROCEDURES

The advanced procedures considered herein incorporate programmed variations of throttle setting and flap configuration during the entire takeoff from brake release to termination of the climbout. The results of an initial application of these procedures indicate that there are benefits in terms of noise alleviation at the sideline and flyover monitoring stations.

The advanced procedures considered in this paper do not conform to current FAR safety and noise certification regulations since they involve programmed changes in the aircraft and engine configuration during takeoff and climbout. Furthermore, since certain combinations of configuration and thrust will not meet current criteria in the event of engine failure, it is assumed that automated systems could return the aircraft immediately to a safe condition in an emergency. Only such cases are considered herein. It is clear that future aircraft will incorporate digital computers which could perform such functions, provided that thorough investigation proves the operational safety of the procedures. The main purpose of this phase of the study is to illustrate the possible benefits to both airlines and the public of considering possible future regulatory changes.

The example aircraft is the same as in the prior discussion and the climbout velocity is always chosen to be V_2 plus 5.1 m/s (10 kt). Flap variations will not be considered because the reference profile incorporates a flap setting of 20^o which already develops the best L/D. Throttle cutback will begin when the aircraft reaches a distance of 5944 m (19500 ft) unless limited by the altitude restriction. The reference profile is the high profile (with cutback) of figure 7. This profile was calculated using normal takeoff power, and, it resulted in noise levels of 113.6 EPNdB at the sideline and 115.8 EPNdB at the flyover station. This profile is shown as procedure A in figure 8. The throttle variation is shown as a ratio to the normal throttle setting. For the reference profile, the throttle is held at the normal level (1.0) throughout takeoff and climbout and is cutback to 78 percent.

For the lowest profile (procedure B), the takeoff throttle is set at 92 percent to just meet a field length of 3810 m (12500 ft). This throttle setting is maintained until the throttles are cut back to 79 percent at a distance of 6355 m (20850 ft). The altitude above the flyover monitor is only 219 m (720 ft). The derated takeoff and climbout throttle setting results in a low sideline noise level of 111.5 EPNdB; however, because of the low altitude above the flyover monitor, the noise level there is 118.6 EPNdB. Of all the procedures to be described, this profile results in the lowest sideline noise level and the high flyover noise level.

The highest profile of figure 8 (procedure C) is developed by operating the engines at an increased level of thrust during the takeoff and climbout. The higher level of thrust (approximately a 16 percent increase) is developed by operating the engines at the maximum operating temperature. (The normal throttle setting for this engine is actually a derated thrust level selected to maintain the best ratio for the jet velocities in the primary and secondary streams. The jet velocity ratio is a significant factor in the determination of the coannular noise relief of the jet streams.). By operating the engines at the higher thrust level, the benefit of the coannular noise relief is reduced, but the aircraft has superior takeoff performance. The aircraft reaches the obstacle at 2940 m (9640 ft) from brake release, 509 m (1670 ft) sooner, and with a velocity 2 m/s (4 kt) greater than the aircraft utilizing normal takeoff thrust. The aircraft is at an altitude of 524 m (1720 ft) above the flyover monitoring station. This procedure results in the highest level of sideline noise 116.2 EPNdB, but the lowest flyover noise level of 112.6 EPNdB.

The noise results for the profiles on figure 8 indicate that, by employing a derated throttle takeoff, the sideline noise level can be reduced by 2.1 EPNdB, but that the corresponding flyover noise is increased by 2.8 EPNdB. By increasing the takeoff thrust, the flyover noise can be reduced by 3.2 EPNdB accompanied by an increase in the sideline noise of 2.6 EPNdB. The climb procedure for this aircraft can be tailored to reduce the noise level that is most sensitive at any particular airport.

Neither of the foregoing procedures varied the throttle setting below the limiting altitude of 213 m (700 ft). The following discussion will present procedures that do employ throttle variations in an attempt to reduce the noise levels at both monitoring stations.

The three procedures (D, E, and F) shown in figure 9 employ throttle variations. All three takeoffs utilize maximum takeoff thrust (1.16) during ground roll and until the aircraft reaches the obstacle. As the aircraft climbs from the obstacle to an altitude of 61 m (200 ft) the thrust levels for the three procedures are reduced linearly with altitude to values of 1.05, 1.0, and 0.90 for procedures D, E, and F, respectively. The higher thrust levels of procedures D and E are retained throughout the climb until cutback is initiated at a distance from brake release of 5944 m (19500 ft). For procedure F, the thrust level of 0.90 is maintained until the aircraft reaches an altitude of 91 m (300 ft); then it is increased to 1.0 at an altitude of 122 m (400 ft). Then this normal thrust level is maintained until the cutback point is reached. The thrust levels and altitudes for these three procedures were arbitrarily selected in an effort to determine their effect on both sideline and flyover noise levels. The initial thrust reductions above the obstacle were made in the hope of counteracting the usual sideline noise level increase as the aircraft climbs to altitudes where the ground shielding effects decrease. The thrust increase from the lowest level of procedure F was incorporated to improve the climbout performance; the location of the thrust increase was assumed to be beyond the point of maximum noise on the sideline. The climb profiles reflect the thrust schedules in that lower thrust results in lower altitudes at any given distance from brake release. The altitudes above the flyover monitoring station for procedures D, E, and F are 442, 396, and 369 m (1450, 1300, and 1210 ft) respectively.

The noise levels for these programmed throttle procedures are shown in figure 10 for the sideline and the flyover stations. For comparison, the noise levels for the fixed throttle procedures discussed earlier are also shown.

The sideline noise levels for procedures D, E, and F are 115.1, 114.0, and 113.4 EPNdB, indicating a reduction in noise with reduced climbout thrust. All procedures have a lower noise level than the takeoff procedure which maintained the thrust level of 1.16 throughout the climb. The noise level of procedure F is slightly lower than that of the takeoff with normal thrust. For all procedures discussed in this section, the maximum sideline noise level occurred at a distance of 4570 m (15000 ft) from brake release. If the throttle increase of procedure F, which began at approximatley 3660 m (12000 ft) from brake release, had been delayed, the sideline noise level might be lower; however, the anticipated improvement might be lost because of the lower flight path.

The flyover noise levels for the three programmed throttle procedures, D, E, and F are 113.2, 113.5, and 113.9 EPNdB respectively. All procedures have a lower noise level than that of the normal thrust takeoff; but, due primarily to lower climbout altitude, have higher noise levels than for the takeoff which maintained the thrust level of 1.16.

The average of the sideline and flyover noise levels for each procedure is indicated by the tic mark on the bars of figure 10. Based on these average values, procedure F has the lowest noise levels of all procedures investigated.

The present results indicate that there are benefits in terms of sideline and flyover noise levels by incorporating advanced procedures. The results presented herein are crude since no attempt has been made to optimize the variations of the parameters investigated. Changes in other operational parameter such as the V_R, the climbout speed, or the location of the cutback point (or combinations of these) may result in further noise reductions. The intent of this section is to demonstrate, using initial results, how the program can be utilized to evaluate noise alleviation procedures.

STANDARD APPROACH PROFILE

The standard approach is a constant velocity descent along a 3° glide slope terminating at a 15.2 m (50 ft) obstacle at the end of the runway. The performance is calculated at two points along this glide path. The first (outer) flight point is arbitrarily selected to be 11.1 km (6 nmi) from the obstacle. For the standard glide slope, this point is at an altitude of 598 m (1960 ft). The second (inner) flight point is above the noise monitoring station 1.84 km (1 nmi) from the obstacle. The altitude at this point is 112 m (368 ft). At each of these points, the equations of motion are balanced in an iterative manner to determine the required throttle setting for a steady glide. This may be done for either a given velocity or a given aircraft angle of attack. The aircraft flap setting may be different for each point. If it is desired to determine an optimum setting, the flap angle must be treated as a parameter in a series of cases. The safety regulations (ref. 6) limit the approach speed to not less than 1.3 times the aircraft stall speed. The maximum speed limit of 128.6 m/s (250 kt) in the terminal area also applies during approach operations.

The variation of L/D and throttle setting with approach velocity during constant glide-angle approaches are shown in figure 11 for two flap settings. The calculations were made for the design landing weight of the AST 105-1 aircraft and represent the average conditions between the two chosen points. The increased L/D of the lower flap setting results in lower required throttle settings at all velocities. Low approach speeds are preferred from a standpoint of reduced touchdown speed and shorter landing distance. The minimum approach speed for the example aircraft is limited to 81 m/s (158 kt) by a requirement for adequate roll control in a 15 m/s (30 kt) crosswind.

Time history data along the approach profile between the two computed points is synthesized using the average flight conditions (velocity and altitude) of the two points. Time history data between the inner flight point and the obstacle are synthesized based on the results computed at the inner point by maintaining a constant velocity during final approach. The noise level is predicted at a station directly under the aircraft at a distance of 1.8 km (1 nmi) from the end of the runway. The noise level when approaching at a constant velocity of 81 m/s (158 kt) is 106.5 EPNdB. This will be used as the reference approach for the advanced procedures, to be described in the following section.

ADVANCED APPROACH PROCEDURES

The procedures considered incorporate increased glide slopes and decelerations from the outer to the inner point. All approaches are for a flap setting of 20° and all have a velocity of 81 m/s (158 kt) at the obstacle. The variation of aircraft altitude, velocity, and throttle setting with the distance to the obstacle are shown in figure 12 for three approaches. The first is the standard, constant velocity approach on a 3° glide slope. The second and third are decelerating approaches on 3° and 6° glide slopes. For the decelerating approaches, the initial velocity above the station 11.1 km (6 nmi) from the obstacle is limited by the minimum thrust level of the engines (approximately 21 percent of normal rated thrust). For the 30° glide slope, the initial velocity is 117 m/s (227 kt) and, for the increased glide slope angle, the initial velocity is 86 m/s (168 kt). These two velocities were calculated with the assumption that drag-producing flaps ($\Delta C_D = 0.01$) would be used throughout the approach. the thrust required for the decelerating approach is determined by assuming a constant deceleration between the outer and the inner points. The resulting throttle level is about 10 percent lower than for the standard approach. The decelerations continue to an arbitrarily selected point 305 m (1000 ft) from the obstacle in an effort to maintain the low thrust level achieved at the 1.8 km (1 nmi) noise monitoring station. Between the inner station and the obstacle, the throttle setting returns to the higher level to permit the final approach at constant velocity. This increase in throttle setting is not as noticeable for the steeper guide slope since the throttle change is smaller because of the smaller deceleration.

The predicted noise level for the decelerating approach at the standard glide angle is 99.9 EPNdB, a reduction of 6.6 EPNdB. The noise level for the steeper decelerating approach is 96.6 EPNdB, a total reduction of 9.9 EPNdB. These two examples of advanced procedures indicate that decelerating approaches can significantly reduce the noise at the monitoring station to levels where other noise sources (i.e. fan, airframe) must be accounted for in the noise predictions.

CONCLUDING REMARKS

A computer program to determine the takeoff and approach performance of an aircraft has been developed. The performance is calculated in accordance with the airworthiness standards of the Federal Aviation Regulations. The aircraft and flight constraints are represented in sufficient detail to permit realistic sensitivity studies in terms of either configuration modifications or changes in operational procedures.

Extensive profile time history data is generated and is placed on an interface file which can be directly input to the NASA Aircraft Noise Prediction Program (ANOPP). Advanced operational procedures for noise alleviation, such as programmed throttle and flap controls, may be investigated. Examples of advanced takeoff procedures are presented which indicate that throttle scheduling is effective in tailoring the flight profile to produce noise reductions in the terminal area. Examples of advanced approach procedures indicate that significant reductions in noise level are possible.

The use of the program for in-house studies of supersonic cruise aircraft technology has afforded the opportunity to compare detailed results with those of two major aircraft manufacturers. Flight paths calculated with the present program, and using the manufacturer aircraft inputs, are in very good agreement with the flight paths computed by the individual manufactures.

APPENDIX

DESCRIPTION OF PROGRAM INPUTS

This appendix contains descriptions of the input data required to define the aircraft configuration and to define the flight profile. The aircraft descriptions are presented to give the reader a feel for the degree of detail available to define a specific aircraft design. The inputs that control the flight profile permit a high degree of flexibility in the simulation of realistic takeoff and approach procedures. Output options are described and sample tabulations are presented which illustrate both the minimum output and the extensive detail of the point-by-point output.

AIRCRAFT INPUTS

The description of the aircraft inputs is divided into three major sets. The first and largest set is concerned with the characteristics of the propulsion system. The second set defines the aerodynamic characteristics of the aircraft in high lift configurations. The third set is concerned primarily with the weight and size of the vehicle and some of its components.

The propulsion characteristics are precomputed, usually from data supplied by an engine manufacturer, for the appropriate temperature day. All engine characteristics are given for a single, full-size engine. These values are multiplied within the program by the number of engines on the aircraft and also are scaled (sized) to the proper thrust level as required by the vehicle inputs. The performance data are considered to be installed in that they include the effects of inlet pressure recovery, horsepower and bleed-air extraction, and nozzle velocity coefficient. The data also include all engine-related drags (inlet bleed, bypass, spillage, and boattail) except the nacelle external skin-friction drag. The latter drag is included in the aerodynamic data and the change in external nacelle drag with engine size is represented by an incremental drag input.

The engine characteristics required for performance calculations are the gross thrust, ram drag and fuel flow. These data are functions of flight Mach number, flight altitude and engine throttle setting. The program can accept data for as many as five Mach numbers at each of five altitudes and up to ten throttle settings. Independent multipliers for each parameter are available which can be used to simulate another engine type or to represent an improvement in specific fuel consumption for a sensitivity study. For refused takeoff calculations, the gross thrust and ram drag for ground-idle operation are required.

If noise predictions are to be made using ANOPP, the present program has the capability to handle up to fourteen additional parameters. These are sufficient to define the engine airflows, jet areas, jet velocities, pressure ratios and jet temperatures for an advanced dual-stream engine. Each of these parameters is a function of flight Mach number, altitude, and throttle setting, and is stored together with the performance variables. During the profile calculations at selected flight points, these parameters are interpolated for the particular flight conditions, and the results are placed together with the aircraft and profile data on the time-history file to interface with the ANOPP program (See Table II.).

The low-speed aerodynamic characteristics of a given configuration are represented in terms of lift and drag coefficients as functions of both aircraft angle of attack and flap angle. The data are input for full-scale trimmed conditions, for a clean configuration (retracted gear), and are based on a given reference wing area. The program can accept as many as fifteen angles of attack for up to four flap angles. Ground effect is represented by inputting two sets of this data: one for the free air (no ground effect) condition, and another for the ground effect case. A linear interpolation between the two sets of data is used during flight path calculations. This results in an overestimate of the ground effect at intermediate altitudes, but the effect on takeoff performance is considered insignificant. For the AST 105-1 configuration used as an example aircraft herein, extensive wind tunnel test results defining the ground effect have been reduced to empirical equations in reference 9. These equations are utilized in the program to compute the ground effect if ground effect data are not input. The program accessing logic could be modified to compute intermediate altitude effects during profile calculations. This procedure could then be used for any configuration for which sufficient ground effect data was available to define empirical equations.

Other aerodynamic inputs required include: drag coefficient for the extended gear as a function of lift coefficient, drag coefficient increment due to an engine out both at sea level and at altitude, and increments in both lift and drag coefficient for spoilers if they are employed during the refused takeoff calculations. An additional incremental drag coefficient is available to represent any desired change in aircraft drag.

The size of the aircraft is defined in terms of the takeoff gross weight, the wing area and the size and number of engines. The wing area and engine size may be defined alternately in terms of wing loading and thrust-to-weight ratio. For approach calculations, the landing weight is required. The aircraft attitude during ground roll, the rotation rate, and the maximum ground angle of attack (as limited by tail scrape) are necessary to define the rotation capability of the vehicle. The time interval required to fully retract the landing gear and the angle of inclination of the engine nozzle axes with respect to the aircraft reference axis are required inputs. The latter input can be used to simulate thrust vectoring. If noise predictions are to be made, the size and dimensional data for the control surfaces and the landing gear is required for use in the calculation of the airframe noise.

PROFILE INPUTS

The inputs that may be used to control the flight profile will be described in sequence. The takeoff requirements are input in terms of a design (or maximum) takeoff field length, an obstacle height, and the atmosphere temperature (i.e. ISA + 10C). The friction coefficients for rolling and braking operations are required. The initial flap configuration and engine throttle setting, which are held constant throughout the standard takeoff procedure, must be input. For an advanced procedure takeoff, either or both of these items may be input as a function of either flight velocity or flight altitude. The velocity at which the aircraft rotation is to begin V_R may be input as a single value or as a series of up to nine velocities. If more than a single velocity is input the program will cycle through the series and complete all requested flight operations for each velocity. The climbout velocity may be specified either as a incremental velocity (with respect to V_2) or as an absolute climb velocity. For standard takeoffs, the flap configuration may be changed at any altitude, above 122 m (400 ft), by inputting the climbout flap angle and the altitude desired. The throttle setting may be reduced to maintain a specified climb gradient at any distance or altitude. For standard procedures, the climb gradient is limited to minimum regulatory levels and throttle changes cannot be made below an altitude of 213 m (700 ft). The restraints for flap and throttle changes may be modified by inputs or bypassed completely for advanced procedure calculations.

Balanced field length may be calculated for any specified engine-failure velocity. These calculations require the time intervals discussed in the main text and illustrated in figure 3.

The approach profile is defined by two segments. The segments are specified in terms of the initial distance from the obstacle and the glide path angle. The obstacle height is given and it is assumed to be at the start of the runway. The aircraft flap configuration and either the angle of attack or the approach velocity must be specified at the start of each approach segment. The velocity is held constant during the second segment.

PROGRAM CONTROL INPUTS

The operational mode of the program itself is controlled by a series of optional parameters. An input is available to select the calculation of either a takeoff profile only, a takeoff and an approach profile, or an approach only. During calculations to determine the takeoff field length, the climbout performance is of secondary interest and the calculations may be terminated at the obstacle. Rather than specifying a series of velocities for rotation as described earlier, an option is available which makes takeoff calculations for a single input V_R and then repeats the calculations for that velocity incremented by 3, 5, 8 and 10 m/s (5, 10, 15 and 20 kt). Balanced field-length calculations (one-engine-out takeoff and refused takeoff) may be made for a specified value of engine failure speed. An automated procedure may be selected in which the exact engine failure speed V_1, which results in a balanced field length is determined. As indicated in the main text, selected configurations, which have a field length less than the available field length, may be operated at a reduced or derated throttle setting. An input option selects an automated search for the derated throttle setting and the appropriate V_R to meet the available field length. During this search, at each trial throttle setting, the initial input V_R is incremented in 3 m/s (5 kt) steps until a minimum field length is calculated. In utilizing this options the input V_R must be sufficiently low to assure that a minimum field length can be determined.

The amount of tabulated output resulting from a given set of calculations is controlled by inputs. The minimum output from the calculations of a particular profile is a summary line of results containing selected parameters at key points along the profile. This form of output can be used to scan results of a series of profile calculations to observe significant trends. A sample listing is presented in Table III. These results are for a series of six rotational velocities as indicated in the sixth column and show the variation of the takeoff field length in the eleventh column. The tabulated output for a given profile can be progressively increased until each calculated flight point is represented. A sample of such a flight point tabulation is presented in Table IV. The tabulation includes nineteen state variables and acceleration rates. An additional option is available which controls the printout of interim results during the iterations required to balance the equations of motion and the incremental step logic at each profile point. Such a listing is useful in the analysis of problems that may develop in some extreme cases.

If noise predictions are to be made for a particular profile, inputs are available to select the points along the profile at which the additional propulsion characteristics are interpolated, and to cause the data to be placed on an external file. The file is the interface file mentioned in the main text for input to the ANOPP for prediction of noise levels.

REFERENCES

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TABLE I

MINIMUM STEADY STATE CLIMB GRADIENTS, PERCENT

Number of Engines	First Segment	Second Segment
2	0.0	2.4
3	0.3	2.7
4	0.5	3.0

TABLE II

PARAMETERS ON TIME HISTORY FILE (FOR NOISE CALCULATIONS)

Profile and Aircraft	Propulsion	
Flight time	Engine jet velocity	Primary and Secondary
Flight altitude	Engine jet nozzle area	
Dist. from brake release	Engine jet density	
Flight velocity	Engine jet temp.	
Flight path angle	Engine pressure ratio	
Aircraft angle of attack	Engine core mass flow	
Aircraft weight	Engine combustor inlet pres.	
Aircraft flap angle	Engine combustor inlet temp.	
Aircraft lift coefficient	Engine turbine inlet temp.	
Aircraft lift-to-drag ratio	Engine fan rotor speed	
Aircraft drag	Engine fan mass flow	
Aircraft net thrust	Engine fan temp. rise	

TABLE III.- SAMPLE OUTPUT LISTING OF SUMMARY RESULTS FOR A SERIES OF SIX CASES

```
 AST 105-1  WITH 516M   +10C DAY

                       SUMMARY OF RESULTS FOR    6. CASES

CASE    GW     W/S    T/W   TOFLP   VROT   ALROT   VLOF   ALLOF   VOBS  TO F.L. VFAIL  BALF.L. FARF.L.
        KN     KPA     -     DEG    M/S     DEG    M/S     DEG    M/S      M     M/S       M       M
                             (1)                   (2)     (2)    (2)     (3)    (4)     (5)
1.10 3051.5    3.9   .254   20.0    91.6   8.00    99.0   7.54   103.7  -3420.   0.0      0.       0.
2.10 3051.5    3.9   .254   20.0    92.6   8.00    99.9   7.31   104.1   3418.   0.0      0.       0.
3.10 3051.5    3.9   .254   20.0    93.6   8.00   100.8   7.16   104.5   3427.   0.0      0.       0.
4.10 3051.5    3.9   .254   20.0    94.7   8.00   101.7   6.90   105.0   3449.   0.0      0.       0.
5.10 3051.5    3.9   .254   20.0    95.7   8.00   102.6   6.70   105.6   3480.   0.0      0.       0.
6.10 3051.5    3.9   .254   20.0    96.7   8.00   103.5   6.45   106.2   3510.   0.0      0.       0.


   (1),   INITIAL VALUE. SHOWN NEG. IF SCHEDULED.
   (2),   WITH ALL ENGINES OPERATING.
   (3),   TO F.L. SHOWN NEG. IF 1ST OR 2ND SEG. GRADS NOT MET.
   (4),   NEGS. ARE PERCENT TGREF, AT SLS. (THROTTLED T.O.)
   (4),   NEGS. ARE PERCENT TGREF, AT OBS. (THROTTLED T.O.)
   (6),   NEGS. ARE FOR CASE TERMINATED, CHECK CASE LISTING.
```

TABLE IV.- SAMPLE OUTPUT LISTING OF DATA

AVAILABLE AT EACH FLIGHT POINT

```
            ****  UNITS FOR FLIGHT POINT OUTPUT DATA  ****

   SYSTEM    LENGTH  FORCE  TIME  ANGLE  WT. PRESSURE  VELOCITY  FUEL FLOW
     SI        M       N    SEC    DEG   N     KPA       M/S       KG/H
    FPS        FT     LBF   SEC    DEG   LBF   PSF       KT        LBM/H



V TAS=111.22     M=  .322    H=  91.44    W=3017764.  DIST=  4236.  TIME=  63.63
V EAS=108.86  Q=   7.26 ALPHA= 6.64   CL= .50246     CD= .06776   DRAG= 382216.  L/D= 7.42
           TT= 903953. TDR= 121305. TFF=     35. TACC=  .0473 NACC=  .0178 GAMMA= 4.338
```

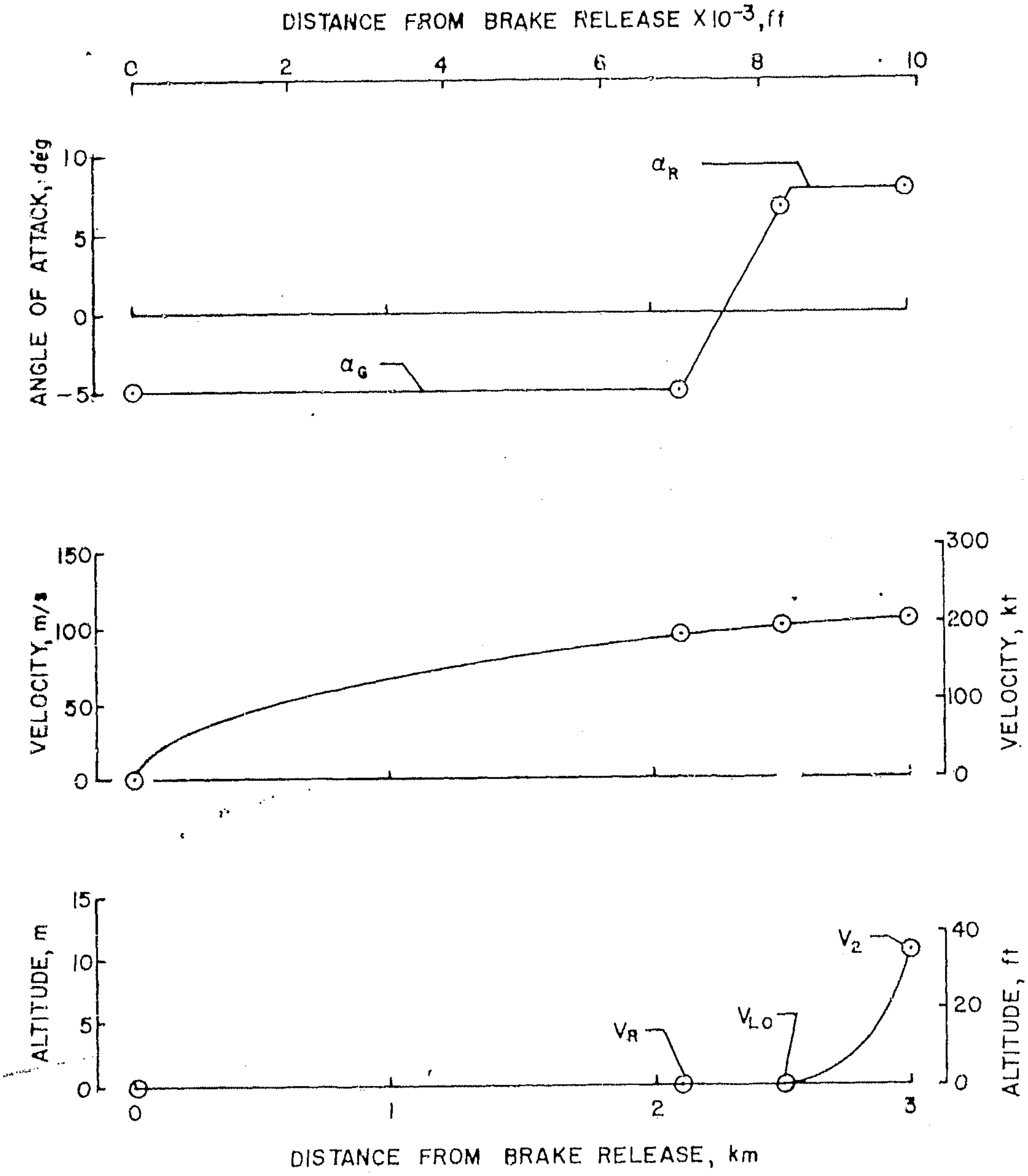

Figure 1. - Take-off to obstacle, all engines operating.

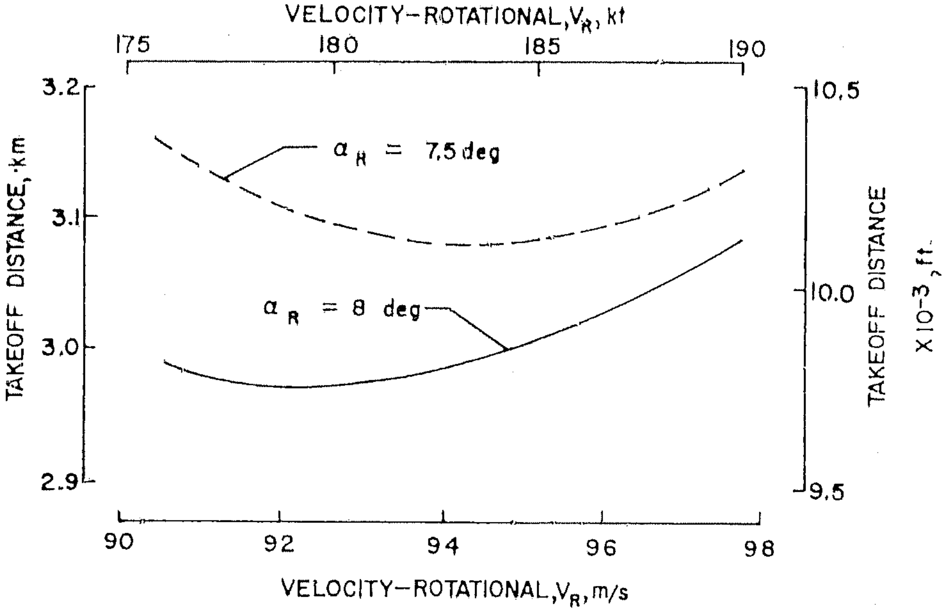

Figure 2. - Variation of take-off field distance with velocity at rotation.

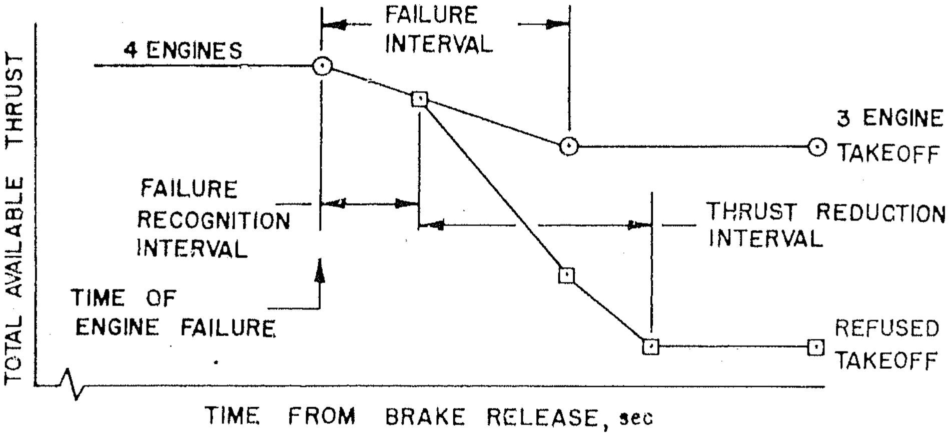

Figure 3. - Schematic variation of total thrust in event of an engine failure.

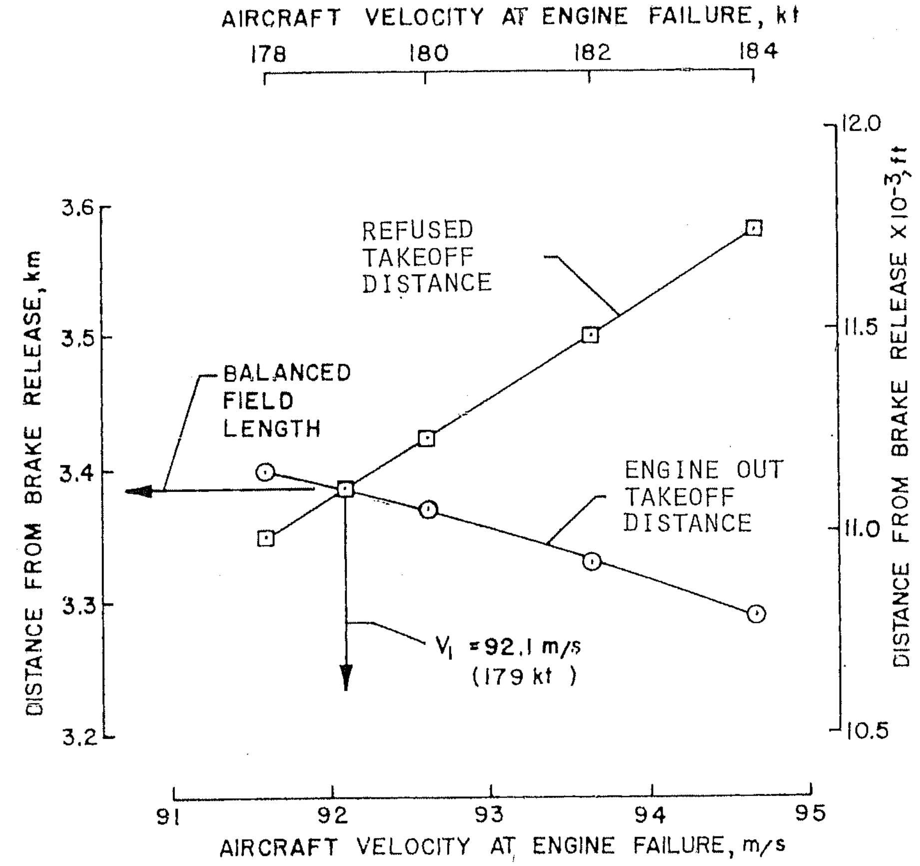

Figure 4. - Determination of balanced field length and V1 for V_R = 94.7 m/s (184 kt).

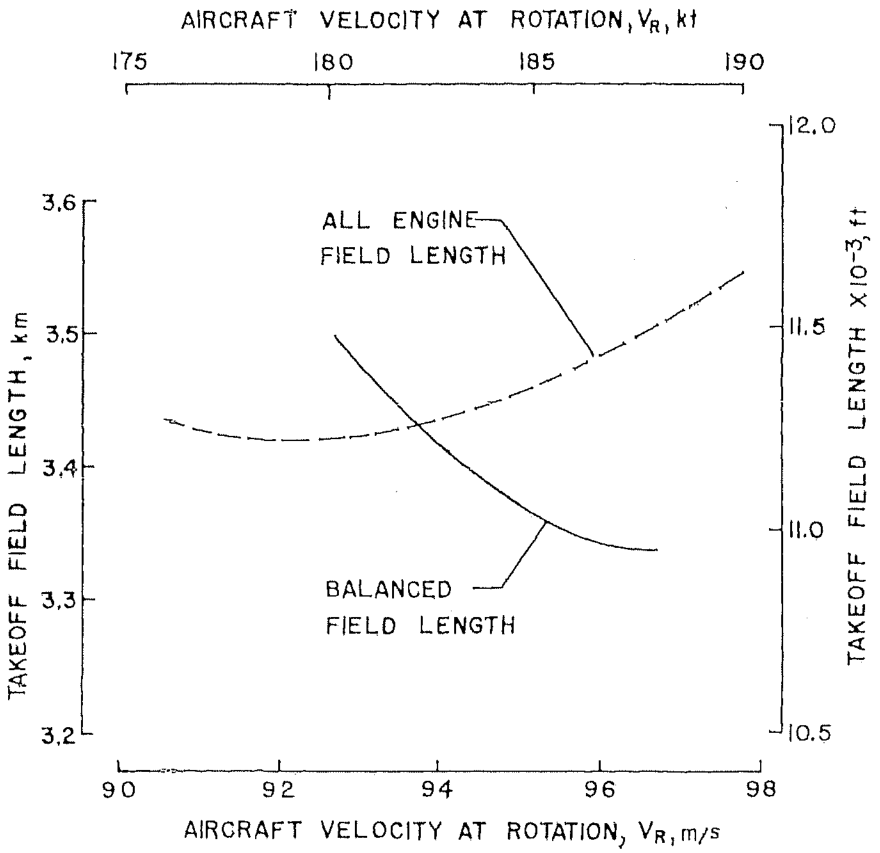

Figure 5. - Variation of field length with aircraft velocity at rotation.

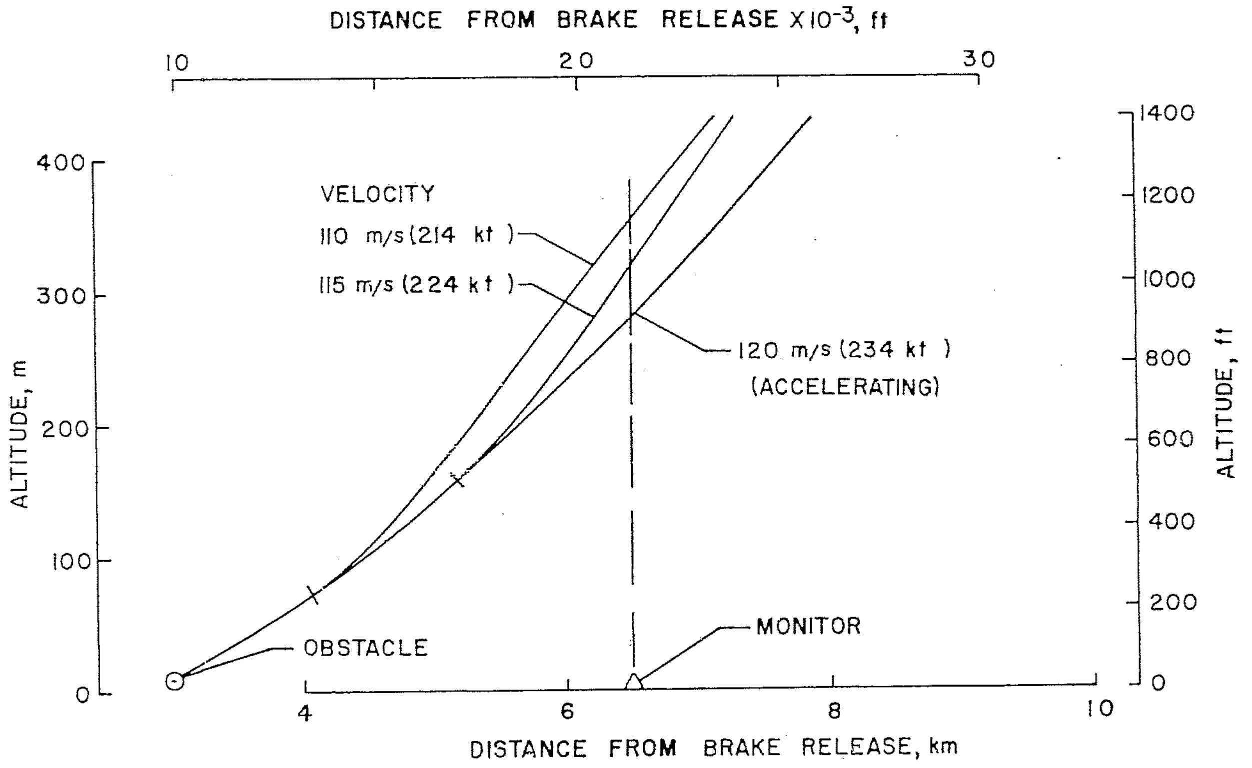

Figure 6. - Climbout profiles for aircraft with V_R = 94.7 m/S (184 kt)

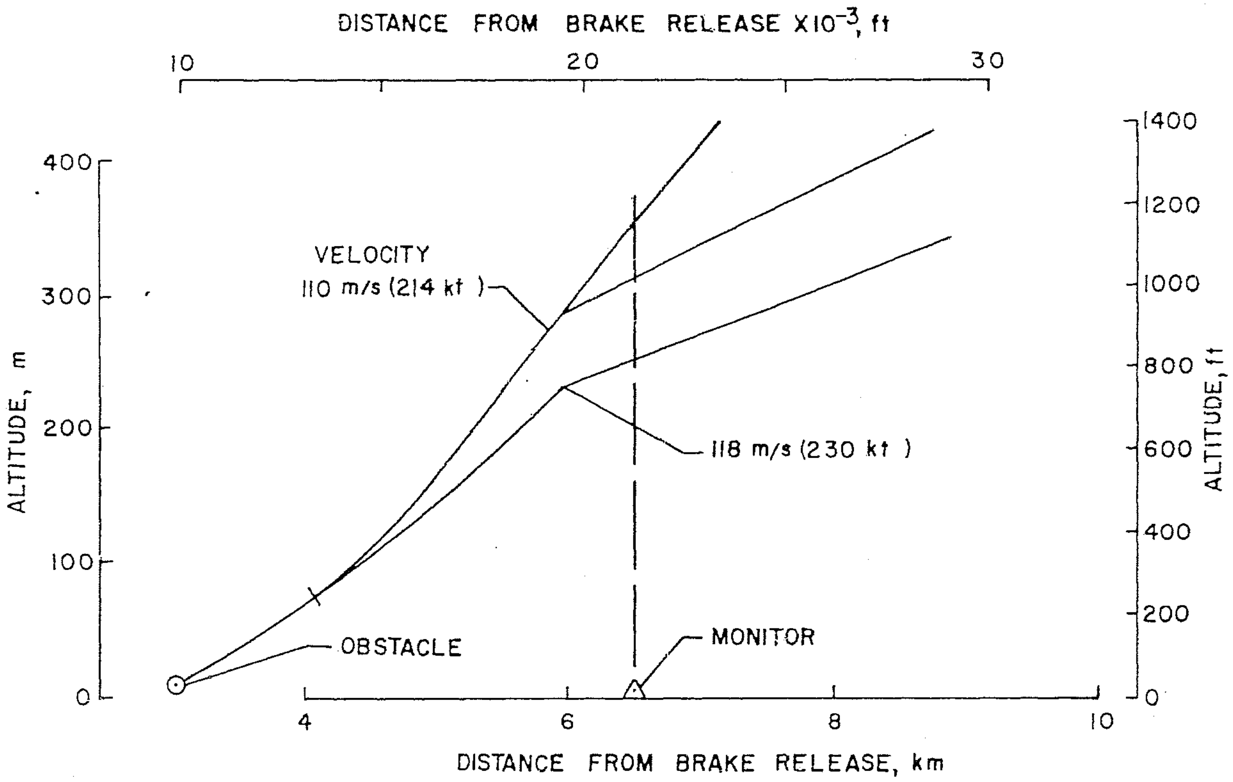

Figure 7. - Climb profiles for aircraft with V_R = 94.7 m/s (184 kt) at 5944 m (1950 ft) from break release.

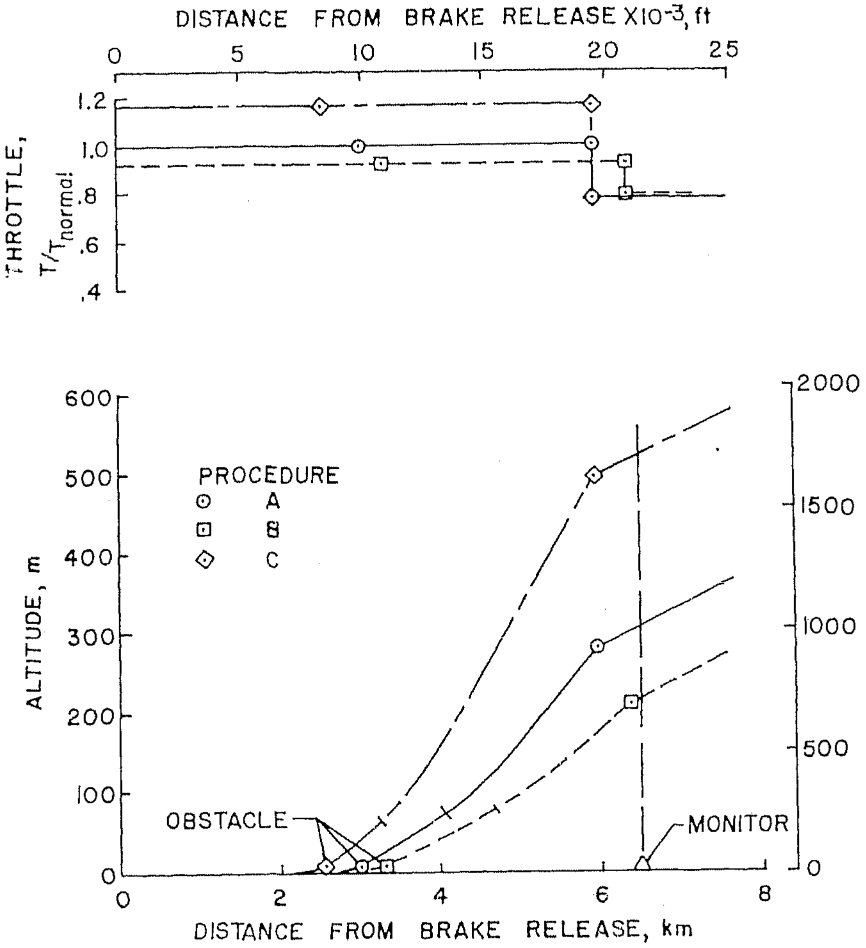

Figure 8. - Advanced procedure take-off profiles with fixed throttle until cutback.

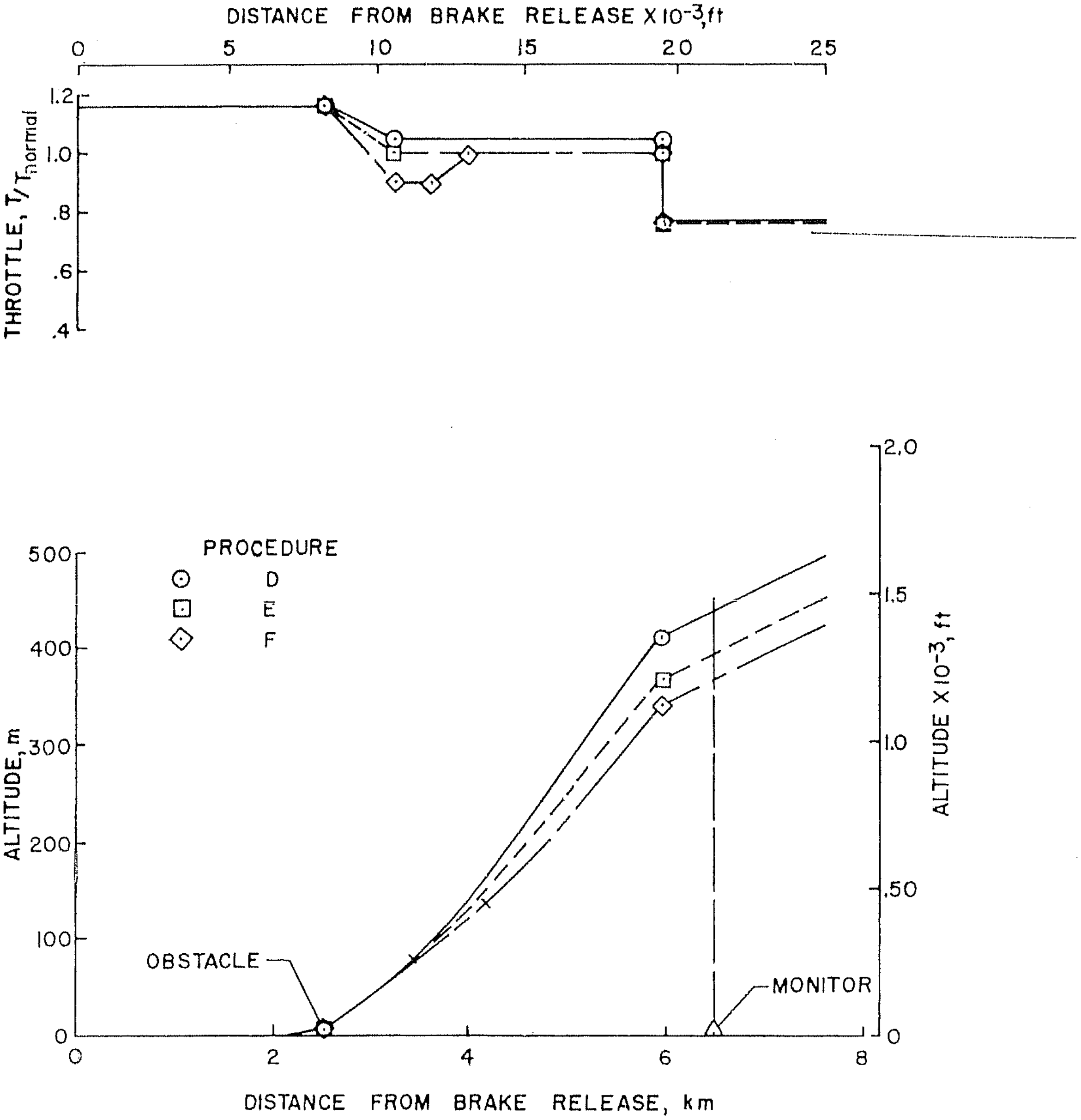

Figure 9. - Advanced procedure take-off profiles with throttle variations during climbout.

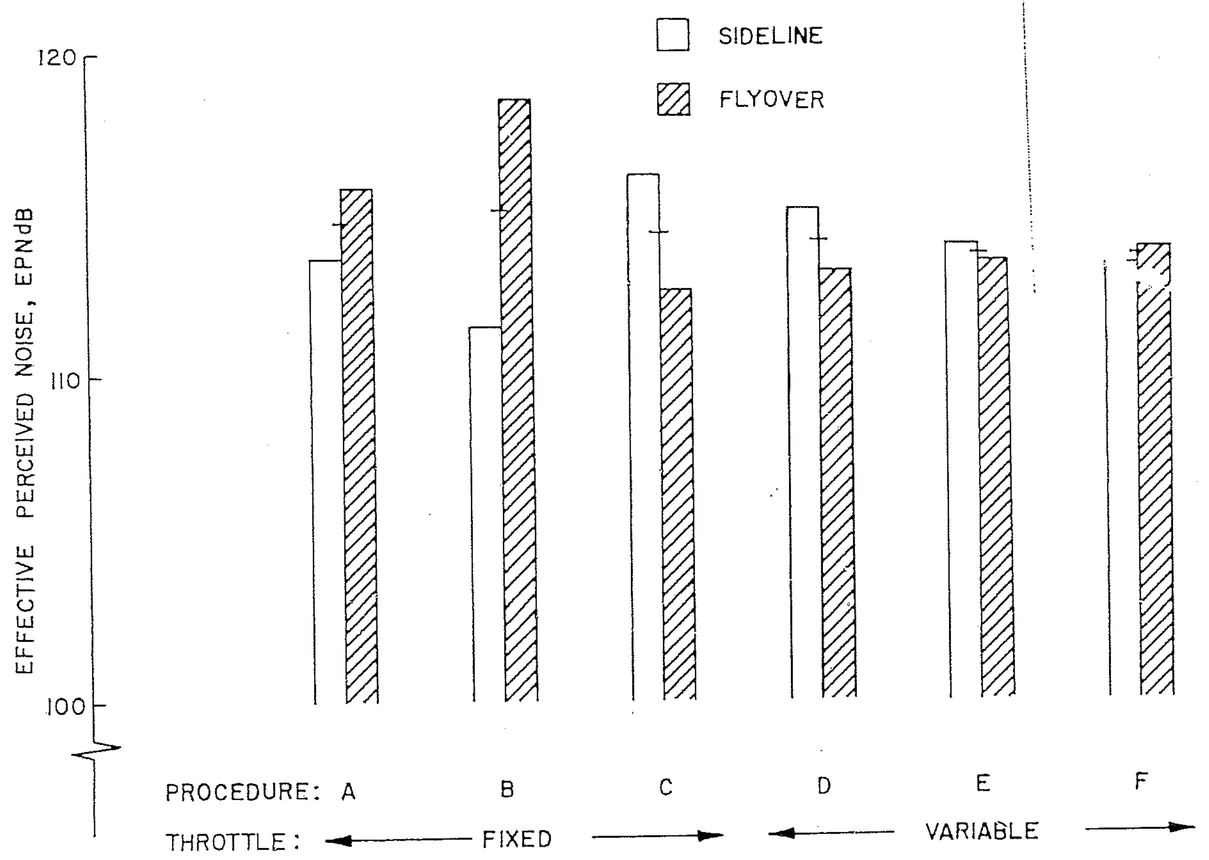

Figure 10. - Take-off noise levels for design point aircraft utilizing advanced throttle procedures. Jet noise only.

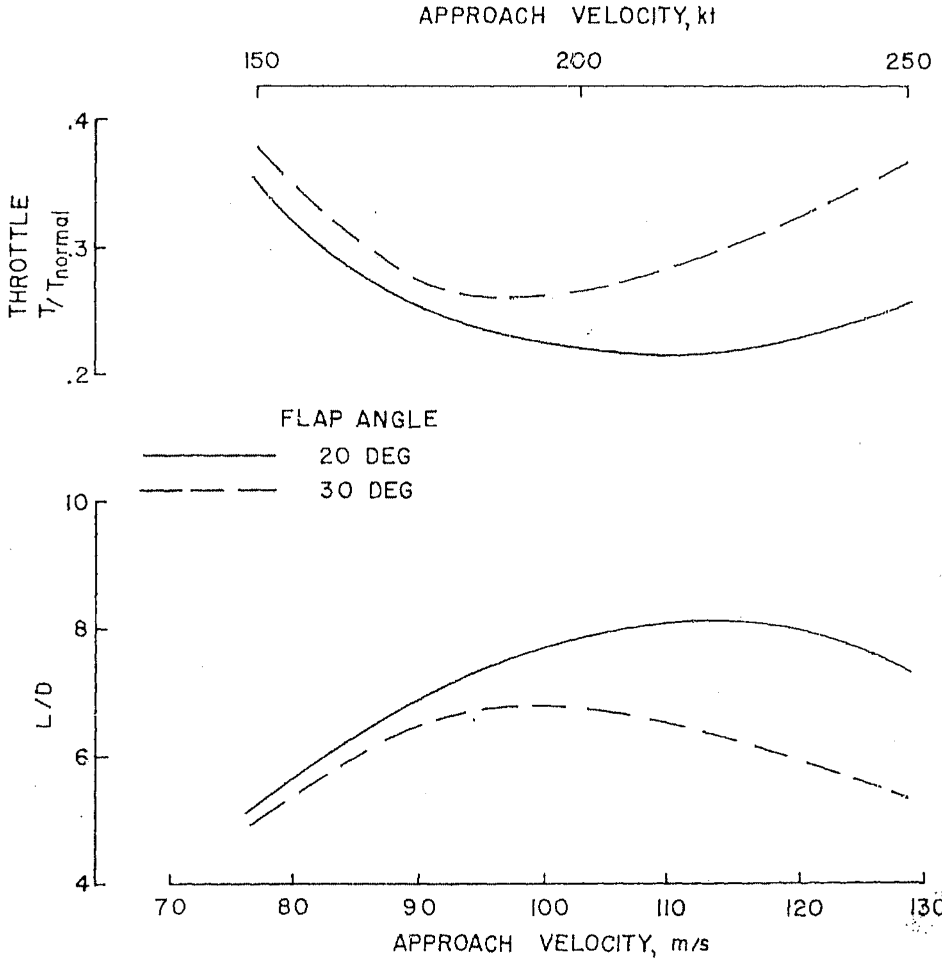

Figure 11. - Variation of selected performance parameters with approach speed for the AST-105-1 on a standard 3° glide slope.

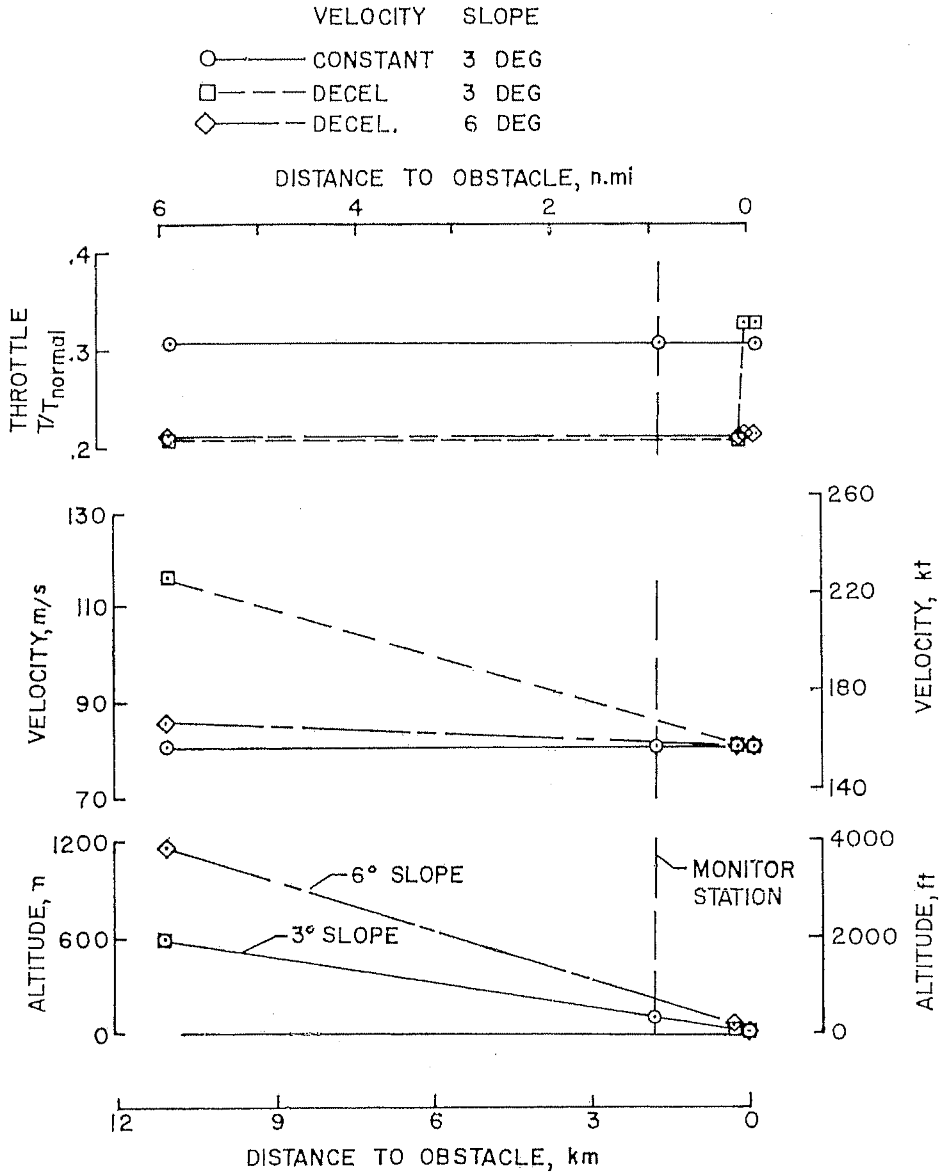

Figure 12. - Advanced approach procedures.