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NOISE MEASUREMENT EVALUATION OF TAKEOFF AND APPROACH PROFILES OPTIMIZED FOR NOISE ABATEMENT

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16. Abstract

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During the takeoff tests, the flaps were set at either 27° or 10° and the climb airspeeds varied from V_2+15 to V_2+50 knots (V_2 refers to the takeoff safety speed of the aircraft). Power was reduced to yield either 500 or 750 ft/min rate of climb when the aircraft reached 1500 ft altitude. The assumed noise sensitive ground track extended along the runway centerline from 3.5 to 5.7 nautical miles from the start of the takeoff roll.

The average of the noise measurements taken at points along the noise sensitive portion of the ground track was used to compare the various takeoff profiles. The takeoff that produced the least average noise, 90.5 EPNdB, used takeoff flaps of 10° and a climb airspeed of V_2+50 knots to 1500 ft altitude, at which point power was reduced to yield a 750 ft/min rate of climb. (Flaps were retracted soon after takeoff while the aircraft was accelerating to V_2+50 knots.) The average noise of a reference profile was 96.4 or 5.9 EPNdB more than the optimum profile. The reference profile used 27° of flaps throughout the takeoff-climbout and a climb airspeed of V_2+15 knots to 1500 ft altitude where the power was reduced to yield a 500 ft/min rate of climb. These results verify previously obtained analytical calculations.

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NOMENCLATURE

EPNdB — effective perceived noise level expressed in decibels

It is a measure which includes the effects of strong tones and long duration of noise exposure in order to evaluate the qualities of noise that are particularly offensive. (This noise measure is explained in detail in ref. 5 where it is expressed as $EPNdB_{t2}$.)

V_2 — calibrated airspeed at which climbout can be safely executed with the critical engine inoperative and the airplane in the takeoff configuration

It is often referred to as – the takeoff safety speed – and is a function of altitude, temperature, flap setting, and aircraft gross weight.

V_{S1} — power off stalling speed of the aircraft in a specified configuration

It is a function of flap position, landing gear position (up or down), and gross weight.

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SUMMARY

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INTRODUCTION

The need to minimize the noise generated by jet aircraft during takeoff-climbout and landing-approach operations has been emphasized by the concern expressed by communities near existing airports. Efforts to solve this problem have concentrated in three areas: the development of quieter engines, the definition and understanding of the subjective response of humans to aircraft noise, and the development of improved operational procedures for noise abatement. This report deals with the third of these areas (for prior studies see refs. 1 through 4) and presents the results of a flight investigation of operational procedures for noise abatement during takeoff and landing. The results of psychoacoustic research, the second area above, are covered in references 5 through 9 and are used freely herein.

The chief objective of this study was to examine the sound level reductions that might be realized by varying the flight profile of a CV–990 airplane during the initial climb after takeoff and the approach to landing. The noise-sensitive ground track for the takeoff-climbout tests was assumed to be between the 3.5 and 5.7 nautical mile points measured from the start of takeoff roll. The 3.5 n.mi. point was chosen as the beginning of the noise-sensitive ground track because of the importance of this point in the FAA noise certification requirements; the final point of the ground-sensitive track was dictated by the physical limitations of the testing site.

The takeoff-climbout profiles flight tested were based on results presented in reference 1. It was pointed out there that to minimize the noise in a specified noise-sensitive section of the ground track the takeoff-climbout profile would require acceleration to a particular climb speed at a low altitude in essentially level flight as soon as possible after liftoff, followed by a climb to the beginning of the noise-sensitive ground track and a sharp power reduction during flight within the section of noise-sensitive ground track. The airspeed and the flap setting used during the climb and the amount of power reduction determined a particular minimum noise profile. The values of these parameters depended primarily on the noise characteristics of the engine and the length and location of the noise-sensitive ground track.

The techniques described in reference 1 could not be used directly to calculate the optimum profile for the CV–990 flight tests, since the lack of a mathematical model for noise generation of the CV–990 fan engines precluded a reliable determination of the optimum profile parameters. For this reason a range of profile parameters was selected for flight testing, with the theoretical results as a guide.

A number of landing and flyby profiles were also flight tested to assess the effect of flap and throttle settings on the perceived noise during the landing approach. The approaches were flown on a standard 3° glide slope. Reduced flap settings on approach require less thrust and therefore offer the potential for reducing the noise level. On a standard glide slope, the greatest possible noise reduction would be obtained if the engines could be operated at flight idle while the aircraft slowly decelerated. Since there was no instrumentation on board the aircraft to fly such a decelerating approach repeatably, noise was measured with engines at flight idle during flyby's at a constant altitude. These noise measurements were then extrapolated by standard techniques to various approach altitudes.

Noise measurement evaluations of some takeoff-climbout techniques have been reported in references 2 to 4 for a number of different aircraft. The noise measurement techniques described in these references were used in collecting, processing, and presenting the data.

The test conditions and the type of instrumentation used in obtaining the noise data are discussed in appendix A. The noise measurement data are discussed in appendix B in terms of sound pressure levels and noise spectra. Appendixes A and B also contain data relating to the aircraft operations and the flight paths that were flown during the test operations.

The tests were conducted at the Wallops Station with the assistance of the Langley Research Center Acoustics Branch staff.

APPARATUS AND METHODS

Airplane Description

The NASA CV–990 airplane used in these tests is shown in figure 1. The gross weight of the airplane varied from 187,000 to 178,500 lb (85,000 to 81,100 kg) at the 1,000 foot test altitude, from 177,300 to 171,300 lb (80,600 to 77,900 kg) at the 2,000 foot test altitude during the flyby tests, from 206,000 to 194,000 lb (93,600 to 88,200 kg) during the takeoff tests, and from 187,000 to 169,000 lb (85,000 to 76,800 kg) during the landing-approach tests. This airplane was powered by four CJ 805–23B axial flow fan-jet engines each of which produced approximately 16,000 lb of thrust (maximum) at sea level.

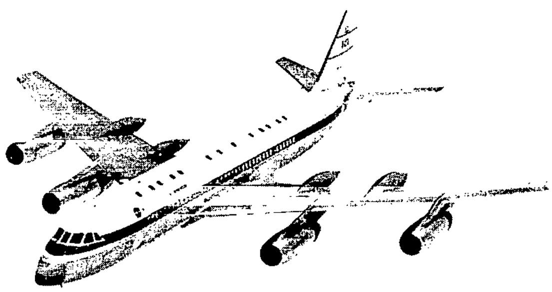


Figure 1.– NASA CV–990 airplane.

Flight Profile Descriptions

The test evaluation program involved takeoff-climbout, landing-approach, and flyby operations. During these tests the airplane was flown by NASA test pilots.

Takeoff-climbout– Each takeoff was initiated from the same point on the runway so that the test results could be repeated for each profile and so that the noise measurements could be compared for the various profiles at each noise measurement station. All takeoffs were performed with gross weights near the maximum gross landing weight rather than maximum gross takeoff weight because of the desirabiliy of performing one takeoff after another. In this takeoff configuration, the CV–990 lifts off the runway at a speed very close to V_2. As a result, V_2+15 knots is achieved soon after liftoff with no change in thrust or aircraft attitude.

Five profiles, described below, were evaluated in the test flights. Profiles 1 and 2 are similar to those used in the past for noise abatement purposes. Profiles 3 to 5 were found (ref. 1) to provide optimum noise abatement under some operating conditions.

Profile 1:

(1) Take-off with 27° flaps, maintain until clear of noise area.
(2) Climb from takeoff at V_2+15 knots to 1500 ft.
(3) At 1500 ft altitude reduce thrust to yield a 500 ft/min rate of climb; maintain that rate of climb until clear of noise area.

Profile 2:

(1) Take off with 10° flaps; maintain until clear of noise area.

(2) Accelerate to V_2+20 knots, while in a shallow climb condition as soon as possible after liftoff; maintain climb speed to 1500 ft.

(3) At 1500 ft altitude reduce thrust to yield a 500 ft/min rate of climb; maintain that rate of climb until clear of noise area.

Profile 3:

(1) Take off with 10° flaps.

(2) While accelerating to V_2+40 knots in a shallow climb, retract flaps to 0°; climb at V_2+40 knots to 1500 ft.

(3) At 1500 ft altitude reduce thrust to yield 500 ft/min rate of climb; maintain that rate of climb until clear of noise area.

Profile 4:

(1) Take off with 10° flaps.

(2) While accelerating to V_2+50 knots in a shallow climb, retract flaps to 0°; climb at V_2+50 knots to 1500 ft.

(3) At 1500 ft altitude reduce thrust to yield 500 ft/min rate of climb; maintain that rate of climb until clear of noise area.

Profile 5:

(1) Take off with 10° flaps.

(2) While accelerating to V_2+50 knots in a shallow climb, retract flaps to 0°; climb at V_2+50 knots to 1500 ft.

(3) At 1500 ft altitude reduce thrust to yield 750 ft/min rate of climb; maintain that rate of climb until clear of noise area.

Landing approach– The landing approach operations used a standard 3° glide slope. To eliminate unnecessary tire wear, approaches were conducted to 10 ft altitude rather than to actual touchdown. Approach speed was $1.3V_{S1}$+10 knots; V_{S1} is the stall speed for the particular aircraft configuration and is a function of gross weight and flap setting.

Profile 1, 50° flap setting, speed $1.3V_{S1}$+10 knots
Profile 2, 27° flap setting, speed $1.3V_{S1}$+10 knots
Profile 3, 10° flap setting, speed $1.3V_{S1}$+10 knots
Profile 4, 0° flap setting, speed $1.3V_{S1}$+10 knots

Flybys– The flyby operations were flown at 1000 ft altitude in level flight directly over microphones located near the flight control tower of the Wallops Station. Flyby speeds were $1.3V_{S1}$+10 knots. (Again, V_{S1} refers to stall speed for the particular test configuration of the aircraft.) The noise was measured at approximately 5 ft above ground level, just as in the above two operations.

50° flaps, constant airspeed, of $1.3V_{S1}$+10 knots
27° flaps, constant airspeed of $1.3V_{S1}$+10 knots
10° flaps, constant airspeed of $1.3V_{S1}$+10 knots

0° flaps, constant airspeed of $1.3V_{S1}+10$ knots

0° flaps, engines idle, airspeed decreasing to $1.3V_{S1}+10$ knots as the aircraft passed over the noise measurement station.

DISCUSSION OF RESULTS

Average Noise Levels With Distance and Flap Setting

The results of this study are given in a series of figures which show the noise level in EPNdB as a function of flap angle and distance along the noise measurement track. These results are divided into three sections: the take-off climbout, the landing-approach, and the flyby tests.

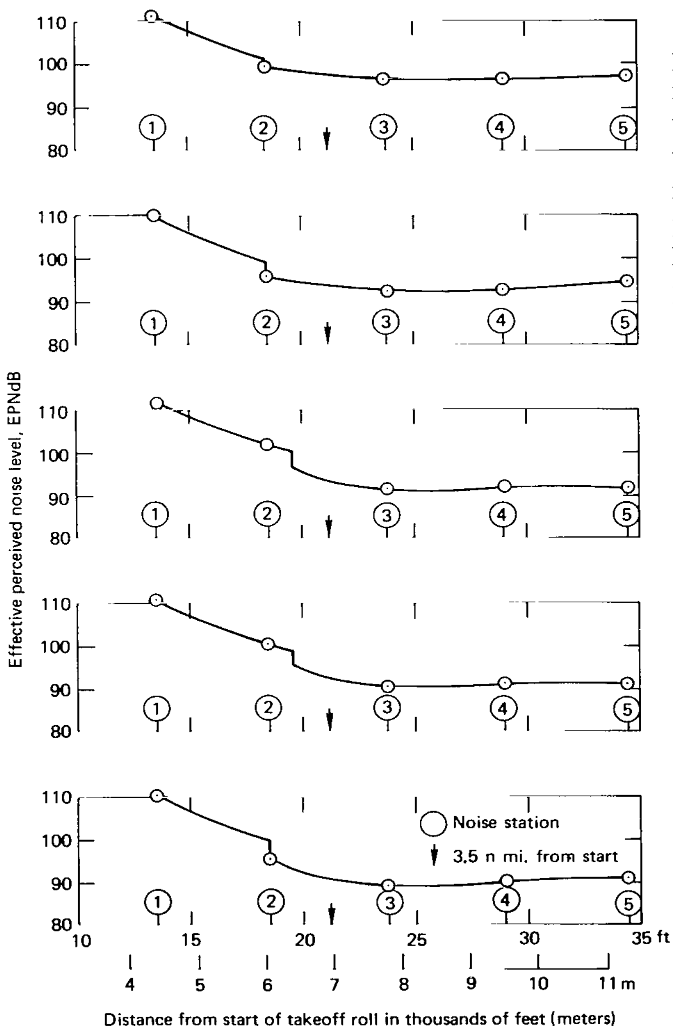


Figure 2.– Average effective perceived noise levels along ground track during take-off climbout noise tests.

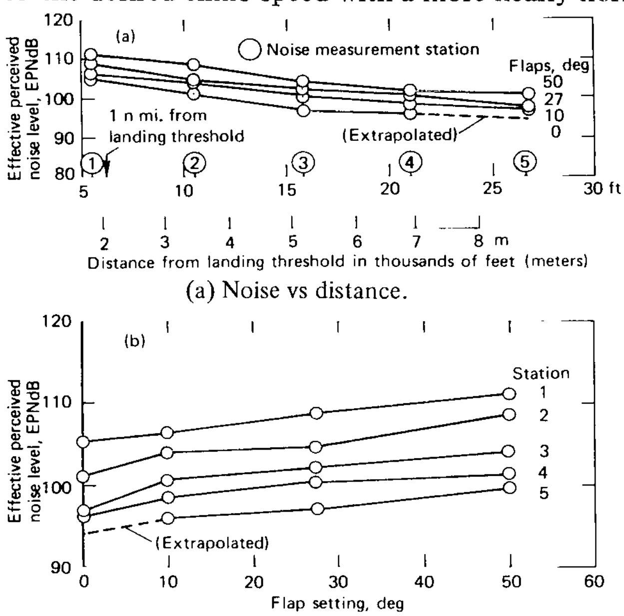
Takeoff-climbout– The effective perceived noise levels as a function of the microphone distance from the start of the takeoff roll are plotted in figure 2. Because the intensity of the noise from an aircraft is not uniform in all directions, the noise levels plotted in figure 2 do not represent the noise levels at precisely the instant the aircraft passed over the individual noise stations. Instead, the data points correspond to the maximum noise levels recorded at each of the five microphone stations during the flyby. The spread of the data between runs generally was within the area of the data symbol at each station for each profile. The noise unit, the EPNdB, is that specified by the FAA noise certification document of reference 6. The discontinuity in the curves portrays the power reduction that occurred at 1500 ft altitude in each test flight. The location of the power reduction point along the ground track is presented as the average distance of each set of tests and was obtained from radar tracking data. The magnitude of the change in noise level at power reduction was estimated by forward and backward extrapolation from known data points.

The results of the takeoff-climbout noise measurements are discussed here with reference to table 1. The data in this table were derived from table 5 and figures 2 and 13 in a manner to be described. The first column of noise data was obtained by averaging, for each profile, the noise measurements of the last three noise measurement stations. These stations are located within the assumed noise-sensitive ground track, which begins at the 3.5 n.mi. point from brake release and ends at the last measurement station. The purpose of averaging the noise measurements for each profile is to arrive at a single number that is representative of that portion of the noise history of the profile lying within the assumed noise-sensitive ground track. According to this measure, profile 1 is the noisiest and profile 5 the least noisy of the five profiles tested. The difference between them is 5.9 EPNdB. This difference and the difference between the noise of profile 1 and that of the other profiles are also given in table 1. Although the greatest change in noise occurs between profiles 1 and 2 as the takeoff flap setting is reduced from 27° to 10°, the noise is decreased even more for the other profiles.

The changes in the average noise between the profiles can be related principally to the engine power (as measured by the engine pressure ratio) and altitude after the aircraft has leveled off following the power reduction at 1500 ft. A lesser influence on the noise is exercised by the speed of the aircraft through its effect on the duration of the noise. In table 1 the average engine pressure ratio after power reduction shows that the engine pressure ratio required to maintain the 500 ft/min climb rate specified for profiles 1 through 4 differs for these profiles. The engine pressure ratio for profile 5 shows an increase over the one for profile 4, reflecting the increased climb rate that was specified for profile 5. Furthermore, the leveling-off altitude after power reduction, given in table 1, is greater for profiles 3 through 5 which use higher climbout speeds than profiles 1 and 2 and fully retracted flaps. The leveling-off altitude tends to be several hundred feet higher than the altitude at the time of power reduction because of the time required to change the flight-path angle from a steep climb prior to 1500 ft to a shallow climb after 1500 ft. Moreover, the difference between the leveling-off altitudes and the power reduction altitude of 1500 ft is greater for profiles 3 to 5 than for profiles 1 and 2, apparently because of the higher airspeeds of the former. The lower engine pressure ratios combined with slightly higher leveling-off altitudes, and the higher airspeeds of profiles 3 through 5, as compared to profiles 1 and 2, result in generally lower effective perceived noise levels for these profiles.

In the takeoff-climbout profiles the initiation of power reduction was keyed to a particular altitude, namely 1500 ft, rather than to the beginning of the noise-sensitive area because altitude is indicated to the pilot whereas distance along the ground track is not. As seen in figures 2 and 13 power is thus generally reduced before the 3.5 n.mi. point. The distance between the actual power reduction point and the 3.5 n.mi. point could therefore have been used to further increase the altitude of the aircraft before it penetrated the noise-sensitive area, and thus to reduce the noise below the values obtained in the tests. An estimate of the noise history of the profiles when power reduction is initiated at the 3.5 n.mi. point can be obtained by extrapolation of the noise and trajectory data given in figures 2 and 13. The method of estimating this noise is to first determine the additional altitude gained for each profile assuming the aircraft continues to climb until it is above the 3.5 n.mi. point and then to correct the measured noise for the change in altitude. Since the changes in altitude expressed as a percentage of the total altitude were small, the inverse square law of sound attenuation was used to correct the measured noise values. The ranking of the five profiles in terms of their noisiness does not change with these corrections. A difference of 6.7 EPNdB was obtained between the average noise of the noisiest and the least noisy profile. This difference in the average noise can be compared with the difference given in reference 1 for a reference profile similar to profile 1 and that of an optimum profile. For a typical turbofan the difference was given as 4 dB and for a turbojet as 7 dB. Although these numbers apply to a somewhat different aircraft and noise model, the flight test result does fall in the range between the two numbers. Thus it appears that the theoretically predicted noise reduction obtained by flying an optimum takeoff-climbout profile can be realized with a profile flown at least under flight test conditions.

Although profile 5 yielded the lowest noise of the five profiles tested, the reason for its superiority over profile 4 is not entirely clear. Up to the power reduction altitude of 1500 ft the altitude-distance trajectories of these two profiles should have been nearly the same, since the instructions to the pilots were identical. Yet a comparison of the altitude-distance trajectories in figure 13 shows that profile 5 achieved the power reduction altitude in a shorter distance from takeoff roll than any of the profiles. Thus the climbout performance of the aircraft was higher during the profile 5 tests than during the tests of the other profiles. Possible factors contributing to this higher performance could have been a more timely retraction of takeoff flaps and acceleration to the desired climb speed with a more nearly horizontal flight-path angle. These factors would help to decrease the distance to accelerate to the desired climb speed so that the aircraft could begin its climb to the power reduction altitude at an earlier point on the ground track. However, the available data did not permit a reliable evaluation of the effect of these factors.



(b) Noise vs flaps.

Figure 3.– Average effective perceived noise levels along ground track of the airplane showing effect of flaps on the ground noise during the approach noise tests.

Landing approach– In figure 3(a) noise levels are plotted in EPNdB versus distance from the landing threshold for a range of selected flap settings. The approaches were made on a standard 3° glide slope and approach speeds were chosen to correspond to the particular aircraft configuration in use as defined by the gross weight and flap setting. The purpose of these tests was to study the relationship of flap setting to noise during the landing approach. The data in figure 3(b) show that there is a reduction of about 6 EPNdB as the flaps are changed from 50° to 0° for the approach conditions tested. While the variation is not exactly linear, on the average there is a reduction of approximately 1/8 EPNdB per degree of flap reduction.

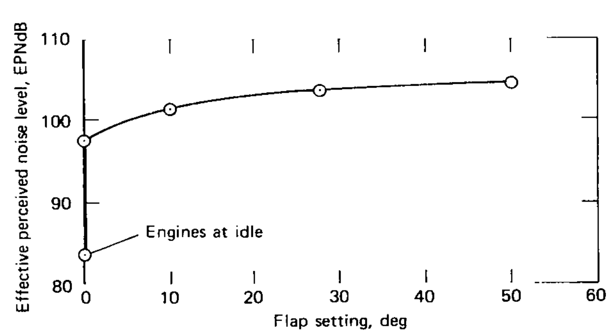
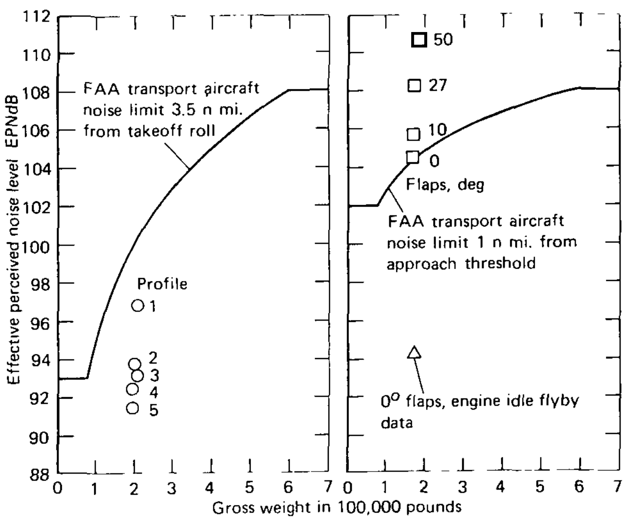


Figure 4.– Variation of effective perceived noise level with flap settings during flyby at an altitude of 1000 ft.

Flyby– Plotted in figure 4 is the variation of noise level in EPNdB with flap setting, which resulted when tests were conducted at a constant 1000 foot flyby altitude. The flyby tests were conducted at the same flap settings as the landing-approach studies 50°, 27°, 10°, and 0°; and, as in the case of the landing approach study, there was approximately a 6 EPNdB reduction in noise as the flap setting was reduced from 50° to 0°. An additional flyby with flaps at 0° was flown at the 1000 foot reference level with the engines operating at the idle condition. The result was a further reduction of 12.5 EPNdB.

Noise Certification and Operational Problems

Reference 6 specified the noise measurement unit to be used for certification purposes, the noise measurement points, the maximum allowable noise levels, and the test conditions. It should be noted that some of the profiles flown in this study require operational procedures that differ markedly from those specified. However, because of the importance that noise certification will have in the future, the data derived from this study are interpreted in certification terms.



(a) Noise 3.5 n.mi. from take-off roll.

(b) Noise 1 n.mi. from approach threshold.

Figure 5.– Average effective perceived noise levels at the critical FAA noise certification points.

Takeoff– For certification purposes the FAA has stipulated the maximum noise level on takeoff at a point 3.5 n.mi. from the start of the takeoff roll. This limit is plotted in figure 5 as a function of gross takeoff weight. The noise values obtained for each takeoff-climbout profile at the 3.5 n.mi. point have also been entered in this figure. These values were obtained by the method described in the previous section and represent the EPNdB that could be expected at the 3.5 n.mi. point if power had been reduced at that point on the ground track rather than at the arbitrary altitude of 1500 ft. The noise from each of the profiles tested falls below the FAA limit; however, the relative noise levels of the various profiles can be seen in the proper perspective.

Approach– A plot of the FAA noise certification limit for landing as a function of gross landing weight at a point 1 n.mi. from the threshold is also presented in figure 5(b). Estimated noise levels during approach, at the 1 n.mi. point, were obtained by interpolation of the data presented in figure 3. An approximation to the noise level at the 1 n.mi. point (altitude, 295 ft) for an engine-idle decelerating approach with 0° flaps is also shown in figure 5(b). The estimate was obtained by applying a distance correction factor to the noise level measured during the flyby test which was conducted with engines at idle and 0° flaps. A decelerating approach to a landing during which the engines are maintained at flight idle can therefore provide a 10.3 EPNdB reduction at the 1 n.mi. point from the runway threshold compared to a 0° flaps approach at constant airspeed; furthermore, it can provide an 18.5 EPNdB reduction compared to a standard approach with landing flaps at 50°. It is seen in figure 5(b) that the noise from a standard approach falls above the certification limit by a wide margin. Of the constant airspeed approaches, only the one with 0° flaps comes close to meeting the certification limits. In contrast, the noise from the decelerating approach falls 10 EPNdB below the upper limit. It should, however, be pointed out that these results are valid only for the CV–990 aircraft equipped with the General Electric CJ–805 turbofan engines. Further tests would have to be conducted to establish if these results also apply to other airframe-engine combinations.

The main obstacle hindering the implementation of decelerating approaches on transport aircraft is the lack of a suitable guidance technique. Should further development produce suitable guidance and control techniques for flying decelerating approaches, significant reduction in noise level could be realized.

The pilots encountered no difficulty in flying the reduced flap profile with flap settings as low as 10°. However, with the flaps fully retracted, glide-slope tracking became difficult. The increased effort in glide-slope tracking was reflected in larger and more frequent excursions from the glide slope with this type of approach. Figure 14 shows the difference in glide-slope tracking accuracy between the approach with no flaps and that with flaps. The increased errors in glide-slope tracking with the 0° flap approach are probably related to the operation of the aircraft on the backside of the power-required curve.

CONCLUSIONS

In the takeoff tests the least noisy profiles were those in which the pilot used a minimum of takeoff flaps, retracted the flaps during acceleration in a shallow climb to V_2+50, and then climbed steeply to the power reduction altitude of 1500 ft (V_2 is the takeoff safety speed of the aircraft). The noisiest ones were those that maintained takeoff flaps throughout the climbout. The noise reduction obtainable with the least noisy profiles was related to the greater thrust reductions and somewhat higher altitudes of these profiles compared to the noisier ones. It appears that retracting takeoff flaps reduces the drag and therefore permits greater thrust reduction which, in turn, reduces the noise. The effective perceived noise level is also reduced because of the increased speed, which tends to reduce the duration of the noise. The difference between the optimum and the noisiest profile was 5.9 EPNdB, which agrees reasonably well with analytical predictions for similar aircraft and test conditions. However, in attempting to apply these results to other aircraft and noise abatement situations some caution must be exercised. The difference between the noise of an optimum and any reference profile depends on many factors and does not lend itself easily to generalizations or to a complete verification by a few flight tests.

Nevertheless, three general conclusions can be drawn from the tests. First, an optimum noise abatement procedure for takeoff can yield worthwhile noise reductions compared to any single segment constant configuration procedure. Second, a profile consisting of an accelerated climb with flap retraction followed by a power reduction can be optimum and should be considered in the development of noise abatement procedures. Third, noise level reduction achievable by optimizing the climbout profile might well make the difference between meeting and exceeding the maximum allowable FAA noise levels.

Noise measurements on landing approach showed a 6.0 EPNdB reduction along the ground track between the 1 and 4.4 n.mi. points from the runway threshold as the flap settings used during the approach were reduced from 50° to 0°. These noise reductions are related to the reduced thrust required to fly with less than full landing flaps. However, with flaps at 0° the pilots had difficulty tracking the glide slope.

The greatest possible noise reduction for an aircraft flying a standard approach path can be obtained by operating the engines at flight idle and letting the aircraft decelerate to the desired landing speed. When noise measurements obtained from such a decelerating flight at constant altitude with engines at flight idle were adjusted to approach altitudes, they yielded a total noise reduction of 18.5 EPNdB compared to an approach with full landing flaps. For the particular aircraft tested, only the noise level from this type approach fell within the maximum noise limit recently established for future aircraft by the FAA. Consequently, decelerating approaches flown with greatly reduced power settings may assume some importance in the future. However, practical implementation of a decelerating approach in routine airline operations will have to overcome the adverse safety factors associated with this type of approach.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Nov. 16, 1970

APPENDIX A

TEST CONDITIONS AND INSTRUMENTATION

Tests were conducted in the vicinity of the NASA Wallops Station, September 16 – 20, 1968. The runway (elevation 38 ft (11.4 m) above mean sea level) and the generally flat terrain near the Wallops Station were used to perform simulated takeoff-climbout, landing-approach, and flyby operations. The noise associated with these operations was measured at ground level. The locations of the noise measuring stations with respect to the runway are noted in figure 6 along with the position of the precision radar tracking station. One microphone was used at each of the five stations. Measurements were made in accordance with the methods recommended in reference 2.

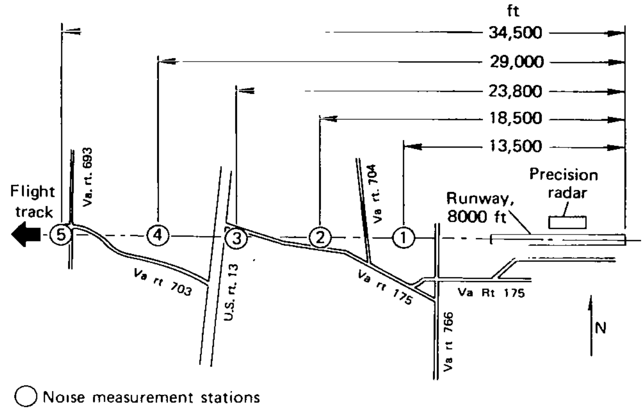
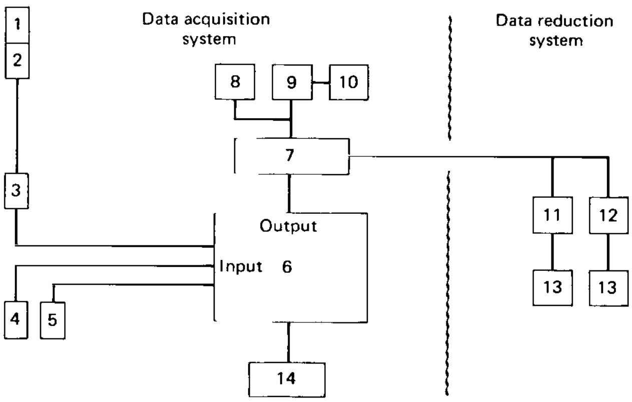


Figure 6.– Schematic diagram of NASA Wallops Station test area showing locations of runway, radar, flight track, and noise measuring stations. Dimensions are in feet.



1. GR type 1560-P5 microphone
2. GR type 1561-P40 preamplifier
3. GR type 1551-CS3 sound level meter
4. 15 watt FM transceiver
5. Voice microphone
6. Ampex SP-300 tape recorder
7. Tape recorder monitor switch box
8. Tektronix model 422 oscilloscope
9. Bell and Howell dc amplifier model 1-163
10. Honeywell oscillograph model 1508
11. GR type 1553 octave band analyzer
12. GR type 1900-A wave analyzer
13. GR Type 1521-B graphic level recorder
14. 110 Vac Homelite generator

Figure 7.– Block diagram showing typical system layout for noise data acquisition and reduction.

ATMOSPHERIC OBSERVATIONS

During the time of the experiments, observations of surface temperature, wind direction and velocity were monitored at the precision radar control unit near the runway. Surface wind velocities were less than 10 knots during the experiments. Conventional radiosonde data were also recorded during the tests. There data are tabulated in table 2.

NOISE MEASUREMENTS

Data Acquisitions

The noise measuring instrumentation used in these tests is illustrated in the block diagram of figure 7. The microphones were of a commercially available piezoelectric type fitted with windscreens and positioned about 5 ft above ground level. Their frequency responses were flat to within

±3 dB over the frequency range 20 to 12,000 Hz. The outputs of the five microphones were recorded on multichannel-direct-record tape recorders. Five recording stations were used for the takeoff-climbout and landing-approach studies; one station was used during the flyby tests. The entire sound measuring system was calibrated in the field by means of conventional discrete calibrators before, during, and after the flight measurements. Radar measured altitude and lateral displacement of the airplane at each noise station are presented in tables 3 and 4 for the takeoff and approach test flights. The data show the variations between the various profiles and indicate the accuracy that can be expected when profiles are repeated in a controlled test condition. Table 5 shows the operating condition of the airplane during the takeoff noise tests as recorded by photographing flight deck instruments.

Data Reduction and Analysis

The original analog noise recordings were edited and copied on a master tape for preparing a digital tape. The digital tape was then used to compute various objective measures of noise. Spot checks of these were made with those obtained from the original tape records.

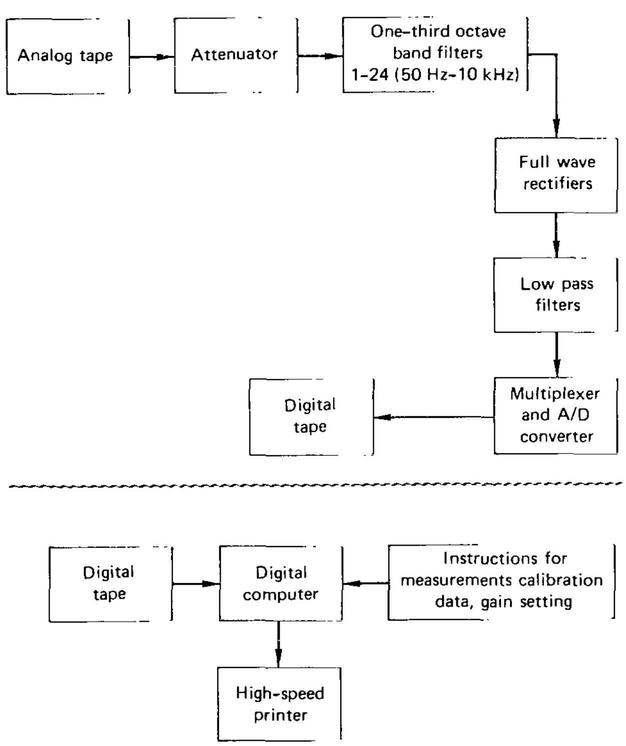


Figure 8.– Simplified block diagram of instrumentation used to compute objective measures of noise from events on analog tape copies.

Figure 8 is a simplified block diagram of the instrumentation used to compute the various measures. The details of the systems used are given in reference 5.

Objective Measures

The loudness of sound is a subjective matter. In order to judge the objectionableness of noise an objective measure must be developed which correlates with the subjective feeling. The development of the objective measures used here is described in detail in reference 5, and the DOT–FAA standards for aircraft certification are published in reference 6. The measured data obtained from the flight tests are presented in three objective forms: (1) sound pressure levels in dB(C) – the overall sound pressure level observed on a standard sound level meter with a C spectral-weighting network; (2) one-third octave band levels in dB – the one-third octave band spectra at time of occurrence of the maximum dB(C) during the flyby of the aircraft; and (3) the effective perceived noise level in EPNdB – a measure which includes the effects of strong tones and long durations of noise exposure in order to evaluate the qualities of aircraft noise that are particularly offensive to persons on the ground.

APPENDIX B

DISCUSSIONS OF NOISE MEASUREMENTS

The results of the noise measurements obtained during the takeoff-climbout, landing-approach, and flyby tests on the CV–990 airplane are presented in figures 9 through 12 in the form of typical noise time histories and 1/3 octave band frequency spectra. The effective perceived noise level in EPNdB for the takeoff, landing, and flyby tests was presented in figures 2, 3, and 4, respectively; and while the EPNdB is the FAA recommended standard noise measure, it is a complicated function of sound level, discrete frequency content, and the duration of sound. For this reason, sound pressure level in dB(C) and the 1/3 octave band level in dB at Max dB(C) are presented in parts (a) and (b) of figures 9, 10, 11, and 12, to show how both sound level and frequency content of the noise vary at each of the noise measuring stations. An indication of duration variation as measured between the 10 dB down points on the sound pressure level figures may be obtained by inspection of the plots.

None of the data presented in this report have been corrected for standard day atmospheric conditions or for distance differences. Correction factors would be less than one decibel in all cases because of the consistent flying by the test pilots and the stable near-standard atmospheric conditions.

Plots of the takeoff-climbout and the landing-approach profiles are given in figures 13 and 14, respectively. These were obtained from ground-based radar tracking of these two phases of the noise studies.

A summary of flight data, which was obtained during the takeoff noise tests by photographing the panel instruments as the aircraft passed over each noise measurement station, was presented in table 5.

NOISE SOUND PRESSURE LEVELS

Typical time histories of sound pressure level in terms of dB(C) as measured at the various microphone positions during the noise tests are presented in figures 9(a), 10(a), 11(a), and 12(a). The zero on the time scale is arbitrarily established to correspond to the peak level measured.

Examples of the noise levels measured during the takeoff-climbout tests for profiles 1 and 5 are given in figures 9(a) and 10(a), respectively. A comparison of profiles 1 and 5 shows the greatest discernible differences and it is for this reason that they are presented. Profiles 2, 3, and 4 provide data that, in general, fall between that of profiles 1 and 5. Representative landing-approach data are presented in figure 11(a) and an example of the data obtained during the 1000 ft altitude flyby tests is given in figure 12(a).

Takeoff-Climbout

The data presented in figure 9(a) were recorded during a profile 1 test, and the data in figure 10(a) were recorded during a profile 5 test flight. A comparison of figures 9(a) and 10(a), station by station, indicates that an obvious reduction in sound pressure level results when profile 5 is flown. The reductions are greatest at stations 3, 4, and 5 which were located within the assumed sound sensitive area.

Landing Approach

Time histories of sound pressure level in terms of dB(C) as measured at the various microphone positions during a typical landing approach with 50° flap setting are presented in figure 11(a).

Flyby

Examples of the time histories of sound pressure levels in terms of dB(C) obtained during the flyby tests are given in figure 12(a). The flybys were made under normal cruise conditions for each flap setting used; in addition, with flaps fully retracted noise measurements were also made with engines in the flight-idle condition. The engines-idle tests were made at the 1000 ft altitude rather than during a landing-approach test for obvious safety reasons. The gradual decrease in sound pressure level as the flaps were reduced from 50° to 0° during normal operating conditions is shown in figure 12(a).

NOISE SPECTRA

In figures 9(b), 10(b), 11(b), and 12(b) are presented the 1/3 octave band spectra at the time of occurrence of the Max dB(C) in the noise time histories of figures 9(a), 10(a), 11(a), and 12(a), respectively. The 1/3 octave band spectra are plotted as a function of the band center frequency in Hertz.

Takeoff-Climbout

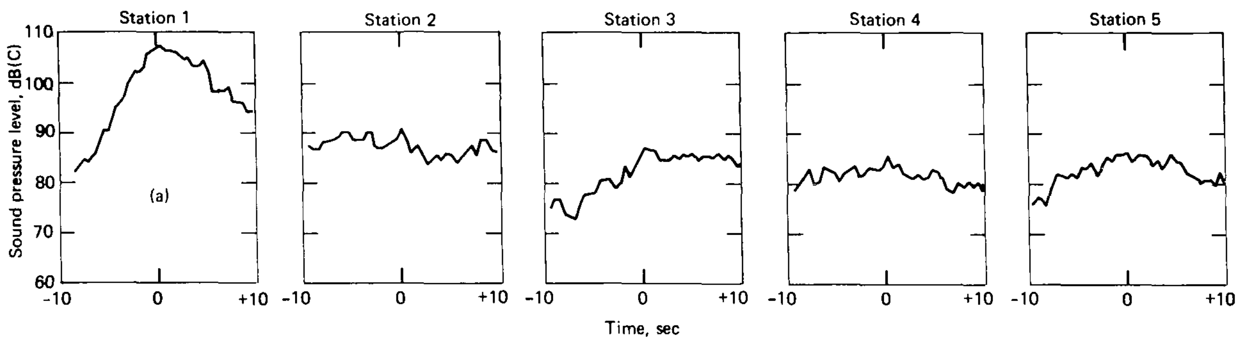
In figures 9(b) and 10(b) are shown the spectra for the profile 1 test, and profile 5 test, respectively. The data are presented for each of the five noise measurement stations. A station-by-station comparison of the data indicates that the high frequencies are attenuated more by flying profile 5 than they are by flying profile 1.

Landing Approach

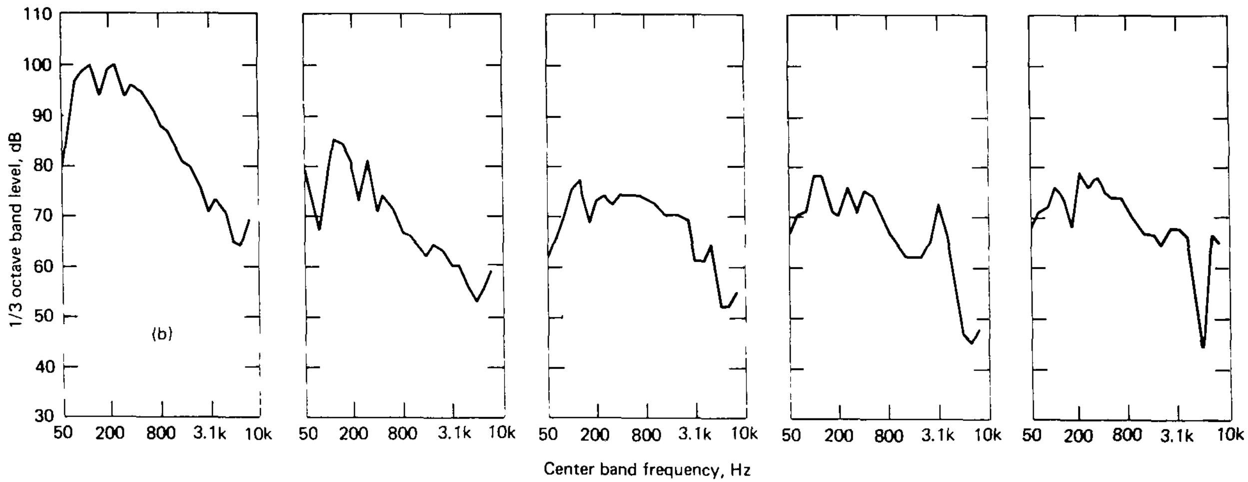
In figure 11(b) are presented the 1/3 octave band spectra for a landing-approach profile when 50° flaps were used. In contrast to the takeoff profiles, the frequency distributions are quite similar at each of the five noise measurement stations. The constancy of the frequency distribution can no doubt be attributed to the fact that the engine power settings and the flap settings are maintained constant throughout the approach.

Flyby

Figure 12(b) presents the 1/3 octave band spectra for the 1000 ft altitude flyby tests as a function of the flap settings. While the frequency distributions have similar shapes, there is a marked drop in amplitude and a definite shift in the high frequency content as the flaps are reduced from 50° to 0°. The engine idle, 0° flap condition shows a change in frequency distribution as well as a large reduction in amplitude.

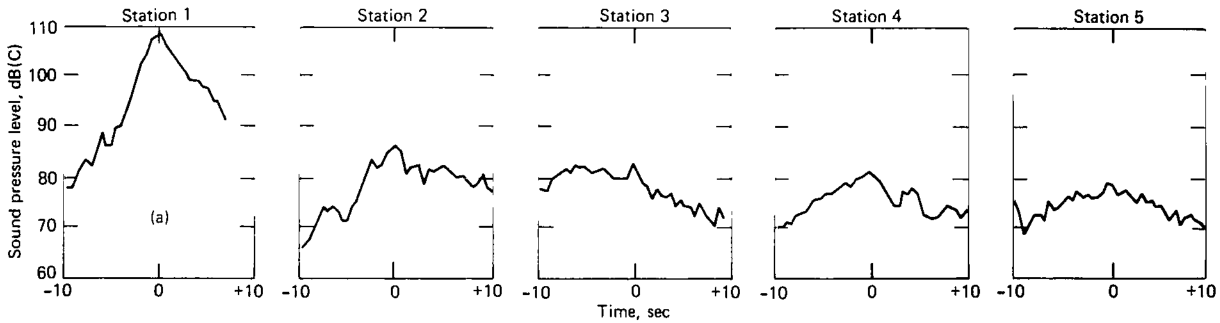


(a) Time histories.

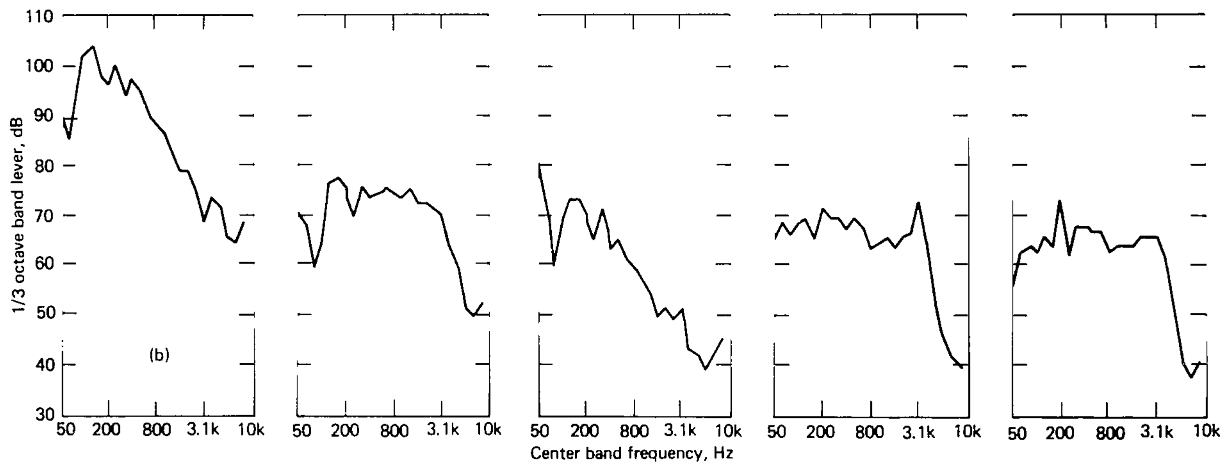


(b) 1/3 octave band levels.

Figure 9.– Typical time histories and 1/3 octave band levels of noise measured at various ground stations during the profile 1 takeoff noise tests.

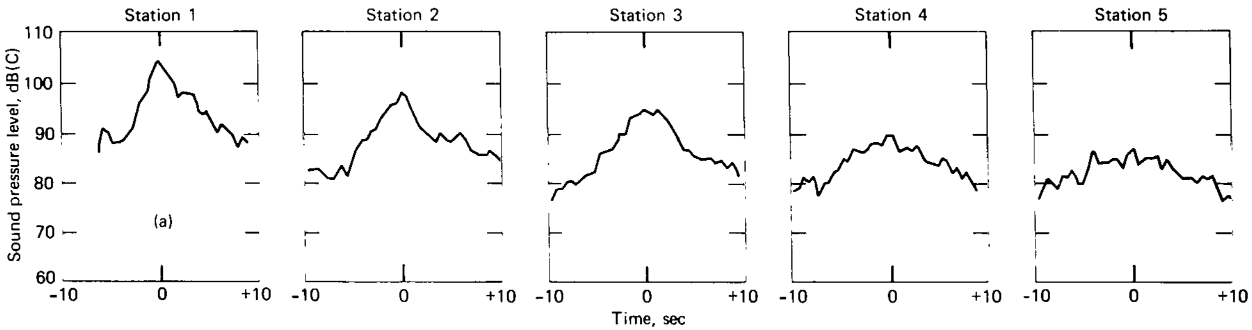


(a) Time histories.

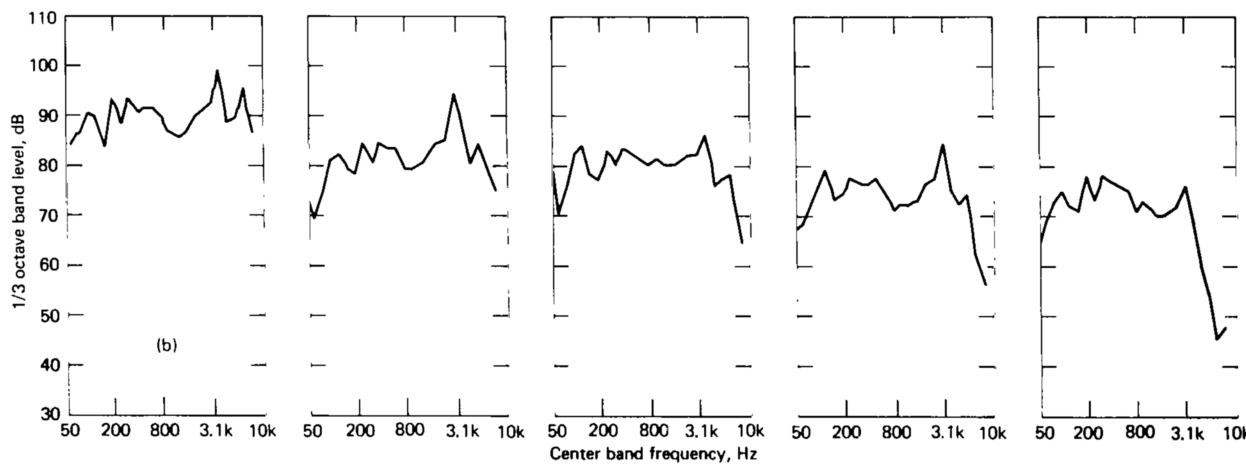


(b) 1/3 octave band levels.

Figure 10.– Typical time histories and 1/3 octave band levels of noise measured at various ground stations during the profile 5 takeoff noise tests.

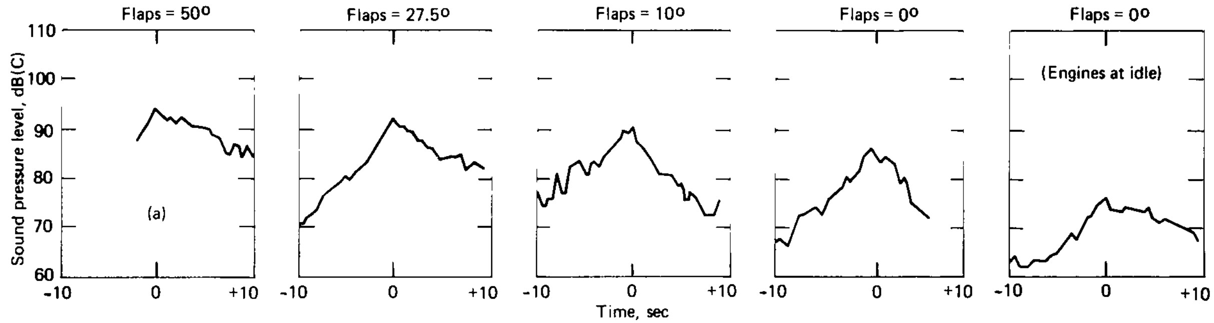


(a) Time histories (50° flaps).

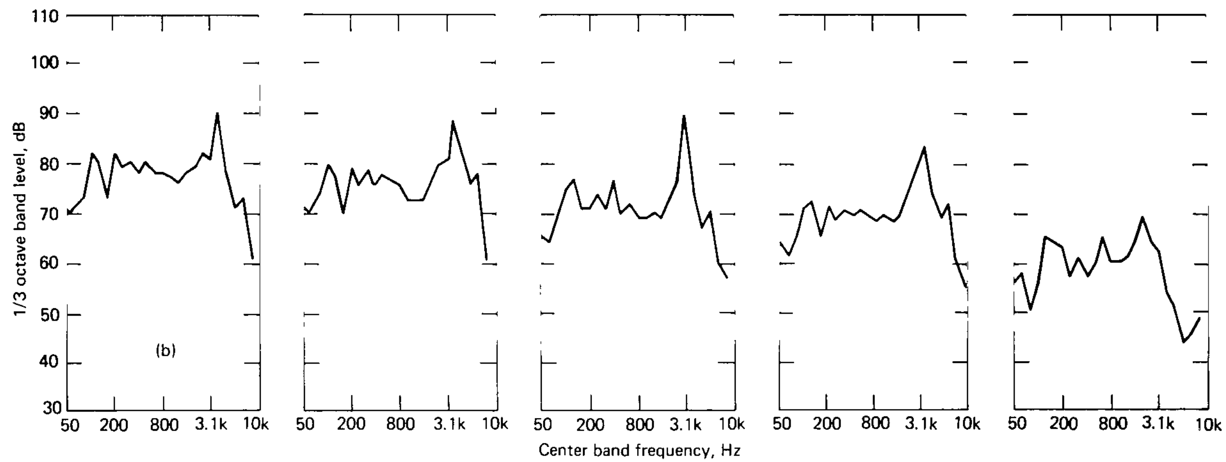


(b) 1/3 octave band levels (50° flaps).

Figure 11.– Typical time histories and 1/3 octave band levels of noise measured at various ground stations during the approach noise tests.

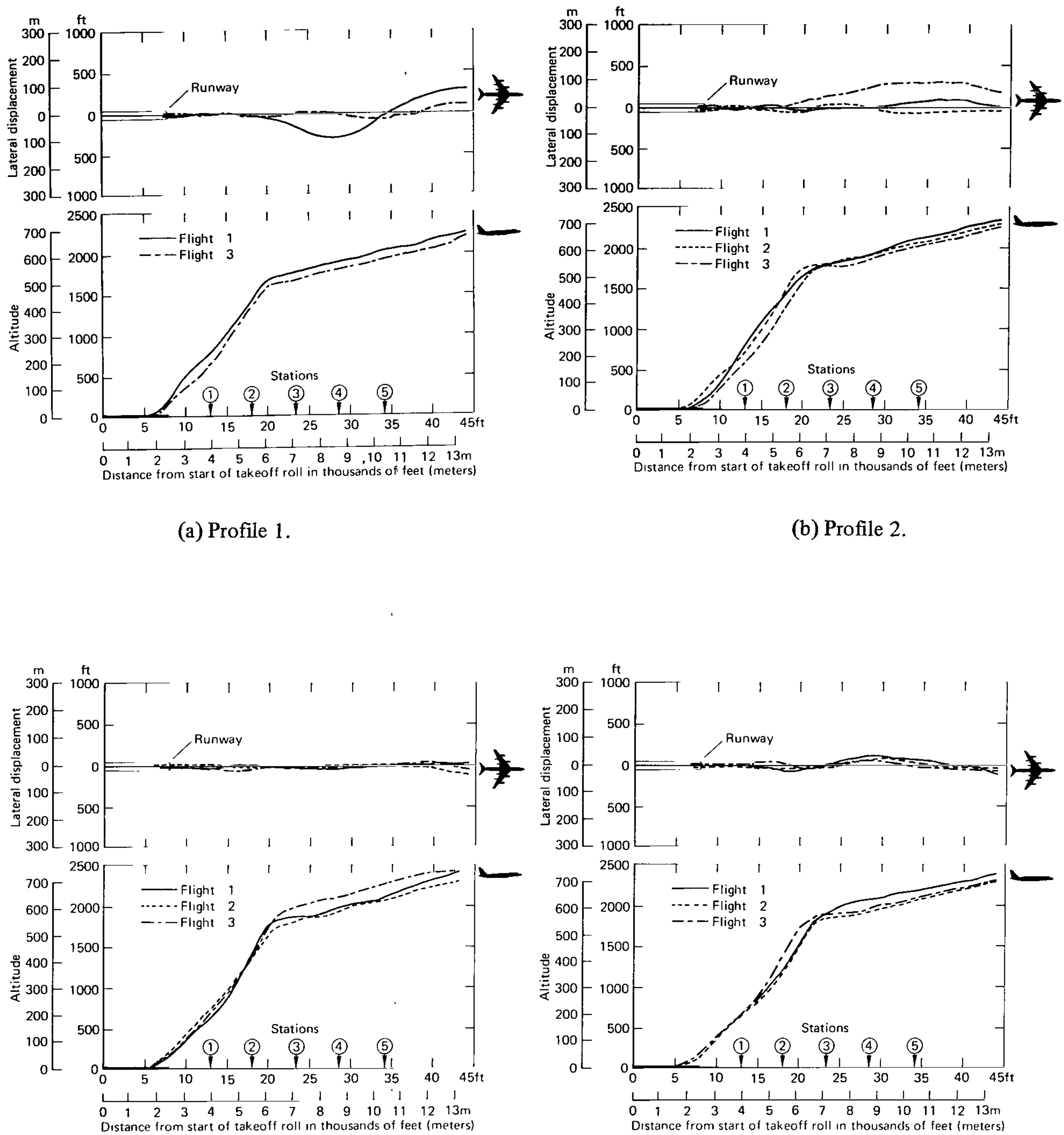


(a) Time histories.



(b) 1/3 octave band levels.

Figure 12.– Typical time histories and 1/3 octave band levels of noise measured at a single ground station during the flyby noise tests. (Altitude of the aircraft was 1000 ft.)



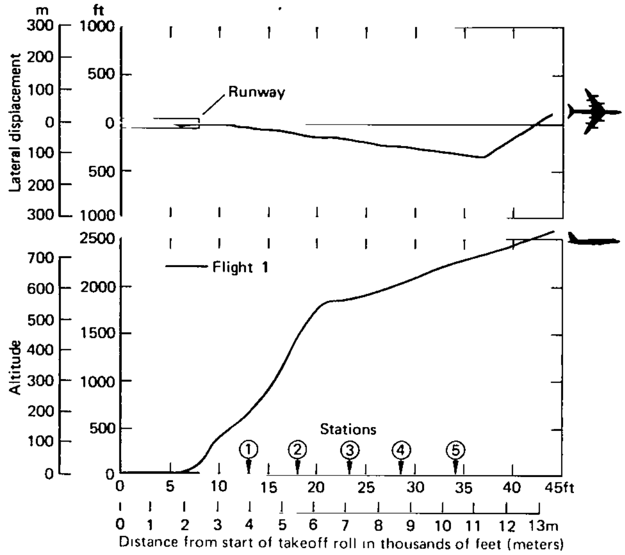
(a) Profile 1.

(b) Profile 2.

(c) Profile 3.

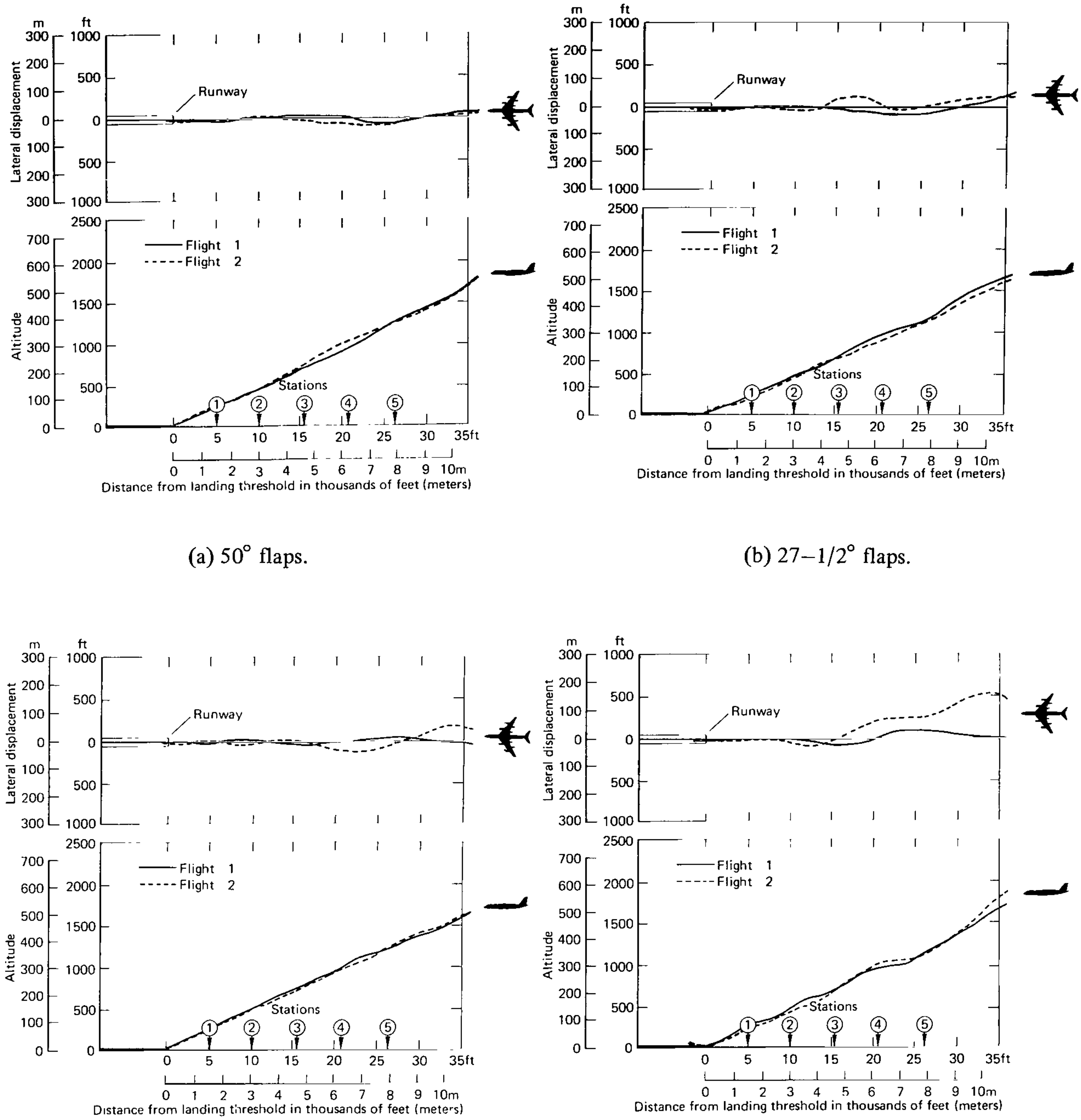
(d) Profile 4.

Figure 13.– Altitude-plan-position data from ground-based radar-takeoff tests.



(e) Profile 5.

Figure 13.– Concluded.



(a) 50° flaps.

(b) 27–1/2° flaps.

(c) 10° flaps.

(d) 0° flaps.

Figure 14.– Altitude-plan-position data from ground-based radar-approach tests.

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TABLE 1.– SUMMARY COMPARISON OF TAKEOFF-CLIMBOUT TRAJECTORIES

Profile	Average noise at last three stations, EPNdB		Altitude after leveling off, ft	Average engine pressure ratio after power reduction
		ΔdB_1*		
1	96.4	0	1750	1.42
2	93.1	3.3	1750	1.36
3	91.8	4.6	1830	1.33
4	91.1	5.3	1880	1.32
5	90.5	5.9	1820	1.36

*Difference in average noise in EPNdB – profile 1 compared to profile n.

TABLE 2.– SURFACE AND UPPER AIR ATMOSPHERIC CONDITIONS DURING NOISE TESTS

Date, time	Altitude		Atmospheric pressure, mb	Temperature, C	Percent relative humidity	Wind velocity, knots	Wind direction,* deg
	ft	m					
9–17–68 0715	10	3	1022	15.6	93	6	360
	1000	305	988	17.4	66	8	040
	2000	610	953	15.7	52	12	040
	3000	915	919	13.8	37	14	035
	4000	1220	888	11.9	82	17	040
	5000	1524	856	12.4	56	16	310
9–17–68 1915	10	3	1021	21.1	71	8	055
	1000	305	985	17.8	77	13	060
	2000	610	951	15.3	68	18	030
	3000	915	918	15.4	26	18	025
	4000	1220	885	13.7	31	16	035
	5000	1524	853	12.0	45	14	035
9–18–68 0715	10	3	1021	18.9	80	6	040
	1000	305	987	16.8	64	13	065
	2000	610	951	14.0	76	14	070
	3000	915	917	14.7	29	13	060
	4000	1220	886	13.2	30	12	065
	5000	1524	854	11.2	41	14	080
9–18–68 1315	10	3	1021	23.3	66	10	070
	1000	305	986	19.4	66	14	080
	2000	610	950	16.0	64	15	090
	3000	915	918	15.4	35	17	090
	4000	1220	886	14.4	25	16	092
	5000	1524	854	10.3	35	12	094
9–18–68 1915	10	3	1020	21.1	60	10	070
	1000	305	985	18.5	74	16	065
	2000	610	950	15.9	88	13	082
	3000	915	917	16.0	47	13	080
	4000	1220	886	14.2	24	16	112
	5000	1524	854	13.3	27	11	114

*Direction from which wind is blowing.

TABLE 3.– RADAR MEASURED ALTITUDE AND LATERAL DISPLACEMENT AND THE CALCULATED SLANT RANGE FOR THE CV–990 AIRPLANE AT EACH NOISE MEASURING STATION DURING TAKEOFF NOISE TESTS

Profile	Climb velocity, knots	Flight	Station 1 Altitude ft	Station 1 Altitude m	Station 1 Lateral displacement ft	Station 1 Lateral displacement m	Station 1 Slant range ft	Station 1 Slant range m	Station 2 Altitude ft	Station 2 Altitude m	Station 2 Lateral displacement ft	Station 2 Lateral displacement m	Station 2 Slant range ft	Station 2 Slant range m	Station 3 Altitude ft	Station 3 Altitude m	Station 3 Lateral displacement ft	Station 3 Lateral displacement m	Station 3 Slant range ft	Station 3 Slant range m	Station 4 Altitude ft	Station 4 Altitude m	Station 4 Lateral displacement ft	Station 4 Lateral displacement m	Station 4 Slant range ft	Station 4 Slant range m	Station 5 Altitude ft	Station 5 Altitude m	Station 5 Lateral displacement ft	Station 5 Lateral displacement m	Station 5 Slant range ft	Station 5 Slant range m
1	$V_2 + 15$	1	850	259	20	6	850	259	1520	463	0	0	1520	463	1780	542	170	52	1788	545	1900	579	150	46	1906	581	2040	622	40	12	2040	622
		2	720	219	0	0	720	219	1440	439	20	6	1440	439	1700	518	0	0	1700	518	1820	544	10	3	1820	545	1950	594	50	15	1951	595
2	$V_2 + 20$	1	880	268	0	0	880	268	1530	466	20	6	1530	466	1790	546	0	0	1790	546	1930	588	0	0	1930	588	2110	643	60	18	2111	643
		2	800	244	0	0	800	244	1610	491	60	18	1611	491	1810	552	40	12	1810	552	1930	588	30	9	1930	588	2050	625	80	24	2052	625
		3	880	268	10	3	880	268	1660	506	50	15	1661	506	1780	543	160	49	1787	545	1940	591	170	82	1959	597	2060	628	310	94	2083	635
3	$V_2 + 40$	1	580	177	20	6	580	177	1340	408	0	0	1340	408	1860	567	30	9	1860	567	1970	600	30	9	1970	601	2080	634	0	0	2080	634
		2	680	207	0	0	680	207	1270	387	20	6	1270	387	1780	543	30	9	1780	543	1890	576	0	0	1890	576	2030	619	15	5	2030	619
		3	650	198	50	15	652	199	1310	399	40	12	1310	399	1970	600	0	0	1970	600	2090	637	10	3	2090	637	2230	680	5	2	2230	680
4	$V_2 + 50$	1	640	195	20	6	640	195	1240	378	80	24	1243	379	1920	585	0	0	1920	585	2070	631	80	24	2072	631	2180	664	40	12	2180	665
		2	670	204	40	12	671	205	1220	372	50	15	1221	372	1850	564	40	12	1850	564	1920	585	50	15	1921	585	2050	625	0	0	2050	625
		3	670	204	10	3	670	204	1470	448	0	0	1470	448	1890	576	0	0	1890	576	1970	600	40	12	1970	601	2080	634	20	6	2080	634
5	$V_2 + 50$	1	700	213	60	18	703	214	1540	469	130	40	1545	470	1880	573	180	55	1889	576	2050	625	240	73	2064	629	2230	680	320	98	2252	687

TABLE 4.– RADAR MEASURED ALTITUDE AND LATERAL DISPLACEMENT AND THE CALCULATED SLANT RANGE FOR THE CV–990 AIRPLANE AT EACH NOISE MEASURING STATION DURING APPROACH NOISE TESTS

Approach	Flaps, deg	Flight	Station 1 Altitude ft	Station 1 Altitude m	Station 1 Lateral displacement ft	Station 1 Lateral displacement m	Station 1 Slant range ft	Station 1 Slant range m	Station 2 Altitude ft	Station 2 Altitude m	Station 2 Lateral displacement ft	Station 2 Lateral displacement m	Station 2 Slant range ft	Station 2 Slant range m	Station 3 Altitude ft	Station 3 Altitude m	Station 3 Lateral displacement ft	Station 3 Lateral displacement m	Station 3 Slant range ft	Station 3 Slant range m	Station 4 Altitude ft	Station 4 Altitude m	Station 4 Lateral displacement ft	Station 4 Lateral displacement m	Station 4 Slant range ft	Station 4 Slant range m	Station 5 Altitude ft	Station 5 Altitude m	Station 5 Lateral displacement ft	Station 5 Lateral displacement m	Station 5 Slant range ft	Station 5 Slant range m
1	50	1	250	76	30	9	252	77	460	140	0	0	460	140	720	219	40	12	721	220	950	290	0	0	950	290	1280	390	50	15	1281	390
		2	270	82	30	9	272	83	470	143	20	6	470	143	770	235	40	12	771	235	1050	320	80	24	1053	321	1250	381	50	15	1251	381
2	27–1/2	1	250	76	20	6	251	76	500	152	10	3	500	152	740	226	20	6	740	226	1000	305	70	21	1002	306	1200	366	80	24	1203	367
		2	250	76	10	3	250	76	480	146	40	12	482	147	700	213	100	30	707	216	920	280	30	9	920	281	1150	351	20	6	1150	351
3	10	1	260	79	10	3	260	79	500	152	10	3	500	152	750	229	40	12	751	229	1000	305	0	0	1000	305	1210	368	30	9	1210	369
		2	170	82	0	0	270	82	510	155	10	3	510	155	730	222	0	0	730	222	980	299	120	37	987	301	1230	375	30	9	1230	375
4	0	1	290	88	20	6	291	89	500	152	10	3	500	152	720	219	80	24	724	221	950	290	30	9	950	290	1170	357	90	27	1173	358
		2	250	76	20	6	251	76	460	140	60	18	464	141	720	219	20	6	720	219	1020	311	230	70	1046	319	1150	351	270	83	1181	360

TABLE 5.– OPERATING CONDITIONS OF CV–990 AIRPLANE DURING TAKEOFF NOISE TESTS OBTAINED FROM FLIGHT DECK PHOTOGRAPH READOUTS

Profile	Climb velocity, knots	Flight	Date	Airplane gross weight (in thousands) lbm	Airplane gross weight (in thousands) kg	Photo	Indicated airspeed, knots	Altitude ft	Altitude m	Rate of climb ft/min	Rate of climb m/min	Flap setting, deg	Compressor N_1, percent rpm for engine 1	2	3	4	Engine pressure ratio for engine 1	2	3	4	Fuel flow, lb/hr for engine (in thousands) 1	2	3	4
						1	167	860	262	1750	533	27	99	99	98	99	1.91	1.90	1.91	1.92	9.50	9.50	9.00	9.20
						2	164	1580	482	2300	701	27	94	94	93	96	1.56	1.57	1.56	1.62	5.50	6.00	5.50	6.00
		1	9–17–68	206	94	3	169	1820	555	540	164	27	90	90	90	92	1.42	1.44	1.42	1.45	4.20	4.60	4.20	4.50
						4	164	2000	610	450	137	27	90	90	89	91	1.40	1.41	1.39	1.42	4.00	4.30	4.00	4.20
						5	163	2100	640	300	91	27	90	90	90	92	1.42	1.45	1.43	1.46	4.20	4.60	4.30	4.50
1	V_2 + 15					1	167	770	235	2000	610	27	98	99	98	99	1.88	1.92	1.88	1.88	9.00	10.00	9.00	9.00
						2	165	1500	457	2500	762	27	98	99	98	99	1.90	1.93	1.90	1.90	9.00	9.00	8.50	9.00
		2	9–18–68	202	92	3	167	1810	552	600	182	27	92	92	91	92	1.50	1.50	1.48	1.49	4.85	5.50	4.85	4.85
						4	167	1920	585	450	137	27	90	90	90	92	1.40	1.42	1.40	1.44	4.10	4.45	4.10	4.35
						5	164	2060	628	408	124	27	90	90	91	92	1.44	1.46	1.48	1.40	4.35	4.75	4.80	5.00
						1	170	950	289	2650	808	10	99	99	98	99	1.91	1.91	1.89	1.88	9.50	9.80	9.00	9.00
						2	173	1600	488	2100	640	10	94	94	92	94	1.52	1.52	1.50	1.52	5.00	5.50	4.70	5.00
		1	9–17–68	205	93	3	178	1900	579	600	183	10	90	90	90	91	1.38	1.39	1.39	1.40	4.00	4.20	4.10	4.00
						4	177	2070	631	700	213	10	89	89	89	90	1.34	1.35	1.35	1.37	3.55	3.80	3.70	3.80
						5	179	2210	674	500	152	10	88	88	88	90	1.34	1.35	1.35	1.36	3.55	3.75	3.70	3.80
						1	178	840	256	2250	686	10	99	99	98	99	1.90	1.89	1.87	1.89	9.50	9.50	9.00	9.00
						2	174	1660	506	2800	853	10	92	92	90	94	1.46	1.48	1.43	1.50	5.00	4.85	4.25	4.75
2	V_2 + 20	2	9–18–68	200	91	3	174	1920	585	500	152	10	90	90	90	90	1.39	1.39	1.39	1.39	4.00	4.10	4.00	3.90
						4	175	2050	625	500	152	10	88	88	88	90	1.34	1.35	1.34	1.35	3.55	3.80	3.50	3.50
						5	173	2190	667	460	140	10	88	88	88	90	1.34	1.35	1.33	1.34	3.50	3.70	3.50	3.50
						1	177	920	280	2250	686	10	99	98	98	99	1.89	1.89	1.88	1.89	9.50	9.50	9.00	9.00
						2	170	1720	524	2200	670	10	90	90	89	92	1.42	1.41	1.38	1.44	4.00	4.30	3.80	4.20
		3	9–18–68	197	89	3	173	1910	582	600	183	10	89	88	89	90	1.37	1.37	1.37	1.37	3.80	3.90	3.85	3.75
						4	173	2050	625	550	168	10	89	88	89	90	1.37	1.36	1.37	1.37	3.80	3.90	3.85	3.75
						5	175	2185	666	500	152	10	89	88	89	90	1.38	1.37	1.37	1.37	3.80	3.90	3.85	3.75
						1	194	665	203	1750	533	0	99	99	98	99	1.90	1.90	1.87	1.89	10.00	10.00	9.00	9.30
						2	200	1475	449	3600	1097	0	99	99	98	100	1.92	1.91	1.88	1.90	9.50	9.80	9.00	9.00
		1	9–17–68	202	92	3	198	1930	588	500	152	0	89	88	89	90	1.34	1.34	1.34	1.36	3.65	3.80	3.70	3.80
						4	200	2070	631	550	168	0	89	89	89	90	1.33	1.34	1.33	1.35	3.60	3.75	3.70	3.75
						5	200	2230	680	700	213	0	89	88	89	90	1.33	1.34	1.33	1.35	3.60	3.75	3.60	3.70
						1	189	780	238	1900	579	0	99	99	98	99	1.91	1.90	1.88	1.89	10.00	10.00	9.00	9.00
						2	198	1390	424	2750	838	0	99	99	98	99	1.90	1.92	1.90	1.89	10.00	10.00	9.00	9.00
3	V_2 + 40	2	9–18–68	206	93	3	195	1880	573	500	152	0	88	88	88	90	1.34	1.34	1.34	1.34	3.65	3.70	3.70	3.70
						4	198	2015	614	600	183	0	88	88	88	90	1.34	1.34	1.34	1.34	3.65	3.70	3.75	3.65
						5	199	2150	655	600	183	0	89	89	89	90	1.35	1.36	1.34	1.34	3.75	3.90	3.75	3.65
						1	190	655	200	2000	610	2	99	99	98	100	1.91	1.90	1.90	1.90	10.00	10.00	9.00	9.00
						2	200	1380	421	2900	884	0	99	99	98	99	1.90	1.92	1.90	1.90	10.00	10.00	9.00	9.00
		3	9–18–68	203	92	3	191	2075	632	700	213	0	88	88	88	90	1.33	1.34	1.32	1.35	3.50	3.70	3.50	3.65
						4	197	2190	667	550	168	0	88	88	88	89	1.32	1.33	1.32	1.33	3.50	3.65	3.50	3.50
						5	198	2350	716	570	174	0	88	88	88	89	1.32	1.33	1.32	1.33	3.50	3.65	3.50	3.50
						1																		
						2	211	1540	469	3250	991	0	100	99	98	99	1.92	1.91	1.88	1.88	8.50	8.50	8.50	8.50
		1	9–17–68	200	91	3	207	2080	634	1000	305	0	88	89	88	90	1.30	1.31	1.30	1.32	3.20	3.50	3.30	3.50
						4	207	2195	669	550	168	0	88	88	88	89	1.28	1.28	1.28	1.30	3.20	...	...	...
						5	204	2300	701	500	152	0	88	88	87	89	1.28	1.29	1.28	1.31	3.20	...	...	...
						1	190	730	222	1700	518	2	99	99	98	100	1.89	1.89	1.85	1.90	9.50	9.50	8.50	9.50
						2	209	1305	398	2800	853	0	99	99	98	100	1.89	1.89	1.86	1.90	9.50	9.50	8.50	9.50
4	V_2 + 50	2	9–18–68	199	90	3	204	1905	580	550	168	0	88	88	88	90	1.34	1.34	1.33	1.33	3.65	3.80	3.70	3.55
						4	209	2025	617	600	183	0	89	88	89	90	1.33	1.32	1.32	1.32	3.60	3.65	3.65	3.50
						5	209	2180	664	550	168	0	88	88	88	89	1.32	1.32	1.32	1.32	3.50	3.60	3.55	3.50
						1	208	770	235	1900	579	0	100	99	99	100	1.90	1.90	1.88	1.89	10.00	10.00	9.00	9.00
						2	209	1565	477	3500	1067	0	95	94	92	95	1.77	1.78	1.76	1.76	5.00	5.00	4.90	4.90
		3	9–18–68	194	88	3	204	1935	590	500	152	0	88	88	88	90	1.30	1.31	1.30	1.32	3.30	3.50	3.40	3.40
						4	209	2040	622	500	152	0	88	88	88	90	1.32	1.32	1.32	1.32	3.55	3.65	3.55	3.50
						5	210	2195	669	500	152	0	88	88	88	90	1.32	1.32	1.32	1.32	3.55	3.65	3.50	3.50
5	V_2 + 50	1	9–18–68	197	89	none	202	1500′	457	750	229	0	---	---	---	---	1.38	1.38	1.38	1.38	---	---	---	---
		2	9–18–68	195	88	none	201	1500′	457	750	229	0	---	---	---	---	1.38	1.38	1.38	1.38	---	---	---	---

Note: Profile 5 data from pilot's log – no photographic data available.

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