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Comparison of Aircraft Noise-Contour Prediction Programs

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A comparison was made of Version 1.3 of the FAA Integrated Noise Model (INM) and Version 3.4 of the USAF/NOISEMAP computer programs. Those programs are widely used to predict the location of aircraft noise contours around airports and to determine the size of the areas enclosed. Large differences were found in the noise data bases. There were also differences in flight-profile data bases, ground attenuation factor, and in the way the change in noise duration is handled for curved flight paths. The two programs were used to calculate sound exposure level contours produced by individual operations of various air-carrier and general-aviation jets. The programs were also used to calculate contours of cumulative day-night average sound level around a hypothetical average major intercontinental airport (AVPORT). Large differences in contour areas and shapes were found.

Introduction

NOISE contours around an airport or air base have been used as a planning and evaluation tool since the 1950s as a result of studies first conducted under sponsorship of the U.S. Air Force. A principal usage of noise contours has been as a component of long-range efforts by local, regional, and national authorities to avoid or minimize adverse community reactions to noise produced by aircraft during takeoff and landing operations. Another principal usage for noise contours has been to help quantify the magnitude of the impact of aircraft noise on communities around airports, on a local as well as national basis. An additional major use of noise contours has been to evaluate the effect (benefit or disbenefit) of various proposed changes such as the addition of noise suppression devices to an engine, modifications to flight paths, increases in the number of operations per day, runway extension or the addition of a new runway, or even the creation of a totally new airport.

Noise contours are also often used to illustrate how much quieter a new or modified aircraft is than an older or unmodified aircraft. In such cases, good advantage is taken of the large change in the area enclosed by a given contour that accompanies a relatively small change (in decibels) in the noise level at the source.

Contour calculation methods are complex because the typical airport situation is complex with many flight paths, aircraft types, and engine power settings. Because of this complexity, all contour calculations, except those which are quite limited in scope, are carried out with the help of a large-scale digital computer.

We began the study reported here by conducting a survey to determine which aircraft noise contour programs were currently in the public domain and in wide use. It turned out that only two noise-contour programs met the criteria of being 1) widely available, 2) in the public domain, 3) acceptable to government agencies, and 4) used by many organizations. Those programs were a) the NOISEMAP program prepared over a period of several years under the sponsorship of the U.S Air Force (USAF), and b) the Integrated Noise Model (or INM) program, prepared under the sponsorship of the U.S. Department of Transportation (DOT) and the Federal Aviation Administration (FAA).

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The purpose of the study reported here was to examine the technical basis for the noise contour calculation methods and to determine the differences in the contours resulting from the various technical differences in the methods.

In the next sections we present a discussion of the general approach to the calculation of noise contours and a technical evaluation of the key elements used in determining contours. Some of the key elements are 1) noise data base, 2) flight profiles, 3) ground attenuation, 4) fuselage shielding, and 5) nonuniform flight paths.

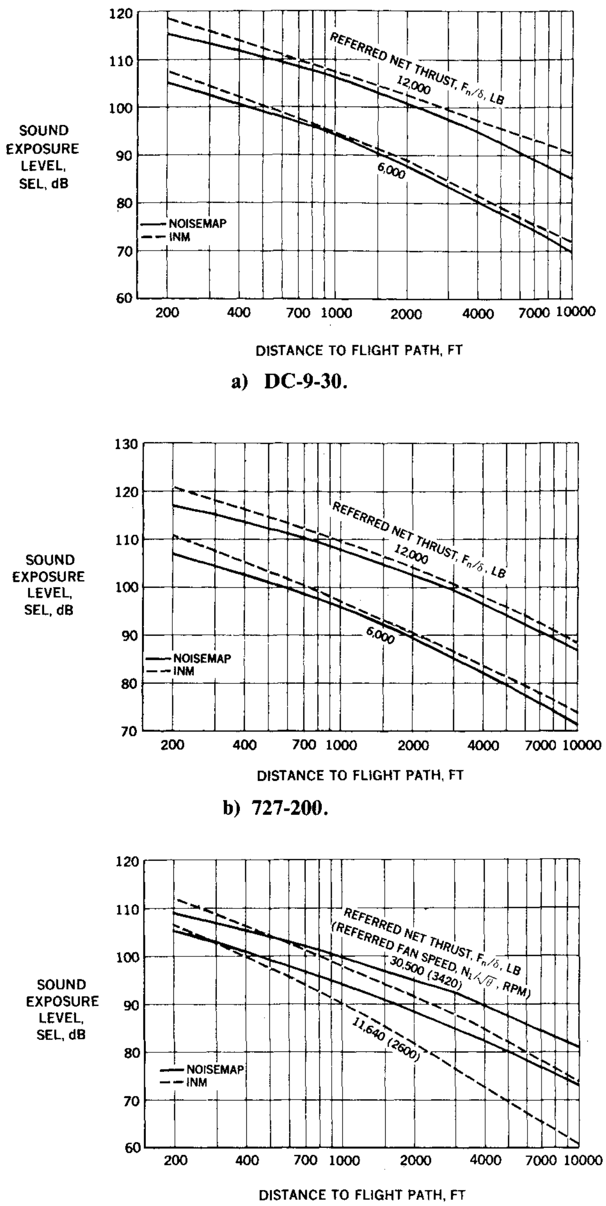
We then compared noise contours using the INM and NOISEMAP computer programs for operations by individual aircraft as well as operations by several aircraft of a variety of types. The multiple-aircraft noise contours were calculated for a fictitious average airport which is described in detail later. All calculations were performed using Version 1.3 of INM and Version 3.4 of NOISEMAP. A newer version of INM—Version 2.6—was released by the FAA in Sept. 1979. It is not expected, however, that the results or conclusions of this paper would change significantly if Version 2.6 of INM were to have been used instead of Version 1.3.

General Contour-Calculation Procedure Used by INM and NOISEMAP

General procedures used by INM and NOISEMAP to calculate aircraft-noise contours are similar, although there are many differences in detail. In this section, we describe the general procedure used by both computer programs for calculating noise exposure contours. In the following section we describe some of the differences in technical details which often result in significant differences in the location and size of the contours calculated by the two programs.

Both INM and NOISEMAP employ noise data bases which give values of effective perceived noise level (EPNL) or sound exposure level (SEL) as a function of distance of closest approach of an airplane to an observer for various engine thrust or power settings. Both computer programs also contain airplane performance data for the various aircraft in their data bases. Airplane performance data are used in the determination of the height of an airplane above the ground and the engine thrust as a function of distance from brake release or landing threshold.

Various flight tracks (the projection of the flight path on the ground plane) consisting of straight or curved segments may be chosen. Once the flight path and flight track of a particular airplane have been determined, the noise level at a point on the ground is found by first calculating the distance of closest approach of the flight path to a ground point. Then the noise data base is used to find the EPNL or SEL



a) DC-9-30.

b) 727-200.

c) DC-10-10.

Fig. 1 SEL/distance/thrust curves from data base in Integrated Noise Model (INM) and NOISEMAP.

corresponding to that distance for the engine thrust setting. Next, adjustments are applied to account for excess ground attenuation (EGA)§ and changes in the duration correction factor in EPNL or SEL caused by curved flight paths and by differences between the airplane speed and a reference airspeed. Noise contributions resulting from all operations at a given airport in a given time period are calculated and summed on a mean-square basis to obtain the total noise exposure at a point. The ability to calculate noise exposure at an arbitrary ground point makes it possible to calculate the locations of contours of equal noise exposure.

Technical Approaches Used by INM and NOISEMAP

Noise Data Base

The noise data base for INM is stored in the computer program in tabular form. Version 1.3 of INM contains data on 44 different airplanes including a variety of commercial jet transports and general aviation airplanes. The data can be deduced from the listing supplied by the FAA with the computer program.

The noise data base for NOISEMAP is documented in several reports. Data for military aircraft are given in Refs. 1-6. Data for commercial jet- and propeller-powered transports and general aviation airplanes are given in Refs. 7 and 8.

Comparisons of EPNL and SEL vs distance curves were made using data obtained from the INM computer program and from Refs. 7 and 8 for the NOISEMAP data. SEL comparisons for the DC-9, 727, and DC-10-10 airplanes are given in Figs. 1a-c. Additional comparisons of EPNL and SEL data are given in Ref. 9. Each figure contains two sets of curves. The upper set is for a takeoff thrust setting and the lower set is for an approach thrust setting. Thrust is indicated by the symbol F_n/δ for referred net thrust where δ is the ratio of the ambient pressure to the standard ambient pressure at sea level. The figures show that there are large differences between the INM and NOISEMAP noise data bases for all of the airplanes shown. For the DC-10-10 airplane there are extremely large differences, especially at large distances.

Because of the large differences, we now describe how the data for the curves were obtained. The curves labeled NOISEMAP were plotted directly from data tabulated in Refs. 7 and 8. For all airplanes except the DC-10-10, the thrusts shown were exactly those for which data were tabulated. For the DC-10-10, the value of low-pressure shaft speed N_l, not thrust, was fixed in the NOISEMAP data tables at the values shown in Fig. 1c. The corresponding values of thrust were obtained by using the following formula from Table A-III of Ref. 10, which relates thrust per airplane for a three-engine airplane to percent N_l for the CF6 engine: Thrust, per airplane, in pounds $= 91{,}500\ [1 + 0.02579\ (\%\, N_l - 100)]$.

According to Table A-I of Ref. 10, takeoff thrust corresponds to 100% N_l (i.e., 3420 rpm) as calculated from the formula from the above mentioned Table A-III. That value of thrust is 30,500 lb (per engine), which is the value indicated in Fig. 1c for takeoff. Knowing the value of N_l corresponding to 100% thrust, the formula relating thrust to percent N_l was used to find the value of thrust of 11,640 lb (per engine) indicated in Fig. 1c for the approach condition at a shaft speed of 2600 rpm (76%).

It was convenient to plot all curves for constant values of referred net thrust rather than constant values of N_l and thrust because all of the data in the INM tables are for constant values of thrust, even for airplanes with high-bypass-ratio engines. In order to obtain curves for the particular values of thrust shown in Fig. 1 for data from the INM data base it was usually necessary to interpolate linearly between data for other thrust values. However, that interpolation process is exactly the procedure used by the INM computer program when calculating a noise contour. So the comparisons of the two data sets shown in Fig. 1 were made in a way consistent with the way in which the basic data are actually used in the two computer programs to calculate contours.

Ground Attenuation

In both INM and NOISEMAP, adjustments are applied to the noise vs distance curves to account for "excess ground attenuation" (EGA) when the airplane is at a shallow angle with respect to a ground observation point. The adjustment procedures are quite different for the two programs.

The procedure in INM is a modification of a procedure proposed in Ref. 11. A curve of EGA, in decibels, vs distance from a ground observation point to the airplane is used for the case when the airplane is on the ground. A single curve is assumed to hold for all airplanes and engine-power settings. For an airplane elevation angle β greater than 10 deg the adjustment is assumed to be zero. For angles between 0 and 10 deg an interpolation formula is used to bridge the gap.

§In NOISEMAP, the ground attenuation adjustment is included as part of the noise data base.

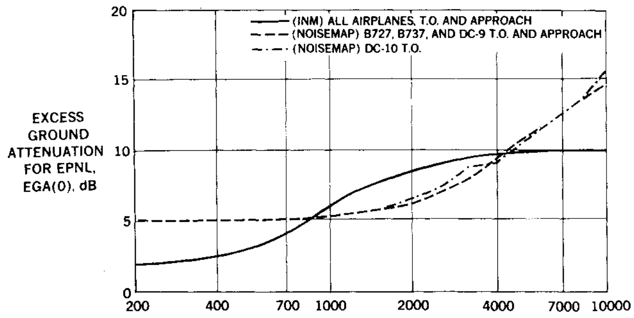


Fig. 2 Excess ground attenuation for EPNL at elevation angle β of 0 deg.

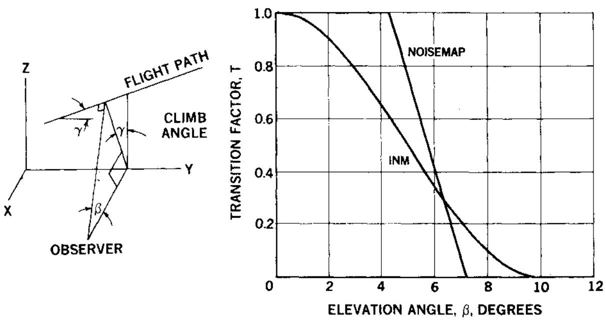


Fig. 3 Interpolation curves for transition factor T defining excess ground attenuation for EPNL at elevation angle β relative to excess ground attenuation for EPNL at $\beta=0$ deg, i.e., EGA $(\beta)=(T)$ [EGA (0)].

Mathematically,

$$\mathrm{EGA}(\beta)=\{[1+\cos(18\beta)]/2\}\mathrm{EGA}(0) \qquad 0\leq\beta\leq 10\ \mathrm{deg}$$
$$=0 \qquad \beta>10\ \mathrm{deg} \tag{1}$$

where EGA (0) is the excess ground attenuation for $\beta=0$.

The procedure in NOISEMAP to account for EGA "ground-to-ground" propagation ($\beta=0$) is described in detail in Ref. 12. We give a qualitative description of the procedure here. The NOISEMAP method assumes that EGA is a function of the spectral content of the aircraft noise. Empirical curves give EGA as a function of frequency. The curves are then applied to measured aircraft noise spectra for specific airplanes at various engine thrust settings to calculate the spectral changes caused by EGA. From the calculated spectral changes, changes in EPNL or SEL are then calculated.

For NOISEMAP the result of the above method is two sets of noise data for each airplane. One set is for "air-to-air" propagation. The other is for "ground-to-ground" propagation. The noise data for ground-to-ground (and air-to-air) propagation are given in Refs. 7 and 8 for commercial jet- and propeller-powered transports and for general-aviation aircraft.

As for the INM procedure, an interpolation formula is used in NOISEMAP to bridge the gap between elevation angles where air-to-air propagation is dominant and zero elevation angle where ground-to-ground propagation applies. The interpolation formula for NOISEMAP is the following:

$$\mathrm{EGA}(\beta)=\mathrm{EGA}(0) \qquad 0\leq\beta\leq 4.3\ \mathrm{deg}$$
$$=(2.5-0.3491\,\beta)\mathrm{EGA}(0) \qquad 4.3\ \mathrm{deg}<\beta<7.2\ \mathrm{deg}$$
$$=0 \qquad \beta\geq 7.2\ \mathrm{deg} \tag{2}$$

The ground-to-ground excess attenuations for several airplanes are shown in Fig. 2 as calculated by INM and by NOISEMAP procedures. A comparison of the INM interpolation formula, Eq. (1), with the NOISEMAP interpolation formula, Eq. (2), is given in Fig. 3. The ground-to-ground excess attenuation curve for INM is the same for SEL as for EPNL. For NOISEMAP, different ground-to-ground excess attenuation curves are used for SEL calculations than for EPNL calculations. However, the interpolation curves for both programs are used for both EPNL and SEL calculations.

Fuselage Shielding

The INM computer program applies an additional adjustment which is significant for small elevation angles. The adjustment is called a fuselage shielding correction and is adopted from the never-published proposal in Ref. 11. It yields a reduction in EPNL or SEL of 3 $(1-\sin\beta)$ in decibels. No fuselage shielding adjustment is applied in NOISEMAP.

Nonuniform Flight Paths

Adjustments to the basic input-noise-data base must be made in order to obtain EPNL or SEL values for cases where the flight path of an airplane is other than along a uniform straight path with constant airspeed. Adjustments are required because EPNL and SEL are time integrals of aircraft noise over a defined duration. The time integrals can be represented by the sum of the maximum value of the tone-corrected perceived noise level (PNLTM) or of the A-weighted sound level (MXL) plus a duration correction factor D.

The duration correction factor depends on the time variation of the airplane position and speed and is different for a straight, constant-speed flight path, a flight path consisting of several straight segments, and a curved flight path. The noise data base, on the other hand, is considered by both computer programs to be applicable only for an airplane flying along a straight, constant-speed flight path.

Both INM and NOISEMAP apply adjustments to the duration correction factor, but the procedures for doing so are completely different. In the INM procedure, an adjustment is applied *only* for observer locations inside a curved track segment. The necessity for such an adjustment can be seen by considering an extreme example where an airplane is flying in a horizontal circle and the observer is located directly beneath the center of the circle. For that case, the duration would be infinite, and an assumption that EPNL or SEL is only a function of distance of closest approach would be completely wrong. Details of the INM adjustment procedure are given in Ref. 13 and will not be repeated here. However, it should be mentioned that the adjustment procedure is stated in Ref. 13 to be empirical.

NOISEMAP employs an analytical method to calculate an adjustment for nonuniform flight path effects. The only assumptions in the NOISEMAP method are that 1) the sound field from the airplane noise source is cylindrically symmetric and 2) the noise (EPNL or SEL) falls off as the inverse cube of the distance from the airplane. The inverse-cube dependence was chosen to account for inverse-square attenuation and to provide an approximation for atmospheric absorption. With just those two assumptions the actual value of the duration correction factor appearing in EPNL or SEL is completely determined for any flight path. However, the analysis is just used to calculate an adjustment to the duration correction factor for differences between the actual flight path and a uniform ideal straight flight path.

Airspeed Adjustment

Both INM and NOISEMAP adjust the noise data for nonreference airplane speeds. The reference airspeed is 160 knots. The method of adjustment is the same for both INM and NOISEMAP: the duration correction factor is adjusted by a quantity proportional to 10 log V, where V is the airplane ground speed. Thus for a reference ground speed of 160 knots a correction of $10 \log_{10} (160/V)$ is added.

Flight Profiles

Flight profiles are stored in the INM computer program in tabular form. The tabular data give airplane height above ground, airspeed, and engine thrust as a function of distance from brake release or landing threshold. Takeoff profiles may consist of as many as seven segments corresponding to Air Transport Association (ATA) takeoff procedures.¶ Different takeoff profiles are stored for different airplanes and for different stage lengths. Specification of stage length in the program input actually is a way of specifying airplane takeoff gross weight. Linear interpolation is used to obtain flight profile data for conditions between tabulated values.

The process of determining the takeoff flight path from a stage length involves an assumption of an average takeoff gross weight applicable to the stage length. If the weight is assumed to be a relatively high fraction of the maximum takeoff gross weight (say 90%) and airline practice corresponds to a smaller fraction (say from 75 to 80%), then the assumed weight will be higher than it normally would be. The result of assuming too high a weight would be that the takeoff flight path, for a given stage length, would be shallower (i.e., would have a lower climb gradient) than in normal airline practice. The airplane would then be lower to the ground and the takeoff noise contour would probably be larger than it would be if more-representative takeoff gross weights were used.

Flight profiles for the NOISEMAP computer program are calculated from slightly simplified airplane equations of motion. Empirical values for parameters in the equations were derived from various sources including information presented in the certified operating manuals for the airplanes included in the data base.

For jet-propelled airplanes, the variables in the NOISEMAP procedure are 1) maximum takeoff and maximum landing gross weights, 2) engine thrust, 3) takeoff and landing flap settings, and 4) ratio of drag coefficient to lift coefficient C_D/C_L.

Comparisons of computed climbout profiles and profiles obtained from a manufacturer's operations manual are shown in Ref. 10. The comparisons showed good agreement.

Noise Contour Calculations

In the remainder of this paper, we present actual noise contours calculated for individual and multiple-aircraft operations. The multiple-aircraft noise exposure contours were calculated for the AVPORT defined below.

AVPORT Definition

An AVPORT representing an average major intercontinental airport was defined based, in part, on a statistical study of ten large regional airports in the United States.[14] The definition included 1) AVPORT altitude, average air temperature, surface area, runway lengths and directions, and 2) average number of airplane operations by airplane type, time of day, and stage length. Operations at the AVPORT were considered to include commercial subsonic jet transports and business jets. No operations by Concorde supersonic transports were included at the AVPORT.

To avoid unnecessary complication of the AVPORT layout, parallel runways and runways exclusively for general-aviation aircraft were not included. Two nearly perpendicular runways of sufficient length to handle all of the jet traffic were chosen. The runways were designated as runways 09-27 and 02-20.

¶The procedures called ATA in INM and NOISEMAP are those recommended by the ATA in FAA Advisory Circular 91-39. In 1976 the ATA recommended new procedures but they were not incorporated in either NOISEMAP or INM.

Runways and Flight Tracks

All flights from a given runway were assumed to have one takeoff and one landing track. Each takeoff track assumed a 45-deg clockwise turn beginning 4 n.mi. from the end of the runway. Each landing track assumed a straight-in approach to the landing threshold. Runway utilizations were determined from averages of those given in Ref. 14 for the ten study airports with the result that 80% of the traffic used runway 09-27 with 80% of that traffic using runway 09. Similarly, 80% of the traffic on runway 02-20 were determined to use runway 02. Therefore, 64% of the traffic used runway 09, 16% used runways 27 and 02, and 4% used runway 20.

Fleet Mix

Table 1 shows the air carrier traffic by type and number of daily departures for the AVPORT. The number of daily departures was determined from statistics compiled by the Civil Aeronautics Board,[15] for departures from the ten study airports over a 12-month period ending June 30, 1978.

The AVPORT fleet mix given in Table 1 includes only those airplanes whose takeoff gross weights are greater than 75,000 lb. Two-, three-, and four-engine narrow- and wide-bodied airplane categories are all represented. The fleet mix reflects the dominance of JT8D- and JT3D-powered airplanes comprising about 74 and 13% of the U.S. domestic fleet in 1978, respectively.

The 19 air-carrier jet transports in the fleet mix in Table 1 was supplemented by a mix of eight business-jet airplanes having takeoff gross weights of less than 75,000 lb. Daily

Table 1 Daily operations for AVPORT air carrier jet transports (>75,000 lb)

Airplane	No. of daily departures	Total air-carrier departures, %
727-200	127.3	30.0
727-100	76.2	18.0
DC-9-30/50	63.3	14.9
737-100/200	29.6	7.0
DC-10-10	20.4	4.8
L-1011	17.8	4.2
DC-9-10	15.6	3.7
707-100B/C	14.6	3.4
DC-8-60	14.4	3.4
707/300B/C	13.0	3.1
747-200	10.2	2.4
DC-8-50	7.2	1.7
BAC-111	4.6	1.1
DC-10-30/40	2.9	0.7
DC-8-20/30	2.5	0.6
720B	2.1	0.5
707-100/300	1.2	0.3
A300B	0.5	0.1
747-100	0.4	0.1
	423.8	100.0

Table 2 Daily operations for AVPORT general aviation jet transports (<75,000 lb)

Airplane	No. of daily departures	Total GA departures, %
Learjet 23, 24, 45	6.1	27.7
Sabreliner	4.7	21.3
Gulfstream II	4.6	21.0
Jetstar	3.1	14.1
HS-125	2.1	9.5
Jet Commander	0.8	3.6
Learjet 35, 36	0.3	1.4
Cessna Citation	0.3	1.4
	22.0	100.0

departures for business jets were determined from statistics for Washington National Airport,[16] and are presented in Table 2.

The number of total daily departures by airplane type was subdivided into departures by stage length, takeoff gross weight, and time of day. Average departure percentages by stage length and time of day were obtained from the study by Wyle Laboratories of 23 major U.S. airports,[14] and were applied to the AVPORT fleet mix.

Inputting the fleet mix described in Tables 1 and 2 into NOISEMAP and INM posed several problems. First, Version 1.3 of INM only accepted a maximum of 15 airplane types but 19 air carrier airplanes were defined for the AVPORT. To overcome that problem, the following fleet mix changes were made for INM calculations: BAC-111 operations were considered to be DC-9-30 operations; L-1011 operations were considered to be DC-10-10 operations; 720B operations were considered to be 707-100B/C operations; 747-100 operations were considered to be 747-200 operations; and the few A300B operations were deleted. Second, Version 1.3 of INM provided only one airplane choice for business jets—a turbofan-powered Sabreliner—which is a relatively quiet airplane and not indicative of the noise produced by the general-aviation business-jet fleet defined in Table 2. The magnitude of the error caused by having to replace AVPORT business-jet traffic with rather quiet Sabreliners could be significant for airports where business-jet traffic constituted a significant fraction of the total number of operations.

NOISEMAP categorizes all air-carrier airplanes as 2-, 3-, or 4-engine narrowbody airplanes or 3- or 4-engine widebody airplanes. In addition, there is no provision for 2-engine widebody (A300B) airplanes. The NOISEMAP data base represents the noise for an average airplane in each of the above categories. For airports such as the AVPORT where a mixture of airplane types operate, using an average is reasonable. However, for those airports where a particular airplane type is dominant in its respective category, a significant error could be incurred by using averages. In NOISEMAP, DC-9, BAC-111, and 737 operations are lumped together in the 2-engine norrowbody category. 707 and DC-8 operations are lumped together in the 3-engine widebody category; all 727 models are lumped together in the 3-engine narrowbody category; and all 747 models are lumped together in the 4-engine widebody category. NOISEMAP provides two choices for business jets: 1) Cessna Citation—representing the quietest general aviation jets—and 2) a composite consisting of 70% turbojet-, 16% large turbofan-, and 14% small turbofan-powered airplanes. The composite was considered to be a reasonable model of the current business jet fleet. Therefore, for NOISEMAP calculations, the AVPORT general-aviation business-jet operations were modeled using the composite jet fleet data.

Operational Procedures

At any point on the ground, the noise exposure from a single flight is a function not only of airplane/engine type, but also of engine thrust, airplane height above ground, ground track profile, and flight speed. All civil airplanes follow specified takeoff and landing procedures for a given airfield and type of airplane. To obtain as much uniformity as possible between the INM and NOISEMAP noise-contour comparisons, the operational procedures were chosen, for both programs, to be those described in FAA Advisory Circular 91-39.

The takeoff procedures specified in Advisory Circular 91-39 call for climb at takeoff thrust and at a speed V_2+10 knots to a height of 1500 ft above ground level (AGL). Thrust is then reduced to maximum climb thrust and speed is held at V_2+10 knots up to a height of 3000 ft where acceleration to 250 knots is begun at maximum climb thrust.

Approach procedures used at the AVPORT call for a descent at maneuvering-flap speed to 2500 ft AGL. At 2500 ft AGL, level flight with approach flaps and thrust is initiated and maintained until a 3 deg glideslope is intercepted. On the glideslope at 1000 ft AGL, landing flaps are selected and held until the end of the touchdown roll.

An important quantity affecting airplane performance is airplane takeoff gross weight (TOGW). TOGW affects an airplane's climb gradient and flight speed for a specified thrust schedule and flap/slat configuration. Selection of airplane TOGW is made in different ways in INM and NOISEMAP. For INM, the user specifies a takeoff stage length for which the program internally specifies a TOGW. For NOISEMAP the user specifies TOGWs for each category of aircraft. However, the program includes a recommended stage length to go with the specified TOGW.

The fairest comparison of the outputs of NOISEMAP and INM is a comparison of the two models with nearly equal TOGW for the jet transports rather than equal stage length. For the calculations reported here, the stage lengths specified in INM were chosen so as to lead to nearly the same TOGW's as specified for NOISEMAP calculations. Both NOISEMAP and INM store values of thrust, speed, and height AGL for various aircraft types as a function of TOGW.

Table 3 Comparison of calculated single-event noise-contour areas from INM and NOISEMAP

		SEL area, mi.^{2}		EPNL area, mi.^{2}	
Airplane	Value, dB	NOISEMAP	INM	NOISEMAP	INM
DC-9-30	90	15.6	25.5	23.5	17.8
	95	6.6	9.4	10.7	7.7
	100	3.4	3.1	5.3	3.4
727-200	90	19.8	23.3	28.3	40.3
	95	8.8	9.9	15.6	16.6
	100	4.1	4.1	6.9	6.1
DC-8-63	90	26.6	12.9	33.9	56.4
	95	14.6	5.8	22.3	19.9
	100	5.8	2.9	11.7	8.8
DC-10-10	90	7.9	3.9	13.4	5.0
	95	2.8	1.7	5.3	2.4
	100	1.1	0.7	2.1	1.1
747-200	90	31.3	9.5	33.6	18.4
	95	17.0	4.0	21.5	6.6
	100	6.3	1.8	10.5	2.7
Business jet	90	23.7	4.4	16.8	5.2
	95	11.8	1.5	8.1	2.1
	100	5.6	0.5	4.0	0.8

Result of Calculations

Single-Airplane Noise-Exposure Contour Areas

Single-airplane (single-event) noise exposure contour areas were calculated using INM and NOISEMAP for six airplanes in the AVPORT fleet. For some of the airplanes, the computer programs allow the user to specify either "standard" or "quiet" nacelles. For this study the "standard" nacelle option was always specified.

Table 3 summarizes the calculated areas enclosed by the individual-airplane noise contours. There often were large differences between the areas calculated by NOISEMAP and INM.

A consequence of the large differences in enclosed area is that quite different estimates of community noise exposure may be calculated for a given fleet mix at an airport depending upon which computer program or noise descriptor is used.

Noise-Exposure Contour Plots

Plots of noise exposure contours can be easily obtained from INM and NOISEMAP. The INM-generated contours shown in this section were obtained by plotting the contour coordinates output by INM, since INM directly calculates and

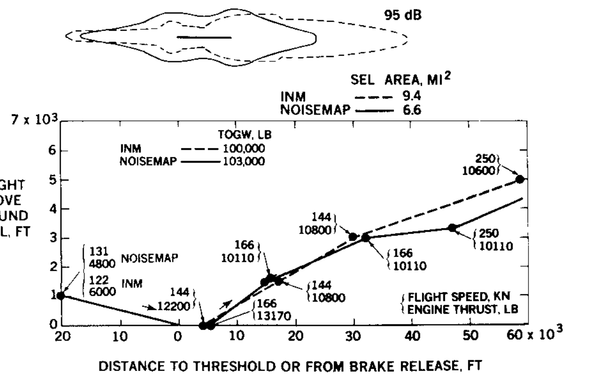


Fig. 4 SEL noise contours/flight profiles/noise curves for a DC-9-30 from INM and NOISEMAP.

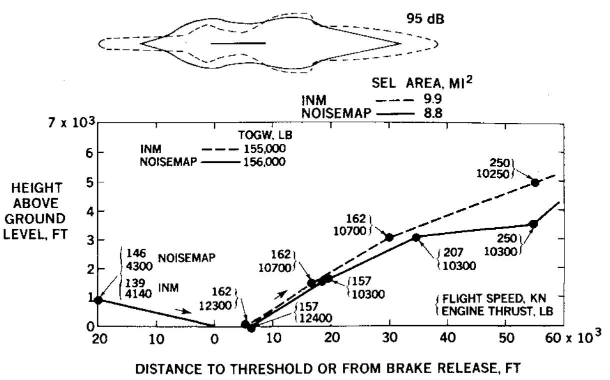


Fig. 5 SEL noise contours/flight profiles/noise curves for a 727-200 from INM and NOISEMAP.

prints coordinates of points on a specified contour. NOISEMAP, in contrast to INM, calculates and prints values of noise exposure at fixed grid points. Therefore we obtained contour locations by linear interpolation of the noise exposure values calculated by NOISEMAP at the fixed grid points.

Single-Airplane Noise-Exposure Contours

The contour plots presented in this section compare single-airplane (single-event) noise-exposure contours from INM and NOISEMAP for several types of airplanes. Flight profiles are shown in each figure to help explain differences in the noise contours. Only SEL contours are shown. However, EPNL contours were also calculated and the results are given in Ref. 17. Results for the EPNL contours were similar to those for the SEL contours.

Flight profiles consist of several segments which describe the airplane height as a function of distance to threshold for approach or distance from brake release for takeoff. At the end of each takeoff segment and at the beginning of the approach segment, the airplane flight speed and the nominal thrust produced by each engine is given within brackets for both INM and NOISEMAP. Thrust and speed values for INM were obtained directly from the data base. The values for NOISEMAP were obtained by using "delta" SEL or EPNL values included in the NOISEMAP data base along with the simplified equations of motion given in Ref. 10.

Figure 4 shows the 95-dB SEL contours and the flight profiles for a DC-9-30 airplane.** Differences in the size and shape of the contours may be explained by differences in the respective flight profiles, noise data, and flyover adjustments given in the INM and NOISEMAP data bases for a DC-9-30 airplane. The thrusts in the data bases are indicative of a JT8D-7-powered airplane in INM and a JT8D-9-powered airplane in NOISEMAP.

A comparison of the flight profiles in Fig. 4 shows the approach profiles to be identical, because of the defined constant-glideslope approach procedure. The takeoff profiles are similar up to the acceleration segment. NOISEMAP, however, assumes a lower approach thrust, a higher takeoff thrust and a lower cutback thrust (or maximum climb thrust) than INM does. Furthermore, NOISEMAP assumes higher takeoff and climb speeds than INM does. During the acceleration segment, INM assumes a steeper climb gradient and a more gradual acceleration to the 250-knot air-traffic-control-restricted speed than NOISEMAP does.

Figure 1a shows that for the same takeoff thrust setting, INM assumes higher noise levels than those in NOISEMAP. The higher noise levels partially offset the higher takeoff thrust settings in NOISEMAP. When the airplane is on or near the ground, the wider NOISEMAP-generated SEL contour is the result of a smaller correction for "excess ground attenuation" (EGA) in NOISEMAP than in INM. After thrust reduction, the lower NOISEMAP thrust, and the lower noise level for a given thrust, result in a contour that "closes" at a much shorter distance from brake release than the contour calculated by INM. Most of the differences in the location and shape of the contours calculated by INM and NOISEMAP are considered to be the result of differences in the noise data base and the thrust level assumed by the two programs.

Figure 5 shows the 95-dB SEL contours and flight profiles for a Boeing 727-200 airplane. The 727 takeoff profiles show that INM assumes a better climb performance than NOISEMAP does at all points along the flight path especially after start of the acceleration segment. The values of engine thrust and flight speed for the two programs are similar. However, an error in the NOISEMAP profile results in an apparent acceleration after the thrust reduction point. The error, which is discussed in more detail in Ref. 18, is too small to account for a significant part of the differences between the contours.

The noise curves in Fig. 1b show that for the same thrust the 727 noise levels in INM are higher than those in NOISEMAP. However, because of differences between the EGA models in INM and NOISEMAP, the portion of the SEL contour corresponding to the airplane ground roll during takeoff is smaller for INM than for NOISEMAP. After liftoff, the higher SEL values in INM result in a longer contour than that calculated by NOISEMAP. During approach, the higher SEL levels in INM also result in a longer contour for the 727.

The final SEL contour comparison is for a McDonnell Douglas DC-10-10 airplane. The noise-exposure contours in Fig. 6 show that there are large differences between the contours calculated using INM and NOISEMAP.

The flight profiles, engine thrust, and airplane speeds from INM and NOISEMAP are similar for the DC-10-10. Most of the differences in the noise contours can therefore be attributed to differences in EGA and the noise data bases in the INM and NOISEMAP programs.

Figure 1c shows that the sound exposure levels in NOISEMAP for a DC-10-10 are higher than the corresponding sound exposure levels in INM at takeoff thrust and at distances appropriate for a 95-dB SEL contour. At approach thrust, the SEL values in the two data bases are close. The differences in EGA in INM and NOISEMAP are important when the airplane is on or near the ground. For the DC-10-10, the differences in EGA account for much of the differences between the two 95-dB SEL contours. Differences in EGA are especially important for the DC-10-10 since the DC-10-10 is a newer-design airplane and generates less noise

**A 1000-ft grid spacing was used for the NOISEMAP-generated contours in this paper. That spacing is the standard "default" value in the NOISEMAP computer program. The NOISEMAP-generated contour areas reported in Ref. 17 were for a 5000-ft grid spacing. It was erroneously stated there that they were the contour areas for a 1000-ft grid spacing.

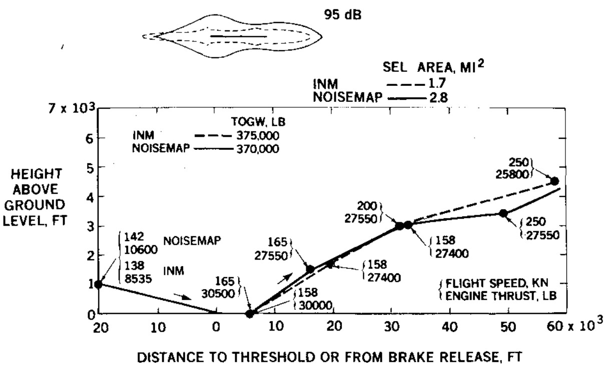


Fig. 6 SEL noise contours/flight profiles/noise curves for a DC-10-10 from INM and NOISEMAP.

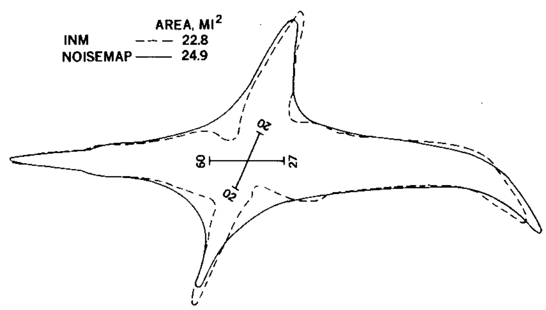


Fig. 7 AVPORT 70-dB DNL contours from INM and NOISEMAP.

at a given distance and equivalent power setting than either of the older-design airplanes represented by the DC-9 or the 727. Contours at the 95-dB level for the DC-10-10 therefore lie much closer to the runway than do the 95-dB contours for the DC-9 or the 727.

Multiple-Airplane Noise-Exposure Contours

Multiple-airplane noise contours were drawn from the tabulated INM and NOISEMAP outputs for all operations at the AVPORT. Contours were drawn for day-night average sound levels (DNL) of 65, 70, and 75 dB and noise-exposure forecast (NEF) levels of 30, 35, and 40 dB.

Figure 7 compares 70-dB DNL noise contours at the AVPORT as calculated by the INM and NOISEMAP computer programs. The sizes and shapes of the contours are similar although the calculated enclosed areas differ by 2.1 mi.^{2} The primary differences between the contours are in the areas between the runways where the "arms" of the contours join. The NOISEMAP-generated contours undergo smooth changes in slope in the region between the runways, whereas the INM contours have more-abrupt changes in shape.

The calculated 35-dB NEF noise contours at the AVPORT are not shown here, but they were similar to the 70-dB DNL contours. The sizes and shapes of the 35-dB NEF contours were comparable, although the calculated enclosed areas differed by 2.9 mi.^{2} The largest differences in the NEF contours also occurred in the region between the runways.

Conclusions and Recommendations

A comparison of the outputs from Version 3.4 of the NOISEMAP and Version 1.3 of the INM computer programs showed significant differences between both the single- and multiple-airplane noise exposure contours calculated by the two programs. The principal cause of differences between INM- and NOISEMAP-generated contours was the difference between the noise data bases in the two computer programs. Other causes were differences in methods of accounting for excess ground attenuation and differences in specification of engine thrust and flight speed along a flight path.

There was close agreement between takeoff profiles in the two programs, for similar takeoff gross weights of a given airplane type, except for the segments corresponding to the airplane acceleration phase from a speed of $V_2 + 10$ knots to the 250-knot air-traffic-control speed restriction.

Best agreements between INM- and NOISEMAP-generated contours were for JT8D-powered DC-9 and 727 airplanes. The relatively good agreement between the INM-calculated multiple-airplane noise exposure contours for the AVPORT and NOISEMAP-calculated contours is largely caused by the predominance of JT8D-powered airplanes in the AVPORT fleet, since the best agreement in single-airplane contour areas was for JT8D-powered airplanes.

For any given set of aircraft types, or mix of types, operating from an airport, accurate estimates of a community's exposure to aircraft noise require that the user of either INM or NOISEMAP have an in-depth understanding of airplane and engine performance as well as the noise-reduction design features incorporated within the engine inlet and exhaust ducts.

Efforts have been initiated by the FAA and USAF to modify INM and NOISEMAP in order to improve the accuracy of calculated results. Revisions are also being made to the noise and aerodynamic data bases and to the computational algorithms, see Refs. 19 and 20 for example. A major change will be the incorporation of the new method prepared by the SAE A-21 Committee for predicting lateral attenuation effects for noise propagated to the side of an aircraft's flight path.[21] It is anticipated that continuing efforts to achieve greater accuracy in each of the computer programs will eventually eliminate the large differences which this paper has shown can exist. For the time being, users of the two computer programs should be aware of the effects which this paper has discussed on the shape and area of calculated contours of aircraft noise.

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References

[1]Speakman, J.D., Powell, R.G., and Cole, J.N., "Community Noise Resulting From Aircraft Operations: Acoustic Data on Military Aircraft," USAF Report AMRL-TR-73-110, Vol. 1, Nov. 1977.

[2]Speakman, J.D., Powell, R.G., and Lee, R.A., "Community Noise Resulting From Aircraft Operations: Air Force Bomber/Cargo Aircraft Noise Data," USAF Report AMRL-TR-73-110, Vol. 2, Nov. 1977.

[3]Speakman, J.D., Powell, R.G., and Lee, R.A., "Community Noise Resulting From Aircraft Operations: Air Force Attack/Fighter Aircraft Noise Data," USAF Report AMRL-TR-73-110, Vol. 3, Feb. 1978.

[4]Speakman, J.D., Powell, R.G., and Lee, R.A., "Community Noise Resulting From Aircraft Operations: Air Force Trainer/Fighter Aircraft Noise Data," USAF Report AMRL-TR-73-110, Vol. 4, Feb. 1978.

[5]Speakman, J.D., Powell, R.G., and Lee, R.A. "Community Noise Resulting From Aircraft Operations: Air Force Propeller Aircraft Noise Data," USAF Report AMRL-TR-73-110, Vol. 5, Feb. 1978.

[6]Speakman, J.D., Powell, R.G., and Lee, R.A., "Community Noise Resulting From Aircraft Operations: Acoustic Data on Navy Aircraft," USAF Report AMRL-TR-73-110, Vol. 6, Feb. 1978.

[7]Bishop, D.E., Mills, J.F., and Beckmann, J.M., "Effective Perceived Noise Level Versus Distance Curves for Civil Aircraft," Bolt Beranek and Newman Report 2747R, Feb. 1976.

[8]Bishop, D.E., Mills, J.F., and Beckmann, J.M., "Sound Exposure Level Versus Distance Curves for Civil Aircraft," Bolt Beranek and Newman Report 2759R, Feb. 1976.

[9]Chapkis, R.L. and Marsh, A. H., "Comparison of Aircraft Noise Contour Prediction Programs," Final Report EPA Contract No. WA-8-1484-A, Sept. 1978.

[10]Galloway, W.J., Mills, J.F., and Hays, A.P., "Data Base for Predicting Noise From Civil Aircraft: Flight Profile Prediction," Bolt Beranek and Newman Report 2746R, March 1976.

[11] SAE Committee A-21, "Procedures for Developing Aircraft Noise Contours Around Airports," Society of Automotive Engineers Draft Aerospace Recommended Practice SAE ARP 1114 (proposed in March 1970 but never issued).

[12] Dunderdale, T.C., "Sensitivity of Runup Noise Predictions to the Excess Ground Attenuation Algorithm," USAF Report AMRL-TR-77-76, May 1977.

[13] Bartell, C., "Integrated Noise Model, Computation of Noise Exposure Values," Draft DOT Contractor Report. (Also, Wyle Research Report No. WCR 77-1, Jan. 1977.) (Unpublished.)

[14] "Costs and National Noise Impact of Feasible Solution Sets for Reduction of Airport Noise," Environmental Protection Agency Report (NTIS No. PB-269 749), Feb. 1976.

[15] "Airport Activity Statistics of Certificated Route Air Carriers 12 Months ended June 30, 1978," Civil Aeronautics Board, U.S. Department of Transportation, Federal Aviation Administration.

[16] "Aircraft Noise Monitoring Report—Washington National Airport and Dulles International Airport," Federal Aviation Administration, April 1979.

[17] Chapkis, R.L., Blankenship, G.L., and Marsh, A.H., "Comparison of Aircraft Noise Contour Prediction Programs," AIAA Paper 80-1057, June 1980.

[18] Blankenship, G.L., "Study of AVPORT Noise Contours by NOISEMAP and INM," DyTec Engineering, Inc. Report 8002, prepared for the U.S. Environmental Protection Agency under subcontract to ORI, Inc., Feb. 1980.

[19] Connor, T.L., "Integrated Noise Model—The Federal Aviation Administration's Computer Program for Predicting Noise Exposure Around an Airport," INTER-NOISE 80, Vol. I, pp. 127-130, *Proceedings of the 1980 International Conference on Noise Control Engineering,* Miami, Fla., Dec. 1980.

[20] Speakman, J.D., "NOISEMAP—The USAF's Computer Program for Predicting Noise Exposure Around an Airport," INTER-NOISE 80, Vol. II, pp. 823-826, *Proceedings of the 1980 International Conference on Noise Control Engineering,* Miami, Fla., Dec. 1980.

[21] SAE Committee A-21, "Prediction Method for Lateral Attenuation of Airplane Noise During Takeoff and Landing," Society of Automotive Engineers Aerospace Information Report AIR 1751, March 1981.