Considerations for Modeling of Aircraft Noise

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ABSTRACT

Noise continues to be a major environmental problem at airports throughout the country. A brief review is given of the federal actions that have occurred over the last 30 years in attempts to reduce and abate aircraft noise impacts. The current Federal Aviation Administration (FAA) emphasis on land use compatibility studies is noted. An overview and simple sensitivity analysis of the primary airport noise analysis tool--the FAA's Integrated Noise Model (INM), is presented. The analysis includes the effects of aircraft type, stage length, airport elevation, and temperature selection. By reviewing the results of this analysis, users of the INM can increase their awareness of the sensitivity of the generated noise contours to input variables.

Although it may be argued that concerns over aviation noise were originated by some beachgoers near Kitty Hawk, North Carolina, on December 17, 1903, it is widely noted that the federal government began addressing the aircraft noise issue in the early 1950s. According to Foster (1), the U.S. Air Force first initiated research and development programs aimed at controlling aircraft noise in 1952.

There was little governmental coordination until 1965, when the President's Office of Science and Technology formed the Jet Aircraft Noise Panel, which directed a program to reduce the noise impact. Initiatives from the panel were assisted by an interagency program of aircraft noise control established as part of the Transportation Act of 1966. Formal regulatory authority to protect the public from unnecessary aircraft noise and sonic booms was given to the Federal Aviation Administration (FAA) under the Aircraft Noise Control Act in 1968.

In 1972 the Noise Control Act brought the Environmental Protection Agency into the picture in an advisory role. This act directed the FAA to prescribe regulations that were economically reasonable, safe, and technically practical for effectively controlling and abating aircraft noise. Subsequently, major legislation, funding, research, and development focused on source control, in particular with Federal Aviation Regulation (FAR) Part 36 requirements between 1969 and 1977. The effects became apparent through the 1970s and into the 1980s.

Specifically, in 1969, FAR Part 36 noise standards were applied to aircraft of new design such as the DC-10 and L1011, which are significantly quieter than the first-generation turbojet aircraft. After their feasibility had been demonstrated, the noise standards were extended in 1973 to new production airplanes. As a result, 727 and DC-9 aircraft manufactured since 1973 had to meet the 1969 standards. In 1976 the same noise standards were applied to all larger civil turbojet aircraft including those designed before 1969 and manufactured before 1973.

The stringency of the standards was increased in 1977 for new aircraft designs such as the 757 and MD-80. The new standards are commonly referred to as Stage 3 limits; Stage 2 limits are those initially adopted in 1969, and Stage 1 are aircraft that are unable to meet either of the noise standards. As of January 1, 1985, only aircraft that meet Stage 2 or Stage 3 may operate in the United States without an exemption. Since 1973 only aircraft that meet Stage 2 standards have been produced and since 1977 only Stage 3 aircraft have been approved for new design.

As newer and quieter aircraft were being introduced into the fleet, a general trend of reduced noise exposure around airports, even with increased operations, was projected. However, the effects of the Airline Deregulation Act of 1978 disturbed this trend. The older and noisier aircraft were not being retired, but were being used more and more by small air carriers.

In a statement before the House Subcommittee on Transportation, Aviation, and Material (West Palm Beach, Florida, April 1, 1985), John Wesler, Director of FAA's Office of Environment and Energy, explained why the problem persists and the difficulties in obtaining added compliance with stricter standards:

> There are approximately 2,900 larger commercial airplanes now in use by U.S. air carriers, and over 100 in use by private operators. Of these, approximately 350 were designed for and meet the Stage 3 noise limits. Perhaps 200 more in current use could meet that standard with minimal modifications or weight limitations. This leaves on the order of 2,350 larger aircraft which would have to be retired completely from U.S. service and replaced by new models or re-engined, since the use of "quiet nacelles" or "hush kits" cannot reach Stage 3 noise performance. The only aircraft currently being re-engined are the Douglas DC 8-60 series, which comfortably meet the Stage 3 noise standards with new engines. Many of the existing Stage 2 aircraft are relatively new and have a great deal of useful life left. Consequently, the reasonableness of such a major replacement of re-engining program is obviously one which requires a great deal of study and discussion.

The passage of the Aviation Safety and Noise Abatement Act (ASNA) of 1979 provided the foundation for a parallel effort toward source control by bringing the FAA into the land use compatibility arena. ASNA required the FAA to identify land uses normally compatible with various exposures of noise

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and to promulgate regulations for airports to voluntarily submit noise exposure maps and compatibility and control programs for dealing with expected noise impacts.

FAR PART 150

In response to ASNA, the FAA issued FAR Part 150, Airport Noise Compatibility Planning (interim rule, 1981; final rule, 1985), which prescribes the requirements for airports for which noise maps and planning programs are to be submitted. The procedures are a formal and legal outgrowth of the FAA's prototype Airport Noise Control and Land Use Compatibility (ANCLUC) programs of 1977-1982. The purpose of the program is twofold. First, it gets the airport operator to identify present and future noise patterns and noncompatible land uses around the airport (noise exposure maps), so that some degree of legal protection through constructive knowledge is established for subsequent actions. Second, a program is formulated of solutions to the noise problems identified by the noise maps. The solutions take the form of operational controls, such as flight path location and preferential runway usage, or land use planning techniques such as zoning and acquisition.

As an incentive to get airports to voluntarily comply with FAR Part 150, the Airport and Airway Improvement Act of 1982 provided for not less than 8 percent of the Airport Improvement Program (AIP) funds to be used for noise compatibility planning and programs following ASNA. For an airport to use federal AIP funds for noise projects, the airport must conduct a FAR Part 150 study. After formal review and finding by the FAA that the program meets ASNA provisions, noise abatement and mitigation actions detailed in the plan become eligible for AIP noise funds. In 1984 the amount available for noise compatibility programs was $64 million.

Noise planning meeting the criteria contained in FAR Part 150 is eligible for 75 percent federal funding to primary airports enplaning 0.25 percent or more of the total number of passengers enplaned annually at all commercial service airports (i.e., major and medium hubs) and 90 percent federal funding for all other commercial service and public-use airports. Measures designed to achieve compatible land use or attenuate noise or both that are included in approved programs, such as land acquisition and soundproofing, are eligible for 80 percent federal assistance.

Thus, the major efforts being put forth today by the FAA and airport operators are to identify the noise around airports and to plan for its control. To do this, the FAA has developed standardized noise planning tools and methods. In particular, the L_{dn} or DNL (day-night noise level) metric was selected as the choice for determining average noise exposure around an airport. The FAA has also developed a computer program to predict noise exposure levels around an airport based on aircraft operational and sound level data. The program, Integrated Noise Model (INM), provides a means for determining existing and future noise levels under a variety of alternatives. It is the key tool for conducting a FAR Part 150 study. In fact, FAR Part 150 requires that only the INM or an FAA-approved equivalent be used for noise compatibility planning studies.

INM BACKGROUND

The INM is a computer-based mathematical model used for predicting total impact of aircraft noise at and around airports. The INM calculates noise exposure from information provided by the user (physical layout of airport runways and flight tracks, any nonstandard alternate operational or performance data, frequency and time of operation) and data contained in the model (aircraft noise levels, operational and performance data). Results can be expressed for a variety of noise metrics either at specific receiver locations or as contours of equal noise exposure for selected values.

Version 1 of the model was released in 1978. It had a limited data base but provided the first step toward consistency in aircraft noise analysis. The following year, the FAA released Version 2, which expanded the aircraft data base and input options. In 1982 the currently used Version 3 was issued. It included further enhancements for determining noise impacts and updated the data base of aircraft noise levels and performance. A fourth version is under development with special emphasis on tasks to produce a fully standardized method of calculating airport noise (2).

The identification of a noise metric and the refinements of a selected model are necessary and proper steps for obtaining consistency in the determination of aircraft noise impacts. However, even with a completely accurate model, there is great latitude in the use and application of the model. The user has complete control over the selection of the scenario he wishes to model. Associated with this are the assumptions made to represent the scenario. These include the determination of what constitutes the time period (average or peak day) to be modeled, the description of flight tracks or corridors, the selection of typical aircraft from the data base, determination of operational conditions, and the projection of future operations and conditions. The dictum "garbage in equals garbage out" is highly appropriate. The following discussion focuses on the major areas of user choice in running the INM and the possible effects of those choices.

DATA BASE LIMITATIONS

The INM data base (3) has a selection of 66 aircraft, including commercial, military, and general aviation types. Associated with each aircraft is at least one of 38 sound exposure level (SEL) curves that describe thrust-distance-noise relationships. In addition, there are 56 approach profiles and 199 takeoff profiles in the data base that describe velocity, altitude, and thrust level as a function of horizontal distance from a reference point.

The proper selection of an aircraft and its operational characteristics is dependent on the best determination of those aircraft that use the airport compared with those available in the model. Earlier aircraft noise impact analyses generally considered aircraft as one of the following:

Two-engine narrow body	(DC-9, B737)
Three-engine narrow body	(B727)
Four-engine narrow body	(B707)
Three-engine wide body	(DC-10/L1011)
Business jet	(Lear)

Standard take-off and approach profiles were assigned to all aircraft. Whatever was produced by the computer program was generally accepted as the truth. Because the selectivity was limited, consistency may have been good, but reality could be far away.

Today the flexibility of the INM allows for more refinement of the aircraft selection process. For example, the variety of common narrow-body commer-

TABLE 1 Common Narrow-Body Jet Aircraft in INM Data Base 8

Type	INM Name
Four engines	
DC-8-50/JT3D-3	DC850
DC-8-60/JT3D-7	DC860
DC-8-60/CFM-56[a]	DC8CFM
DC-8-60/JT3D-7QN	DC8QN
Three engines	
B727-200/JT8D-7	727200
B727-100/JT8D-7	727100
B727-200/JT8D-15	727D15
B727-200-JT8D-9QN	727Q9
B727-100/JT8D-7QN	727Q7
B727-200/JT8D-15QN	727Q15
B727-200/JT8D-17	727D17
Two engines	
BAC111/SPEY512	BAC111
DC-9-30/JT8D-9	DC930
DC-9-10-JT8D-7	DC910
DC-9-30/JT8D-9QN	DC909
DC-9-10/JT8D-7QN	DC907
DC-9-50/JT8D-17	DC950
DC-9-80 (MD-80)/JT8D-209[a]	DC980
B737/JT8D-9	737
B737/JT8D-9QN	737QN
B737/JT8D-17	737D17

[a]Narrow-body aircraft with high-bypass-ratio jet engines.

cial aircraft available in the model is listed in Table 1. The choice is dependent on the aircraft series and engine configuration. Selecting an aircraft from this group is often not an easy choice because it is difficult to determine the exact series and engines of aircraft using an airport. For example, the most prolific and noisiest engine, the JT8D, was manufactured in over 10 different configurations; FAA registration figures show over 75 models of the B727.

To a lesser degree, the problem is also evident for wide-body aircraft, as shown in Table 2. It should be noted that the recently introduced B757 aircraft, although not actually considered a wide body, uses the quieter high-bypass-ratio engines characteristic of the wide-body fleet. A similar situation exists for the new MD-80 (DC980), which is not a wide-body aircraft and technically does not have high-bypass-ratio engines but produces significantly less noise than relative aircraft. With the new-generation aircraft entering the national fleet, the old generality that a narrow body is loud and a wide body is quiet is no longer valid.

TABLE 2 Common Wide-Body Jet Aircraft in INM Data Base 8

Type	INM Name
Three engines	
DC-10-10/CF6-6D	DC1010
DC-10-30/CF6-6D	DC1030
DC-10-40/JT9D-20	DC1040
L1011/RB211-22B	L1011
L1011-500/RB211-524	L10115
Two engines	
A300/CF6-50C	A300
B767/CF6-80A	B767
B757/RB211-535C[a]	757RB
B757/JT10D[a]	757JT

[a]Narrow-body aircraft with high-bypass ratio jet engines.

The same problem exists for business jet aircraft. Table 3 shows a general aviation aircraft selection available in the INM, ranging from light turbofan (Citation) to turbojet aircraft (Lear 25). The composite jet is an approximation of the national fleet average.

TABLE 3 Common General Aviation Jet Aircraft in INM Data Base 8

Type	INM Name
Lear 35/TFE-731	GALTF
Lear 25/CJ610	GALTJ
Sabre 75/CF700	GAMTF
Citation/JT15D	GALQFT
Composite GA Jet	COMJET

Often the modeler does not have adequate information to be as specific as the model allows, or he has too much information that needs reducing, or the desired aircraft is still not in the model. He may also be faced with trying to select an aircraft fleet of limited known composition for projecting future noise conditions. In any event, the modeler is faced with a predicament of which aircraft to use in the model. An assumption of representative aircraft must be made.

AIRCRAFT COMPARISONS

In order to gain an understanding of the relative contributions of specific aircraft types and engines to noise contours and to provide a simplistic indication of the sensitivity of the INM to aircraft selection and parameter changes, a graphical analysis of individual noise contours produced by the INM was initiated. By using the INM to produce noise contours for a given DNL and specific number of operations, the contour can be representative of an associated single-event noise exposure level for a particular aircraft. The derivation of this methodology is as follows:

$$DNL = SEL + 10 \log (N_d + 10 N_n) - 49.4 \quad (1)$$

$$SEL = DNL - 10 \log (N_d + 10 N_n) + 49.4 \quad (2)$$

where

- DNL = average day-night noise level,
- SEL = sound exposure level,
- N_d = number of day operations (7 a.m. to 10 p.m.), and
- N_n = number of night operations (10 p.m. to 7 a.m.).

Assuming $N_d = 10$ and $N_n = 0$, the following values are obtained:

SEL	DNL
90	50.6
95	55.6
100	60.6
105	65.6

An SEL of 95 (DNL = 55.6) was selected as the level for comparison of all aircraft and parameter modifications in this analysis. DNL contours of 55.6 were prepared by the INM for 10 approaches and 10 departures for each aircraft in Tables 1-3. In addition, contours were prepared for other aircraft in the INM for comparison. Each contour was plotted at a similar scale with approaches from the left and departures to the right. Figures 1 through 9 show the contours of various groups of aircraft along with their INM name and calculated contour area in square miles.

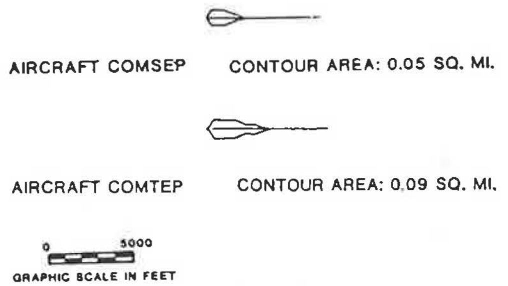

FIGURE 1 General aviation propeller aircraft noise contours.

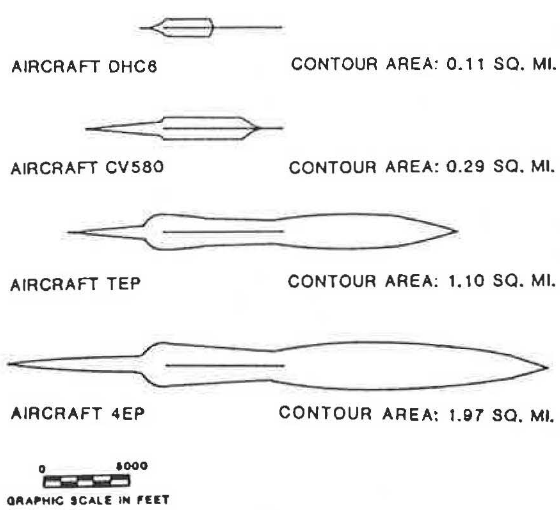

FIGURE 2 Turboprop and large-propeller aircraft noise contours.

Figure 1 shows the relative levels of the single-engine (COMSEP) and twin-engine (COMTEP) general aviation propeller aircraft used in the model. As expected, these were the smallest of those studied. Very little approach noise is noted. In Figure 2, larger propeller and turboprop aircraft are shown. The DHC6 is a small turboprop with short-take-off-and-landing (STOL) performance abilities. This is made evident by the short departure contour. Although not characteristic of the small commuter turboprop fleet, it is the only selection of this type in the data base. The CV580 is a large twin-engine turboprop. Large twin-engine and four-engine propeller aircraft are shown as the TEP and 4EP contours. These represent the old DC-3 and DC-6,7, respectively, and are relatively loud.

A significant difference in contours among general aviation jets is shown in Figure 3. The smallest is the GALQTF, a light, quiet turbofan jet represented by the Cessna Citation. The largest is the GALTJ, or light turbojet, shown as the Lear 25. The COMJET, or composite general aviation jet, is available for modeling of unknown fleet operations. It appears to be dominated by turbojet contributions. The last two contours are much larger than the two-engine commercial jet (DC-9, 737) contours. Because of this, the modeler should be careful in identifying actual general aviation jet activity, particularly if it is a significant portion of the overall operations.

Figure 4 shows the commercial two-engine DC-9 narrow-body aircraft noise contours. The DC-910 and the DC-930 are the untreated and noncomplying (with federal noise regulations) aircraft. Specific models of these aircraft have been issued exemptions and can still operate in the United States. The DC9Q7 and DC9Q9 are the acoustically treated quiet nacelle versions of the DC-910 and DC-930, respectively. The significant difference of the treatment is obvious for approach noise, but there is very little dif-

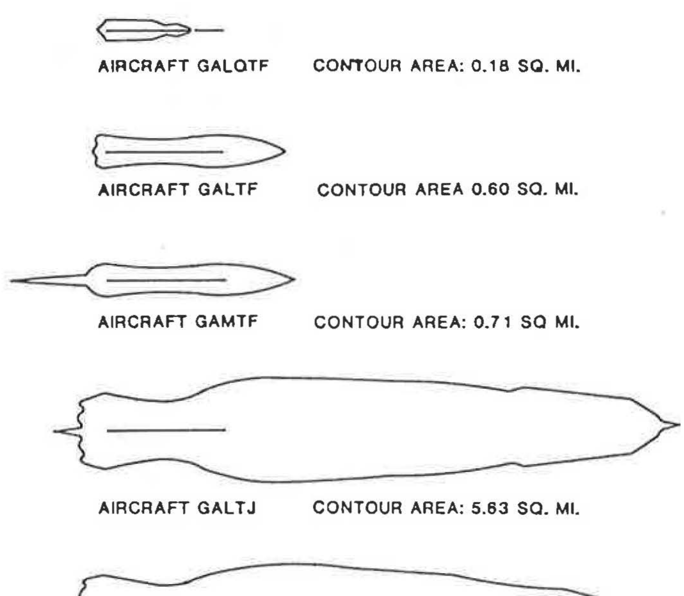

FIGURE 3 General aviation jet aircraft noise contours.

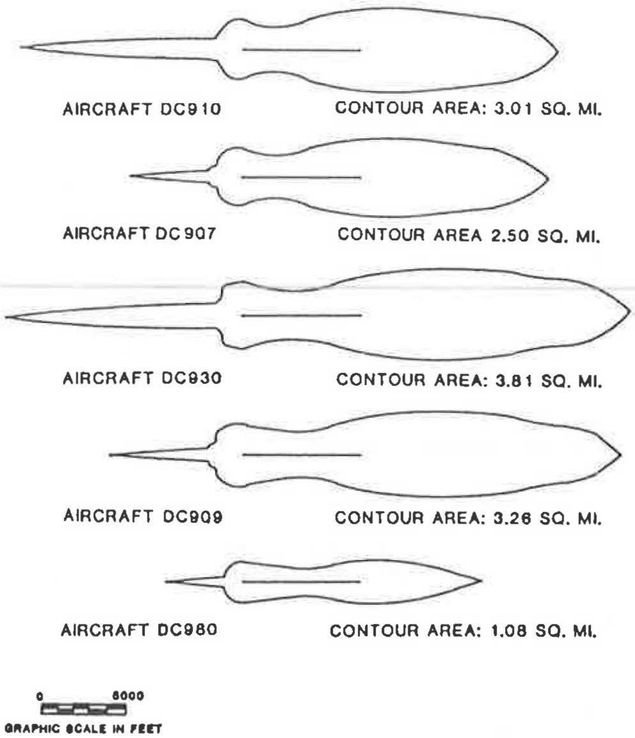

FIGURE 4 DC-9 aircraft noise contours.

ference in departure noise. Also shown is the DC-980 or MD-80. This is the new version of the DC-9 with newer higher-bypass-ratio engines. Significant noise reduction for departures as well as approaches is noted. Improved performance characteristics add to the noise reduction.

Other two-engine, narrow-body aircraft contours are shown in Figure 5. The BAC111, often considered to be one of the noisiest aircraft, has the longest approach noise contour. The 737 and 737QN contours are quite similar to those of the DC-930 and DC-9Q9. Still, there are specific differences among all of the two-engine, narrow-body aircraft.

The differences between the 727-100 and 727-200 three-engine, narrow-body aircraft are shown in Figure 6. All these aircraft are required to comply with federal noise regulations. The 727Q7 contour shows the reduction achieved by quiet nacelle addition to the 727-100. Again, there is more reduction in approach noise. The 727Q15 contour represents the 727-200 with the more powerful but treated nacelle engines. The contour is broader and shorter, depicting more power along with higher performance.

Three-engine, wide-body aircraft contours are shown in Figure 7. These aircraft have high-bypass-ratio engines and produce much less noise than the older low-bypass-ratio engines found on the DC-9, 737, and 727. These aircraft either meet or approach the most stringent federal noise requirements (FAR Part 36, Stage 3). There is very little difference between the DC-1030 and L1011 contours.

Figure 8 shows the contours for three of the new-generation two-engine, high-bypass-ratio aircraft. The contours are significantly smaller than those produced by low-bypass-ratio aircraft. The continued introduction of these and other new-generation aircraft into the fleet will eventually contribute to the reduction of aircraft noise impacts.

The effect of acoustically treating the engines against completing re-engining of an aircraft is shown in Figure 9. The four-engine, narrow-body DC8QN represents the low-bypass-ratio engine with quiet nacelle treatment. The DC8CFM is the same aircraft with new high-bypass-ratio engines. The beneficial effects of noise reduction are obvious, and performance and fuel efficiency are increased as well.

STAGE LENGTH COMPARISONS

The effect of weight on departure performance of an aircraft may be noticed in the noise contour shapes. An INM user specifies the weight of an aircraft departure indirectly by assigning a stage length or first-destination distance category for each flight. Profiles for different stage lengths have different climb performance and thrust levels. Each stage length is associated with a take-off weight representative of a typical load factor and fuel required

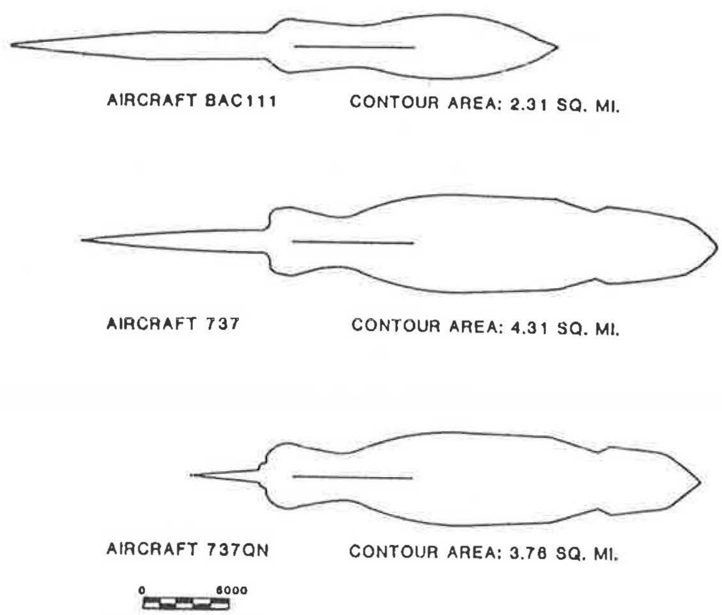

FIGURE 5 BAC111 and B727 aircraft noise contours.

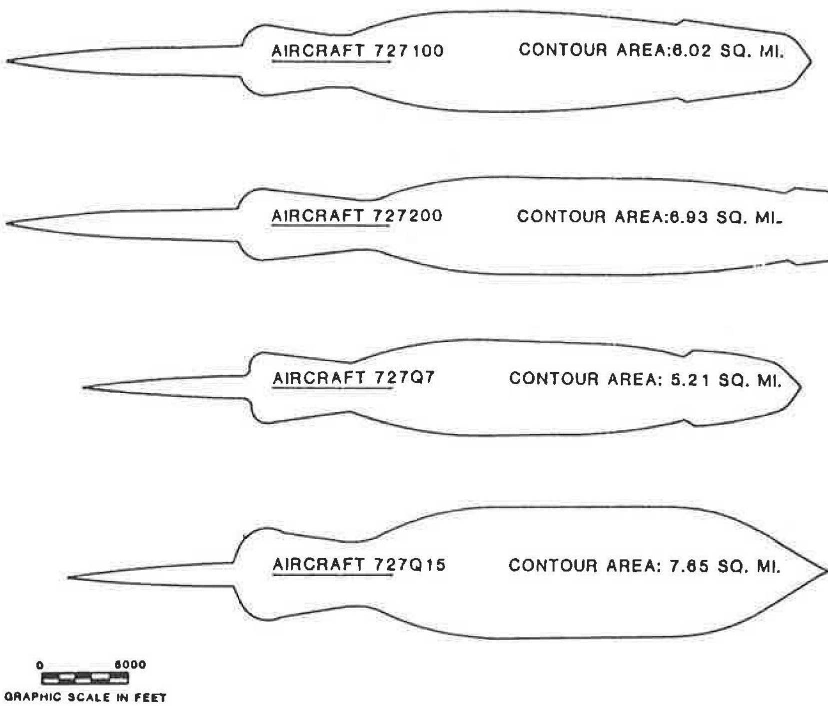

FIGURE 6 B727 aircraft noise contours.

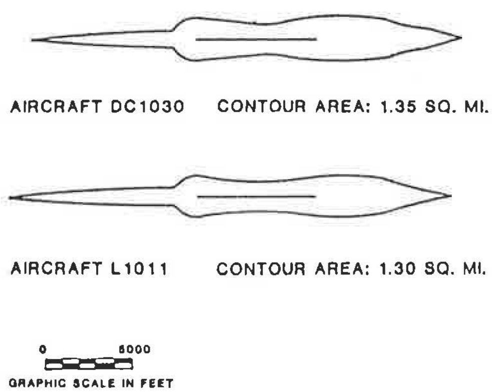

FIGURE 7 DC-10 and L1011 aircraft noise contours.

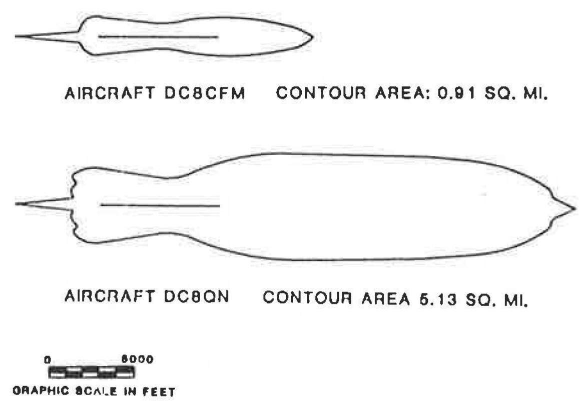

FIGURE 9 DC-8 aircraft noise contours.

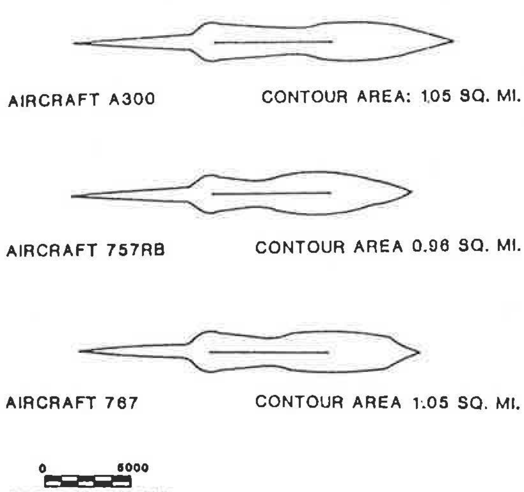

FIGURE 8 A300-B757-B767 aircraft noise contours.

for such a flight. The following are the ranges of the aircraft stage lengths in the INM:

Stage Length	Distance (nautical mi)
1	0-500
2	500-1,000
3	1,000-1,500
4	1,500-2,500
5	2,500-3,500
6	3,500-4,500
7	4,500 and greater

All of the previous contours shown in Figures 1-9 were modeled with aircraft departures of stage length 1. For comparison purposes, the DC-9, 727, 767, and L1011 were modeled by assigning different stage lengths. The effects are shown in the contours in Figures 10-13.

The DC-9 is usually used for short-haul operations (less than 1,000 nautical mi). Figure 10 shows the contours for the typical stage lengths of the

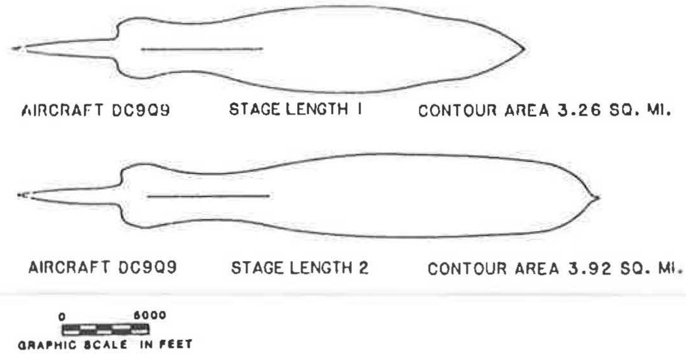

FIGURE 10 DC-9 stage length comparison.

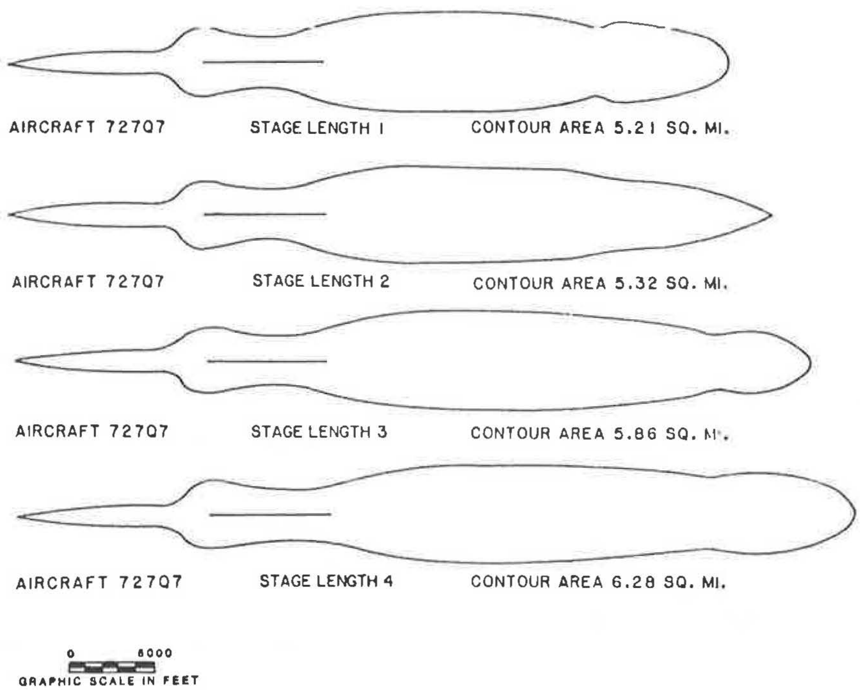

FIGURE 11 B727 stage length comparison.

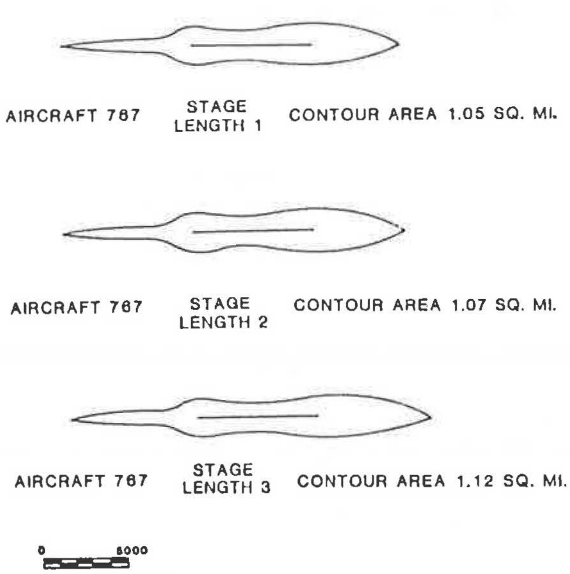

FIGURE 12 B767 stage length comparison.

DC9Q9. Stage length has no effect on approach noise but does show some change on departure contours. The 727, a workhorse for short- to medium-haul flights, shows increasing noise exposure with increasing stage length, as shown in Figure 11. The higher-performance 767 aircraft shows less noise and less variation as a result of stage-length changes, as shown in Figure 12. Finally, the contours of Figure 13 for a long-haul aircraft, the L1011, show moderate change in shape and area from stage lengths 1 to 3 to 6.

ALTITUDE AND TEMPERATURE COMPARISON

The INM provides the user with the opportunity to select the altitude or elevation and temperature at the airport to be modeled. The contours in Figures 1-13 were generated for an airfield with an elevation of 50 ft and temperature of 80°F. To see the effect of changes in these parameters, the 727Q7 was modeled at runway elevations of 50, 1,000, and 5,000 ft. Also, the 727Q7 was modeled with an elevation of 50 ft and changes in temperature from 80° to 50° to 20°F. The results are shown in Figures 14 and 15.

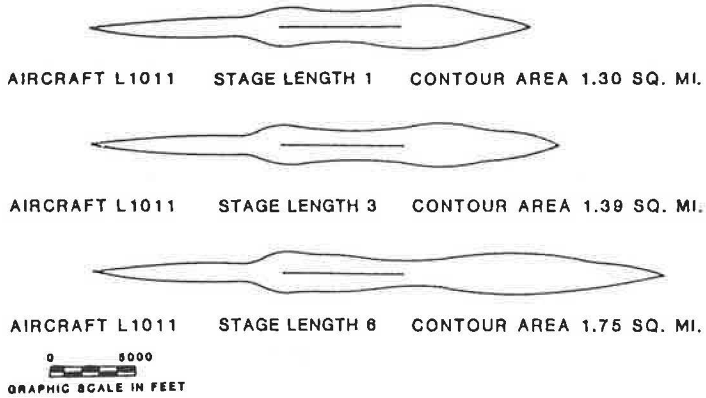

FIGURE 13 L1011 stage length comparison.

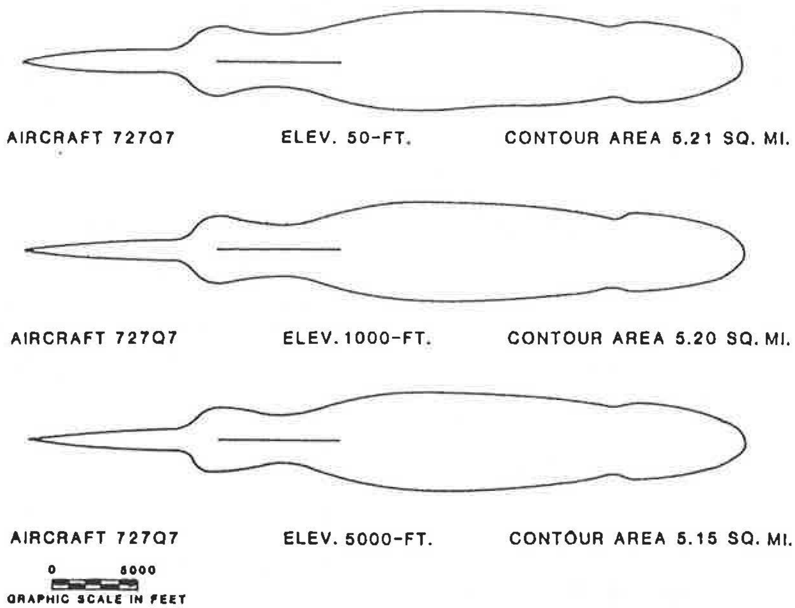

FIGURE 14 B727 airport elevation comparison.

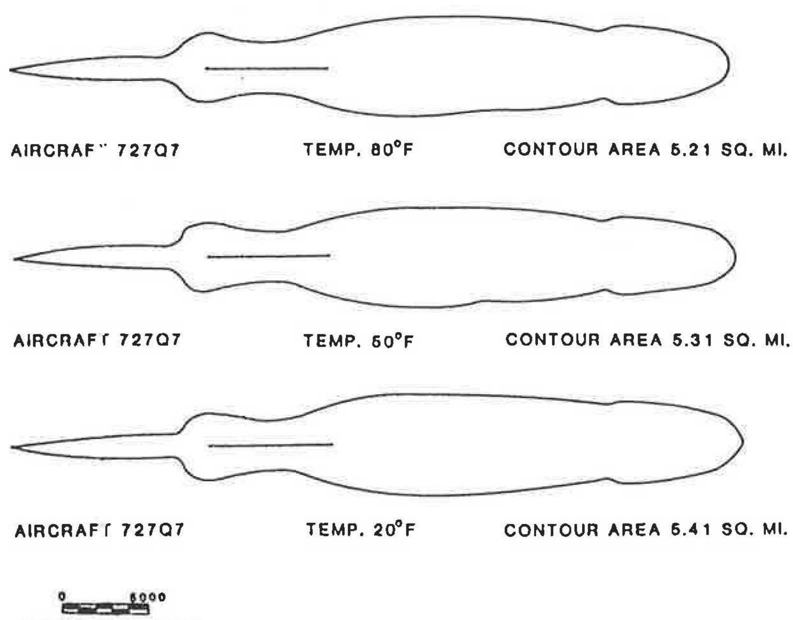

FIGURE 15 B727 airport temperature comparison.

Visually, there appears to be no major difference for the contours with changes in either elevation or temperature. Contour areas show a slight decrease in area with increasing altitude and increasing temperature. This is contradictory to the idea that with increasing elevation and temperature, aircraft performance drops and the noise is spread out longer on departure. Further investigation reveals that the INM uses the elevation and temperature parameters for adjusting aircraft velocity (referenced at 160 knots). At higher elevations and temperatures, an aircraft must achieve greater ground speed for flight. With this higher velocity, there would be a shorter noise exposure time for a fly-over and a corresponding reduction in contour size. This would appear to agree with the contours shown in Figures 14 and 15.

However, the INM does not appear to adjust the departure profile for changes in elevation and temperature. For example, at higher elevations, additional runway roll would be needed to achieve the necessary airspeed. With this, an aircraft would be at a lower altitude over a given point down range. The profile would be extended and increased noise should occur. Whether or not this effect is accounted for and offset by the velocity correction is not clear. Preliminary indications are that it may be necessary for the user to modify departure profiles by extending runway roll distance for a particular elevation and temperature or select alternative stage lengths that provide desired profiles.

OTHER COMPARISONS

There are several other areas in which the sensitivity of the INM could be determined. However, this type of analysis would require the user to provide his own information and data on particular aircraft noise levels and operational characteristics. The foregoing analysis focused only on those parameters that are immediately available to the user in a "default" form.

Several studies have been conducted aimed at validating particular components of the INM and its data base (4-6). The components included comparisons of INM flight profiles and noise curves with observed values. Recommendations for corrections to the model were made in those studies.

CONCLUSIONS

This paper has provided a review and insight into the current airport noise analysis process and the problems facing the modeler. The extensive data base and the flexibility for user input make the INM a valuable state-of-the-art tool for today's noise compatibility studies as well as environmental impact assessments. Because critical decisions are being made based on information derived from the INM, users must seriously consider all assumptions made in a modeling effort. The simple sensitivity analysis done in this effort gives an indication of the latitude available for some assumptions dealing with aircraft type, stage length, elevation, and temperature.

No recommendations are made in such areas as combining aircraft into groups or stage length selection. Rather, this information may be used as guidance in selecting particular aircraft types or configurations for an analysis. The study does point to the need to adequately assess the sensitivity of the INM to changes in airport elevation and temperature. Specifically, the effect of these parameters on the aircraft departure profiles needs to be clarified.

In addition, a more intensive and complete investigation into the sensitivity of the INM to variations of all input variables should be conducted. The identity of the variables and their ranges that have the most effect on noise levels should be determined. The analysis should consider not only the absolute effects, but how these effects would materialize in typical model usage.

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