Computer Method for Airport Noise Exposure Forecast

1972

John Michael Bateman

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COMPUTER METHOD FOR AIRPORT
NOISE EXPOSURE FORECAST

BY

JOHN MICHAEL BATEMAN

A Research Report Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Environmental Systems Management

FLORIDA TECHNOLOGICAL UNIVERSITY

March 1972
COMPUTER METHOD FOR AIRPORT
NOISE EXPOSURE FORECAST

By
John Michael Bateman

ABSTRACT

The major problem facing air transportation for the next decade is aircraft noise. The noise level due to the operation of large jet aircraft has created a very serious annoyance problem to the people living near or adjacent to jet airports. The noise problem has developed both for take-off and landing operations of these aircraft with take-off noise causing the greatest annoyance factor.

A technique called Noise Exposure Forecast (NEF) has been developed to identify the annoyance factor of these noises to people and activities on the ground. With these NEF ratings or numbers, planners can better determine the type of buildings and activities to locate in the vicinity of airports.

This paper presents a computer method for determining NEF areas or contours which eliminate the necessity of performing laborious hand calculations and iterations normally required to determine a given NEF locus about an airport. A land use compatibility table showing land use versus NEF numbers is given on page 3. A sample computer program is given on pages 21 through 25 of the appendix and a sample computer output page is given on page 26. The computer technique developed for this paper can be used for any airport.
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INTRODUCTION

The impact of aircraft noise on the development and use of land near airports has caused serious and continuing problems in many communities. Effective land use planning has been limited by lack of knowledge of what noise levels to expect with future types of aircraft and rapidly changing aircraft operations; there have been problems of noise measurement and of interpreting the noise in terms of the probable effect on people and on the varied activities of people. All of the scientific and technical problems have not been solved, and many of the hazards of making long range forecasts in a rapidly developing field of technology still remain. However, sufficient studies have been undertaken in recent years to permit the development of practical engineering guides for establishing the influence of aircraft noise on many important work tasks and activities. (1)

Problems brought on by intrusion of aircraft noise into communities are complex. More than half-a-dozen variables such as noise duration, spectral shape of the noise, temporal pattern of the noise, background noise in which the aircraft noise is immersed, etc., are required to describe the noise stimulus. Evidence is strong that other considerations beyond noise are involved in the response of people in the community to aircraft noise. (2)

When exposure to noise is considered, we generally think only in terms of the "noise level." Although this is a major factor
in a description of the noise stimulus, many other factors must also be taken into account to provide a reasonably complete and meaningful specification. A useful description of any wide-band noise must specify both its overall intensity or sound pressure level and the distribution of this sound throughout the frequency spectrum. If the sound is an intermittent one, as are most aircraft noises, the duration of each occurrence must be described, and the rate of occurrence must be considered. In addition, the rate of rise or fall of the level of a time-varying sound must be specified if we are to accurately characterize the sound. There are further complications such as the presence of pure tone or narrow-band components in a broad-band noise also to be considered. (3) For land use planning in the vicinity of and adjacent to airports that service large jet aircraft, a method of determining noise exposure of any given area as a function of its relative location to an airport is imperative. With the Noise Exposure Forecast (NEF) number determined for a given location, the type of land use (e.g., residential, commercial, industrial, etc.) can be determined by the use of empirical data showing the effects on people or activities of that particular NEF number. For NEF numbers under thirty, there is little interference with normal activities; NEF numbers over forty are associated with serious noise problems. (4) A more detailed breakdown of NEF number versus land use suitability is given in the Table.

This paper outlines a computer technique for determining NEF area, resulting from take-off and landing operations in the
<table>
<thead>
<tr>
<th>NOISE EXPOSURE FORECAST AREAS</th>
<th>Residential</th>
<th>Commercial</th>
<th>Hotel, Motel</th>
<th>Offices, Public Buildings</th>
<th>Schools, Churches, Hospitals</th>
<th>Theaters, Auditoriums</th>
<th>Outdoor Amphi-Theaters</th>
<th>Outdoor Recreation (Non-Spectator)</th>
<th>Industrial</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>Note (c)</td>
<td>Notes (a) and (c)</td>
<td>Note (a)</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>30 - 40</td>
<td>Note (b)</td>
<td>yes</td>
<td>Note (c)</td>
<td>Note (c)</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>&gt; 40</td>
<td>no</td>
<td>Note (c)</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>yes</td>
<td>Note (c)</td>
</tr>
</tbody>
</table>

**NOTE:**
(a) A detailed noise analysis should be undertaken by qualified personnel for all indoor or outdoor music auditoriums and all outdoor theaters.
(b) Case history experience indicates that individuals in private residences may complain, perhaps vigorously. Concerted group action is possible. New single-dwelling construction should generally be avoided. For apartment construction, Note (c) applies.
(c) An analysis of building noise reduction requirements should be made and needed noise control features should be included in the building design.
vicinity of airports. NEF areas are based upon the aircraft noise described in terms of the effective perceived noise levels (which include corrections for duration of exposure and the presence of discrete frequencies) plus adjustments for the number and type of operations, the time of day, and the mixture of aircraft types. The selection of appropriate criteria for aircraft noise is based upon established parameters for steady-state noise with the addition of adjustment factors for the transient nature of aircraft flyover noise. These adjustment factors are based upon consideration of the effects of intermittent noise on speech communication, and take into account the frequency of occurrence and the importance of speech communication to the given work activity. The NEF computation technique in this paper may be utilized to describe the noise exposure environment in the vicinity of any airport. (5) NEF procedures provide estimates of the total noise environment arising from the multiple operations of aircraft during take-off and landing operations in the vicinity of an airport. The NEF values are calculated from knowledge of: (a) the aircraft flyover noise described in terms of the effective perceived noise level (EPNL), and (b) the average number of flyovers per daytime and nighttime periods. (6) The basic equations for calculating the NEF values at a given ground position will be presented later in the method of analysis.

The first step in determining NEF areas is to obtain a description of the aircraft operations expected at the airport under study. For flight operations, the following information is required:
the aircraft type, the number of take-offs and landings, the percentage utilization of each runway, and the track and profile geometry of the flight paths used. (3) For a particular airport, day and night runway utilization and aircraft data are supplied as input to the computer. The computer output consists of NEF distances, which are distances from the runway or flight track to ground locations having a specified NEF value. With this information, contours of various NEF numbers can be constructed on a map of the area adjacent to the airport, and land use can be planned based upon these NEF areas.

Noise Exposure Forecast contours should be of interest to those concerned with the planning and development of compatible land uses around airports, such as airport operators, land planning and zoning officials, land developers, and those governmental officials (local, state and federal) concerned with community planning, urban renewal, or the development of public airports in the United States. (3)
DEFINITION OF TERMS USED

Noise Exposure Forecast (NEF)
Cumulative noise exposure accounting for frequency of operation and time of day. (4)

Perceived Noise Level (PNdB)
A quantity calculated from measured noise levels that correlates very well with one's subjective response in terms of annoyance and noisiness to various kinds of aircraft noise. (1)

Effective Perceived Noise Level (EPNdB)
Perceived noise level with pure tone, and duration corrections. (4)

Sound Pressure Level (SPL)
Twenty \( \log_{10} \frac{p}{p_0} \) decibels, where \( p \) is the rms sound pressure, and \( p_0 \) is a reference sound pressure (usually 0.0002 dynes per square cm., which corresponds approximately to the threshold of hearing at 1,000 hertz). (7)

Decibel (dB)
A dimensionless unit which compares the magnitude of powers on a logarithmic scale. The number of decibels expressing the relative magnitudes of two powers is ten times the logarithm to the base ten of the ratio of the powers. Since the square of sound pressure
corresponds to the power, the corresponding expression for sound
pressure level becomes twenty times the logarithm to the base ten
of the ratio of the pressures. (7)

NEF Distance (Y)

The distance perpendicular to the flight track at which the
desired NEF value occurs. (5)
LIMITATIONS OF THE STUDY

The procedures of this paper do not take into account ground absorption and impedance; changing jet exhaust noise generated due to the accelerating sound source and changing effective jet velocities; and ground run-ups and ground operations. A recent study, using microphones placed at several locations to the side of an active runway, shows quite a consistent decrease in the perceived noise level between the start of take-off roll and the approximate point of lift-off. On the average, this noise drop is about five PNdB. The values computed by the techniques of this paper will therefore, give slightly higher noise levels for the 4,000 or so feet of take-off roll. However, the NEF procedures given in the references did not account for landing aborts or ILS practice approaches, where the aircraft does not land but flies over the runway at several hundred feet. Therefore, some conservatism in the NEF areas is desirable.
METHOD OF CALCULATION

From reference (5), the effective perceived noise level may be defined as:

\[ \text{EPNdB} = \text{PNdB} + D + F \]  

(1)

where,

- \( \text{PNdB} \) = maximum calculated perceived noise level at any instant of time during the flyover
- \( D = \text{ten log } t/15 \), where \( t \) is the time interval in seconds during which the noise level is within ten dB of the maximum \( \text{PNdB} \)
- \( F \) = correction for the presence of discreets frequency components

The total noise exposure at a given point may be viewed as being composed of noise produced by different aircraft flying along different flight paths. For aircraft classification \( i \) on flight path \( j \), the \( \text{NEF}_{ij} \) can be expressed as follows.

For daytime (0700-2200)* operations:

\[ \text{NEF}_{D(ij)} = \text{EPNdB}_i + 10 \log \frac{n_{D(ij)}}{K_D} - C \]  

(2a)

For nighttime (2200-0700)** operations:

\[ \text{NEF}_{N(ij)} = \text{EPNdB}_i + 10 \log \frac{n_{N(ij)}}{K_N} - C \]  

(2b)

* 7:00 a.m. to 10:00 p.m.
** 10:00 p.m. to 7:00 a.m.
where,

\[ n_{D(ij)} = \frac{N_{D(i)} \cdot P_{ij}}{100} \quad \text{and} \quad n_{N(ij)} = \frac{N_{N(i)} \cdot P_{ij}}{100} \]  

(3)

\[ N_i = \text{average number of take-offs or landings per active day of aircraft classification } i \text{ for the entire airport. As noted by the D and N subscripts, separate computations are made for daytime and nighttime operations} \]

\[ P_{ij} = \text{average utilization of flight path or runway } j \text{ for aircraft classification } i \text{, expressed as a percentage} \]

\[ K_D = 20 \]

\[ K_N = 1.2 \]

\[ C = 75 \]

In Equation (2a) the size of \( K_D \) has been selected so that the correction for number of operations during daytime hours is zero for 20 operations per day. The correction is consistent with the corrections of previous techniques used in generating noise contours around airports. (8)

The ratio of \( K_D \) to \( K_N \) in Equation (2a) and (2b) has been selected so that for the same average number of operations per hour throughout the day, the NEF correction will be ten greater for the nighttime operations.

Taking into account the normalization factor, \( C \), and the adjustment factors for number of operations, Equation (2) can be rewritten as follows.
For daytime operations:

\[ \text{NEF}_D(ij) = \text{EPNdB}(i) + 10 \log n_D(ij) - 88 \]  \hspace{1cm} (4a)

For nighttime operations:

\[ \text{NEF}_N(ij) = \text{EPNdB}(i) + 10 \log n_N(ij) - 76 \]  \hspace{1cm} (4b)

The total noise exposure at a ground position using the larger of the daytime and nighttime values, is given by the addition of the NEF values on an energy basis for the different aircraft classifications.

For flight path \( j \), we have:

\[ \text{NEF}_j = 10 \log \sum_{i} \text{antilog}_{10} \frac{(\text{NEF}_{ij})}{10} \]  \hspace{1cm} (5)

Where the noise exposure at a given position would be affected by noise from several operations or flight paths, the total noise exposure is based upon the addition on an energy basis of the NEF values for the separate flight paths:

\[ \text{NEF}_{\text{total}} = 10 \log \sum_{j} \text{antilog}_{10} \frac{(\text{NEF}_j)}{10} \]  \hspace{1cm} (6)
NEF COMPUTER PROCEDURES

The computer procedures for determining NEF contours were developed using Fortran IV computer language. The program was designed to generate NEF distances at 2000 foot intervals along the active runway or flight track when supplied the following input data:

1. NEF number of desired contour (DNEF)
2. Aircraft classification (ACFT)
3. Average number of daytime operations (ND)
4. Average number of nighttime operations (NN)
5. Percentage of runway utilization (P)

Using equations (3) through (6) plus EPNdB and flight path data, the computer first determines at what distance along the flight path the NEF contour converges with the flight path. This is accomplished by setting altitude (Z) equal to the slant distance (See Figure 4) for the desired NEF number. The distance along the flight path can then be determined from a curve fit equation of Figure 1. The computer uses this information to determine how far along the flight path the NEF distances are to be computed.

For computing take-off NEF contours, EPNdB values are obtained from a graph subroutine of Figure 2, and the NEF distance is computed using an iterative process (described in Reference 5) beginning at the start of take-off roll (FP=0). This procedure is repeated
every 2000 feet along the flight path using the data of Figure 1, (i.e., curve fitting) to determine altitude, until the flight path distance previously calculated for NEF closure is reached. Computer output consists of "Distance to Take-off Start" and "NEF Distance Normal to Flight Path."

The same procedure is used to determine the NEF contours for approach. A graph subroutine of Figure 3 is used for EPNdB determination, and a three degree glide slope is assumed for computing altitudes.

Figure 4 shows a hypothetical NEF 30 contour and a typical solution for a specific example is presented on page 26.

A sample computer program for take-off operations is shown in the Appendix.
FIGURE 1. Takeoff Profiles

Two and Three Engine Turbofan

Short Range Large Fan or Jet

Long Range Large Fan or Jet

Distance From Start of Takeoff Roll - Ft.

Altitude - Ft.
FIGURE 2. Variation in Effective Perceived Noise Levels

Takeoff Power

- Large Turbofan Aircraft
- Large Turbojet Aircraft
- Two and Three Engine Turbofan Aircraft

Distance from aircraft in feet
FIGURE 3. Variation in Effective Perceived Noise Levels

Approach Power

- Large Turbofan Aircraft
- Large Turbojet Aircraft
- Two and Three Engine Turbofan Aircraft

Distance from Aircraft in Feet

EPNL - dB
FIGURE 4. NEF Distance Geometric Relationships
SUMMARY

In the years following the introduction of jet propelled aircraft it was discovered that the noise level due to the operation of these aircraft created a very serious annoyance problem to the people living in the neighborhood of jet airports. The problem was concerned primarily with take-off of aircraft although, with the new large (jumbo) turbofan aircraft, there was increasing evidence of landing noise becoming a problem.

Noise Exposure Forecast (NEF) procedures have been developed in the studies of reference (5) and the procedures in this paper were developed using the equations and values from this reference. Since computation and plotting of noise contours for aircraft flight movements was a tedious task for the analyst, computer routines to utilize the analytical and graphic descriptions of flight patterns were developed for computing contours that may be displayed or plotted as map overlays.

With jet aircraft traffic continually increasing, land use planning at future airport sites and in the vicinity of existing airports will require more and more aircraft noise impact predictions. Computer methods such as the one described in this paper for determining NEF contours around airports should be of great value since NEF areas have differing land use compatibility with respect to aircraft
noise. When studies of existing or new airport sites are performed NEF contours should be examined as a guide to land utilization and zoning.
REFERENCES


JOB BATEMAN

DRIVE CART SPEC CART AVAIL PHY DRIVE
0000 0001 0001 0000

M10 ACTUAL 8K CONFIG 8K

DUP

DELETE GRAPH

ST ID 0001 DB ADDR 5064 DB CNT 000C

FOR

ST ALL

WORD INTEGERS

SUBROUTINE GRAPH(CURVE,X,Y,N)
DIMENSION CURVE(2,50)
DOI1=1,N
IF(X-CURVE(1,1))3,2,1
3 IHIGH=1
GO TO 4
2 Y=CURVE(2,I)
RETURN
1 CONTINUE
Y=CURVE(2,N)
RETURN
4 ILOW=IHIGH-1
IF(ILOW)5,5,6
5 Y=CURVE(2,1)
RETURN
6 XDIFF=CURVE(1,IHIGH)-CURVE(1,ILOW)
YDIFF=CURVE(2,IHIGH)-CURVE(2,ILOW)
XFRAC=X-CURVE(1,ILOW)
Y=CURVE(2,ILOW)+(YDIFF*(XFRAC/XDIFF))
RETURN
END

VARIABLE ALLOCATIONS
DIFF(R)=0000 YDIFF(R)=0002 XFRAC(R)=0004 I(I)=0006

STATEMENT ALLOCATIONS
=003A 2 =0040 1 =004B 4 =005F 5 =0069 6 =0071

FEATURES SUPPORTED

WORD INTEGERS

LED SUBPROGRAMS

DDX FSUBX FMPY FDIV FLD FLDX FSTO SUBSC SUBIN

EGER CONSTANTS

I=000E

REQUIREMENTS FOR GRAPH

VARIABLES 0 VARIABLES 14 PROGRAM 162

ENTRY POINT ADDRESS IS 000F (HEX)

OF COMPILATION
STORE WS UA GRAPH
RT 10 0001 DB ADDR 5064 DB CNT 000C
FOR
1ST ALL
NE WORD INTEGERS
OCS(CARD,1403 PRINTER)
AIRPORT NOISE CONTOURS, RESEARCH PAPER BY J. M. BATEMAN
REAL NEFN,NEFD,NIGHT,NEF,TRY1,TRY2,TRY,CD,CN,DAY,Z,D,XVAL,EPNL,
INEF2,YVAL,INEF,A,B,LTRY,Y,YVALN,YVALD,X,NN,ND,YIVAL
DIMENSION YUFX(2,13)
DATA YUFX/300.,129.9,400.,127.6,500.,125.5,600.,123.7,800.,120.4,
11000.,117.6,1500.,111.8,2000.,107.8,3000.,103.0,4000.,100.0,5000.,
297.9,6000.,36.2,8000.,93.7/
DIMENSION YUFX(2,13)
DATA YUFX/93.7,8000.,96.2,6000.,97.9,5000.,100.4,4000.,103.0,3000
1.,107.8,2000.,111.8,1500.,117.6,1000.,120.4,800.,123.7,600.,125.5
2,500.,127.6,400.,129.9,300.0./
FP=0.0
DNEF=30.
ND=20.
ACFT=B
P=100.
W=0.0
WRITE(5,100)DNEF
100 FORMAT(1HX,'NOISE EXPOSURE FORCAST =',E15.5,/) WRITE(5,101)ND
101 FORMAT(1HX,'AVERAGE DAY OPERATIONS =',E15.5,/) WRITE(5,102)NN
102 FORMAT(1HX,'AVERAGE NIGHT OPERATIONS =',E15.5,/) WRITE(5,105)ACFT
105 FORMAT(1HX,'AIRCRAFT CLASSIFICATION =',E15.5,/) WRITE(5,103)P
103 FORMAT(1HX,'PERCENT RUNWAY USAGE =',E15.5,/) WRITE(5,104)
104 FORMAT(1HX,'DIST TO TUFF START',14X,'DIST NORMAL TO FLT PATH',/) CD=ND*P/100.
CN=NN*P/100.
DAY=10.#(ALOG(CD)/2.30259)-88.
NIGHT=10.#(ALOG(CN)/2.30259)-76.
YVALN=DNEF-NIGHT
YVALD=DNEF-DAY
IF(YVALD-YVALN)41,42,42
41 YVALN=YVALD
42 XVAL=YVALN
CALL GRAPH(YUFX,XVAL,YIVAL,13)
Z=YIVAL
IF(Z-150.)43,43,44
43 X=(Z*.05)+4000.
44 X=((Z-150.)/.152)+7000.
70 TRY1=7000.
IF(FP>7000.)1,1,2
1 Z=(FP-4000.)*.05
IF(Z)20,20,3
20 Z=0.
GO TO 3
2 Z=(FP-7000.)*.152+150.
3 TRY=.75#TRY1
D=SQR(T(Z**2.+TRY**2.))
XVAL=D
CALL GRAPH(YUFX,XVAL,YIVAL,13)
EPNL=YVAL
NEFN=EPNL+NIGHT
NEFD=EPNL+DAY
IF(NEFN-NEFD)5,4,4
5) NEFN=NEFD
4) NEF=NEFN
NEF2=NEF
TRY=TRY1
D=SQR(T(2**2.5+TRY**2.)
XVAL=D
CALL GRAPH(YOFX,XVAL,YVAL,13)
EPNL=YVAL
NEFN=EPNL+NIGHT
NEFD=EPNL+DAY
IF(NEFN=NEFD)8,7,7
8) NEFN=NEFD
7) NEF=NEFN

NEF1=NEF
TRY2=.75*TRY1
A=(NEF1-NEF2)/((ALOG(TRY1)/2.30259)-(ALOG(TRY2)/2.30259))
B=NEF2-A*(ALOG(TRY2)/2.30259)
LTRY=(DNEF-B)/A
TRY=10.*LTRY

6) TRY1=TRY2
TRY2=TRY
D=SQR(T(2**2.5+TRY**2.)
XVAL=D
CALL GRAPH(YOFX,XVAL,YVAL,13)
EPNL=YVAL
NEFN=EPNL+NIGHT
NEFD=EPNL+DAY
IF(NEFN=NEFD)10,9,9
10) NEFN=NEFD
9) NEF=NEFN
NEF1=NEF2
NEF2=NEF
A=(NEF1-NEF2)/((ALOG(TRY1)/2.30259)-(ALOG(TRY2)/2.30259))
B=NEF2-A*(ALOG(TRY2)/2.30259)
LTRY=(DNEF-B)/A
TRY=10.*LTRY
TEST=ABS(DNEF-NEF)
IF(0F-0.05)11,11,6
11) Y=TRY
WRITE(5,22)FP,Y
22) FORMAT(10X,E15.5,20X,E15.5,/) FP=FP+2000.
IF(X-FP)71,71,70
71) WRITE(5,22)X,W
CALL EXIT

END

1. YOFX(R)=0032-0000 Y1OFX(R)=0066-0034 NEFN(R)=0068 NEFD(R)=006A
2. TRY1(R)=0070 TRY2(R)=0072 TRY(R)=0074 CD(R)=0076
3. Z(R)=007C D(R)=007E XVAL(R)=0080 EPNL(R)=0082
4. NEF1(R)=0086 A(R)=008A B(R)=008C LTRY(R)=008E
5. VALD(R)=0094 X(R)=0096 NN(R)=0098 ND(R)=009A
6. DNEF(R)=00A0 ACFT(R)=00A2 P(R)=00A4 W(R)=00A6

DITEMENT ALLOCATIONS
00 =00D2 101 =00E5 102 =00F7 105 =0109 103 =0118 104 =0130 22 =01
6 =0201 70 =0208 1 =0216 20 =0223 2 =0229 3 =0233 5 =02
=02F9 10 =0337 9 =033B 11 =038B 71 =03A4

ADDRESS ALLOCATIONS
FEATURES SUPPORTED

ONE WORD INTEGERS

SUPP

RATED

FOR

COMS

COMMON

0

VARIABLES

174

PROGRAM

768

END OF COMPIALATION

/ XEQ

ALLEGED SUBPROGRAMS

FALOG

GRAPH

FSQRT

FABS

FAXB

FADD

FSUB

FMPY

FDIV

FLD

REAL CONSTANTS

.000000E 00=00AE

.300000E 02=00B0

.200000E 02=00B2

.400000E 01=00B4

.230259E 01=00BA

.880000E 02=00BC

.760000E 02=00BE

.150000E 03=00C0

.152000E 00=00C6

.700000E 04=00C8

.750000E 00=00CA

.200000E 01=00CC

INTEGER CONSTANTS

5=00D0

13=00D1

MORE REQUIREMENTS FOR

COMMON

0

VARIABLES

174

PROGRAM

768

END OF COMPIALATION

/ XEQ