



# ESDU 98019

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## Computer-based estimation procedure for single-stream jet noise Including far-field, static jet mixing noise database for circular nozzles

Associated software: ESDUpac A9819  
ESDUpac B9819  
ESDUpac C9819  
VIEWpac M9819



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## THE PREPARATION OF THIS DATA ITEM

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## COMPUTER-BASED ESTIMATION PROCEDURE FOR SINGLE-STREAM JET NOISE – INCLUDING FAR-FIELD, STATIC-JET MIXING NOISE DATABASE FOR CIRCULAR NOZZLES

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## COMPUTER-BASED ESTIMATION PROCEDURE FOR SINGLE-STREAM JET NOISE – Including far-field, static-jet mixing noise database for circular nozzles

### 1. NOTATION

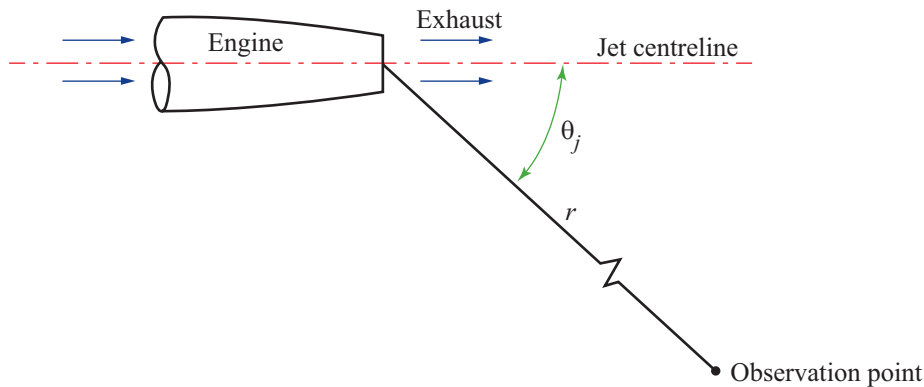
|            |                                                                                           | <i>Units</i>     |                     |
|------------|-------------------------------------------------------------------------------------------|------------------|---------------------|
|            |                                                                                           | <i>SI</i>        | <i>British</i>      |
| $A_j$      | exit area of jet exhaust nozzle                                                           | m <sup>2</sup>   | ft <sup>2</sup>     |
| $a_0$      | ambient speed of sound                                                                    | m/s              | ft/s                |
| $C_v$      | exhaust nozzle velocity coefficient                                                       |                  |                     |
| $D_j$      | effective jet nozzle diameter [for circular nozzle<br>= $(4A_j/\pi)^{1/2}$ ] <sup>†</sup> | m                | ft                  |
| $f$        | frequency                                                                                 | Hz               | Hz                  |
| $P_r$      | fully expanded nozzle pressure ratio                                                      |                  |                     |
| $p_{ISA}$  | ambient pressure under sea level ISA conditions                                           | kPa              | lbf/ft <sup>2</sup> |
| $p_0$      | ambient pressure                                                                          | kPa              | lbf/ft <sup>2</sup> |
| $R$        | gas constant <sup>‡</sup>                                                                 | J/kg K           | ft lbf/slug K       |
| $r$        | radial distance from nozzle exit to observer                                              | m                | ft                  |
| $SPL$      | one-third octave band sound pressure level                                                | dB <sup>††</sup> | dB <sup>‡</sup>     |
| $Sr$       | Strouhal number ( $Sr = fD_j/V_j$ )                                                       |                  |                     |
| $T_{js}$   | jet static temperature                                                                    | K                | K                   |
| $T_0$      | ambient temperature                                                                       | K                | K                   |
| $V_j$      | fully expanded jet velocity                                                               | m/s              | ft/s                |
| $\gamma$   | ratio of specific heat capacity at constant pressure to that at constant volume           |                  |                     |
| $\theta_j$ | angle of line to observer with engine exhaust axis                                        | degree           | degree              |

<sup>†</sup> Although it is suggested that flow area is used in the calculation of  $D_j$ , in most practical circumstances the use of geometric areas will not lead to significant errors.

<sup>‡</sup> The gas constant value is 287.052 J/kg K in SI units and 3089.811 ft lbf/slug K in British units.

<sup>††</sup> The reference pressure for all decibel levels is 20  $\mu$  Pa (*i.e.* 0.000 02 N/m<sup>2</sup>) or  $0.42 \times 10^{-6}$  lbf/ft<sup>2</sup>.

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Sketch 1.1

## 2. NOTES

This Item provides a computerized method for estimating exhaust noise spectra from a given database. The procedure is an interpolation/extrapolation routine which, because of the variables considered, is applicable to estimating the noise from a single-stream jet. Because the procedure is essentially one of interpolation of noise spectra, the particular form of the database need not be restricted to data for an isolated single-stream jet. However, in other and more complex situations, due consideration must be given to the underlying physics of the noise generating process.

In order to provide a basic prediction procedure and illustrate the use of this method, a comprehensive database is provided for the case of far-field, single-stream, static jet mixing noise. The database is provided in two forms: an unsmoothed form and a smoothed form where data at angles above  $\theta_j = 50$  degrees have been smoothed.

The major advantage of this method over earlier graphical approaches, as described in References 6 and 7, is the ease with which the database may be altered. This means that new data can be added as they become available without modifications to the computing procedure. In addition, because the earlier methods have had to rely on data from a wide range of nozzle configurations, they may not provide the best predictions for specific geometric configurations.

A simple introduction to jet mixing noise, together with other types of gas turbine exhaust noise, is given in ESDU 74001 (Reference 3).

## 3. CALCULATION METHOD

### 3.1 General Description

The program predicts noise levels by using a series of interpolations/extrapolations on a database using normalized jet velocity and temperature ratio as the independent variables. The process is repeated through the Strouhal number range of interest for the appropriate sound radiation angle or angles. More details about the calculation procedure are provided in the next three sections.

### 3.2 Database Parameters

Any data that are input into the database are defined in terms of the parameters listed in Section 4.2. The noise data must lie within a specific range of Strouhal number,  $Sr$ , which in the program is expressed in terms of  $\log_{10} Sr$  and this parameter must lie within the range of  $-1.5$  to  $1.5$ . Data may be input into the database only at values of  $\theta_j$  that are integer multiples of 10 degrees within the range of 0 to 170 degrees.

The program normalizes the data for nozzle exit area, radial distance and atmospheric pressure. At the same time, normalization by a term  $[80 \log_{10}(V_j/a_0)]$  is also carried out to adjust the data for gross parameter variations and present a “flatter” surface for interpolation/extrapolation. The normalization is performed according to the relationship

$$SPL_{normalized} = SPL - 10 \log_{10}(A_j/r^2) - 20 \log_{10}(p_0/p_{ISA}) - 80 \log_{10}(V_j/a_0), \quad (3.1)$$

where  $p_{ISA}$  is 101.325 kPa in SI units or 2116 lbf/ft<sup>2</sup> in British units.

It must be noted that this normalization process has implications that must be considered carefully with some types of data. For example, if input data have been corrected to lossless atmospheric conditions, then the normalization process will be completely valid and predictions including corrections for atmospheric attenuation can be made at any radial distance. However, if measured data are input, predictions can only be made accurately at the actual measurement distance.

When data are input to the database an optional procedure in the program may be used to remove spectral irregularities resulting from experimental error. This procedure is specified in Appendix A. Note that the use of the smoothing option may affect extrapolation at extremes of the spectrum.

### 3.3 Interpolation Procedure

A least-squares bipolynomial surface fit on the selected database considering  $\log_{10}(V_j/a_0)$  and  $\log_{10}(T_{js}/T_0)$  as the independent variables is performed and the resulting equation is solved for the jet operating conditions at which the  $SPL$  is to be estimated. The optimum combination of terms from the least-squares regression equation, *i.e.* that which produces the lowest standard error, is automatically selected for the final regression equation. The procedure requires a minimum of three points in the database. If the database contains points located such that it is not possible to fit a least-squares surface through them (*e.g.* if one of the independent variables is constant or limited in range), appropriate notification is printed out.

The interpolation procedure is repeated throughout the Strouhal number range of interest for the appropriate angle,  $\theta_j$ . For values of  $\theta_j$  that are not integer multiples of 10 degrees (data are stored in the database in 10 degree angular increments), quadratic interpolation using the nearest database angles is carried out. If there are insufficient data for quadratic interpolation, linear interpolation is carried out.

If sufficient data are not available to estimate spectrum values at the edges of the frequency range using the surface-fitting routine, linear extrapolation based on the slope from the two nearest spectral points is carried out.

The program incorporates a weighting method by which data in the database nearer the point at which spectrum levels are to be estimated are weighted more heavily than data further away. Details of this weighting procedure are given in Appendix B.

## 3.4 Output Computations

The noise predictions are denormalized to the required conditions after the surface fits have been performed.

The option to specify the frequency range within which one-third octave band noise levels are output is provided. OASPL and dBA are calculated over the specified frequency range. PNdB is also calculated.

The user should be aware that because the database provided is specified over a fixed Strouhal number range a significant amount of extrapolation may occur at high frequencies when predicting the noise from large diameter nozzles. Extrapolated values are indicated in the output.

On output the option to correct for atmospheric attenuation is offered according to the procedure in Reference 4. This particular procedure has been used because the database as supplied to ESDU and provided with this Item (see Section 5) was corrected to lossless atmospheric conditions using it. Other procedures for computing atmospheric attenuation [such as that provided in ESDU 78003, (Reference 5)] may be substituted into the program.

The “standard error” (see Appendix C) is also printed out.

## 4. COMPUTER PROGRAMS

There are four programs associated with this Item, programs A9819<sup>†</sup>, B9819, C9819 and M9819.

Programs A9819 and M9819 estimate jet noise levels in one-third octave band levels in the frequency range set by the user. A database (described in Section 5) is provided for the estimation of far-field jet mixing noise from a static source with a circular nozzle. The user has the option to use either a smoothed form or an unsmoothed form of this database.

The program when run requires the user to enter the name of the file containing the input data. The structure of this input file is shown in Section 4.3. Program B9819 can be run to create such input files conveniently.

The two programs described above follow the standard and familiar ESDU Aircraft Noise Series means of providing software. However, for users with MATLAB<sup>®</sup> <sup>‡</sup> installed on their systems an additional program, M9819, is included. When this program is run, a graphical user interface is launched through which input data may be entered. These data are stored in a file named by the user. The option to load the interface with data from an existing file is available. Clicking on the ‘RUN’ push-button starts program execution, with results output in the standard way to a text file named by the user. In addition, spectral plots of the results are generated, displayed and written to Tagged Image File Format (TIFF or TIF) files. The files containing spectral plots for the case in the Example of Section 7 are displayed in that Section. The first line of the Run Title in the input file is reproduced on each plot.

Program C9819 can be run to create a new database using the user’s data, which can then be used by program A9819 to estimate single-stream jet noise.

<sup>†</sup> The full ESDUpac number has an appended V followed by two digits. These digits indicate the ESDUpac version number. For example, the full ESDUpac number for version 1.0 of ESDUpac A9819 is A9819V10. See Introduction to ESDUpacs for a full description of the ESDUpac numbering system. The current version of the ESDUpac is given on the example program output.

<sup>‡</sup> MATLAB is a registered trademark of The Math Works, Inc.

## 4.1 File Structure of the Database Provided

Both forms of the database provided consist of ten files each, each file containing spectral data for a range of jet operating conditions, at a given angle. The angular range covered is from 30 degrees to 120 degrees. File names describe the angle for which data are included in the file and the file name extension is used as a database identifier. For example, in the smoothed database provided, data at  $\theta_j = 30$  degrees are contained in a file named 'ANG 30.PRV1.' The corresponding file in the unsmoothed database is named 'ANG 30.PRV2'. The 'PRV' is used to indicate that the file forms part of the database provided.

The first row of each file contains the run title/date input by the user when generating the database. After that row, there are as many rows as there are jet operating conditions, *i.e.* combinations of temperature ratio and normalized jet velocity.

The column structure of a file in the database is shown in the following table.

**TABLE 4.1 Structure of the database**

| Column number | Contents                            |
|---------------|-------------------------------------|
| 1             | Angle, $\theta_j$ (deg)             |
| 2             | Temperature ratio, $T_{js}/T_0$     |
| 3             | Normalized jet velocity, $V_j/a_0$  |
| 4             | <i>SPL</i> at $\log_{10} Sr = -1.5$ |
| 5             | <i>SPL</i> at $\log_{10} Sr = -1.4$ |
| .             | .                                   |
| .             | .                                   |
| .             | .                                   |
| 34            | <i>SPL</i> at $\log_{10} Sr = 1.5$  |

## 4.2 Creating a New Database

Program C9819 can be used to create a new database using the user's data. This program also offers the user the option to expand an existing database by adding fresh data. When the program is run, prompts similar to those shown in the following table appear on the screen.

|                                                                                                                                                                                                                              |         |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| Select whether you wish to                                                                                                                                                                                                   |         |
| i) create a new database                                                                                                                                                                                                     | Enter 1 |
| ii) add data to an existing database                                                                                                                                                                                         | Enter 2 |
| If 1, enter a 4 - character word which will identify the database you create by serving as the file name extension.                                                                                                          |         |
| If 2, enter the character identifier of the database you wish to expand.                                                                                                                                                     |         |
| Run title and date (maximum of 275 characters)                                                                                                                                                                               |         |
| Units                                                                                                                                                                                                                        |         |
| SI units                                                                                                                                                                                                                     | Enter 1 |
| British units                                                                                                                                                                                                                | Enter 2 |
| Do you wish to smooth spectra?                                                                                                                                                                                               |         |
| Enter Y or N                                                                                                                                                                                                                 |         |
| For each set of operating conditions, enter the name of the file that contains the operating conditions and spectral data followed by RETURN. The data contained in this file must be in the format shown in the next table. |         |
| When all file names have been entered, press RETURN at the prompt for the file name.                                                                                                                                         |         |

The program requests the user for names of files that contain spectral data over an angular range, at a given set of jet operating conditions. Each file must contain data for one set of jet operating conditions. Therefore, there must be as many files as there are sets of operating conditions. In each file, data for a maximum of 17 angles at 10 degree intervals can be input. If data are not available at some angles, zeros must be inserted.

When all file names have been entered, the user must press the RETURN key, and the input will then be complete.

The format for each file is given in the following table. If for some frequencies there are no data, zeros must be inserted.

| $D_j$              | $A_j$              | $T_0$             | $p_0$ | $V_j$ | $T_{js}$ | Distance |                    |
|--------------------|--------------------|-------------------|-------|-------|----------|----------|--------------------|
| Angle 1            |                    | Angle 2           |       | .     | .        | .        | Angle 17           |
| SPL at 40 Hz (dB)  |                    | SPL at 40 Hz (dB) |       | .     | .        | .        | SPL at 40 Hz (dB)  |
| .                  | .                  | .                 | .     | .     | .        | .        | .                  |
| .                  | .                  | .                 | .     | .     | .        | .        | .                  |
| .                  | .                  | .                 | .     | .     | .        | .        | .                  |
| .                  | .                  | .                 | .     | .     | .        | .        | .                  |
| SPL at 40 kHz (dB) | SPL at 40 kHz (dB) | .                 | .     | .     | .        | .        | SPL at 40 kHz (dB) |