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Computer-based estimation procedure for near-field single-stream jet noise

Associated software: ESDUpac A9906
ESDUpac B9906
ESDUpac C9906
VIEWpac M9906



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THE PREPARATION OF THIS DATA ITEM

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COMPUTER-BASED ESTIMATION PROCEDURE FOR NEAR-FIELD SINGLE-STREAM JET NOISE

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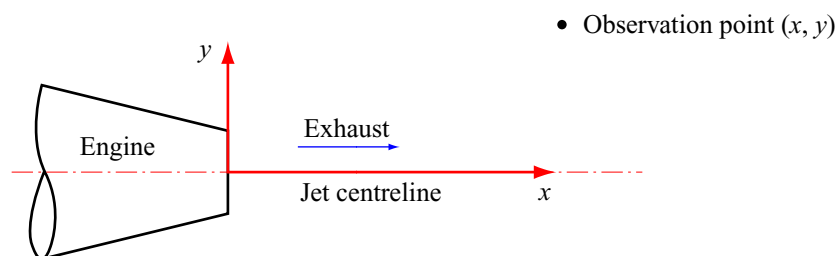
COMPUTER-BASED ESTIMATION PROCEDURE FOR NEAR-FIELD SINGLE-STREAM JET NOISE

1. NOTATION

		Units	
		SI	British
A_j	flow area of jet exhaust nozzle	m ²	ft ²
a_0	ambient speed of sound	m/s	ft/s
D_j	effective jet nozzle diameter [= $(4A_j/\pi)^{1/2}$] [*]	m	ft
f	frequency	Hz	Hz
M_j	fully-expanded jet Mach number		
p_{ISA}	ambient pressure under ISA conditions	kPa	lbf/ft ²
p_0	ambient pressure	kPa	lbf/ft ²
r	distance between source location and measurement location (see Appendix D)	m	ft
SPL	one-third octave band sound pressure level	dB [†]	dB [†]
Sr	Strouhal number ($Sr = f D_j / V_j$)		
T_{js}	jet static temperature	K	K
T_0	ambient temperature	K	K
V_j	fully-expanded jet velocity	m/s	ft/s
x	axial distance from jet pipe nozzle exit plane, measured in jet direction (see Sketch 1.1)	m	ft
y	radial distance from jet axis (see Sketch 1.1)	m	ft
β	shock noise parameter ($\beta = \sqrt{M_j^2 - 1}$)		

^{*} 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.

[†] The reference pressure for all decibel levels is 20 μ Pa (*i.e.* 2×10^{-5} N/m²) or 0.42×10^{-6} lbf/ft².



Sketch 1.1

2. NOTES

This Item provides a computerized method for estimating near-field exhaust noise spectra from any given database. The program estimates noise levels in one-third octave bands with a variety of output options. The procedure uses interpolation/extrapolation routines which, because of the variables considered, make the procedure applicable to estimating the near-field noise from single-stream jets. Because the procedure is essentially one of interpolation of noise spectra, the particular form of the database need not be restricted to jet mixing noise data for a single-stream jet. The method assumes that the database used is applicable to a particular half-plane from the jet centre-line. To provide a basic prediction procedure, a set of three comprehensive databases for the case of near-field, single-stream, jet noise from a circular nozzle are included. These data are for axisymmetric jets.

It is a feature of the method that the database may be altered with ease so that, given new data for any particular nozzle configuration, predictions can be made in the half-plane of the measurements without modifications to the computing procedure. Thus non-axisymmetric jets, for example, can be handled by successive applications of the method to each half-plane for which data are available. Interpolation for making predictions at points between such half-planes is not provided.

The method should, however, be applied with caution to other than axisymmetric single-stream jets without any other noise sources present because the prediction accuracy will deteriorate if the axial distribution of the noise sources is markedly different from that assumed.

A simple introduction to jet mixing noise, together with other types of gas turbine exhaust noise, is given in ESDU 74001 (Reference 4). An early graphical method of estimating near-field jet noise is given in ESDU 72002 (Derivation 1)*. Computer-based procedures for estimating far-field single-stream jet noise and co-axial jet noise are given in ESDU 98019 (Reference 7) and ESDU 01004 (Reference 8) respectively.

3. CALCULATION METHOD

3.1 General Description

The jet noise estimation program predicts noise levels by using a series of interpolations/extrapolations on a database. These interpolations/extrapolations are carried out in two stages using the database information relating to the nine spatial locations closest to the location of interest. For each of these nine locations, the noise levels are first estimated for the specific jet operating conditions of interest. These levels are evaluated at discrete frequencies (although interpolation is carried out in terms of Strouhal number) at intervals over the range of frequencies required. Because a simple inverse square law of sound propagation does not apply in the near-field, a further stage of interpolation is required based on the distances between the location of

* This method is applicable to full-scale engines of approximately 0.6 m nozzle diameter.

interest and the nine database locations considered. The outputs from this second stage interpolation are the one-third octave band sound pressure levels, for the required jet operating conditions, at the specific spatial location of interest. Other output options (see Section 3.4) may then be evaluated. Data are stored in the database in normalized form and de-normalized prior to the output of results. The database must contain data for a minimum of nine spatial locations.

If data for only one set of jet operating conditions are available, and spatial interpolation is required, the program offers the option to bypass the first interpolation stage.

3.2 Database Parameters

Any data that are input into the database are defined in terms of the parameters listed in Table 4.1. 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 1.8 .

The program normalizes the data for the ratio of distance from the locations assumed for the sources (see Appendix D) to the measurement location, and for atmospheric pressure.

Thus, the normalization is performed according to the relationship

$$SPL_{normalized} = SPL + 20 \log_{10}(r/D_j) - 20 \log_{10}(p_0/p_{ISA}), \quad (3.1)$$

where p_{ISA} is 101.325 kPa in SI units or 2116 lbf/ft² in British units.

Within the computation procedure, a further normalization term based on jet velocity is applied (see Section 3.3.1).

Data entered into the database may be in SI or British units without affecting the normalization process.

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 either end of the spectrum. It must also be noted that, if the smoothing option is exercised, the shape of the spectrum is likely to be affected adversely where shock noise is present.

3.3 Interpolation Procedure

The nine nearest locations to the location at which the SPL is to be estimated are selected from the database. For each of these locations, a least-squares quadratic equation is fitted through the data using variables based on functions of jet operating conditions (see Section 3.3.1) and the resultant regression equation is then solved for the required jet operating conditions. This process is repeated over the Strouhal number range required.

Using the SPL s calculated for the nine locations, a further spatial interpolation/extrapolation provides the SPL at the required location. If sufficient data are not available to estimate spectrum values at the edges of the frequency range, linear extrapolation based on the slope from the two nearest spectral points is carried out, and a warning is printed.

The program incorporates weighting methods by which data in the database nearer the jet operating conditions and the location at which spectrum levels are to be estimated are weighted more heavily than data further away. Details of these weighting procedures are given in Appendix B.

3.3.1 Selection of variables

The program may be run using either one or two independent variables determining the jet operating conditions. If shock noise is present, the principal variable is $\log_{10} \beta$. When there is no shock noise present, the principal variable is the normalized jet velocity, $\log_{10} (V_j/a_0)$. If, however, the temperature ratio, T_{js}/T_0 , varies independently of jet velocity for the data in the database, as is the case with all three of the databases provided, the interpolation must be carried out using two independent variables, with $\log_{10} (T_{js}/T_0)$ as the second variable. For each variable used at least three values are needed.

To adjust the data for gross parameter variations and provide a better fit through the data, the term $80 \log_{10} (V_j/a_0)$ is removed from the normalized *SPL* before the least-squares fits are performed. This term is added again at the de-normalization stage.

3.4 Output Computations

The results may be output in either of the following forms:

- (i) one-third octave band sound pressure levels, *SPL*,
- or
- (ii) one-third octave band sound pressure levels, *SPL*, together with the spectrum pressure level (dB/Hz) and the spectrum sound pressure $[(N/m^2)/Hz]^*$ for each band.

* This unit may also be written as Pa/Hz.

The user must specify the frequency range within which noise levels are output. The *OASPL* over the frequency range specified is calculated. It must be noted that if *OASPLs* are to be compared, the frequency limits within which they have been calculated should be identical. The dBA and PNdB values are also calculated.

An indicator of the accuracy of prediction of the one-third octave band levels (see Appendix C) is also printed out.

4. COMPUTER PROGRAMS

There are four programs associated with this Item, programs A9906*, B9906, C9906 and M9906.

Programs A9906 and M9906 estimate jet noise levels using a database, in the frequency range set by the user. Three different databases (described in Appendix E) are provided for the estimation of near-field jet mixing noise from a static source with a circular nozzle.

The program when run requires the user to enter the name of the input file. The structure of this input file is shown in Section 4.2. Program B9906 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[†] installed on their systems an additional program, M9906, is included. When this program is run, a graphical user interface is launched through which input

* 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 A9906 is A9906V10. See Introduction to ESDUpacs for a full description of the ESDUpac numbering system.

† MATLAB is a registered trademark of the Math Works Inc.

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 cases 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 C9906 can be run to create a new database using the user's data, which can then be used by program A9906 to estimate single-stream near-field jet noise.

The database is contained in a set of files, each file referring to a specific location. The column structure of a file is shown in the table below. Each row is for a jet operating condition at that location.

Column structure of the database file

Column Number	Contents
1	Normalized jet velocity, V_j/a_0
2	Temperature ratio, T_{js}/T_0
3	SPL at $\log_{10} Sr = -1.5$
4	SPL at $\log_{10} Sr = -1.4$
.	.
.	.
.	.
36	SPL at $\log_{10} Sr = 1.8$

4.1 Creating a Database

Program C9906 can be used to create a new database from the user's data. When the program is run, prompts similar to those shown in the following table appear on the screen.

Enter a name (up to 3 characters long) which will be used as the filename extension by which the new database files will be identified.	
Enter run title and date in any format you like. This information will be reflected in the contents file, CONT9906.***.	
Select whether you want to use	
SI units	Enter 1
British units	Enter 2
If the database has	
shock noise	Enter 1
no shock noise	Enter 2
Do you want to smooth spectra?	
Answer Y or N	
Enter name of database input file (see below)	

Data written to the database are read from an input file that must be structured in a specific way. The file may be considered to contain a two-dimensional array with the column structure shown in the table below. Each row therefore must contain the location, the jet operating conditions and the associated spectrum levels in the format of this table. The spectral data at any particular location must be grouped together in successive rows, though no demarcation between groups is required.

TABLE 4.1 Column structure of database input file

Column number	Parameter
1	x coordinate, x (m or ft)
2	y coordinate, y (m or ft)
3	Effective jet nozzle diameter, D_j (m or ft)
4	Ambient temperature, T_0 (K)
5	Ambient pressure, p_0 (Pa or lbf/ft ²)
6	Jet velocity, V_j (m/s or ft/s)
7	Static jet temperature, T_{js} (K)
8	SPL at 40 Hz (dB)
9	SPL at 50 Hz (dB)
10	SPL at 63 Hz (dB)
.	.
.	.
.	.
.	.
41	SPL at 80 kHz (dB)

Note

1. If SPL s are not available to cover the entire frequency range of 40 Hz to 80 kHz zeros must be input in the appropriate columns.
2. The half-plane of the data is defined by y being positive.

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Data in each group are normalized in sequence and transferred to the files that constitute the database. At the same time, the spatial location of each file and the file number that corresponds to it are entered in a separate “CONTENTS” file. The structure of the “CONTENTS” file is shown in the following table. The maximum number of files that can be stored is system-dependent.

TABLE 4.2 Structure of the contents file

File No.	Location	
	x/D_j	y/D_j

4.2 Estimating Jet Noise

The program estimates near-field jet noise using a database selected by the user.

There are three databases provided with this Item. These are referred to as ESDU1, ESDU2 and ESDU3.

The main attributes of these databases are given in this section, but more detailed descriptions are provided in Appendix E.

The database known as ESDU1 has been derived from ESDU 72002 (Derivation 1). Data at temperature ratios (T_{js}/T_0) of 1, 2 and 4 are provided for normalized jet velocity (V_j/a_0) values in the range of 1.5 to 3.0. **This database, however, does not contain shock noise.**

Both databases, ESDU2 and ESDU3, were provided by DERA, Pyestock (Derivation 3).

The database, ESDU2, contains subsonic data over a normalized jet velocity range of nominally 1 to 1.8 and a temperature ratio range of 1 to 3.

The database, ESDU3, contains supersonic data over a normalized jet velocity range of nominally 2 to 4 and temperature ratio range of 1 to 3. This database must be used if shock noise is to be estimated.

In summary, if only jet noise is to be estimated and jet velocities are high ($V_j/a_0 > 2.0$), database ESDU1 should be used.

For lower jet velocities, either ESDU1 or ESDU2 can be used. ESDU1, however, has been derived from full-scale jets and because of the Strouhal number range covered, is more suitable for larger diameter jets, whereas a wider frequency range would be covered for smaller jets by database ESDU2.

Additionally, ESDU2 contains data at negative values of x/D_j , whereas ESDU1 does not.

If shock noise is to be estimated, database ESDU3 must be used. ESDU3 also has data at negative values of x/D_j .

Alternatively, a database created by the user using program C9906 can be used.

Input data required for estimating jet noise, the case data, are entered from a file.