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Prediction of noise generated by fans and compressors in turbojet and turbofan engines

Associated software: ESDUpac A9808
B9808
M9808



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THE PREPARATION OF THIS DATA ITEM

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PREDICTION OF NOISE GENERATED BY FANS AND COMPRESSORS IN TURBOJET AND TURBOFAN ENGINES

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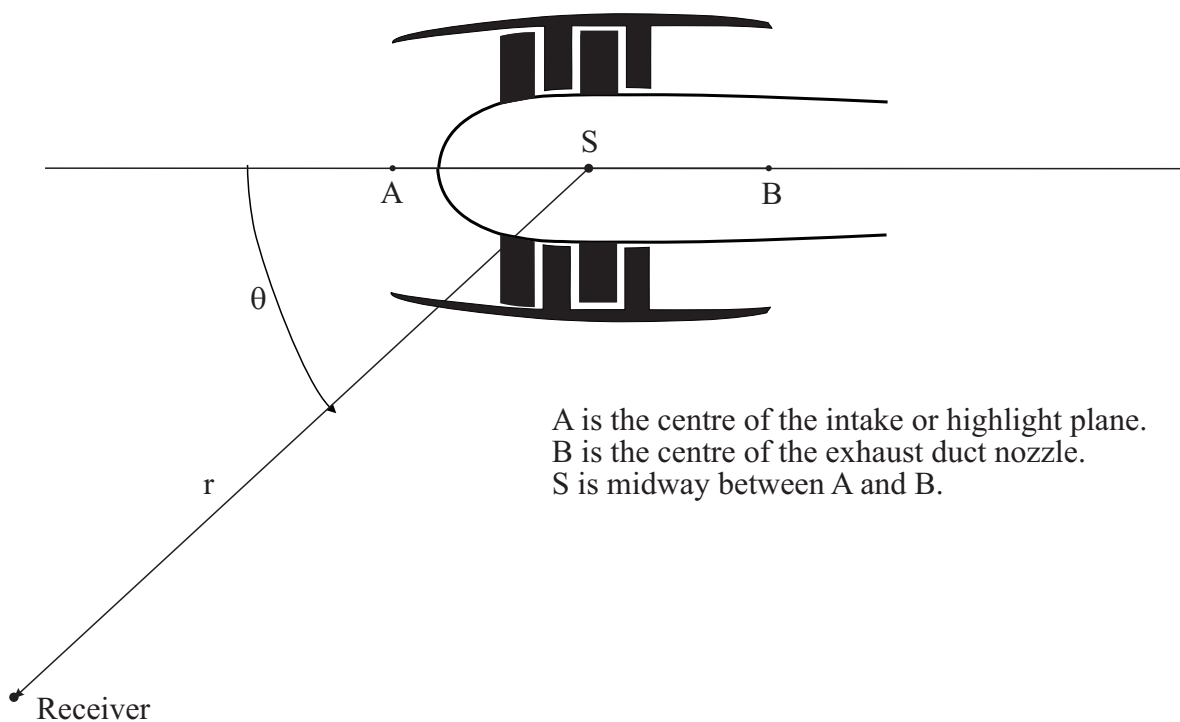
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PREDICTION OF NOISE GENERATED BY FANS AND COMPRESSORS IN TURBOJET AND TURBOFAN ENGINES

1. NOTATION

		Units	
		SI	British
B	number of rotor blades		
BPF	blade passing frequency	Hz	Hz
C	constant used in Appendix B		
C_1, C_3	stator and rotor chords (see Sketch B.1)	m	ft
C_2, C_4	stator and rotor spacing (see Sketch B.1)	m	ft
F_1, F_2, F_3, F_4, F_5	functions defined in Appendix B		
f	frequency	Hz	Hz
k	harmonic order		
L	constant used in equations in Appendix B	dB	dB
L_p	characteristic peak level of fundamental tone	dB	dB
M_a	flight Mach number		
M_T	rotor tip Mach number		
M_{TR}	rotor tip relative inlet Mach number = $\sqrt{M_x^2 + M_T^2}$		
M_{TRD}	M_{TR} at fan design point		
M_x	flow Mach number		
$\dot{m}$	mass flow rate passing through fan	kg/s	lbm/s
$\dot{m}_0$	reference value of $\dot{m}$ (= 0.454 kg/s or 1lbm/s)	kg/s	lbm/s
RSS	rotor-stator spacing in per cent (see Sketch B.1 in Appendix B)		
r, θ, ϕ	spherical coordinates defining source-receiver geometry (shown in Sketches 1.1 and A.1)		
S_1, S_2	parameters used in determining RSS (see Sketch B.1)		

V	number of stator blades		
ΔT	total temperature rise across a fan or compressor	K	K
ΔT_0	reference value of ΔT (= 0.555 K)	K	K
δ	cut-off factor given by $M_T/(1 - V/B)$		



Sketch 1.1

2. INTRODUCTION

This Item allows the user to estimate the noise generated by axial-flow fans or compressors in turbojet and turbofan engines with and without inlet guide vanes. Throughout the rest of this Item, the term 'fan' will be used to describe both configurations. Engines could be static or in flight. Sound pressure levels in one-third octave bands in the frequency range of 50 Hz to 10 000 Hz are calculated for lossless free-field ambient conditions with no temperature gradient or wind. These results can be corrected for the effects of a real atmosphere and for ground reflection using other ESDU Data Items (References 6, 7 and 8). It should be noted that the effect of any sound-absorbing liners should be taken into account when making an estimation of the far-field noise level.

The main input parameters that need to be specified are the mass flow rate, the total temperature rise associated with a fan stage, both the design point and the operating point values of the rotor tip relative inlet Mach number, certain data about the fan geometry and the flight Mach number. The total temperature rise, if not readily available, may be estimated using Reference 5.

The method allows the user to estimate fan noise radiated

- (i) from both intake and discharge ducts,
 - (ii) from only the intake duct
- or
- (iii) from only the discharge duct.

For the first case, the distance, r , from S , is required as input and is determined as shown in Sketch 1.1. For the second case, r is measured from the reception point to point A in Sketch 1.1. Similarly, for the third case r is measured from the reception point to point B.

3. BASIC PREDICTION PROCEDURE

The prediction procedure is based on Heidmann's method described in Derivation 2 and is a modified version of the Boeing-Ames procedure given in Derivation 1. Heidmann's method was improved for small engines (under 6000 lbf or 26.7 kN sea-level rated static thrust) by incorporating the modifications described in Derivation 3. Together, these two prediction procedures currently form part of the NASA Aircraft Noise Prediction Program (ANOPP) (Reference 9). It has been found that the ANOPP small engine method with a minor change at high frequencies gives an improved prediction when compared with independent data from Derivation 4 for all engines regardless of size. This is the basis of the recommended ESDU procedure in this Item. These improvements are described in Appendix B.

In this Item, the user is offered the choice between using the NASA ANOPP methods or the procedure recommended by ESDU (referred to as the ESDU method). With the ANOPP methods, the user has the option to select the Heidmann method or the small engine method with the AlliedSignal modifications irrespective of the actual thrust of the engine.

The method considers the noise radiated from the inlet duct and the discharge duct separately. In both cases there is a broadband noise component and a discrete tone component. However, in the noise emitted from the fan or compressor inlet duct there is an additional combination tone or "buzz-saw" component when the relative tip speed is supersonic. At each angle, the component spectra are summed on an energy basis. For multi-stage fans, the final spectrum is obtained by summing the sound energy from each stage. The program does not correct noise levels automatically for blade row attenuation. However, estimated values for the attenuation in forward and rearward arcs may be input by the user, and these values will be subtracted from the noise levels. Some simple guidelines on estimating blade row attenuation in the forward arc are provided in Section B.4

For each component, the procedure predicts the spectrum shape, the spectrum level and the free-field directivity. The spectrum shape, which is essentially fixed for each component, is placed within the frequency range according to the value of the blade passing frequency. The spectrum levels are predicted from the mass flow rate, the total temperature rise associated with a fan stage, and both the design and operating values of the rotor tip relative inlet Mach number. Corrections are then applied to these basic spectrum levels or shapes. These corrections depend on:

- (i) the presence or absence of inlet guide vanes,
- (ii) the rotor-stator spacing,

- (iii) inlet flow distortions which are present for static and low speed ground-roll operations and absent at the higher speeds occurring in flight,
- and (iv) tone cut-off where the fundamental tone is suppressed according to a criterion determined by the number of rotor and stator blades and the value of the rotor tip Mach number.

The equations used to perform the predictions are given in Appendix B.

4. APPLICATION AND ACCURACY

The prediction procedure in this Item is applicable to multi-stage turbofans with and without inlet guide vanes. Since the Item has only been validated for up to two stages the user is advised to exercise caution when interpreting results for more than two fan or compressor stages. It is assumed that the operating point is near the steady-state operating line and caution must be exercised if the operating point is above the design point. It is also assumed that inlet and discharge ducts do not amplify or attenuate the generated noise.

The method predicts free-field SPL values in one-third octave bands from 50 Hz to 10 kHz for a still lossless atmosphere, and these vary with the polar angle θ but not the azimuthal angle ϕ (see Sketch A.1). OASPL and dBA values are also output.

It is difficult to quantify the accuracy of prediction of spectra since the prediction is very much dependent on the specific fan. Comparisons between predictions and experimental data are also made more difficult at frequencies below the blade passing frequency by the strong presence of other jet engine noise sources in the measurements. However, using data made available to ESDU (Derivation 4) the rms error was calculated for values of θ between 30 degrees and 150 degrees. The rms error* between measured one-third octave band sound pressure levels and estimated levels using the recommended ESDU procedure was under 5 dB. This value of rms error improves if the angular range is restricted.

This Item has not been validated for flight. However, the consequent Doppler effects, which influence the frequency of sound at the receiver and also change its amplitude as a consequence of convective amplification, have been included in the conventional manner as expressed, for example in Reference 9.

In general, this method predicts adequately the general properties of far-field noise spectra. The trends exhibited by experimental data are predicted in a satisfactory manner, but the method does not always predict the detailed variations in the spectra from angle to angle. This is so, especially for non-typical fan operating conditions.

* The rms error is an indicator of the accuracy of prediction. It has been calculated here from comparisons of measured data with predictions using the expression

$$\text{rms error} = \sqrt{\sum (\text{measured value} - \text{predicted value})^2 / (\text{number of samples})}.$$

The rms error can be used in an analogous way to standard deviation to obtain degrees of confidence in the prediction, i.e. twice rms error corresponds to 90% confidence and three times rms error to 95% confidence.

5. COMPUTER PROGRAM

There are three computer programs associated with this Item, A9808, M9808 and B9808.

Programs A9808* and M9808 provide a means of predicting noise spectra from fans and compressors in turbojet and turbofan engines.

Programs B9808 facilitates the creation of input data files required by Program A9808.

Typically, the program to estimate flight spectra can be run by either typing in the program name or by clicking on the icon associated with executable version of the program. The user is then prompted to enter the name of the input file.

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, M9808, is included. When this program is run, a graphical user interface is launched through which input data may be entered. The data are stored in a file named by the user. The option to load the interface with data from an existing file is also 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. Files containing spectral plots for the case in the Example in Section 7 are displayed in that Section.

In order to run ESDU programs from the Aircraft Noise Series sequentially and conveniently, a means by which data can be transported automatically between programs is being implemented. This is to be achieved by the creation of data files by all appropriate programs which can then be read by subsequent Data Item programs. These data files contain reference data, such as those for ambient conditions, and spectral data for any number of locations. Each program can read data from and write data to files named by the user. The format of the data file is given in Appendix A.

5.1 Input Data

Program A9808, when run, requires the user to enter the name of the input file containing the case data.

The program can be run by either clicking on the icon associated with the executable version of the program or by typing in the program name.

* 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 A9808 is A9808V10. See introduction to ESDUpacs for a full description of the ESDUpac number system. The current version of the ESDUpac is given on the example program output.

The structure of the input file is shown in the following table.

Run title (maximum 75 characters)
Run title (maximum 75 characters)
Run title (maximum 75 characters)
Output file name
Common input data file name (see Appendix A)
Common output data file name (see Appendix A)
Units (1 for SI, 0 for British)
Method of prediction
i) Heidmann method. Enter 0.
ii) Heidmann method with AlliedSignal small engine modifications. Enter 1.
iii) ESDU method. Enter 2.
If fan noise is to be predicted from
i) both inlet and discharge ducts, enter 1
ii) only the inlet duct, enter 2
iii) only the discharge duct, enter 3.
Number of stages (maximum of five)
For each stage, enter in order the data specified in the four following lines.
Number of stator blades at stage
Number of rotor blades at stage
Enter the minimum rotor-stator spacing, RSS, (in per cent) as defined in Sketch B.1 in Appendix B on page 17
Total temperature rise across stage, K
.
.
.
Blade row attenuation, dB in forward arc, <i>i.e.</i> $\theta \leq 90^\circ$ deg
Blade row attenuation, dB in rear arc <i>i.e.</i> $\theta > 90^\circ$ deg
Rotor shaft rotational speed (rev/min)
Mass flow rate through fan or compressor, kg/s or lbm/s
Rotor tip relative inlet Mach number at fan design point
Rotor tip relative inlet Mach number at operating point
Rotor tip Mach number
If inlet guide vanes are present, enter 1. Otherwise enter 0.
Flight Mach number
Air pressure at fan location, kPa
If a common input data file name has been specified above, the input is complete.
Air pressure at receiver location, kPa
Ambient air temperature, K
Number of receiver locations (maximum of 100)
<i>r</i> , θ for 1st location
<i>r</i> , θ for 2nd location
.
.
.
<i>r</i> , θ for last location

5.2 Output data

Output data are written to a file named by the user in the input file. Three lines of descriptive text can be entered in the input file to title the run written to the output file.

Reference data and output data are also written to a file named by the user and written in the format shown in Appendix A. The value of the azimuthal angle, ϕ , written to the output file is set to the arbitrary value of 90 deg.

6. DERIVATION AND REFERENCES

6.1 Derivation

The Derivation lists the sources that assisted in the preparation of this Item.

- | | | |
|----|---------------------------|--|
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PEARL, N.A. | Aircraft noise source and contour estimation. Boeing Commercial Airplane Co.; NAS2-6969. NASA CR-114649, 1973. |
| 2. | HEIDMANN, M.F. | Interim prediction method for fan and compressor source noise. NASA TM X-71763, 1975. |
| 3. | HOUGH, J.W.
WEIR, D.S. | Aircraft noise prediction program (ANOPP) fan noise prediction for small engines. NASA CR-198300, 1996. |
| 4. | – | Unpublished data. Rolls-Royce plc, Derby, UK, 1998. |

6.2 References

The references are selected sources of information supplementary to that given in this Item.

- | | | |
|----|----------------|--|
| 5. | ESDU | One-dimensional compressible gas flow in ducts. ESDU 74028, ESDU, London, UK, October 1974. |
| 6. | ESDU | Evaluation of the attenuation of sound by a uniform atmosphere. ESDU 78002, ESDU, London, UK, December 1977. |
| 7. | ESDU | Evaluation of the attenuation of broad-band sound by a non-uniform still atmosphere. ESDU 78003, ESDU, London, UK, September 1978. |
| 8. | ESDU | The correction of measured noise spectra for the effects of ground reflection. ESDU 94035, ESDU, London, UK, November 1994. |
| 9. | ZORUMSKI, W.E. | Aircraft noise prediction program theoretical manual. NASA TM-83199. |