Noise Produced by Turbulent Flow Into a Rotor: Users Manual for Noise Calculation

R. K. Amiet, C. G. Egolf, and J. C. Simonich

United Technologies Research Center
East Hartford, CT

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June 1989
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Noise Calculation Programs

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**ROUTINE - NOPHAN**

**PURPOSE** - The main program which begins the calculation. It also does the summation over radius.

**AUTHOR** - Roy K. Amiet

**INPUT**

**COMMON BLOCKS**

**COMMON /ROTCA/**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL</td>
<td>RD</td>
<td>Chord/turbulence length scale</td>
</tr>
<tr>
<td>BN</td>
<td>RD</td>
<td>Number of blades</td>
</tr>
<tr>
<td>COC</td>
<td>RD</td>
<td>Sound speed / chord</td>
</tr>
<tr>
<td>RC</td>
<td>RD</td>
<td>Blade radius/chord</td>
</tr>
<tr>
<td>RIC</td>
<td>RD</td>
<td>Far-field distance / chord</td>
</tr>
<tr>
<td>RPS</td>
<td>RD</td>
<td>Rotational speed revolutions / sec</td>
</tr>
<tr>
<td>DXDZ</td>
<td>RD</td>
<td>Deformation tensor</td>
</tr>
<tr>
<td>ALPHA</td>
<td>RD</td>
<td>Tip path plane angle of attack</td>
</tr>
<tr>
<td>AO</td>
<td>RD</td>
<td>Speed of sound</td>
</tr>
</tbody>
</table>
| THIN  | RD   | Minimum observer polar angle in degrees 
(\theta = 0 along rotor axis in thrust direction) |
| TMAX  | RD   | Maximum observer polar angle in degrees                     |
| D     | RD   | Diameter of rotor                                           |
| DELT  | RD   | Desired increment in polar angle between successive calculations |
| PMIN  | RD   | Minimum observer azimuthal angle in degrees 
(\phi = 0 in direction of mean wind) |
| PHMAX | RD   | Maximum observer azimuthal angle in degrees                  |
| DELP  | RD   | Desired increment in azimuthal angle between 
successive calculations                             |
| ZM    | RD   | Axial Mach number                                           |
| FM    | RD   | Flow Mach number in rotor plane                             |
| UU    | RD   | Rms turbulence velocity / axial velocity                    |
| GWS   | RD   | Geostrophic wind speed (m/s)                                |
| WUINF | RD   | Vertical component of the rms turbulence normalized by the stream velocity |

**COMMON /NOPCB/**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>I</td>
<td>Number of azimuthal integration points</td>
</tr>
<tr>
<td>HF</td>
<td>I</td>
<td>First harmonic</td>
</tr>
<tr>
<td>HL</td>
<td>I</td>
<td>Last harmonic</td>
</tr>
<tr>
<td>NUM</td>
<td>I</td>
<td>Number of points</td>
</tr>
<tr>
<td>IH</td>
<td>I</td>
<td>Homogenous or nonhomogenous indicator</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td>Homogenous case</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>Nonhomogenous</td>
</tr>
<tr>
<td>NR</td>
<td>I</td>
<td>Number of radial points</td>
</tr>
</tbody>
</table>
**LOCAL VARIABLES**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DH</td>
<td>RD</td>
<td>Fractional harmonic spacing between frequency calculations</td>
</tr>
<tr>
<td>DR</td>
<td>RD</td>
<td>Increment between radial points</td>
</tr>
<tr>
<td>H</td>
<td>RD</td>
<td>Frequency of sound in multiples of blade passage harmonics</td>
</tr>
<tr>
<td>HOLD</td>
<td>RD</td>
<td>Last harmonic calculated</td>
</tr>
<tr>
<td>IARRAY</td>
<td>I</td>
<td>Array containing integer words from a data member record</td>
</tr>
<tr>
<td>I2</td>
<td>I</td>
<td>Do loop index</td>
</tr>
<tr>
<td>IIX</td>
<td>I</td>
<td>Do loop index</td>
</tr>
<tr>
<td>IP</td>
<td>I</td>
<td>Number of P values</td>
</tr>
<tr>
<td>ISTAT</td>
<td>I</td>
<td>Status of calls to data member routines</td>
</tr>
<tr>
<td>J1</td>
<td>I</td>
<td>Do loop index</td>
</tr>
<tr>
<td>K</td>
<td>I</td>
<td>Do loop index</td>
</tr>
<tr>
<td>LPOUT</td>
<td>I</td>
<td>Logical unit to write</td>
</tr>
<tr>
<td>NOPIN2</td>
<td>RD</td>
<td>Array containing data member name of NOP input file</td>
</tr>
<tr>
<td>NP</td>
<td>I</td>
<td>Do loop index</td>
</tr>
<tr>
<td>NR</td>
<td>I</td>
<td>Number of radial points</td>
</tr>
<tr>
<td>NT</td>
<td>I</td>
<td>Do loop index</td>
</tr>
<tr>
<td>NWRDS</td>
<td>I</td>
<td>Number of words read in from data member record</td>
</tr>
<tr>
<td>P2</td>
<td>RD</td>
<td>Pressure averaged around azimuth</td>
</tr>
<tr>
<td>P22</td>
<td>RD</td>
<td>Previous P2 value</td>
</tr>
<tr>
<td>PH</td>
<td>RD</td>
<td>Angle of flight Mach number</td>
</tr>
<tr>
<td>RARRAY</td>
<td>RD</td>
<td>Array containing the real words from a data member record</td>
</tr>
<tr>
<td>RCP</td>
<td>RD</td>
<td>Radial point</td>
</tr>
<tr>
<td>RCP1</td>
<td>RD</td>
<td>Previous radial point</td>
</tr>
<tr>
<td>SUM</td>
<td>RD</td>
<td>Sum of pressure squared contributions to noise</td>
</tr>
<tr>
<td>TH</td>
<td>RD</td>
<td>Polar angle of observer</td>
</tr>
</tbody>
</table>

**OUTPUT**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>RD</td>
<td>Frequency of sound in multiples of blade passage harmonic</td>
</tr>
<tr>
<td>F1</td>
<td>RD</td>
<td>Frequency of sound in Hz</td>
</tr>
<tr>
<td>PSD</td>
<td>RD</td>
<td>Spectrum level in dB (per unit Hz)</td>
</tr>
<tr>
<td>NPL</td>
<td>RD</td>
<td>Summation counter</td>
</tr>
<tr>
<td>NML</td>
<td>RD</td>
<td>Summation counter</td>
</tr>
<tr>
<td>N</td>
<td>RD</td>
<td>Summation counter</td>
</tr>
</tbody>
</table>

**FUNCTIONS**

1. To call subprogram to read in input values
2. To call subprogram giving spectrum integrated over azimuth
3. To perform integration of spectrum over radius

**SUBPROGRAMS CALLED**

MMCLOS WMGETR WMOPRD NOPINP PX XFETCH XSTORE
CALLING PROGRAMS

ANOP EXEC

ERRORS

NON-FATAL
1. Error opening data member for input
FATAL
none

ENTRY

Print the input quantities for checking
Write the values of the deformation tensor
If beginning harmonic is negative, return to matrix input
If harmonic spacing is negative, return to previous input
If number of steps is negative, return to first input
Calculate frequency step size
Print headings for the eventual output
Initialize the frequency variable
Input of zero for L2 defaults to a single frequency step
DO 60 K=1,L2
  Increment frequency
  Initialize radius
  Initialize sum
  DO 22 I2=1,19
    Increment blade radial position
    Calculate tip Mach number at this radius
    Call subroutine giving azimuthally averaged spectrum at this radius
    Halve first value in trapezoidal integral over radius
    Add to integrated spectrum
  END DO
  Calculate PSD
  Calculate harmonic
  Write results
END DO

EXIT
ROUTINE - NOPINP

PURPOSE - To read in input variables and calculate the mean and turbulence properties for an atmospheric boundary layer

AUTHOR - J. C. Simonich

INPUT

USER PARAMETERS

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>RD</td>
<td>Speed of sound (m/s)</td>
</tr>
<tr>
<td>D</td>
<td>RD</td>
<td>Diameter of rotor (m)</td>
</tr>
<tr>
<td>C</td>
<td>RD</td>
<td>Blade chord (m)</td>
</tr>
<tr>
<td>BN</td>
<td>RD</td>
<td>Number of blades</td>
</tr>
<tr>
<td>FF</td>
<td>RD</td>
<td>Distance from rotor to observer (m)</td>
</tr>
<tr>
<td>RPS</td>
<td>RD</td>
<td>Rotational speed in rev/sec</td>
</tr>
<tr>
<td>NF</td>
<td>I</td>
<td>First harmonic</td>
</tr>
<tr>
<td>HL</td>
<td>I</td>
<td>Last harmonic</td>
</tr>
<tr>
<td>NUM</td>
<td>I</td>
<td>Number of frequency points</td>
</tr>
<tr>
<td>TMIN</td>
<td>RD</td>
<td>Minimum observer polar angle in degrees (theta=0 along rotor axis in thrust direction)</td>
</tr>
<tr>
<td>TMAX</td>
<td>RD</td>
<td>Maximum observer polar angle in degrees</td>
</tr>
<tr>
<td>DELT</td>
<td>RD</td>
<td>Desired increment in polar angle between successive calculations</td>
</tr>
<tr>
<td>PMIN</td>
<td>RD</td>
<td>Minimum observer azimuthal angle in degrees (phi=0 in direction of mean wind)</td>
</tr>
<tr>
<td>PMAX</td>
<td>RD</td>
<td>Maximum observer azimuthal angle in degrees</td>
</tr>
<tr>
<td>DELL</td>
<td>RD</td>
<td>Desired increment in azimuthal angle between successive calculations</td>
</tr>
</tbody>
</table>

DATA MEMBER ROTNOP(ABL0T1) - This is the output from the FM ABL

GWS, LWX, WUINF

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWS</td>
<td>RD</td>
<td>Geostrophic wind speed (m/s)</td>
</tr>
<tr>
<td>LWX</td>
<td>RD</td>
<td>Correlation length scale</td>
</tr>
<tr>
<td>WUINF</td>
<td>RD</td>
<td>Vertical component of the rms turbulence normalized by the velocity</td>
</tr>
</tbody>
</table>

DATA MEMBER ROTNOP(ROT0T1) - This is the output from the FM ROT

TITLE

MR, J, IH
R2, ALPHA, R
STRENG

If IH=0 (homogenous case) read in following:
T, U, V, W, X, Y, Z
XSL1, YSL1, ZSL1, XSL2, YSL2, ZSL2
USA, VSA, WSA

4
**LOCAL VARIABLES**

**Name**  
**Type**  
**Description**

**IARRAY**  
**I**  
Array to store a data member record

**IMHDR**  
**I**  
Array containing the length of the largest record and the number of records written

**II**  
**I**  
Do loop index

**ISTAT**  
**I**  
Status of calls to data member routines

**ITYPE**  
**I**  
Indicator of user parameter type

**JJ**  
**I**  
Do loop index

**LPOUT**  
**I**  
Logical unit to write
MEXIST I Indicator of existence of data member
NEL I Indicator of number of elements in user parameter
NOPIN1 RD Array containing data member name of ABL output file
NOPIN2 RD Array containing data member name of ROT output file
NWRDS I Number of words read in from data member record
PI RD 3.14159...
RARRAY RD Storage area for real variables being read in from data member record

OUTPUT

COMMON BLOCKS

NOPCA - see NOPMAN
NOPCB - see NOPMAN

FUNCTIONS
1. To input variables for NOP.
2. To input variables from FM ROT.
3. For homogenous case read in deformation tensor and calculate axial mach number, flow mach number and rms turbulence velocity.

SUBPROGRAMS CALLED
MNCLIOS, MNGETR, MNOPRD, MNVUM, NEUTRAL, STABLE, UNSTAB, XFETCH, XSTORE, XGETP, XASKP

CALLING SUBPROGRAM
NOPMAN

ERRORS
NON-FATAL
1. Error finding user parameter in table
2. Error in opening data member
3. Error reading in record from data member

FATAL
none

ENTRY
Input values from data member ROTNOP(NOPIN1)
If L > 0 call STABLE
If L < 0 call UNSTAB
If L = 0 call NEUTRAL
Calculate vertical component of the rms turbulence normalized by the stream velocity
Input data member ROTNOP(ROTOT1)
If IH=0 read in deformation tensor
EXIT
ROUTINE - NOPPX

PURPOSE - To take the cross product of column vectors N2 and N3 of E and place the result in column N1.

AUTHOR - Roy K. Amiet

INPUT

ARGUMENTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOPIN2</td>
<td>RD</td>
<td>Array containing data member name</td>
</tr>
<tr>
<td>F1</td>
<td>RD</td>
<td>Observer frequency</td>
</tr>
<tr>
<td>RCP</td>
<td>RD</td>
<td>Radial point</td>
</tr>
<tr>
<td>TH</td>
<td>RD</td>
<td>Polar angle of observer</td>
</tr>
<tr>
<td>PH</td>
<td>RD</td>
<td>Angle of flight Mach number</td>
</tr>
</tbody>
</table>

COMMON BLOCK

NOPCA

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL</td>
<td>RD</td>
<td>Chord/turbulence integral length scale</td>
</tr>
<tr>
<td>BN</td>
<td>RD</td>
<td>Blade number</td>
</tr>
<tr>
<td>COC</td>
<td>RD</td>
<td>Sound speed/chord</td>
</tr>
<tr>
<td>R1C</td>
<td>RD</td>
<td>Far-field distance/chord</td>
</tr>
<tr>
<td>RPS</td>
<td>RD</td>
<td>Revolutions/second</td>
</tr>
<tr>
<td>DXDZ</td>
<td>RD</td>
<td>Deformation tensor</td>
</tr>
<tr>
<td>ZH</td>
<td>RD</td>
<td>Axial Mach number</td>
</tr>
<tr>
<td>FM</td>
<td>RD</td>
<td>Flight Mach number in rotor plane</td>
</tr>
<tr>
<td>UU</td>
<td>RD</td>
<td>RMS turbulence velocity/axial velocity</td>
</tr>
</tbody>
</table>

COMMON BLOCK

NOPCB

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>I</td>
<td>Number of azimuthal integration points</td>
</tr>
<tr>
<td>IH</td>
<td>I</td>
<td>Specifies homogenous or inhomogenous calculation</td>
</tr>
</tbody>
</table>

OUTPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2</td>
<td>RD</td>
<td>Pressure averaged around azimuth</td>
</tr>
<tr>
<td>NP1</td>
<td>I</td>
<td>Counter for upward summation in NTITRB subroutine</td>
</tr>
<tr>
<td>NM1</td>
<td>I</td>
<td>Counter for downward summation in NTITRB</td>
</tr>
</tbody>
</table>
**subroutine**

**N** | **I** | Counter for rescaling of CVT in YITRB subroutine

**LOCAL VARIABLES**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM</td>
<td>RD</td>
<td>Local tip Mach number</td>
</tr>
<tr>
<td>AJ</td>
<td>RD</td>
<td>Float J</td>
</tr>
<tr>
<td>DEL</td>
<td>RD</td>
<td>Azimuthal step size</td>
</tr>
<tr>
<td>C</td>
<td>RD</td>
<td>Cosine theta</td>
</tr>
<tr>
<td>S</td>
<td>RD</td>
<td>Sine theta</td>
</tr>
<tr>
<td>CA</td>
<td>RD</td>
<td>Cosine psi</td>
</tr>
<tr>
<td>S4</td>
<td>RD</td>
<td>Sine psi</td>
</tr>
<tr>
<td>QM</td>
<td>RD</td>
<td>Expression in analysis</td>
</tr>
<tr>
<td>BFZ2</td>
<td>RD</td>
<td>Expression in analysis</td>
</tr>
<tr>
<td>SQ1</td>
<td>RD</td>
<td>Expression in analysis</td>
</tr>
<tr>
<td>RER</td>
<td>RD</td>
<td>Retarded radius/actual radius</td>
</tr>
<tr>
<td>SUM</td>
<td>RD</td>
<td>Sum of azimuthal spectral contributions</td>
</tr>
<tr>
<td>G</td>
<td>RD</td>
<td>Azimuthal angle gamma</td>
</tr>
<tr>
<td>I</td>
<td>I</td>
<td>DO loop counter</td>
</tr>
<tr>
<td>C2</td>
<td>RD</td>
<td>Cosine gamma</td>
</tr>
<tr>
<td>S2</td>
<td>RD</td>
<td>Sine gamma</td>
</tr>
<tr>
<td>C5</td>
<td>RD</td>
<td>Cosine (gamma + psi)</td>
</tr>
<tr>
<td>S5</td>
<td>RS</td>
<td>Sine (gamma + psi)</td>
</tr>
<tr>
<td>ALP</td>
<td>RD</td>
<td>Angle alpha</td>
</tr>
<tr>
<td>C1</td>
<td>RD</td>
<td>Cosine alpha</td>
</tr>
<tr>
<td>S1</td>
<td>RD</td>
<td>Sine alpha</td>
</tr>
<tr>
<td>RM</td>
<td>RD</td>
<td>Mach number component along chord</td>
</tr>
<tr>
<td>C3</td>
<td>RD</td>
<td>Cosine of angle phi in analysis</td>
</tr>
<tr>
<td>X</td>
<td>RD</td>
<td>Observer coordinate</td>
</tr>
<tr>
<td>Y</td>
<td>RD</td>
<td>Observer coordinate</td>
</tr>
<tr>
<td>Z</td>
<td>RD</td>
<td>Observer coordinate</td>
</tr>
<tr>
<td>SS</td>
<td>RD</td>
<td>Modified radius</td>
</tr>
<tr>
<td>FP</td>
<td>RD</td>
<td>Frequency measured on blade</td>
</tr>
<tr>
<td>XX</td>
<td>RD</td>
<td>Value of x wavenumber</td>
</tr>
<tr>
<td>YK</td>
<td>AD</td>
<td>Value of y wavenumber</td>
</tr>
<tr>
<td>T</td>
<td>RD</td>
<td>Blade passage time</td>
</tr>
<tr>
<td>T1</td>
<td>RD</td>
<td>Time between eddy chops</td>
</tr>
<tr>
<td>XX</td>
<td>RD</td>
<td>Specific value of x in analysis</td>
</tr>
<tr>
<td>YY</td>
<td>RD</td>
<td>Specific value of y in analysis</td>
</tr>
<tr>
<td>ZZ</td>
<td>RD</td>
<td>Specific value of z in analysis</td>
</tr>
<tr>
<td>T2</td>
<td>RD</td>
<td>Time T1 plus propagation time difference</td>
</tr>
<tr>
<td>CVT</td>
<td>AD</td>
<td>Step size for summation over wavenumber</td>
</tr>
<tr>
<td>ZK0</td>
<td>RD</td>
<td>Initial value of wavenumber in summation</td>
</tr>
<tr>
<td>AD</td>
<td>RD</td>
<td>Contribution to sum of particular azimuthal station</td>
</tr>
</tbody>
</table>

**SUBPROGRAMS CALLED**

NOPNI  NOPLFT

**CALLING PROGRAMS**

NOPMAN

**ERRORS**
NON-FATAL
  1. Error reading in data member record
FATAL
  none

ENTRY
Calculate TM, the local tip Mach number
Float J
Calculate DEL, the azimuthal step size
C, S and C4, S4, are the cosine and sine of theta and psi
  respectively
Q is a factor appearing in the analysis
BFZ2 is a Prandtl-Glauert factor
SQL is a factor appearing in the analysis
RER is the observer retarded distance/actual distance
Initialize Wp1,...,G
DO 50 I=1,J    Integration over azimuthal angle gamma
  Increment gamma
  Find cosine and sine of gamma and gamma + psi respectively
  Calculate ALP, the angle of the rotor blade wrt the rotor plane
  Calculate C1 and S1, the cosine and sine of alpha
  Calculate RM, the Mach number of rotor segment wrt to fluid
  Calculate C3, the cosine of an angle in the analysis
  Calculate observer coordinates in rotor fixed coordinates
  Calculate sigma, a modified observer distance
  Calculate FP, the frequency on the blade
  Calculate XX and YY, the x and y wavenumbers
  Calculate T1, the time between blade passes
  Calculate C1, the time between eddy intersections
  Calculate XX, YY, ZZ which are X, Y, Z values
  Calculate CVT which is 2*Pi/eddy passing distance Z
  Calculate ZKO, the initial radian frequency in the summation
  Call turbulence summation subroutine
  Call airfoil response subroutine
  Increment counters
  Contribution to spectrum from azimuthal integration
  Summation over azimuthal spectrum
  End DO
  Multiply by remaining factors
EXIT
** ROUTINE - NOPCRS 

PURPOSE - To take the cross product of column vectors N2 and N3 of E and place the result in column N1.

AUTHOR - Roy K. Amiet

** INPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>RD</td>
<td>3x3 rotation matrix.</td>
</tr>
<tr>
<td>N1</td>
<td>I</td>
<td>Column into which the cross product is to be placed.</td>
</tr>
</tbody>
</table>

** OUTPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>RD</td>
<td>Unit vectors along coordinates</td>
</tr>
</tbody>
</table>

** LOCAL VARIABLES

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>N2, N3</td>
<td>I</td>
<td>Column vectors for which the cross product is found.</td>
</tr>
<tr>
<td>ELM</td>
<td>RD</td>
<td>Normalizes the output to a magnitude of 1.</td>
</tr>
</tbody>
</table>

** SUBPROGRAMS CALLED

None

** CALLING PROGRAMS

NOPKVC

** ERRORS

None

ENTRY

Calculate N2 and N3 so that N1, N2, N3 are in cyclic permutation.
Calculate cross product of column vectors N2 and N3; place result column N1.
Find the magnitude of vector N1.
Normalize vector N1.

** EXIT
ROUTINE - NOPKVC

PURPOSE - To calculate effect of rapid distortion on turbulence spectrum.

AUTHOR - Roy K. Amiet

INPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DK</td>
<td>RD</td>
<td>Wavevector</td>
</tr>
<tr>
<td>DXDZ</td>
<td>RD</td>
<td>Deformation tensor</td>
</tr>
<tr>
<td>VN</td>
<td>RD</td>
<td>Unit vector normal to blade</td>
</tr>
</tbody>
</table>

OUTPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ED</td>
<td>RD</td>
<td>Three coordinate vectors downstream of contraction.</td>
</tr>
<tr>
<td>EU</td>
<td>RD</td>
<td>Three coordinate vectors upstream of contraction.</td>
</tr>
<tr>
<td>DM</td>
<td>RD</td>
<td>Magnitude of downstream wavevector.</td>
</tr>
<tr>
<td>DKUK</td>
<td>RD</td>
<td>Ratio of downstream to upstream wavevectors.</td>
</tr>
<tr>
<td>UQDQ</td>
<td>RD</td>
<td>Ratio of upstream to downstream turbulent velocities.</td>
</tr>
</tbody>
</table>

LOCAL VARIABLES

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>F(I)</td>
<td>RD</td>
<td>For temporary storage of EU(I,3).</td>
</tr>
<tr>
<td>AF1</td>
<td>RD</td>
<td>Magnitude of wavevector, to be used for normalization.</td>
</tr>
</tbody>
</table>

FUNCTIONS

1. To calculate the effect of rapid distortion on the wavevector and Fourier component amplitude

SUBPROGRAMS CALLED

NOPCRS

CALLING PROGRAMS

NOPWH

ERRORS

NONE

ENTRY

Find magnitude of wavevector.
\* DO I = 1,3
    \* Set third column of ED equal to wavevector direction.
    \* Set second column of ED equal to blade normal.
    END DO
\* Find cross product of first two vectors
\* Find cross product of previous result with third vector of ED.
\* DO I=1,3
    \* DO J=1,3
        \* Initialize EU
        \* DO K=1,3
            \* Take product of ED with deformation matrix to find EU.
            \* END DO
        \* END DO
    \* END DO
\* Store third column of EU in F.
\* Find the magnitude of first column of EU.
\* Normalize the first column of EU
\* Find the cross-product of columns 1 and 2 of EU.
\* Find cross-product of previous result with third vector of EU.
\* Calculate ratio of downstream to upstream wavevector magnitude.
\* Calculate ratio of upstream to downstream turbulent velocities.
\* EXIT

***
ROUTINE - NOPFNRL

PURPOSE - To calculate the Fresnel integrals C and S. Ref. Abromowitz and Stegun, p 302.

AUTHOR - Roy K. Amiet

INPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>RD</td>
<td>Fresnel integral argument</td>
</tr>
</tbody>
</table>

OUTPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>C</td>
<td>Fresnel integrals in form C - iS</td>
</tr>
</tbody>
</table>

LOCAL VARIABLES

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>C</td>
<td>Intermediate variables from Abromowitz and Stegun.</td>
</tr>
<tr>
<td>H</td>
<td>C</td>
<td>To rotate G in complex plane.</td>
</tr>
</tbody>
</table>

FUNCTIONS

1. To calculate a value for the Fresnel integrals

SUBPROGRAMS CALLED

None

CALLING PROGRAMS

NOPLFT

ERRORS

NONE

ENTRY

Calculate G from Abromowitz and Stegun equations p 302.
Calculate H.
Calculate E = C - iS following Abromowitz and Stegun.

EXIT
ROUTINE - NOLIFT

PURPOSE - To calculate the airfoil gust response function.

AUTHOR - Roy K. Amiet

INPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>RD</td>
<td>Chordwise distance</td>
</tr>
<tr>
<td>SG</td>
<td>RD</td>
<td>Far-field distance modified by Prandtl-Glauert factor</td>
</tr>
<tr>
<td>RM</td>
<td>RD</td>
<td>Chordwise Mach number component</td>
</tr>
<tr>
<td>XX</td>
<td>RD</td>
<td>Chordwise wavenumber</td>
</tr>
<tr>
<td>YK</td>
<td>RD</td>
<td>Spanwise wavenumber</td>
</tr>
</tbody>
</table>

OUTPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GL2</td>
<td>RD</td>
<td>Square of effective lift, including noncompactness</td>
</tr>
</tbody>
</table>

LOCAL VARIABLES

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2</td>
<td>RD</td>
<td>Column vectors for which the cross product is found.</td>
</tr>
<tr>
<td>UM</td>
<td>RD</td>
<td>Normalizes the output to a magnitude of 1.</td>
</tr>
<tr>
<td>RMI</td>
<td>RD</td>
<td>Similarity Mach number for skewed gusts</td>
</tr>
<tr>
<td>UMI</td>
<td>RD</td>
<td>Specifies use of low or high frequency solution.</td>
</tr>
<tr>
<td>T2</td>
<td>RD</td>
<td>Intermediate dummy variable.</td>
</tr>
<tr>
<td>CM</td>
<td>RD</td>
<td>Magnitude of E.</td>
</tr>
<tr>
<td>E</td>
<td>RD</td>
<td>Complex representation of Fresnel integrals; C - iS</td>
</tr>
</tbody>
</table>

FUNCTIONS

1. To calculate the airfoil response function for given values of the wavenumbers

SUBPROGRAMS CALLED

NOPFML

CALLING PROGRAMS

NOPPX

ENTRY

UM is proportional to airfoil chord/acoustic wavelength.
RMI is Graham's similarity Mach number for skewed gusts.
UMI used in following line for branching test.

Case of (UMI -.75) NEG, ZERO, POS

NEG: Use modified Sears function
ZERO: Use modified Sears function
POS: Use high reduced frequency solution
Call Fresnel integrals
Find absolute value
Calculate square of effective lift

End case.

EXIT

***
ROUTINE - NORMT

PURPOSE - To take the cross product of column vectors N2 and N3 of E and place the result in column N1

AUTHOR - Roy K. Amiet

INPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL</td>
<td>RD</td>
<td>Chord/turbulence integral length scale</td>
</tr>
<tr>
<td>CVT</td>
<td>RD</td>
<td>Step size for summation over wavenumber</td>
</tr>
<tr>
<td>X</td>
<td>RD</td>
<td>X wavenumber component</td>
</tr>
<tr>
<td>Y</td>
<td>RD</td>
<td>Y wavenumber component</td>
</tr>
<tr>
<td>Z</td>
<td>RD</td>
<td>Z wavenumber component</td>
</tr>
<tr>
<td>ALP</td>
<td>RD</td>
<td>Angle alpha</td>
</tr>
<tr>
<td>G</td>
<td>RD</td>
<td>Gamma</td>
</tr>
<tr>
<td>DXDZ</td>
<td>RD</td>
<td>Deformation tensor; 9 components</td>
</tr>
</tbody>
</table>

OUTPUT

ARGUMENT

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVV</td>
<td>RD</td>
<td>Pressure averaged around azimuth</td>
</tr>
<tr>
<td>NP</td>
<td>I</td>
<td>Counter for upward summation in NTITRB subroutine</td>
</tr>
<tr>
<td>NM</td>
<td>I</td>
<td>Counter for downward summation in NTITRB subroutine</td>
</tr>
<tr>
<td>N</td>
<td>I</td>
<td>Counter for rescaling of CVT in NTITRB subroutine</td>
</tr>
</tbody>
</table>

LOCAL VARIABLES

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EK</td>
<td>RD</td>
<td>Constant in Karman spectrum</td>
</tr>
<tr>
<td>DK</td>
<td>RD</td>
<td>Wavevector; 3 components</td>
</tr>
<tr>
<td>C1</td>
<td>RD</td>
<td>Cosine alpha</td>
</tr>
<tr>
<td>S1</td>
<td>RD</td>
<td>Sine alpha</td>
</tr>
<tr>
<td>C2</td>
<td>RD</td>
<td>Cosine gamma</td>
</tr>
<tr>
<td>S2</td>
<td>RD</td>
<td>Sine gamma</td>
</tr>
<tr>
<td>VM</td>
<td>RD</td>
<td>Normal to blade</td>
</tr>
<tr>
<td>RCT</td>
<td>RD</td>
<td>Expression in analysis</td>
</tr>
<tr>
<td>DXDZR1</td>
<td>RD</td>
<td>Intermediate deformation matrix</td>
</tr>
<tr>
<td>DXDZR</td>
<td>RD</td>
<td>Final deformation matrix after rotation</td>
</tr>
<tr>
<td>CVT1</td>
<td>RD</td>
<td>Dummy for CVT</td>
</tr>
<tr>
<td>ED</td>
<td>RD</td>
<td>Downstream unit vectors parallel to axes</td>
</tr>
<tr>
<td>EU</td>
<td>RD</td>
<td>Upstream unit vectors parallel to axes</td>
</tr>
<tr>
<td>DKM</td>
<td>RD</td>
<td>Wavevector amplitude downstream at rotor face</td>
</tr>
<tr>
<td>DKUK</td>
<td>RD</td>
<td>Ratio of downstream to upstream wavevector amplitudes</td>
</tr>
</tbody>
</table>
UQDQ  RD  Ratio of upstream to downstream velocity amplitudes
XXUO  RD  Upstream x value of wavevector; initial value
YKUO  RD  Upstream y value of wavevector; initial value
XYO   RD  Expression in Karman spectrum; initial value
DKX1  RD  Wavevector amplitude downstream at rotor face
DKUK1 RD  Ratio of downstream to upstream wavevector amplitudes
UQDQ1 RD  Ratio of upstream to downstream velocity amplitudes
XXU  RD  Upstream x value of wavevector
YKU  RD  Upstream y value of wavevector
ZKU  RD  Upstream z value of wavevector
XY   RD  Expression in Karman spectrum
DN   RD  Denominator in Karman spectrum
DELI  RD  Temporary variable for testing end of iteration
AN   RD  Float N
ZK1  RD  Value of x wavenumber
ZK2  RD  Value of y wavenumber

SUBPROGRAMS CALLED
NOPKVC

CALLING PROGRAM
NOPPX

ERRORS
NONE

ENTRY
Calculate k0 which equals 0.71468342/L equals 0.373417(c/L)/b;
Define wavevector in airfoil fixed coordinate system; x along chord, y along span, and z along normal.
Sine and cosine of angles alpha and gamma.
Calculate normal to airfoil in same coordinate system as for DK.
Calculate rotation matrix. The first three components give the chord direction, the second three give the spanwise direction and the third three give the normal direction.

DO 50 I=1,3
DO 30 J=1,3
  Initialize DXDZRL
  DO 90 K=1,3
    Calculate DXDZRL
  END DO
END DO

DO 70 I=1,3
DO 60 J=1,3
  Initialize DXDZR
  DO 91 K=1,3
    Calculate DXDZR
  END DO
END DO

Introduce dummy for CVT
Call deformation program YOPKVC
Calculate denominator for upstream turbulence with $k_z = 0$.
This will be used for comparison later in program.
Make CVT as large as possible without losing accuracy. Increase
by factors of two and test size of DEL1.
Initialize sum variable, SVV.
Begin summation with minimum but still positive value of $ZK$ after
subtracting integer number of CVT values.
Initialize counters NP and NM for number of steps up and down in $k_z$.
Sum over increasing values of $ZK$.
  Increment upward summation counter
  Set third wavevector component
  Call deformation program YOPKVC
  Calculate upstream values of three wavevector components
  Calculate $XY$, an intermediate variable
  Calculate $DN$, the denominator of the Karman spectrum
  Add to summation, SVV
  Check for excessive summations
  Increment $z$ wavevector component
  Check to see how large the denominator has become.
End upward summation
Sum over decreasing values of $ZK$.
  Increment downward summation counter
  Decrement $z$ wavevector component
  Set third wavevector component
  Call deformation program YOPKVC
  Calculate upstream values of three wavevector components
  Calculate $XY$, an intermediate variable
  Calculate $DN$, the denominator of the Karman spectrum
  Add to summation, SVV
  Check for excessive summations
  Check to see how large the denominator has become.
End downward summation
Multiply SVV by remaining factors
EXIT
Appendix A: Computer Program for Noise Produced by Rotor-Turbulence Interaction

A computer program implementing the algorithm discussed in the Theory Manual for Noise Calculation is given in the Computer Listings to follow. Computer Listing 1 is the main executive portion of the program; it prompts for inputs and prints the output. It also performs the integration over the rotor span.

The inputs to the program, including the symbols used in the program, are:

- $c/L = \text{chord/turbulence length scale}$
- $BN = \text{Blade number}$
- $C0C = \frac{c_0}{c} = \text{sound speed/chord}$
- $RC = \text{Blade radius/chord}$
- $R1C = \frac{r}{c} = \text{far-field distance/chord}$
- $RPS = \text{Revolutions/sec}$
- $ZM = M_z = \text{axial Mach number}$
- $FM = \text{Flow Mach number in rotor plane}$
- $UU = \sqrt{\frac{u^2}{V_z}}$
- $TH = \theta = \text{observer angle wrt z axis; observer in x,y plane}$
- $SUMS = \text{Number of terms in azimuthal summation; N in equation (B3)}$
- $PSI = \psi = \text{angle of } M_f \text{ wrt z axis; } M_f \text{ is positive inward as in figure 1}$
- $DH = \text{Frequency step size in fractions of a harmonic}$
- $AL1 = \text{Initial harmonic number}$
- $L2 = \text{Number of frequency steps}$

The numerical constant 203.95 occurring in the expression for PSD is obtained by introducing equation (82) into equation (63) and multiplying by the blade number. This gives

\[ S_{pp}(\omega_0, x) = \frac{B}{2\pi} \int_0^{2\pi} \left( \frac{\omega}{\omega_0} \right)^2 \left( \frac{\omega z p_d b}{c_0 \sigma_z^2} \right)^2 \pi U_b d |l|^2 b^2 F \, d\gamma \]  

where

\[ F = \frac{2\pi}{b^2 u^2 l^2} \sum_{n=-\infty}^{\infty} \Phi_{ww}(K_x, K_y, K_z(n)) \]

Atmospheric pressure $P_0 = 10^{+6}/0.987 \text{ dynes/cm}^2$ and reference pressure $P_r = 0.0002 \text{ dynes/cm}^2$. $S_{pp}$ must be multiplied by $4\pi$ to convert from a two sided $-\infty < \omega < \infty$ to a one sided $0 < \omega < \infty$ spectrum and to convert to a unit Hertz rather than a unit radian frequency of measurement. Using the relations

\[ \bar{K}_x = \omega b / U_b \quad c_0^2 = \gamma P_0 / \rho_0 \]

this can be written (where $\gamma = 2\pi n/N$)
\[ G_{pp}(f_0)/Pr^2 = \frac{1}{2} \left( \frac{\gamma \pi \rho a}{Pr} \right)^2 \left\{ C B \frac{S}{c} \frac{u^2}{V_z^2} M \frac{\omega^2}{C_0 \omega} \sum_{n=1}^{N} M^3 \left( \frac{2 \pi c \omega}{\sigma_z \omega} \right)^2 (bK_x)^2 \right\} \]  

(A3)

Converting to dB,

\[ 10 \log_{10} \left[ \frac{1}{2} \left( \frac{\gamma \pi \rho a}{Pr} \right)^2 \right] = 203.95 \]  

(A4)

The outputs of the program are:

- **H**  
  Frequency of sound expressed in multiple of blade passage harmonic

- **F1**  
  Frequency of sound in Hz

- **PSD**  
  Spectrum level in dB (per unit Hz)

- **NP1,NM1,N**  
  Counters for certain of the summations for use in diagnosis of output

The programs in the following appendices are standard Fortran code with added line numbers for reference in the documentation. This allows more detailed comments to be used without deleteriously affecting the ability to easily read the code.

The program listing here is for an homogenous turbulence in the rotor plane. This can be easily extended to the nonisotropic case by inputting the deformation tensor at each point of the rotor plane rather than just once. The turbulence spectrum at each point of the rotor plane is then calculated from a rapid contraction of an isotropic turbulence using this deformation tensor. The changes to the main program and one subroutine for this generalization to the nonhomogeneous case are listed below.

Changes to main program:

<table>
<thead>
<tr>
<th>Line #</th>
<th>Code</th>
</tr>
</thead>
</table>
| 12     | 1 'RADIUS/C, FAR-FIELD/C, RPS, IH'(/
| 24     | IF (IH .EQ. 0) READ(1,*) ((DXDZ(I,J), I=1,3), J=1,3) |
| 25     | IF (IH .EQ. 0) WRITE(*,200) ((DXDZ(I,J), J=1,3), I=1,3) |
| 26     | IF (IH .EQ. 0) WRITE(2,200) ((DXDZ(I,J), J=1,3), I=1,3) |
| 28     | IF (IH .EQ. 0) CLOSE(1) |
| 59     | 1 P2,NP1,NM1,N,IH) |

In the subroutine SPX, change the first line of the subroutine to accept the new variable IH and add the following line between lines 46 and 47:

```fortran
SUBROUTINE PX(F1,ZM,CL,BN,C0,C,RC,R1C,RPS,FM,TH,J,PSI,DXDZ,
46a    IF (IH .EQ. 1) READ(1,*) ((DXDZ(I,J), J=1,3), I=1,3)
```

In the above code the parameter IH is an input designating whether a homogeneous or inhomogeneous calculation should be performed. If IH = 0 is input, homogeneous turbulence is assumed. If IH = 1 is input, inhomogeneous turbulence is assumed, and the above read and write statements are deferred to the subroutine SPX.

1 DIMENSION DXDZ(3,3)
2 CHARACTER*10 FNAME
3 CHARACTER*10 NAME1
4 WRITE(*,500)
5 500 FORMAT(' Turbulence ingestion program with integration over',' span') and nonisotropic turbulence. R. K. Amiet 12/84/
6 WRITE(*,'(A)') ' OUTPUT FILE NAME -'
7 READ(*,'(A)') FNAME
8 OPEN(2,FILE=FNAME1,STATUS='NEW')
9 WRITE(*,100)
10 100 FORMAT(' INPUT C/L, BLADE NO., C0/C,',' RADIUS/C, FAR-FIELD/C, RPS')/
11 READ(*,*) CL, BN, C0C, RC, RIC, RPS
12 TM1 = 2.*3.141593*RPS*RC/C0C
13 WRITE(*,'(3F10.3)') TM1, CL, BN, C0C, RC, RIC, RPS
14 WRITE(2,300) TM1, CL, BN, C0C, RC, RIC, RPS
15 300 FORMAT(' INPUT M/TIP = ',F4.3,'
16 ',CHORD/TURB SCALE = ',F7.4/,'
17 ',BLADE NO. = ',F4.0,'
18 ',SOUND SPEED/CHORD = ',F7.1/
19 ',RADIUS/CHORD = ',F5.1,'
20 ',FAR-FIELD/CHORD = ','
21 F6.1/' REV/SEC = ',F5.1/)
22 WRITE(*,'(A)') ' INPUT FILE NAME -'
23 READ(*,'(A)') FNAME
24 OPEN(1,FILE=FNAME,STATUS='OLD')
25 READ(1,*) ((DXDZ(I,J), I=1,3), J=1,3)
26 WRITE(*,'(3F5.3)') ((DXDZ(I,J), J=1,3), I=1,3)
27 200 FORMAT(1X,3F5.2)
28 CLOSE(1)
29 WRITE(*,400)
30 400 FORMAT(' INPUT MZ, FM, UU, THETA, SUMS, PHI')/
31 READ(*,*) ZM, FM, UU, TH, J, PH
32 WRITE(*,900) ZM, UU, TH, FM, J, PH
33 WRITE(2,900) ZM, UU, TH, FM, J, PH
34 900 FORMAT(' MZ = ',F4.3,'
35 ',UU = ',F6.3,'
36 ',THETA = ',F5.0/
37 ',MF = ',F4.3,'
38 ',SUMS = ',I4,'
39 ',PSI = ',F5.1/)
40 WRITE(*,700)
41 700 FORMAT(' INPUT /
42 ',BEGINNING HARMONIC: If < 0, go to matrix input./
43 ',FRACTIONAL HARMONIC SPACING: If < 0, go to previous input./
44 ',NUMBER STEPS: If < 0, go to first input./)
45 READ(*,*) AL1, DH, L2
46 IF (AL1 .LT. 0.) GO TO 10
47 IF (DH .LT. 0.) GO TO 20
48 IF (L2 .LT. 0) GO TO 30
49 DF = RPS*BN*DH
50 WRITE(*,800)
51 WRITE(2,800)
52 800 FORMAT(2X,'HRMNC',SX,'FREQ',6X,'PSD',4X,'SM P',IX,'SM M')/
53 F1 = (AL1/DH-1.0)*DF
54 IF (L2 .EQ. 0) L2=1

Computer Listing 1: Executive program for turbulence ingestion.
DO 60 K=1,L2
52 F1 = F1 + DF
53 RCP = RCP*1.05
54 SUM = 0.
55 DO 22 I2=0,19
56 RCP = RCP - .05*RC
57 TM = TM1*RCP/RC
58 CALL PX(F1,ZM,CL,BN,C0C,UU,RCP,R1C,RPS,FM,TH,J,PH,DXDZ,
59 1     P2,NP1,NM1,N)
60 IF (12 .EQ. 0) P2 = P2/2.
61 SUM = SUM + P2
62 22 CONTINUE
63 PSD = 10.*ALOG10(SUM*RC*.05)
64 H = F1/(RPS*BN)
65 WRITE(*,600) H, F1, PSD, NP1, NM1, N
66 WRITE(2,600) H, F1, PSD, NP1, NM1, N
67 600 FORMAT(1X,F6.1,1X,F8.1,1X,F9.2,1X,I5,216)
68 60 CONTINUE
69 GO TO 70
70 END

Line #  Comment
7-9 Prompt for a filename into which to write the calculated results
10-13 Prompts for inputs
14 Calculation of tip Mach number
15-20 Prints the input quantities for checking
21-23 Prompt for input containing the deformation tensor values
24-28 Read and write the values for the deformation tensor
29-35 Prompt for more input parameters; writes out values to file
36-44 Prompt for final input values; if any are negative the program returns to one of the
previous input prompts
45 DF = frequency step size
46-48 Prints headings for the eventual printout
49 Initialize the frequency variable
50 Input of zero for L2 gives one iteration with this line
51-69 Stepping through frequency range
52 Increment frequency variable
53-54 Initialize radius and summation variables
55-63 Integration over radius
56 RCP = local radius
57 TM = Mt local tip Mach number
58-59 Call routine for summation over γ
60 Divide the first term in the summation by 2; the last term also should halved, but since it
approaches zero, it needn’t be explicitly set to zero.
61 Perform radial summation
63 Introduce remaining factors in equation (69)
64 Calculate harmonic number
65-67 Write outputs

Computer Listing 1: Executive program for turbulence ingestion.
Appendix B: Subroutine Calculating the Main Problem Parameters and Integrating over Azimuth

This subroutine is called by the main turbulence ingestion program in Appendix A. It calculates geometry and integrates over azimuthal angle. The inputs to the subroutine are:

F1 Observer frequency
ZM Axial Mach number; see figure 1
CL Chord/turbulence integral length scale
BN Blade number
COC Sound speed/chord
UU RMS turbulence intensity/axial velocity
RC Local blade radius/chord
R1C Far-field distance/chord
RPS Revolutions per second
FM Flight Mach number in rotor plane; see figure 1
TH Polar angle of observer; see figure 1
J Number of azimuthal integration points
PSI Angle of flight Mach number with the y axis; see figure 1
DZDX Deformation tensor

The outputs are:

P2 Sound level from a radial blade segment
NP1,NM1,N Counters used in the summations; used for diagnostic purposes

The program calls the subroutines TRBN1 and LEFF, the turbulence and the airfoil response calculations. The subroutine performs the azimuthal integration over $\theta$ in Eq. (63).
Subroutine SPX

Program written by R. K. Amiet.

SUBROUTINE PX(F1,ZM,CL,BN,C0C,UU,RC,R1C,PBS,FM,TH,J,PSI,DXDZ,
P2,NP1,NM1,N)
DIMENSION DXDZ(3,3)
PI = 3.14159
TM = 2.*PI*PBS*RC/C0C
AJ = J
DEL = 360./AJ
C = COS(TH/57.2958)
S = SIN(TH/57.2958)
C4 = COS(PSI/57.2958)
S4 = SIN(PSI/57.2958)
QM = FM*S+S4+ZM+C
SQ1 = SQRT(QM**2+BFZ2
RER = (SQ1+QM)/BFZ2
NP1 = 0
NM1 = 0
SUM = 0.
G = 90. - DEL
DO 50 I=1,J
G = G + DEL
C2 = COS(G/57.2958)
S2 = SIN(G/57.2958)
C5 = COS((G+PSI)/57.2958)
S5 = SIN((G+PSI)/57.2958)
ALP = 57.2958+ATAN2(ZM,TM+FM+C5)
C1 = COS(ALP/57.2958)
S1 = SIN(ALP/57.2958)
RM = SQRT(ZM**2 + (TM + FM*C5)**2)
C3 = C*S1 - S*C1*S2
X = R1C*(TM*PBS*C1 - C3)
Y = R1C*(S*C2 + FM*PBS*S5)
Z = R1C*(C*C1 + S*S1*S2 + TM*PBS*S1)
SG = SQRT(X**2*(1.-RM**2)*(Y**2+Z**2))
FP = F1*(1.+TM*(S2*S-FM*PBS*C5)/SQ1)
XK = PI*FP/(C0C*RM)
YK = PI*FP*Y/(SG*C0C)
T = 2.*PI*RC/(TM*C0C*BN)
T1 = T*TM*S1/C1/ZM

Computer Listing 2: Subroutine for calculating principle parameters in problem
CALL LFT(X, SG, RM, XK, YK, GL2)

NP1 = NP1 + NP
NM1 = NM1 + NM
AD = GL2*SVV*RM*(RM*Z*FP*XK/(F1*SG**2))**2
SUM = SUM + AD
50 CONTINUE
P2 = 2.48E20*SUM*BN*(UU*ZM)**2/(C0C*AJ)
RETURN
END

Line # Comment
1-2 Inputs
5 TM = Mt = local tip Mach number
6 Float J
7 DEL = azimuthal step size
8-11 C, S and C4, S4 = cosine and sine of θ and ψ respectively
12 QM = M_s cos θ; Eq. (43)
13 BFZ2 = 1 - M_s^2; Eq. (43)
14 SO1 = (1 - M_s^2 sin^2 θ)^1/2
15 RER = r_e/r; Eq. (42)
16-19 Initialize variables
20-53 Integration over azimuthal angle γ
21 Increment γ
22-25 C2, S2 and C5, S5 = cosine and sine of γ and γ + ψ respectively
26 ALP = α; Eq. (34)
27-28 C1, S1 = cosine and sine of α
29 RM = M_b; Eq. (36)
30 C3 = cos θ; Eq. (49)
31-33 X, Y, Z = x_s, y_s, z_s; Eq. (48)
34 SG = σ
35 FP = frequency on blade; Eq. (55)
36-37 XK, YK = specific wavenumbers Ū, Ūy; Eqs. (9), (14)
38 T = time between blade passes
39-40 T1 = time between eddy intersections; Eq. (62) for line 39. Equation (62) is not appropriate for eddies stretched in axial direction; for this case the diagonal distance in figure 3 is not appropriate; given here is the result for an eddy of infinite axial length corresponding to the limit M_2 → 0; Eq. (62).
41-43 XX, YY, ZZ = X, Y, Z in Eqs. (62), (64)
44 CVT = 2π/Z = step size in Eq. (70)
45 ZK0 = ω_0 T_2/Z = initial radian frequency in Eq. (70)
46 T2 = T_2; Eq. (65)
47 Call turbulence summation subroutine
48 Call airfoil response subroutine
49-50 Increment counters
51 Contribution to spectrum from azimuthal integration; Eqs. (50) and (69)
52 Summation over azimuthal spectrum
54 Multiplication by remaining factors in Eq. (69)

Computer Listing 2: Subroutine for calculating principle parameters in problem
Appendix C: Subroutine for Summing over the Turbulence Spectrum for Blade to Blade Correlation

This subroutine calculates the summation in Eq. (69) over the turbulence spectrum. The output SVV of this program is

\[ SVV = \frac{2\pi}{b^2 u^2 Z} \sum_{n=-\infty}^{\infty} \phi_{ww} (\lambda, K_y, K_z^{(n)}) \]  

(E1)

The inputs to the program and the equivalent symbols used in the report are:

- \( CL = c/L \)
- \( XK = K_x \)
- \( ZK0 = \omega_0 T_z/Z \)
- \( CVT = 2\pi b/Z \)
- \( YK = K_y \)
- \( DXDZ(I,J) = \partial x_i / \partial \xi_j \) (\( x_i = \) precontraction coordinate; \( \xi_j = \) post contraction coordinate)
- \( ZK1, ZK2 \) represent \( K_z^{(n)}/k_e \). \( ZK1 \) is used for increasing values of \( n \) and \( ZK2 \) for decreasing values.

Other parameters in the program are: \( EK = k_e b \) where \( k_e \) is given in Eq. (32). CVT is the step size in the summation. Since the spectrum is written in a form with the wavenumbers \( k_x \) and \( k_y \) normalized by \( k_e \), CVT must also be so normalized. Note that this changes CVT in the main program, but this is of no concern since CVT is used only in this subroutine.

The summation over \( n \) is over the range \( \pm \infty \). In numerically carrying out this summation it is easiest to begin where the individual terms are maximum and sum to either side of this point until the terms become negligible. Thus, the integer \( N \) is the optimum value of \( n \) at which to begin the summation. The optimum value would be \( n = 0 \) except for the offset \( \omega_0 T_z/Z \) occurring in \( K_z^{(n)} \) (see Eq. (69)).

If the step size CVT is too small, very many terms in the summation would be required. For this case, the summation can be replaced by an integral. For the case of an isotropic turbulence the integral can be carried out in closed form as in Eq. (31).

The parameters \( ZK1 \) and \( ZK2 \) represent \( K_z^{(n)}/k_e \). \( ZK1 \) is used for increasing values of \( n \) and \( ZK2 \) for decreasing values.

The integers \( NP \) and \( NM \) count the number of summation steps in the upward and downward directions respectively. If either goes over 100 the summation is terminated, although this case has never been encountered. If the output specifies that \( NP \) or \( NM \) reached the value of 100, further checking should be done to ensure that a sufficient number of steps were taken. Generally the summation is terminated when the term \( DN \) (denoting the denominator in Eq. (32)) becomes greater than 200 times the initial value of the denominator.

Finally, the coefficient \( 0.11561 = 55 \sqrt{15/6} / (9\sqrt{\pi} \Gamma(1/3)) 4\pi \). The factor \( 4\pi \) comes from Eq. (30) and the remaining factors come from the expression for \( I \).
**EDDYNI.FTN; Summation over turbulence spectrum.**

Written by R. K. Amiet; final version 1985

**SUBROUTINE TRBNI(CL,CVT,XK,YK,ZK,ALP,G,DXOZ,SVV,NP,NM,N)**

**DIMENSION EU(3,3), ED(3,3), VN(3), DK(3), DXDZ(3,3),**

**DXDZR(3,3), ROT(3,3), DXDZR1(3,3)**

1. EK = .373417*CL
2. DK(1) = XK
3. DK(2) = YK
4. DK(3) = 0.
5. C1 = COS(ALP/57.2958)
6. S1 = SIN(ALP/57.2958)
7. C2 = COS(G/57.2958)
8. S2 = SIN(G/57.2958)
9. VN(1) = 0.
10. VN(2) = 0.
11. VN(3) = 1.
12. ROT(1,1) = C1*S2
13. ROT(2,1) = C2
14. ROT(3,1) = S1*S2
15. ROT(1,2) = -C1*C2
16. ROT(2,2) = S2
17. ROT(3,2) = -S1*C2
18. ROT(1,3) = -S1
19. ROT(2,3) = 0.
20. ROT(3,3) = C1
21. DO 50 I=1,3
22. DO 30 J=1,3
23. DXDZR1(I,J) = 0.
24. DO 98 K=1,3
25. DXDZ(I,K)*ROT(J,K) + DXDZR1(I,J)
26. CONTINUE
27. CONTINUE
28. CONTINUE
29. DXDZR1(I,J) = DXDZ(I,K)*ROT(I,K) + DXDZ(I,J)
30. CONTINUE
31. CONTINUE
32. DO 70 I=1,3
33. DO 60 J=1,3
34. DXDZR1(I,J) = 0.
35. DO 91 K=1,3
36. DXDZR1(I,J) = DXDZ1(K,J)*ROT(I,K) + DXDZ1(I,J)
37. CONTINUE
38. CONTINUE
39. CONTINUE
40. CVT1 = CVT
41. CALL KVEC(DK,DXDZ,VM,ED,EK,DKM,DKUK,UQDQ)
42. XKU0 = EU(1,3)*DKM/OKUK
43. YKU0 = EU(2,3)*DKM/OKUK
44. XY0 = EK**2 + XKU0**2 + YKU0**2
45. D0 = XY0**2.83333
46. N = 0
47. 10 N = N + 1
48. CVT = CVT1

**Computer Listing 3: Subroutine for calculating summation over turbulence spectrum.**
IF (N .GT. 1) CVT1 = 2.*CVT1
DK(3) = CVT1
CALL KVEC(DK,DXDZR,VN,ED,EU,DKM1,DKUK1,UQDQ1)

XY = EK**2 + XU**2 + YU**2
DN = (XY + ZKU**2)**2.83333
DEL1 = ABS(1.- DN/D0)
IF (DEL1 .LT. .el) GO TO 18
N = ZK/CVT
AN = N
ZK1 = ZK - AN*CVT
ZK2 = ZK1
NP = 0
NM = 0
20 NP = NP + 1
DK(3) = ZK1
CALL KVEC(DK,DXDZR,VN,ED,EU,DKM,DKUK,UQDQ)
XY = EK**2 + XU**2 + YU**2
DN = (XY + ZKU**2)**2.83333
SVV = SVV + (XY - EK**2)/(UQDQ**2*DN)
IF (NP .GT. 100) GO TO 40
ZK1 = ZK1 + CVT
IF (ON .LT. .00*200.) GO TO 20
80 SVV = .11561*SVV+CVT*EK**.666667
RETURN
END

Computer Listing 3: Subroutine for calculating summation over turbulence spectrum.
Inputs

Define wavevector $k$ in coordinate system fixed to airfoil; $x$ along chord, $y$ along span, and $z$ along normal. $k_z$ will take different values.

Sine and cosine of angles $\alpha$ and $\gamma$.

Normal to airfoil in same coordinate system as in lines 5-7.

Rotation matrix; $\partial x_i/\partial x_5$ with the definitions in Eq. (47). The first three components give the chord direction, the second three give the spanwise direction and the third three give the normal direction.

21 VN(1) written in the unrotated $x_1$ system.
22 VN(2) written in the unrotated $x_1$ system.
23 VN(3) written in the unrotated $x_1$ system.

Calculate deformation tensor in coordinate system defined in lines 5-7. First premultiply, then postmultiply, $DXDZ$ by ROT.

Denominator for upstream turbulence with $k_z = 0$. Used for comparison in lines 77 and 89.

If CVT is too small, will take too many summations. Make CVT larger until start getting significant variation in either the ratio of wavevectors between downstream and upstream.

Initialize sum variable.

Begin with minimum but still positive value after subtracting integer number of CVT values.

Initialize counters for number of steps up and down in $k_z$.

Sum over increasing values of $k_z$. Lines 69-71 calculate upstream values of wavevector. These expressions are placed into isotropic turbulence in 72-83. Line 75: check on number of iterations. Line 76: increment $k_z$. Line 77: check to see how large the denominator has become.

Same comments as lines 53-64 except summation is in downward direction.

Factors multiply sum. Note that CVT is included in the product so that it is o'k to increase CVT in lines 46-58 making the summation step size bigger.

$0.11561 = 55\Gamma(5/6)/[36\pi^{3/2} \Gamma(1/3)]$

Computer Listing 3: Subroutine for calculating summation over turbulence spectrum.
Appendix D: Program for Calculating Airfoil Response Function, $L$, for Leading Edge Noise

Computer Listing 4 gives the subroutine for calculating the effective lift $|L|$ for noise produced by airfoil- turbulence interaction. The inputs to the subroutine and the equivalent notation used in this report are:

<table>
<thead>
<tr>
<th>Program</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X$</td>
<td>$x_3$</td>
</tr>
<tr>
<td>$SG$</td>
<td>$\sigma$</td>
</tr>
<tr>
<td>$RM$</td>
<td>$M_b$; equation (36)</td>
</tr>
<tr>
<td>$XK$</td>
<td>$k_x$; $x$ wavenumber component</td>
</tr>
<tr>
<td>$YK$</td>
<td>$k_y$; $y$ wavenumber component</td>
</tr>
</tbody>
</table>

The output $GL_2$ is the effective lift $|L|^2$ and is calculated in a low frequency and a high frequency regime. The low frequency result is given by equation (27) and the high frequency result by Eqs. (28).

```
Lift function subroutine

Written by R. K. Amiet; final version 1978

SUBROUTINE LFT(X,SG,RM,XK,YK,GL2)
COMPLEX E
B2 = 1.-RM**2
UM = RM*XK/B2
RMI = SQRT(RM**2-B2*(YK/XK)**2)
UMI = UM*RMI/RM
IF (UMI-.75) 10, 10, 20
GL2 = 1./(B2*(1./(1.+2.4*XK/B2)+6.28319*XK/B2))
GO TO 30
10 T1 = ABS(UM+(X/SG-RMI/RM))
CALL FRNL(SQRT(1.27324+T1),E)
CM = CAB(E)
GL2 = .20264*CM**2/(XK*T1*(1.+RMI))
30 RETURN
END
```

<table>
<thead>
<tr>
<th>Line #</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Inputs and output</td>
</tr>
<tr>
<td>3</td>
<td>$B2 = \beta_b^2$</td>
</tr>
<tr>
<td>4</td>
<td>$UM = \mu$</td>
</tr>
<tr>
<td>5</td>
<td>$RMI = M_b$; equation (24)</td>
</tr>
<tr>
<td>6</td>
<td>$UMI = \mu_a$; equation (24)</td>
</tr>
<tr>
<td>7</td>
<td>Check whether to use low or high frequency solution.</td>
</tr>
<tr>
<td>8</td>
<td>Low frequency solution; equation (27)</td>
</tr>
<tr>
<td>10-13</td>
<td>High frequency solution; equation (28a)</td>
</tr>
<tr>
<td>10</td>
<td>$T1 = \Theta_1$; equation (29)</td>
</tr>
<tr>
<td>13</td>
<td>Equation (28a); .20264 = $2/\pi^2$</td>
</tr>
</tbody>
</table>

Computer Listing 4: Subroutine for calculating lift response for leading edge noise
Appendix E: Program for Calculating the Effect of Contraction on the Turbulence Spectrum

Computer Listing 5 gives the subroutine for calculating the effect of a contraction of a turbulence spectrum. This subroutine has as input a 3x3 deformation matrix representing a flow contraction. The program then accepts a flow direction $V_n$ and a wavevector $k$ both for the downstream flow, and calculates the upstream wavevector and flow vector. The inputs to the subroutine and the equivalent notation used in this report are:

<table>
<thead>
<tr>
<th>Program</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k^d$</td>
<td>Downstream wavevector components</td>
</tr>
<tr>
<td>$\partial x_i/\partial \xi_j$</td>
<td>Deformation tensor; equation (71)</td>
</tr>
<tr>
<td>$V_n$</td>
<td>Upwash velocity component normal to the airfoil</td>
</tr>
<tr>
<td>$E_D, E_U$</td>
<td>Tensors representing the three vector components of the upstream and downstream coordinate systems. Each such vector is represented by a column of the matrix.</td>
</tr>
</tbody>
</table>

The outputs are:

<table>
<thead>
<tr>
<th>Program</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D K_M$</td>
<td>Wavevector amplitude downstream at the rotor face</td>
</tr>
<tr>
<td>$D K_U K$</td>
<td>Ratio of downstream to upstream wavevector amplitudes</td>
</tr>
<tr>
<td>$U Q D Q$</td>
<td>Ratio of upstream to downstream velocity amplitudes</td>
</tr>
</tbody>
</table>

* Turbulence contraction calculation.

Written by R. K. Amiet 9/7/83

SUBROUTINE KVEC(DK,DXDZ,VN,ED,EU,DKM,DKUK,UQDO)
DIMENSION E0(3,3), EU(3,3), VN(3), F3(3), OK(3,3), OXOZ(3,3)

DKM = SQRT(DK(1)**2 + DK(2)**2 + DK(3)**2)

DO 10 I=1,3
ED(I,3) = DK(I)/DKM

DO 20 J=1,3
EU(J,2) = VN(J)

CONTINUE

DO 30 I=1,3
CALL CROSS(ED,I)

DO 40 J=1,3
CALL CROSS(ED,J)

DO 50 K=1,3
EU(I,J) = EU(I,J) + DXDZ(K,I)*ED(K,J)

DO 60 K=1,3
EU(I,J) = EU(I,J) + DXDZ(K,I)*ED(K,J)

AF1 = SQRT(EU(1,1)**2 + EU(2,1)**2 + EU(3,1)**2)

Computer Listing 5: Subroutine for calculating effect of contraction on turbulence spectrum
26 \( \text{EU}(1,1) = \text{EU}(1,1)/\text{AF1} \)
27 \( \text{EU}(2,1) = \text{EU}(2,1)/\text{AF1} \)
28 \( \text{EU}(3,1) = \text{EU}(3,1)/\text{AF1} \)
29 \text{CALL CROSS(EU,3)}
30 \text{CALL CROSS(EU,2)}
31 \text{DKUK} = \text{EU}(1,3)\text{F3(1)} + \text{EU}(2,3)\text{F3(2)} + \text{EU}(3,3)\text{F3(3)}
32 \text{UQDO} = \text{AF1}^2\text{DKUK}
33 \text{RETURN}
34 \text{END}

### Comments
3 Calculates the magnitude of the downstream wavevector \( k_d \).
4-7 Reads \( V_n \) into the 2'nd column of \( e_d \) and a unit vector along \( k_d \) into the 3'rd column.
8 Calculates the direction of the vorticity determined by the specified wavevector \( k \) and velocity \( V_n \) directions.
9 Calculates the direction of the velocity produced by the wavevector. \( V_n \) is a component of this velocity.
10-14 Initialize matrix \( e_u \).
15-21 Calculates the values of \( e_u \) from the downstream values \( e_d \) by using equation (71) on each of the 3 column vectors making up \( e_d \). This is not the final form for \( e_u \). The vector \( \hat{e}_1u \) representing the vorticity direction will keep its direction but be normalized to a unit vector. \( \hat{e}_3u \) will be found by taking the cross product of vectors 1 and 2, and \( \hat{e}_2u \) is then determined by taking the cross product of \( \hat{e}_3u \) and \( \hat{e}_1u \).
22-24 \( E \) represents a vector found by taking a unit vector along \( k_d \) and transforming according to equation (B11b). This is used to determine \( k_d/k_u \) using equation (72).
25 The magnitude of the transformed value of the vorticity, needed in equation (73).
26-28 Unit vector in the direction of the upstream vorticity.
29 Determines the unit vector \( \hat{e}_3u \) from the cross product of \( \hat{e}_1u \) and \( f_2u \).
30 Determines the unit vector \( \hat{e}_2u \) from the cross product of \( \hat{e}_3u \) and \( \hat{e}_1u \).
31 Determines \( k_d/k_u \) using equation (72).

**Computer Listing 5: Subroutine for calculating effect of contraction on turbulence spectrum**
Appendix F: Subroutine for Calculating the Cross Product of Two Vectors

Computer Listing 6 gives the subroutine for calculating the cross product of two vectors. The subroutine takes a $3 \times 3$ matrix $E(i,j)$ composed of 3 column vectors $\mathbf{e}_i$ and replaces the $N1$'th vector by the normalized cross product of the other two in proper cyclic order. The inputs to the subroutine and the equivalent notation used in this report are:

<table>
<thead>
<tr>
<th>Program</th>
<th>Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E(i,j)$</td>
<td>Tensor with columns composed of vectors; also represents the output</td>
</tr>
<tr>
<td>$N1$</td>
<td>Column not involved in the cross product</td>
</tr>
</tbody>
</table>

```
* Subroutine for calculating cross product of two vectors
* Written by R. K. Amiet 9/1/83
1 SUBROUTINE CROSS(E,N1)
2 DIMENSION E(3,3)
3 N2 = N1 + 1
4 N3 = N1 + 2
5 IF (N2 .GT. 3) N2 = N2 - 3
6 IF (N3 .GT. 3) N3 = N3 - 3
7 E(1,N1) = E(2,N2)*E(3,N3) - E(3,N2)*E(2,N3)
8 E(2,N1) = E(3,N2)*E(1,N3) - E(1,N2)*E(3,N3)
9 E(3,N1) = E(1,N2)*E(2,N3) - E(2,N2)*E(1,N3)
10 EN1M = SQRT(E(1,N1)**2 + E(2,N1)**2 + E(3,N1)**2)
11 E(1,N1) = E(1,N1)/EN1M
12 E(2,N1) = E(2,N1)/EN1M
13 E(3,N1) = E(3,N1)/EN1M
14 RETURN
15 END
```

<table>
<thead>
<tr>
<th>Line #</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-6</td>
<td>Defines the cyclic sequence 1,2,3 or 2,3,1 or 3,1,2 where N1 is the first number of the sequence.</td>
</tr>
<tr>
<td>7-9</td>
<td>Replaces the N1'th vector by the cross product of the other two.</td>
</tr>
<tr>
<td>10-13</td>
<td>Normalizes the N1'th vector to have a magnitude of 1.</td>
</tr>
</tbody>
</table>

Computer Listing 6: Subroutine for calculating cross product of two vectors
Appendix G: Subroutine for Calculating the Fresnel Integral

Computer Listing 7 gives the subroutine for calculating the Fresnel integrals. The program uses the algorithm given by equations 7.3.9, 7.3.32, 7.3.33 of Abromowitz and Stegun, Handbook of Mathematical Functions, Dover Publications, New York, 1968.

```
* FRNL.FOR Subroutine for calculation of Fresnel integrals
* Written by R. K. Amiet 1976
1 SUBROUTINE FRNL(X,E)
2 COMPLEX E, G, H
3 G = CMPLX((1.+ .926*X)/(2. + 1.792*X + 3.104*X**2),
4 1/(2. + 4.142*X + 3.492*X**2 + 6.67*X**3))
5 H = CMPLX(SIN(1.5708*X**2),COS(1.5708*X**2))
6 E = G*H + CMPLX(.5,-.5)
7 RETURN
8 END
```

Computer Listing 7: Subroutine for calculating the Fresnel integrals.
Appendix H: Sample Calculation

These two test cases use the same inputs, listed below. The only difference between the cases is the deformation tensor. For the first case the tensor represents no deformation. The second represents a deformation by a factor of 4 in the axial direction.

Rev/sec = 10.  Chord/Turb scale = .01  Mach no. $M_f = 0.$
Blade # = 2.  Sound speed/Chord = 1000.  Far field/chord = 100.
Radius/chord = 10.  rms turb vel/U = .010  Theta $\theta = 0.$
Axial Mach no. = $M_z = 0.1$

Case 1
Deformation tensor =
\[
\begin{bmatrix}
1.00 & 0.00 & 0.00 \\
0.00 & 1.00 & 0.00 \\
0.00 & 0.00 & 1.00
\end{bmatrix}
\]

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<th>FREQ</th>
<th>PSD</th>
<th>HRMNC</th>
<th>FREQ</th>
<th>PSD</th>
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<td>45.62</td>
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<td>51.93</td>
<td>8.0</td>
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<td>70.0</td>
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<td>190.0</td>
<td>42.00</td>
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<tr>
<td>5.0</td>
<td>100.0</td>
<td>47.09</td>
<td>10.0</td>
<td>200.0</td>
<td>41.62</td>
</tr>
</tbody>
</table>

Case 2
Deformation tensor =
\[
\begin{bmatrix}
2.00 & 0.00 & 0.00 \\
0.00 & 2.00 & 0.00 \\
0.00 & 0.00 & 0.25
\end{bmatrix}
\]

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<th>PSD</th>
<th>HRMNC</th>
<th>FREQ</th>
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<td>45.51</td>
<td>10.0</td>
<td>200.0</td>
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</table>
**Abstract**

This document describes a users manual for a computer program for the calculation of noise produced by turbulent flow into a helicopter rotor. This inputs to the program are obtained from the atmospheric turbulence model and mean flow distortion calculation, described in another volume of this set of reports. This report includes descriptions of the various program modules and subroutines, their function, programming structure, and the required input and output variables. This routine is incorporated as one module of NASA’s ROTONET helicopter noise prediction program.

**Key Words (Suggested by Author(s))**
- noise prediction
- helicopter noise, turbulence ingestion
- noise, rotor noise

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