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Prediction of Helicopter Rotor Discrete Frequency Noise

A Computer Program Incorporating Realistic Blade Motions and Advanced Acoustic Formulation

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SUMMARY

A computer program has been developed at the Langley Research Center to predict the discrete frequency noise of conventional and advanced helicopter rotors. The program, called WOPWOP, uses the most advanced subsonic formulation of Farassat that is less sensitive to errors and is valid for nearly all helicopter rotor geometries and flight conditions. A brief derivation of the acoustic formulation is presented along with a discussion of the numerical implementation of the formulation. The computer program uses realistic helicopter blade motion and aerodynamic loadings, input by the user, for noise calculation in the time domain. The structure of the program and the subroutines describing the input functions are described in this report. A detailed definition of all the input variables, default values, and output data is included. A comparison with experimental data shows good agreement between prediction and experiment; however, accurate aerodynamic loading is needed.

A second program, which is used to provide graphic output, is described briefly in an appendix. Four realistic example cases are presented. Complete input data, printed output, and graphical output are included in the appendixes for each of the example cases. These examples can be reproduced by users to check the program on their system.

INTRODUCTION

Helicopters have proven to be a very versatile means of transportation and fulfill a unique roll in civil and military aviation. In the past, controllability and performance completely dominated the design requirements. As the helicopter became more mature and its use was expanded, a great deal of importance was then placed on the vibrational and acoustical properties of the helicopter design. This interest has resulted in helicopters that are quieter and vibrate less; however, large gains can still be made in this effort.

Since model and full-scale testing of helicopter rotors can be time-consuming and expensive, a computer program, called WOPWOP, has been developed at the Langley Research Center to predict the discrete frequency noise for helicopter rotors. This paper is intended as a description of the WOPWOP program. WOPWOP is actually an updated version of an earlier computer program developed at Langley by Paul A. Nystrom and F. Farassat, but WOPWOP uses a more advanced acoustic formulation and all realistic blade motions. References 1 and 2 refer to a version of the Nystrom-Farassat program that was developed for advanced propellers. The original helicopter program was not documented and used a considerably different computation strategy; therefore, only the present version of WOPWOP will be discussed.

The program WOPWOP uses acoustic formulation 1A of Farassat (ref. 3). This time-domain formulation is valid in both the near-field and far-field and is appropriate for arbitrary blade motions with loading given on either the actual blade surface or the mean camber surface. In WOPWOP, the flapping, feathering, and lead-lag motion of a helicopter rotor in hover, vertical flight, and forward flight are described using coefficients of a Fourier series. Coefficients up to the second harmonic can be specified. WOPWOP can also be used to simulate propellers correctly in asymmetric flight conditions, rather than to change the loading distribution to account for asymmetry in an axisymmetric flow, as is normally done. The formulation used in WOPWOP does not require a numerical time differentiation found in Farassat's earlier formulation and, for this reason, is better suited to study impulsive blade loadings such as blade-vortex interaction. A brief derivation of Farassat's formulation 1A is included for completeness as well as a discussion of how the formulation is implemented numerically. Special effort has been taken to minimize the mathematical and numerical approximations used.

The program WOPWOP uses input in the form of blade geometry, realistic blade motion, and aerodynamic blade loading that are input through a FORTRAN namelist and three input subroutines. Using this combination for input ensures great flexibility when the program is applied to different engineering applications. The namelist input and input subroutines are described in detail, and the program output is explained as well. In appendix A, a sample procedure to execute WOPWOP on a VAX with the VMS operating system is shown. Appendix B contains four example cases with printed output from the program WOPWOP. An interactive postprocessing program, called WOPPLT, is described in appendix C, and the graphical output for the four example cases is shown in appendix D.

SYMBOLS AND ABBREVIATIONS

BPF	blade passage frequency
c_o	speed of sound in undisturbed medium
E	distance from rotor hub center to lead-lag hinge
E2	radial distance from center of rotor hub
ER	nondimensional radial distance, E2/R
$f(\vec{x},t) = 0$	equation of blade surface
ℓ_i	local force per unit area on fluid in direction i
M	Mach number
M_r	Mach number in radiation direction
$\hat{n}$	unit outward normal vector to surface $f = 0$
OASPL	overall sound pressure level, dB (re 20 μPa)
PCA	pitch change axis
$p'(\vec{x},t)$	acoustic pressure
Q	chordwise position expressed as fraction of chord
R	radius of rotor blade
r	length of radiation vector, $\lvert\vec{x} - \vec{y}\rvert$
$\vec{r}$	radiation vector, $\vec{x} - \vec{y}$

$\hat{r}$	unit radiation vector, $\vec{r}/r$
S	surface area of blade
SPL	sound pressure level
t	observer time
$\hat{t}$	unit tangent vector to surface $f = 0$
v_n	local normal velocity of blade surface
$\vec{v}$	local velocity of blade surface
$\vec{x}$	observer position in frame fixed with respect to undisturbed medium
$\vec{x}_{obs}$	observer location
$\vec{y}$	source position in frame fixed with respect to undisturbed medium
$\vec{y}_o(t)$	position vector from origin of ground-fixed frame (GF) to moving frame (MF)
α_f	rotor-shaft tilt angle
β	blade flapping angle
$\delta(f)$	Dirac delta function
ζ	blade lead-lag angle
$\vec{\eta}$	blade-fixed frame coordinates
θ	blade feathering angle
ρ_o	density of undisturbed medium
τ	source time
ψ	azimuthal angle
∇^2	Laplacian operator

Subscripts:

B	blade-fixed frame (BF)
F	flapping frame (FF)
i,j	indices of summation, i and $j = 1, 2,$ or 3
L	lagging frame (LF)
M	moving frame (MF)
R	rotating frame (RF)

r	radiation direction
ret	evaluated at retarded or emission time
1,2,3	coordinate directions

THEORETICAL FORMULATION

The problem of noise prediction can be represented as the solution of the wave equation if the distribution of sources on the moving boundary (the rotor blade surface) and in the flow field is known. The noise prediction should not be limited to a particular blade geometry or blade motion, and observer positions in both the near-field and far-field should be included. Ffowcs Williams and Hawkings (ref. 4) derived the governing differential equation by applying the acoustic analogy of Lighthill (ref. 5) to bodies in motion. Farassat has developed several integral representations of the Ffowcs Williams-Hawkings (FW-H) equation that are valid for general motions in both subsonic and supersonic flow. These integral representations become solutions to the acoustic problem when the body geometry, motion, and surface loadings are given. Farassat neglects the volume source term, or "quadrupole" term, in the FW-H equation on the basis that the term becomes important only for strongly transonic flow and the source strength is generally not available in practice. However, Hanson and Fink (ref. 6), as well as Schmitz and Yu (ref. 7), have shown that this quadrupole term can be important for high-speed rotating machinery, particularly those with thick blades. This shortcoming of the formulation should be addressed in the future. Formulation 1A of Farassat, which is used in WOPWOP, will be briefly derived in the following section by using the original method. A more complete discussion of this derivation is found in references 3, 8, and 9.

DERIVATION OF FORMULATION 1

The governing differential equation used here is the Ffowcs Williams-Hawkings (FW-H) equation. Let $f(\vec{y},t) = 0$ describe the surface of the blade where $f > 0$ outside the blade. The FW-H equation is

$$\Box^2 p'(\vec{x},t) = \frac{1}{c_o^2}\frac{\partial^2 p'}{\partial t^2} - \nabla^2 p'$$

$$= \frac{\partial}{\partial t}[\rho_o v_n |\nabla f| \ \delta(f)] - \frac{\partial}{\partial x_i}[\ell_i |\nabla f| \ \delta(f)]$$

$$- \frac{\partial^2}{\partial x_i \, \partial x_j}[T_{ij} \ H(f)] \qquad (1)$$

where p' is the acoustic pressure, ρ_o and c_o are the density and speed of sound of the undisturbed medium, respectively, v_n is the local normal velocity of the blade surface, ℓ_i is the force per unit area on the fluid, T_{ij} is the Lighthill stress tensor, and $\square^2$ denotes the wave operator. The quantity ℓ_i is equal to $P_{ij}\hat{n}_j$, where P_{ij} is the compressive stress tensor that includes the surface pressure and viscous stress and $\hat{n}_j$ is the unit outward normal vector to the surface $f = 0$. The Dirac delta function and the Heaviside function are denoted by $\delta(f)$ and $H(f)$, respectively. This notation is consistent with that of Farassat (ref. 3). The source terms on the right-hand side of the FW-H equation are known as the thickness, loading, and quadrupole terms, respectively.

The Green's function for the wave equation in unbounded space is $\delta(g)/4\pi r$ where

$$g = \tau - t + \frac{r}{c_o} \tag{2}$$

and $r = |\vec{x} - \vec{y}|$. Here τ and t are the source and observer times, respectively. The vectors $\vec{x}$ and $\vec{y}$ are the source and observer positions, respectively. Noting that the thickness and loading terms are source terms on the right-hand side of the FW-H equation, one can use the formal solution of the wave equation to give the integral representation

$$\begin{aligned} 4\pi\, p'(\vec{x},t) &= \frac{\partial}{\partial t}\int \frac{\rho_o v_n |\nabla f|\ \delta(f)\ \delta(g)}{r}\, d\vec{y}\, d\tau \\ &\quad - \frac{\partial}{\partial x_i}\int \frac{\ell_i |\nabla f|\ \delta(f)\ \delta(g)}{r}\, d\vec{y}\, d\tau \end{aligned} \tag{3}$$

Note that the $\vec{y}$ frame is fixed to the undisturbed medium. Let a blade-fixed frame $\vec{\eta}$ be defined and related to the $\vec{y}$ frame by

$$\vec{y} = \vec{y}_o(\tau) + A(\tau)\,\vec{\eta}$$

where $\vec{y}_o(\tau)$ is the position of the origin of the frame and $A(\tau)$ is the transformation matrix. Then the Jacobian of the transformation is unity since the determinant of $A(\tau)$ is 1. Using this result, equation (3) may now be written

$$\begin{aligned} 4\pi\, p'(\vec{x},t) &= \frac{\partial}{\partial t}\int \frac{\rho_o v_n |\nabla f|\ \delta(f)\ \delta(g)}{r}\, d\vec{\eta}\, d\tau \\ &\quad - \frac{\partial}{\partial x_i}\int \frac{\ell_i |\nabla f|\ \delta(f)\ \delta(g)}{r}\, d\vec{\eta}\, d\tau \end{aligned} \tag{4}$$

Now change the variable of integration from τ to g, keeping η fixed. The Jacobian of the transformation is $1/|1 - M_r|$ where $M_r = \vec{v} \cdot \hat{\vec{r}}/c_o = v_i\hat{r}_i/c_o$ is the Mach number in the radiation direction. If f is a function of $\vec{\eta}$ only and $d\vec{\eta}$ is written as $d\vec{\eta} = df\, dS/|\nabla f|$, where dS is an element of surface area on $f =$ Constant, the result will be

$$4\pi\, p'(\vec{x},t) = \frac{\partial}{\partial t}\int_{f=0}\left[\frac{\rho_o v_n}{r(1 - M_r)}\right]_{ret} dS - \frac{\partial}{\partial x_i}\int_{f=0}\left[\frac{\ell_i}{r(1 - M_r)}\right]_{ret} dS \qquad (5)$$

where the subscript ret denotes that the integrand is evaluated at the source or retarded time. The spatial derivative of the second integral can be converted to a time derivative giving the result that Farassat has called formulation 1, which is written as

$$4\pi\, p'(\vec{x},t) = \frac{1}{c_o}\frac{\partial}{\partial t}\int_{f=0}\left[\frac{\rho_o c_o v_n + \ell_r}{r(1 - M_r)}\right]_{ret} dS + \int_{f=0}\left[\frac{\ell_r}{r^2(1 - M_r)}\right]_{ret} dS \qquad (6)$$

where $\ell_r = \ell_i\hat{r}_i$ is the force on the fluid per unit area in the radiation direction. Farassat used this formulation for his early work with the time differentiation evaluated numerically.

DERIVATION OF FORMULATION 1A

The speed and accuracy of the calculation is improved by eliminating the numerical differentiation; therefore, using equation (2) and the fact that r is a function of τ gives

$$\left.\frac{\partial}{\partial t}\right|_{\vec{x}} = \left(\frac{1}{1 - M_r}\left.\frac{\partial}{\partial \tau}\right|_{\vec{x}}\right)_{ret}$$

This relation allows the time derivatives to be taken inside the first integral. Then, from using the useful relations

$$\frac{\partial r}{\partial \tau} = -v_r$$

$$\frac{\partial \hat{r}_i}{\partial \tau} = \frac{\hat{r}_i v_r - v_i}{r}$$

$$\frac{\partial M_r}{\partial \tau} = \frac{1}{c_o r}\left(r_i \frac{\partial v_i}{\partial \tau} + v_r^2 - v^2\right)$$

$$\frac{\partial v_n}{\partial \tau} = \left(\frac{\partial v_i}{\partial \tau}\hat{n}_i + v_i \frac{\partial \hat{n}_i}{\partial \tau}\right) \equiv \dot{v}_n$$

the final result is

$$p'(\vec{x},t) = p'_T(\vec{x},t) + p'_L(\vec{x},t)$$

where

$$4\pi\, p'_T(\vec{x},t) = \int_{f=0} \left[\frac{\rho_o \dot{v}_n}{r(1 - M_r)^2}\right]_{ret} dS + \int_{f=0} \left[\frac{\rho_o v_n\left(r\dot{M}_i\hat{r}_i + c_o M_r - c_o M^2\right)}{r^2(1 - M_r)^3}\right]_{ret} dS$$

$$4\pi\, p'_L(\vec{x},t) = \frac{1}{c_o}\int_{f=0} \left[\frac{\dot{\ell}_i\hat{r}_i}{r(1 - M_r)^2}\right]_{ret} dS + \int_{f=0} \left[\frac{\ell_r - \ell_i M_i}{r^2(1 - M_r)^2}\right]_{ret} dS$$

$$+ \frac{1}{c_o}\int_{f=0} \left[\frac{\ell_r\left(r\dot{M}_i\hat{r}_i + c_o M_r - c_o M^2\right)}{r^2(1 - M_r)^3}\right]_{ret} dS$$

Here p'_T and p'_L denote the acoustic pressure due to thickness and loading, respectively. The dots on $\dot{M}_i$, $\dot{\ell}_i$, and $\dot{v}_n$ denote the rate of variation with respect to source time. This integral representation of the FW-H equation is known as formulation 1A of Farassat. It is slightly more general than Farassat reported in reference 3 in that it includes the $\dot{v}_n$ term in the thickness contribution. The importance of this term has not been determined and is thought to be small, but it is included for completeness. Only the quadrupole term in the FW-H equation has been neglected. Formulation 1A is computationally more efficient since the numerical time derivative of formulation 1 has been replaced and impulsive loading can be used as well.

Formulation 1A is valid for arbitrary blade motion and geometry. The sources lie on the actual body surface and can include loading from any mechanisms that act on the blade surface. Near-field and far-field terms are seen explicitly as $1/r^2$ and $1/r$ terms in the integrals, respectively. The observer is assumed to be fixed to the undisturbed medium, but a moving observer can also be used by changing the observer position at each observer time. Formulation 1A is well-suited to helicopter rotors with subsonic tip speeds, especially if the blade does not exceed the section critical Mach number.

PROGRAM DESCRIPTION

Although the acoustic formulation 1A of Farassat allows arbitrary blade motion, geometry, and observer locations, the numerical solution is only of interest for realistic flight conditions and rotor geometries. Thus, the computer program has been written to include all realistic helicopter blade motions. The numerical implementation of formulation 1A and the corresponding approximations will be discussed in this section.

The noise calculation in WOPWOP is commenced by dividing the rotor blade surface into a number of panels. A numerical integration is carried out assuming that the integration over each panel may be approximated using the integrand value at the panel center for the entire panel area. The program WOPWOP determines the panel center and then calculates the contribution to the noise from the panel for all the desired times. This process is repeated for each blade and for all remaining panels to complete the integration over the actual blade surface. The number of panels that can be used is not limited; however, 60 chordwise panels and 40 radial panels could be considered an upper bound. The summed effect of all the panels at the observer location for all observer times desired gives the acoustic pressure time history. The time history is then Fourier decomposed to find the acoustic spectra in terms of sound pressure level (SPL) and phase for each harmonic. The overall sound pressure level (OASPL) is calculated as well.

The observer position is fixed in a ground-fixed reference frame (fig. 1). The observer location is specified in the observer reference frame (OF), where $(OF)_1$ points forward, $(OF)_2$ points to the left, and $(OF)_3$ points upward, forming a right-hand coordinate system. The actual acoustic calculations are performed in a ground-fixed reference frame (GF). The origin of the GF frame corresponds to the OF frame and $(GF)_3$ is rotated an angle α_f in the counterclockwise direction when viewing from the right side of the helicopter (for a rotation of the positive sense). Here $(GF)_2$ and $(OF)_2$ are coincident and α_f describes the angle between the rotor shaft and the vertical. The angle α_f is negative when the rotor shaft is tilted forward.

The rotor blade is described in a blade-fixed reference frame (BF). It is convenient to describe the blade surface, surface normal vector, and surface tangent vector in the BF frame since these quantities are independent of time in the BF frame. Since the acoustic calculations are performed in the GF frame, a series of intermediate reference frames are used to describe the blade-fixed vector quantities in the ground-fixed frame of reference. The transformations used in WOPWOP will be described to clarify the precise motion of the rotor blade in WOPWOP.

Four intermediate reference frames are used to relate quantities in the blade-fixed frame to the ground-fixed frame. These are necessary to include the helicopter forward motion, blade rotation, flapping, feathering, and lead-lag motions. Figure 1 shows the relationship between the ground-fixed frame (GF) and a nonrotating moving frame (MF). MF corresponds to GF at time $t = 0$, and the vector $\vec{y}_o(t)$ relates the origin of the MF frame to the origin of the GF frame. The vector $\vec{y}_o(t)$ is defined as the product of observer time t with the helicopter velocity vector $\overrightarrow{VH}$. A rotating frame (RF) is related to the moving frame (MF) by the angle ψ, which is measured from the tail of the helicopter in a counterclockwise direction when looking from above (fig. 2(a)). RF corresponds to MF when $\psi = 180°$. The flapping motion of the blade is described by the flapping reference frame (FF). Since the actual geometry of helicopters can vary, the flap hinge is assumed to be at the center of the rotor shaft. The flap angle β relates the rotating frame (RF) to the flapping frame (FF) (fig. 2(b)). The lead-lag motion of the blade is assumed to act at a lag hinge that is a distance E from the rotor shaft along the $(FF)_2$-axis. The lead-lag motion takes place in the $(FF)_1(FF)_2$-plane. The lead-lag angle ζ and lag hinge offset E relate the flapping frame (FF) to the lead-lag frame (LF) (fig. 2(c)). The $(LF)_2$-axis is the pitch change axis of the rotor blade. The lead-lag reference frame is related to the blade-fixed frame (BF) by the feathering angle θ (fig. 2(d)). All the blade motions are assumed to be rigid-body motions in WOPWOP.

Coordinate transformations between reference frames become very simple using transformation matrices and matrix algebra. For example, if $\vec{\eta}$ is a position vector of a point in the blade-fixed frame and we want $\vec{y}$, the position vector of the same point in the ground-fixed frame then is

$$\vec{y} = \vec{y}_0(t) + E[T_{MF}](\overrightarrow{FF})_2 + [T_{MB}]\vec{\eta}$$

where

$$\vec{y}_0(t) = t(\overrightarrow{VH})$$

$$[T_{MF}] = [T_{MR}][T_{RF}]$$

$$[T_{MB}] = [T_{MR}][T_{RF}][T_{FL}][T_{LB}]$$

Here $\overrightarrow{VH}$ is the helicopter velocity, t is the observer time, E is the lag hinge offset, and $[T_{XY}]$ is the general transformation matrix relating frame Y to frame X. Time derivatives of vectors can be calculated just as easily by taking the time derivatives of the transformation matrices. The assumed blade motion can be changed by simply changing the definitions of the intermediate reference frames.

In WOPWOP, the flapping angle β, lead-lag angle ζ, and feathering angle θ are described by a truncated Fourier series that includes a constant term and the first and second harmonics. The motion is input by specifying the Fourier coefficients for the angle in question. More general motion could easily be included, but this description is believed to be sufficiently accurate for noise prediction since blade motion is generally calculated or measured in terms of these coefficients.

Having described the motion of the rotor blade, the calculation of the integrand at each panel center follows directly from the theoretical formulation. The vector quantities that are constant on the surface of the panel are calculated in the blade-fixed frame. Then, the retarded time for the panel is calculated. Next, all the quantities are transformed or calculated in the ground-fixed frame and the integrand is calculated. The near-field and far-field components of loading and thickness noise are computed and summed separately. To reduce numerical error, all positive and negative quantities are summed separately and added only once at the end of all calculations.

The retarded-time calculation is made using a numerical technique similar to Newton's method. The contribution of one panel is calculated for all times around the azimuth so that the retarded time from the last calculation can be used as the initial guess for the next calculation. This decreases the number of iterations necessary in the retarded-time calculation when many time points around the azimuth are calculated. To reduce computational time further, the retarded time is calculated only on the mean camber surface and is used for both the upper and lower surfaces. This process reduces the number of retarded-time evaluations by a factor of 2 and has not been found to have any serious effect on the noise calculations.

After the acoustic-pressure time history calculation has been completed, the sound pressure level and phase are calculated using a slow Fourier transform routine. This routine calculates the Fourier coefficients using an integration of the acoustic-pressure time history. The numerical integration is done using Simpson's rule. Overall acoustic pressure, loading pressure, and thickness pressure are formed as a summation of component pressures in the time domain and are then Fourier decomposed. Both the acoustic-pressure time histories and spectra are printed.

DESCRIPTION OF PROGRAM INPUT

The program WOPWOP requires input from three input subroutines and a namelist input. In the following section each of these is described.

INPUT SUBROUTINES

Three input subroutines, FUNE2, FUNE2Q, and FUNPSI, are required by WOPWOP. These subroutines are used to describe the physical and aerodynamic characteristics of the rotor blade and allow great flexibility in the definition of the blade geometry and blade loading. The input to WOPWOP may be described by using either analytic functions or a tabular data form, depending upon how the input subroutines are written. These subroutines must be written by the user. Examples of each type are found in appendix B. Subroutine FUNE2 defines the blade-section geometric twist, chord, pitch change axis location, maximum thickness ratio, and maximum camber ratio as a function of radial position along the rotor blade. All the derivatives of these quantities in the radial direction are defined as well. Subroutine FUNE2Q defines the camber and thickness as functions of radial and chordwise locations. The third subroutine, FUNPSI, describes the aerodynamic blade loading on either the actual blade surface or the mean camber surface as a function of azimuthal position. A description of the variables in each subroutine follows.

Subroutine FUNE2

This subroutine defines the variation of the blade geometry in the radial direction (fig. 3). Variables returned from this subroutine are functions of the radial distance E2. Note that R is the radius of the rotor blade.

Calling sequence: `CALL FUNE2 (E2, R, AAE2, AAE2P, CH, CHP, LED, LEDP, PCAD, PCADP, TRAT, TRATP, CRAT, CRATP)`

Variable	Definition
E2	radial distance from center of rotor hub along pitch change axis (meters)
R	radius of rotor blade (meters)
AAE2	geometric twist of blade section (radians)
CH	chord of blade section (meters)
LED	leading-edge displacement (distance from pitch change axis to leading edge of blade section). This is generally negative (meters).
PCAD	perpendicular distance from chord line to pitch change axis (PCA). Pitch change axis below chord line is positive (meters).
TRAT	maximum thickness ratio of blade section, Thickness/CH
CRAT	maximum camber ratio of blade section, Camber/CH

AAE2P, CHP, LEDP, PCADP, TRATP, and CRATP are derivatives of the above variables with respect to E2. They must all be real variables.

Subroutine FUNE2Q

This subroutine defines the chordwise variation of the rotor blade (fig. 3). Variables returned from this subroutine are functions of the radial location E2 and the nondimensional chordwise position Q.

Calling sequence: CALL FUNE2Q (E2, R, Q, CMBR, CMBRP, THK, THKP)

Variable	Definition
E2	same as in FUNE2
R	same as in FUNE2
Q	nondimensional chordwise position measured along chord line (0. at leading edge, 1. at trailing edge)
CMBR	nondimensional camber function. Distance from chord line to camber line divided by maximum camber displacement (Max. camber = CRAT*CH). For symmetric airfoil, CMBR = 0; for cambered airfoil, 0. <= CMBR <= 1.
THK	nondimensional thickness function. Distance from camber line to upper and lower surface divided by maximum thickness (Max. thickness = TRAT*CH). (Note that this distance is assumed to be perpendicular to the chord line and NOT the camber line.)

The variables CMBRP and THKP are the derivatives of CMBR and THK with respect to Q. They must be real variables.

Subroutine FUNPSI

This subroutine describes the pressure and viscous shear stress distribution on the blade surfaces that must come from a separate analysis or experiment. These distributions are a function of blade azimuthal position (PSI) and location on the blade (E2 and Q). The angle PSI is defined as 0 when the blade points toward the tail of the helicopter and increases in a counterclockwise direction when looking from above the helicopter. The input may be expressed as pressure on the actual upper and lower surfaces (absolute pressure minus atmospheric pressure) or as a differential pressure on the mean camber surface. If the actual surface pressure approach is used, the user can include a description of the viscous shear stress (skin friction) for use in the loading noise calculation even though the noise due to the viscous shear stress is known to be small. If the input is in differential pressure form, the program does not include viscous stress terms in the calculations and these variables must be set equal to 0 in the subroutine. The time derivatives of pressure and viscous shear stress must also be defined to be used. The differential pressure approach is recommended only if differential pressure is all that is available since the torque and power calculation may result in considerable error and there is little advantage gained in program execution speed.

Calling sequence: `CALL FUNPSI (E2, R, Q, PSI, SURFP, DP, SPU, SPL, SIGMAU, SIGMAL, DPCP, SPUP, SPLP, SIGUP, SIGLP)`

Variable	Definition
E2	same as in FUNE2 and FUNE2Q
R	same as in FUNE2 and FUNE2Q
Q	same as in FUNE2Q
PSI	azimuthal angle measured from tail of helicopter in counterclockwise direction when looking from above (radians)
SURFP	.TRUE. - surface pressures and viscous shear forces defined on upper and lower surfaces .FALSE. - differential pressure on mean camber surface. Viscous shear stresses must be set to 0. This method is not recommended.
DP	differential pressure acting on camber surface. This variable is defined as DP = SPL - SPU (pascals).
SPU, SPL	absolute pressure minus atmospheric pressure on upper and lower blade surfaces, respectively (pascals)
SIGMAU, SIGMAL	viscous shear stress (skin friction) acting on upper and lower surfaces, respectively. Must be set equal to 0 if SURFP = .FALSE (N/m^2).
DPCP	time derivative of DP
SPUP, SPLP	time derivatives of SPU and SPL, respectively
SIGUP, SIGLP	time derivatives of SIGMAU and SIGMAL, respectively

The variable SURFP is a logical variable, whereas all other variables are real. The values used for the surface pressure and viscous shear stress must be calculated from some other analysis or measured in an experiment and input to the program through the subroutine FUNPSI. Figure 4 is a schematic flow chart of WOPWOP that shows the level at which each of the three input subroutines are called.

INPUT DATA

A FORTRAN namelist, called $INPUT, is used to read in the basic parameters such as blade dimensions, rotational speed, and forward speed. The namelist also includes several parameters that control the speed and accuracy of program execution. For example, the number of spanwise and chordwise divisions (NSPAN, NLE, and NTE), the number of harmonics calculated (NSPEC), the allowable error in the retarded-time calculation (EPSLON), and similar variables are defined through the namelist input. For each namelist variable, there is a default value defined within the program that applies to the case of a two-blade rectangular rotor. If any variables are not redefined in the namelist input during a particular single-case run, the default values are automatically used. However, once a variable is defined within a job, that value will be retained for all the following cases within that job until it is subsequently redefined.

The namelist is followed by two case identification lines in card image format. The namelist and case identifiers must be written on a data file named WOPIN. Multiple-case runs, which vary the namelist parameters while using the same input subroutines, can be executed within the same job. This execution may be done by submitting sequential namelists and identifiers for each case in one data file.

The observer coordinate system (OF) is defined as follows. The $(OF)_1(OF)_2$-plane is parallel to the ground and the $(OF)_3$-axis points upward. The $(OF)_1$-axis points in the direction of the wind. The origin of this coordinate system is the center of the rotor hub at time $t = 0$. The OF reference frame is shown in figure 1. If the moving observer option of the program is used (MOTION = .TRUE.), then this frame will move with the helicopter but will retain its original attitude, without rotation, with its origin fixed to the center of the rotor hub. The helicopter velocity must be described in the OF frame as a vector $\vec{VH}$, with VH(1) as the forward speed, VH(2) as 0 (always), and VH(3) as the ascent (positive) or descent (negative) speed.

The flapping, feathering, and lead-lag angles are assumed to be harmonic functions, respectively, of the form:

```
BETA = A0 - A1*cos(PSI) - B1*sin(PSI) - A2*cos(2*PSI) - B2*sin(2*PSI)

THETA = AA0 - AA1*cos(PSI) - BB1*sin(PSI) - AA2*cos(2*PSI) - BB2*sin(2*PSI)

ZETA = EE0 - EE1*cos(PSI) - FF1*sin(PSI) - EE2*cos(2*PSI) - FF2*sin(2*PSI)
```

where BETA is the blade flapping angle, THETA is the blade feathering angle, and ZETA is the blade lead-lag angle. All angles are input in the namelist in degrees; however, in the program they are actually used in radian measure. The definition of the collective pitch (AA0) may vary depending upon how the geometric twist of the rotor blade was defined in the subroutine FUNE2.

Definition of Namelist $INPUT

Blade motion coefficients.-

Variable	Default	Definition
A0	2°	coning angle (constant term in flapping-angle expression BETA)
A1	10°	1st harmonic forward/aft flapping. (See flapping expression BETA above.)
B1	10°	1st harmonic lateral flapping. (See flapping expression BETA above.)
A2	0°	2nd harmonic forward/aft flapping. (See flapping expression BETA above.)
B2	0°	2nd harmonic lateral flapping. (See flapping expression BETA above.)
AA0	10°	collective pitch (constant term in feathering-angle expression THETA). The definition of this angle depends upon how the geometric twist is defined in subroutine FUNE2.
AA1	3°	1st harmonic forward/aft feathering. (See feathering expression THETA above.)
BB1	3°	1st harmonic lateral feathering. (See feathering expression THETA above.)
AA2	0°	2nd harmonic forward/aft feathering. (See feathering expression THETA above.)
BB2	0°	2nd harmonic lateral feathering. (See feathering expression THETA above.)
EE0	0°	constant term in blade lead-lag expression ZETA above
EE1	0°	1st harmonic forward/aft lead-lag motion. (See expression ZETA above.)
FF1	0°	1st harmonic lateral lead-lag motion. (See expression ZETA above.)
EE2	0°	2nd harmonic forward/aft lead-lag motion. (See expression ZETA above.)
FF2	0°	2nd harmonic lateral lead-lag motion. (See expression ZETA above.)

Operating conditions.-

Variable	Default	Definition
C	340 m/sec	ambient speed of sound
RHO	1.234 kg/m^3	ambient air density
ALPHAF	-3°	angle of attack of rotor shaft (negative for forward tilt)
REV	300 rpm	rotational blade speed
PTIP	0 Pa	uniform suction pressure acting on blade tip. If parameter DOTIP is .TRUE., subroutine TIPCAL is called and noise contribution from edge of blade is added to loading noise. The importance of this term is discussed in reference 10.
VH	(100,0,0) m/sec	helicopter velocity. Second component of velocity vector must be set equal to 0.
OBS	(100,0,100) m	initial position of observer with respect to X1, X2, X3 frame of reference.

Blade geometry.-

Variable	Default	Definition
RINNER	0.5 m	blade cutout radius
R	5 m	blade radius
E	0 m	lead-lag hinge offset. (Flapping motion is assumed to start at center of rotor hub.)
NBLADE	2	number of blades

Computation information.-

Variable	Default	Definition
NPTS	100	number of points of pressure signature calculated per blade passage period. This quantity must be <401.
NSPEC	40	number of harmonics in acoustic pressure spectrum to calculate. Must be <NPTS/2. If NSPEC > NPTS/2, NSPEC is set equal to NPTS/2.

NSPAN	15	number of spanwise divisions of blade for numerical integration on surface. Divisions are calculated by program to keep equally swept areas for each radial section. For realistic rotor prediction, NSPAN should be chosen such that $8 < \text{NSPAN} < 40$.
NLE	15	number of divisions along chord from leading edge to DOQUAD. These divisions are quadratically spaced with a concentration at leading edge.
NTE	10	number of divisions along chord from DOQUAD to trailing edge. These divisions are linearly spaced.
DOQUAD	0.25	transition point between quadratic (NLE) and linear (NTE) divisions along chord. This is expressed as a fraction of chord as measured from leading edge. The variable DOQUAD may take any value from 0 to 1.
EPSLON	0.5%	maximum allowable error in calculation of retarded time expressed as percentage of observer time step
TZERO	0 sec	starting observer time
TSTOP	0 sec	ending observer time. If this variable is nonzero, the time history will be computed only during the time from TZERO to TSTOP and not for a complete blade passage. This allows very concentrated calculation of acoustic pressure during a small period of rapid variation.

Program logic control.-

Variable	Default	Definition
CENTER	.TRUE.	logical variable that when .TRUE. enables rotation of pressure signatures to center peak pressure in printed output and in plot data
DOTIP	.FALSE.	logical variable that when .TRUE. enables execution of subroutine TIPCAL (see input parameter PTIP) and calculation of tip loading noise
FULL	.TRUE.	logical variable that when .TRUE. enables output of thickness and loading pressure signatures and spectra
MOTION	.TRUE.	logical variable that when .TRUE. signifies that observer is fixed with respect to helicopter
SAVE	.TRUE.	logical variable that when .TRUE. enables computed information to be output on data file WOPPLT.DAT. This data file is required for separate plotting program WOPPLT.

Use of Namelist $INPUT

It is important to choose values for the computational parameters NPTS, NSPEC, NSPAN, NLE, NTE, and DOQUAD to resolve adequately the acoustic pressure time history and assure the convergence of the numerical integration. The value of NPTS should be chosen as the number of points that resolve the pressure time history and allow the desired number of harmonics to be calculated accurately. Typically, 200 to 400 points per blade passage are required for impulsive noise. Even if a small number is used for NPTS, the value at each point will be correct since no numerical time differentiation is used in the formulation. NSPEC must be chosen (or will be set) below the Nyquist frequency. In practice, it has been found that the amplitude of the harmonics calculated near the Nyquist frequency may have considerable aliasing, which can be removed by increasing the values of NPTS.

The variables NSPAN, NLE, NTE, and DOQUAD are used to define the rotor blade computational surface used for numerical integration. NLE and DOQUAD should be chosen to describe accurately the leading edge of the airfoils. NLE is the number of quadratically spaced, chordwise divisions in the computational grid. DOQUAD is the fraction of the chord, starting from the leading edge, that contains quadratic chordwise spacing. NTE chordwise divisions are linearly spaced from DOQUAD to the trailing edge. NSPAN is the number of radial or spanwise divisions along the blade radius. These radial divisions are selected so that each radial station sweeps out equal areas. This is essentially just a quadratic radial spacing with concentration at the blade tip. Experience has shown that nearly 30 chordwise divisions (NLE + NTE) and 13 to 15 spanwise divisions may be necessary for the integration to converge completely for a rectangular blade. For tapered blades or swept tips, more radial divisions may be needed for complete convergence. If fewer divisions are used, the value of acoustic pressure will be in slight error. The convergence torque has been found to be an especially good indicator of convergence of the solution. Further, when the torque converges, additional panels will render little change in the solution.

The value of EPSLON determines the required accuracy of the retarded-time calculation. For small NPTS, EPSLON should be 1 percent or lower. For large NPTS, the time step is small and relatively large values of EPSLON can be used; however, there is little to be gained. The default value of 0.5 percent is recommended since it can be used with confidence for all values of NPTS, and only small computation time savings may result by changing EPSLON.

The variable TZERO is useful to start the computation of the pressure signature at a specific time. This can be used to combine time histories from separate sources, such as main rotor and tail rotor, that are calculated separately. TSTOP may be used if the complete blade passage is not of interest. Using TZERO and TSTOP together, all NPTS calculations of the pressure signature can be concentrated in a small time. The other program control variables in the namelist should not require any explanation beyond what has been given above. The program WOPWOP expects the namelist $INPUT on the file WOPIN. Also required after the namelist $INPUT are two identification lines in card image format. The first line contains IDENT - a 10-character case identifier. The second line contains TEXT - a 79-character case identifier. The namelist $INPUT along with these two additional lines may be repeated in the file for a multiple-case run. Output from the program is on a file WOPOUT, and if logical variable SAVE = .TRUE., plotting information is on a file WOPPLT.DAT.

As mentioned in the "Introduction," WOPWOP can be used to calculate the acoustic pressure for a propeller as well as for a helicopter. WOPWOP is especially suited to calculate the acoustic pressure accurately for a propeller in a nonaxisymmetric flow. To do this, the propeller blade need only be input as a helicopter blade and the flapping and lead-lag angles be set to 0 in the namelist input. Also, the feathering angle will usually be constant for a propeller. WOPWOP will calculate the noise radiation without flow field approximation.

WOPWOP COMMON BLOCKS

Several common blocks are used in the program WOPWOP that may be useful in writing the input subroutines FUNE2, FUNE2Q, and FUNPSI. These common blocks contain useful constants and program variables that may be needed in the input subroutines. Care must be taken to avoid changing the value of the common variable if the common block is used since a change may produce incorrect acoustic pressure predictions. Also, one must avoid using the same name for a variable that is passed through the argument list and through the common block even if the name contains the same value since multiple definitions of a variable in a FORTRAN subroutine are not allowed. All angle measures are in radians for each of the common blocks. Other common blocks are used in WOPWOP but they are not particularly useful in writing the input subroutines. A definition of the common blocks found in WOPWOP and a listing of the variables contained in these common blocks are given as follows:

COMMON /PI/ DTR, PI, RTD, TWOPI

Variable	Definition
DTR	degrees-to-radians conversion factor
PI	π
RTD	radians-to-degrees conversion factor
TWOPI	2π

COMMON /ETC/ C, RHO, ALPHAF, REV, PTIP, VH(3), OBS(3), RINNER, R, DOQUAD, CINV, OMEGA

Variable	Definition
CINV	$1/c_o$
OMEGA	rotor rotation rate, rad/sec

See definitions of other variables in "Input Data" section. Note that ALFHAF is in terms of radian measure.

COMMON /BYFUN/ AAE2, AAE2P, CH, CHP, CMBR, CMBRP, LED, LEDP, PCAD, PCADP, THK, THKP, TRAT, TRATP, CAT, CRATP

See definitions of these variables in the "Input Subroutines" section.

```
COMMON /ANGLES/ PSI, PSIP, CPSI, SPSI, C2PSI, S2PSI,
                A0, A1, B1, A2, B2, BETA, BETAP, BETAPP, CBETA, SBETA, CONB,
                EE0, EE1, FF1, EE2, FF2, ZETA, ZETAP, ZETAPP, CZETA, SZETA, CONZ,
                AA0, AA1, BB1, AA2, BB2, THETA, THETAP, THETPP, CTHETA, STHETA, CONT
```

Variable	Definition
PSI	ψ (azimuthal angle), rad
PSIP	$d\psi/dt$ (same as OMEGA), rad/sec
CPSI	$\cos(\psi)$
SPSI	$\sin(\psi)$
C2PSI	$\cos(2\psi)$
S2PSI	$\sin(2\psi)$
BETA	β (flapping angle), rad
BETAP	$d\beta/dt$, rad/sec
BETAPP	$d^2\beta/dt^2$, rad/sec^2
CBETA	$\cos(\beta)$
SBETA	$\sin(\beta)$
CONB	logical variable when .TRUE. β is constant
ZETA	ζ (lead-lag angle), rad
ZETAP	$d\zeta/dt$, rad/sec
ZETAPP	$d^2\zeta/dt^2$, rad/sec^2
CZETA	$\cos(\zeta)$
SZETA	$\sin(\zeta)$
CONZ	logical variable when .TRUE. ζ is constant
THETA	θ (feathering angle), rad
THETAP	$d\theta/dt$, rad/sec
THETPP	$d^2\theta/dt^2$, rad/sec^2
CTHETA	$\cos(\theta)$
STHETA	$\sin(\theta)$
CONT	logical variable when .TRUE. θ is constant

Other variables are defined in the "Input Data" section.

DESCRIPTION OF PROGRAM OUTPUT

The output data consist of a data sheet listing, pressure signature, and spectra listings for each case identified in the data file WOPIN. (See appendix B.) The data sheet is used to identify each case uniquely. The two-character string identifiers are used at the beginning of the data sheet. Only the 10-character identifier is used on later sections of the output. All the input variables related to the operating conditions, blade geometry, blade motion, and computational information are clearly indicated on the helicopter data sheet under the heading "Input Parameters." Useful quantities calculated during the program execution such as thrust, torque, power, and overall sound pressure level (OASPL) are indicated on the data sheet under the heading "Output Parameters." Also listed under the output parameters are the following variables:

DT	time increment for observer time
PERIOD	time for one blade passage
BPF	blade passage frequency
RMNO	rotational tip Mach number
VMNO	forward Mach number
HMNO	helical-tip Mach number

The computation time is included for each case on the data sheet.

Following the data sheet is a listing of the acoustic pressure signature. If the logical variable FULL = .TRUE., the near-field and far-field components of thickness and loading noise are listed. If FULL = .FALSE., only the overall pressure is printed (five values per line). If the logical variable CENTER = .TRUE., the original end point of the pressure signature is listed as END POINT and the pressure signature is rotated to center the maximum pressure.

The third section of the printed output contains the acoustic pressure spectra for as many harmonics as were specified. This section contains thickness and loading noise spectra only if the logical variable FULL = .TRUE. The acoustic spectra are not printed for the near-field and far-field components separately, although this information is calculated and retained for plotting if the logical variable SAVE = .TRUE.

Examples of the program output are given in appendix B. If the logical variable SAVE = .TRUE., the same output is saved in a condensed form in the data file WOPPLT.DAT for use in a plotting program. The format of the data in the file WOPPLT.DAT is given in appendix C.

PREDICTION EVALUATION

To validate the prediction that can be obtained from the program WOPWOP, two comparisons between experimental data have been included that illustrate the typical prediction that one can expect. Data from a 1/4-scale model tested in the Langley 4- by 7-Meter Tunnel are compared with the predictions made for the first and second example cases. The details of the experimental test may be found in references 11 and 12. Figure 5 shows a typical example in which thickness noise is known to dominate. In this case from reference 11, the helicopter has a forward speed of 100 knots with the observer located in the tip path plane at the location of microphone 4. In this case the rotor blade has an NACA 0012 airfoil section and a high advancing tip Mach number. Nonlinear effects certainly are important but are not included in this prediction.

A second comparison is shown in figure 6. In this case from reference 12, the forward speed is 60 knots and the observer location is below the rotor in the near-field at the location of microphone 2. At this observer location, loading noise is known to dominate. In this comparison, the agreement is not nearly as good; however, the aerodynamic loading model used is rather crude. The actual surface pressures were only approximated, based on the incompressible airfoil theory. The details of the aerodynamic model used for the prediction can be found in appendix B. Also in this case, blade-vortex interaction (BVI) is ignored in the aerodynamic model and, therefore, is not included in this prediction. This case is presented to show the importance of aerodynamic loading input in the loading noise prediction. With improved aerodynamic loading, the prediction is expected to be correspondingly improved.

CONCLUDING REMARKS

The computer program WOPWOP discussed in this report is based on one of many theoretical formulations available for the prediction of rotating blade noise. Farassat's formulation 1A was chosen because it is well-suited to helicopter rotor blades since realistic helicopter blade motions and arbitrary observer positions may be used. This formulation is a refinement of a previous subsonic formulation of Farassat, and for this reason the formulation should work well for research problems, such as blade-vortex interaction, since the numerical time differentiation previously led to numerical difficulties. Also, the formulation clearly identifies the source components of the acoustic radiation, which should help in the design of future rotors.

The program WOPWOP has incorporated the advances of formulation 1A into a versatile tool. Complicated blade designs and motions for advanced rotors can be specified quickly and easily. The rotor blade geometry used by the program can be changed by the rewriting of only two input subroutines. A wide variety of approximations to the rotor aerodynamics and dynamics can be used by modifying the input subroutines as well. Even three-dimensional, unsteady blade loadings can be used if they are available.

Comparisons of the program predictions with experimental data have been very encouraging; however, accurate rotor blade loading is needed for predictions in which the loading noise dominates the acoustic signature. Rotor blade loading will clearly be a key item for the accurate prediction of blade-vortex interaction. For very high speed flow on the rotor, formulation 1A will need to be modified to account for the nonlinear terms neglected in Farassat's derivation. One of Farassat's supersonic formulations could be used if supersonic helicopter rotors become prevalent in the future. It is hoped the WOPWOP will be benficial to users as a tool in rotor design and acoustic research.

NASA Langley Research Center
Hampton, VA 23665-5225
June 6, 1986

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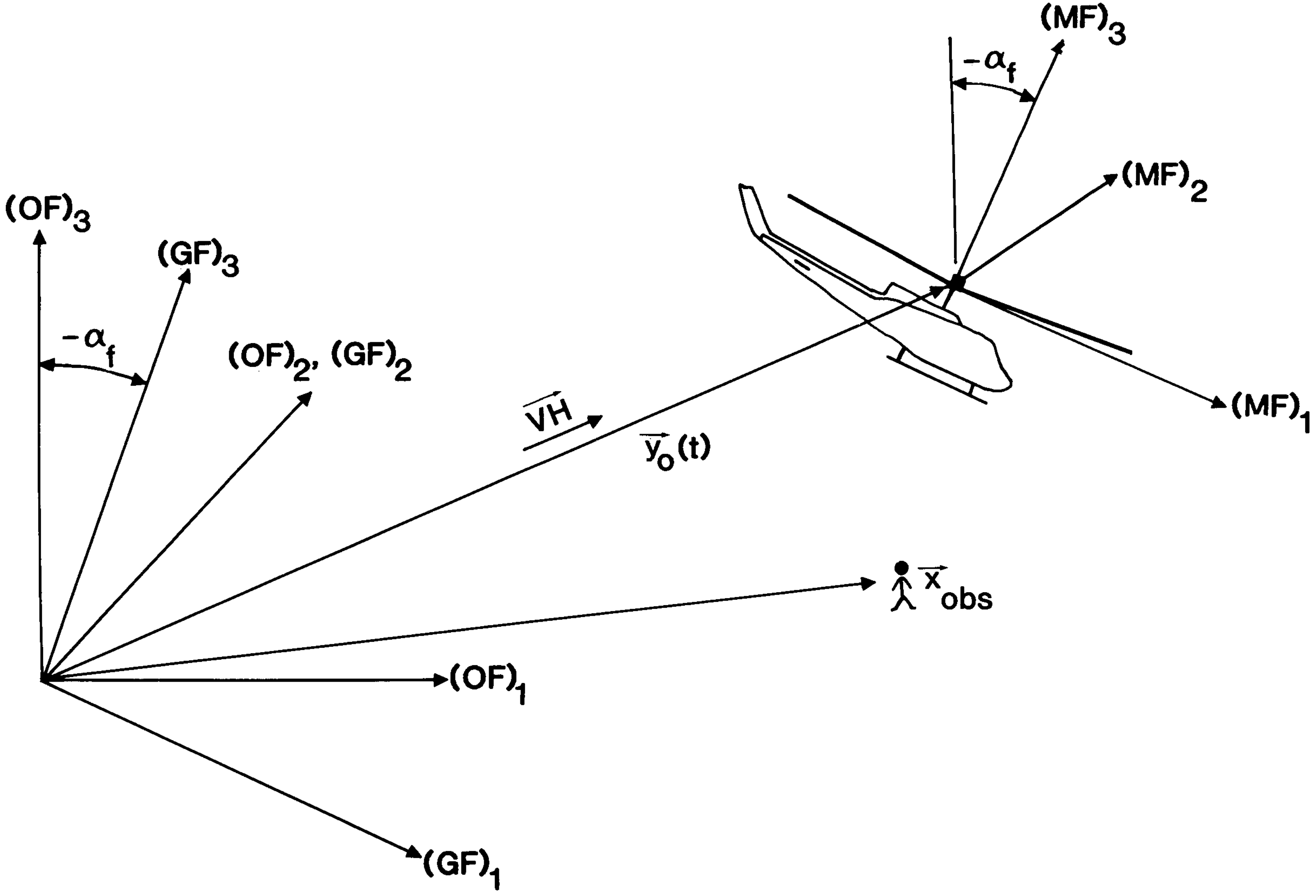
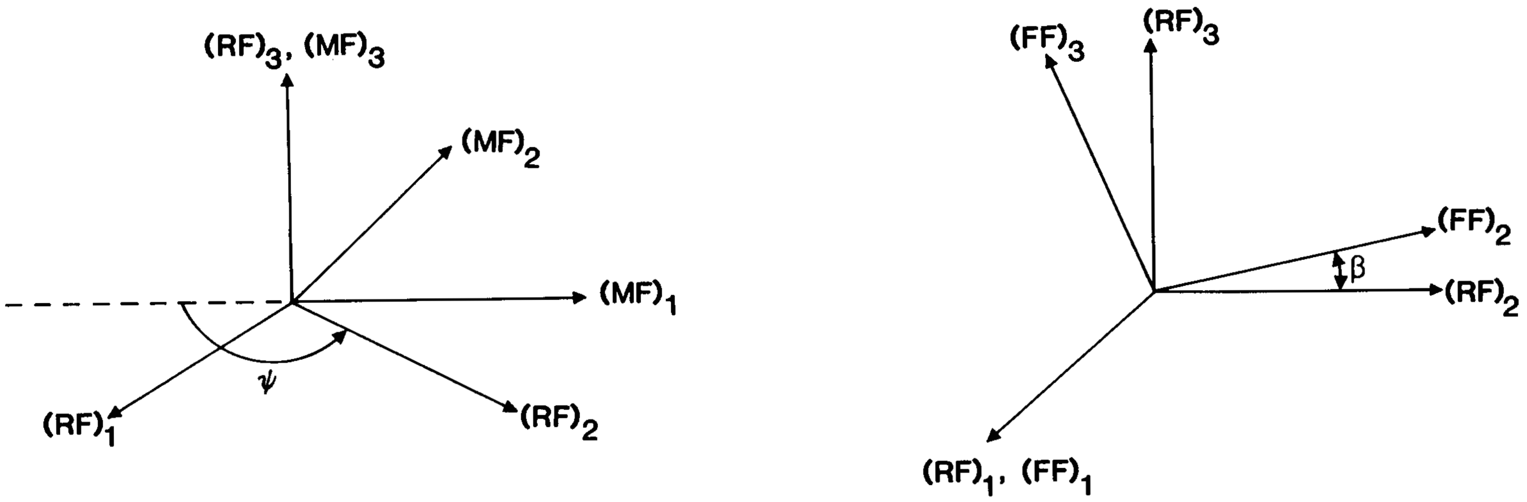
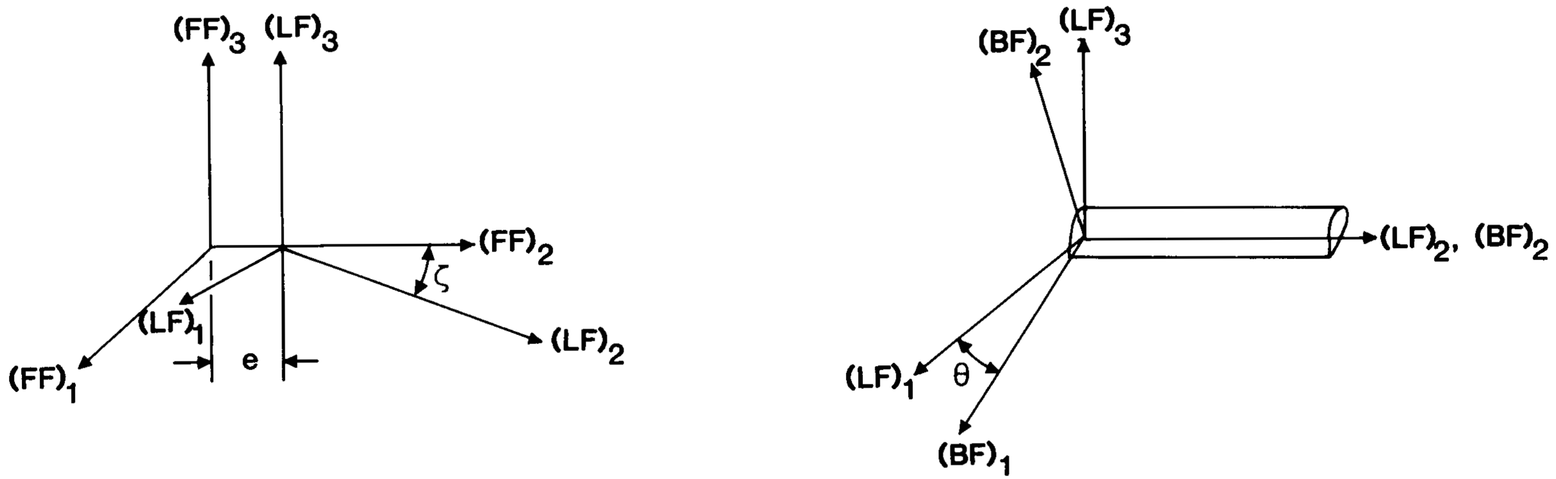


Figure 1.- Ground-fixed and observer reference frames defined.



(a) Moving frame to rotating frame.

(b) Rotating frame to flapping frame.



(c) Flapping frame to lead-lag frame.

(d) Lead-lag frame to blade-fixed frame.

Figure 2.- Intermediate reference frames.

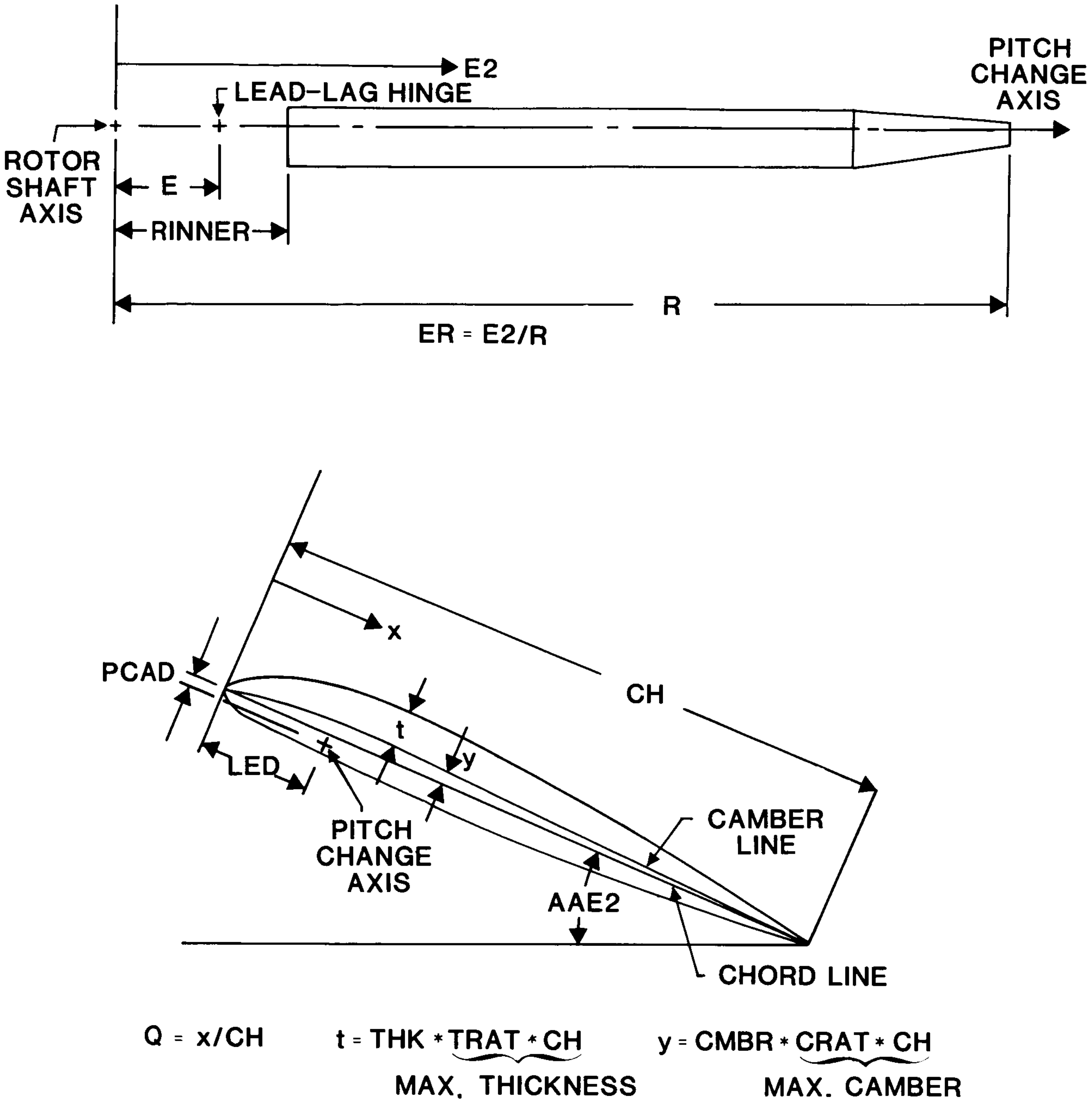


Figure 3.- Rotor geometry definition.

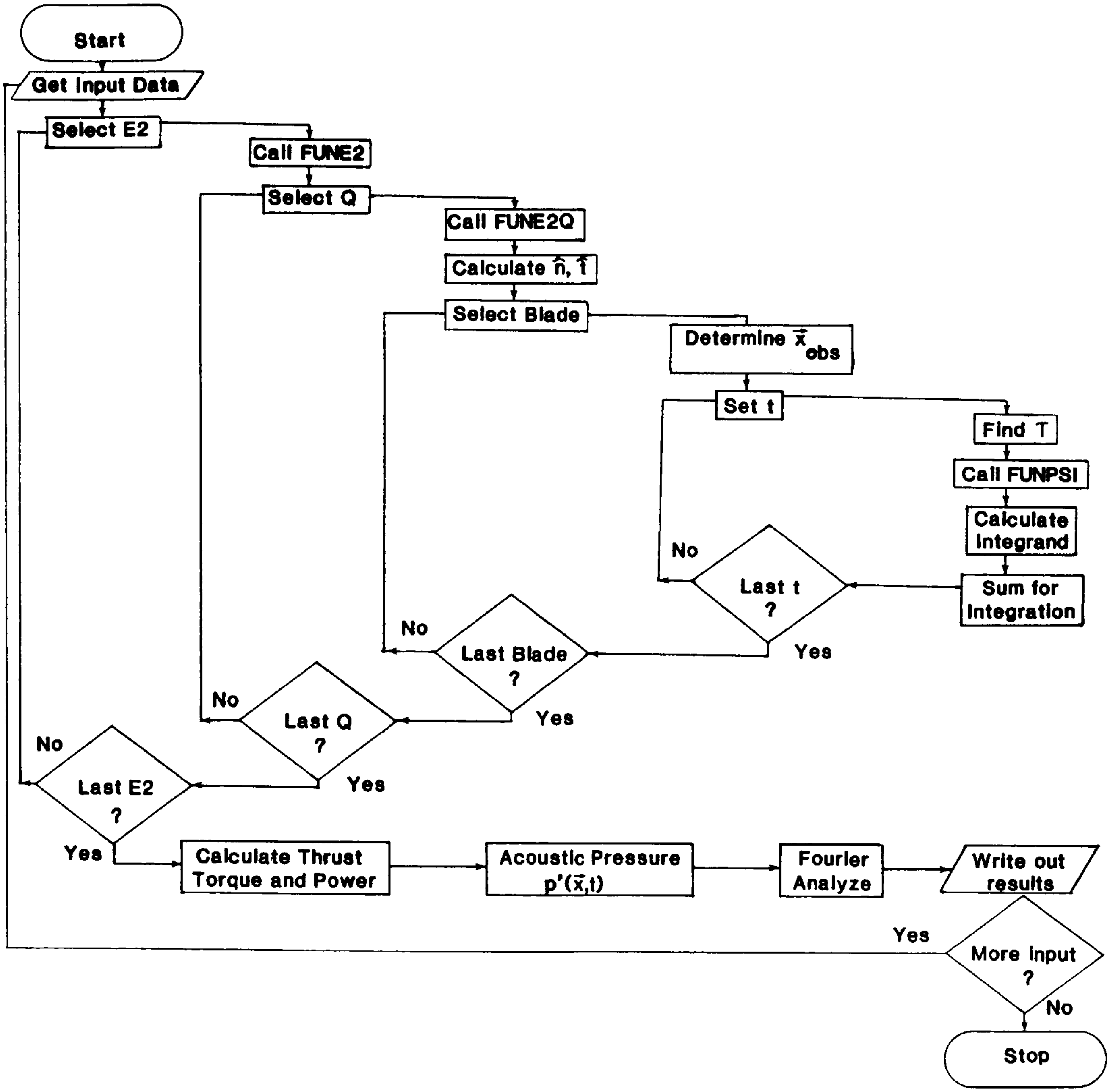


Figure 4.- Schematic flow chart of WOPWOP.

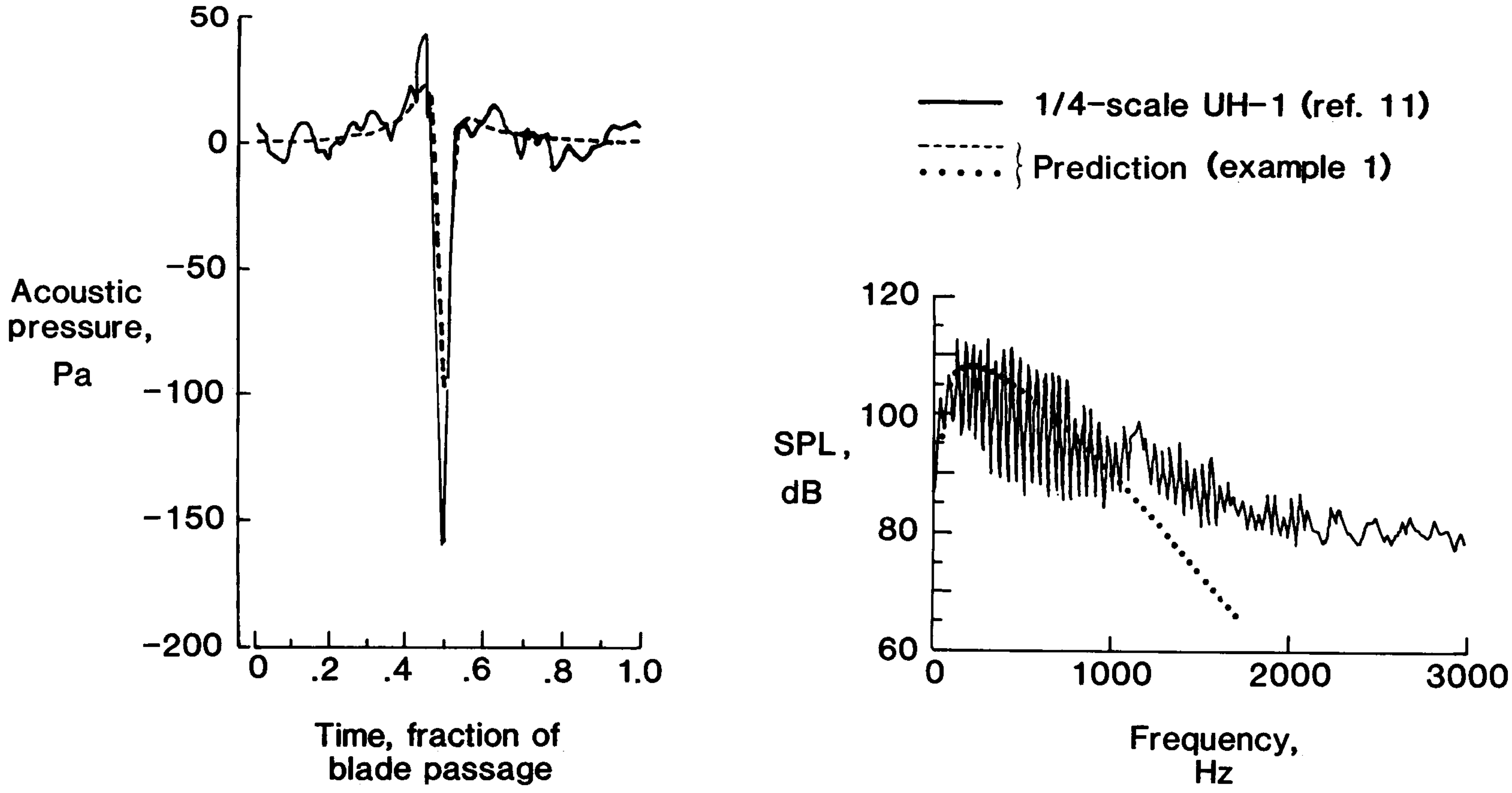


Figure 5.- Experimental data compared with prediction where thickness noise dominates in observer location. Tip Mach number, 0.86; forward speed, 100 knots.

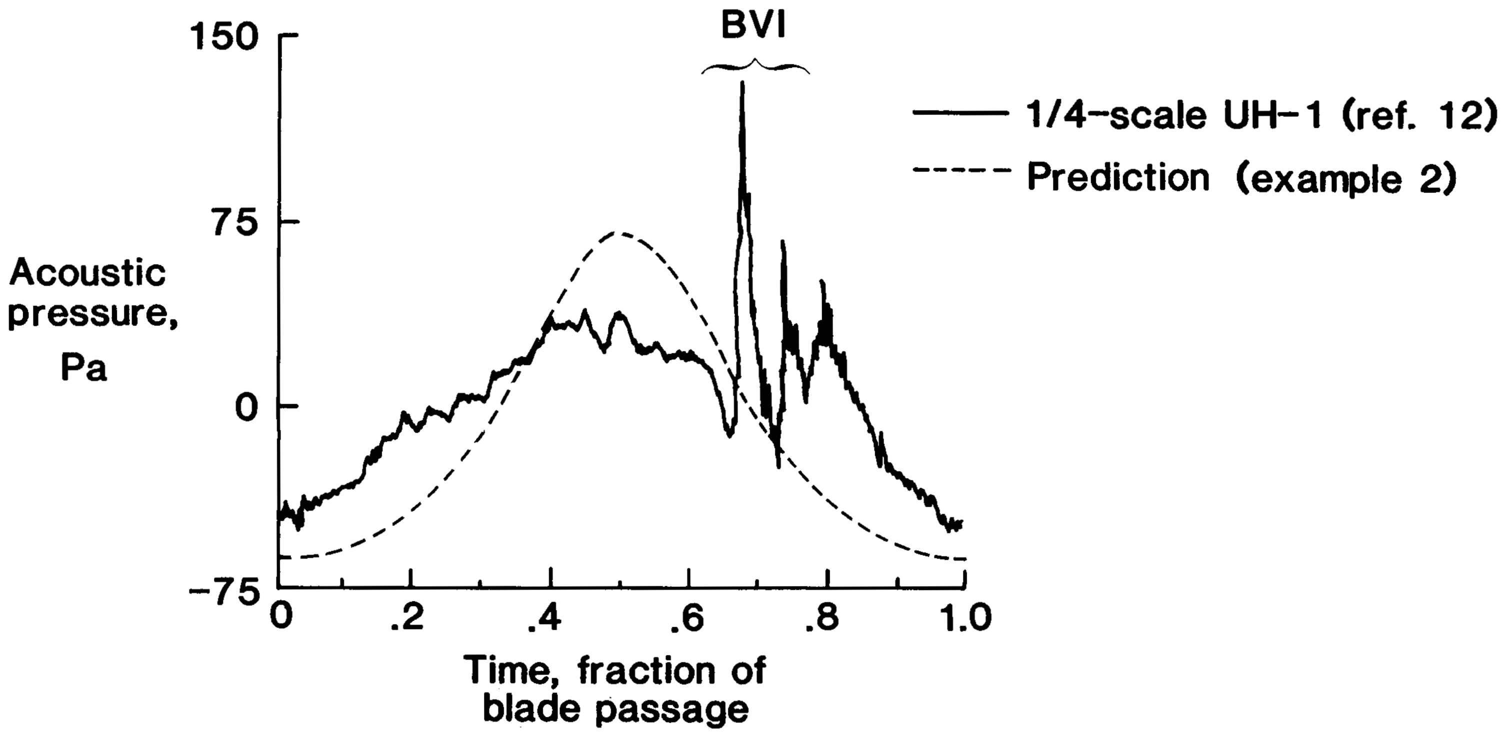


Figure 6.- Experimental data compared with prediction where loading noise dominates in observer location. Tip Mach number, 0.82; forward speed, 60 knots.

APPENDIX A

EXAMPLE OF EXECUTION PROCEDURE

This appendix presents an example procedure for the execution of the program WOPWOP. This procedure will be presented in a general outline form and then as a specific procedure for a VAX computer operating under VMS. The program is written in FORTRAN 77 and is quite transportable. The program has been run on a VAX-780 and Control Data CYBER 170 series computer at the Langley Research Center. The only machine-dependent code in WOPWOP is a system call to determine the time and data of execution. WOPWOP is normally run on a VAX-780 at the Langley Research Center. The outline of execution is as follows:

I Write input subroutines FUNE2, FUNE2Q, and FUNPSI.

II Compile input subroutines FUNE2, FUNE2Q, and FUNPSI with a FORTRAN 77 compatible compiler.

III Link WOPWOP, input subroutines, and any needed libraries.

IV Write a data file WOPIN for namelist input data.

V Execute WOPWOP:
  (1) Output will be in the data file WOPOUT.
  (2) Plot information for WOPPLT will be in the file WOPPLT.

* OPTIONAL *

VI Plot data using WOPPLT or comparable program.

This procedure would be written as follows for a VMS operating system:

```
              ┌ $ FOR FUNE2.FOR
              │ $ FOR FUNE2Q.FOR
Batch job     < $ FOR FUNPSI.FOR
              │ $ LINK WOPWOP,FUNE2,FUNE2Q,FUNPSI
              └ $ RUN WOPWOP

Interactive     $ RUN WOPPLT
```

It is assumed that the files FUNE2.FOR, FUNE2Q.FOR, FUNPSI.FOR, WOPIN.DAT, WOPWOP.OBJ, and WOPPLT.EXE are already in the default directory. The needed FORTRAN source code can be obtained in accordance with the policies of the Langley Research Center by contacting the author.

APPENDIX B

FOUR EXAMPLE CASES WITH PRINTED OUTPUT FROM WOPWOP

In this appendix four example cases are presented for reference. These cases illustrate the flexibility of the input subroutines and demonstrate how both tabular loading data and loading data in a functional form may be used as input for the program WOPWOP. These example cases all show some very realistic predictions that may be used to verify the code installation at other sites.

The example cases are representative of actual predictions made for a 1/4-scale UH-1 baseline main rotor. This rotor is a rectangular blade with linear twist distribution and NACA 0012 airfoil sections throughout. The pitch change axis is along the quarter-chord. In subroutines FUNE2 and FUNE2Q, the geometry of the UH-1 rotor blade is described. The first two cases uses a loading distribution by a separate computer code C81 (the AGAJ77 version). (See refs. 13, 14, and 15.) The third case uses a mathematical model for the loading that is appropriate for hover. The fourth case uses the same operating conditions and loading as the second case, but it has a stationary observer well below the rotor. The graphical output for the four example cases is presented in appendix D.

In the first two example cases the results from the quasi-steady aerodynamic analysis of code C81 are summarized as a table of section lift coefficients c_l (CL), section drag coefficients c_d (CD), and section Mach number M (MACH) as a function of radial and azimuthal location. The data used for these examples are listed after the input subroutines for completeness. The c_l, c_d, and M tables are interpolated to find their values at the desired location. The pressure distribution for each airfoil section is modeled based upon the lift coefficient of each section. This is done using the engineering application of thin wing sections described by Abbott and Von Doenhoff (ref. 16). A very simple compressibility correction is then used. This method assumes that the velocity distribution can be described as three independent components due to thickness, camber, and angle of attack. The total velocity distribution is related simply to the pressure distribution. The incompressible velocity distributions are listed for a variety of thickness distributions and mean lines in reference 16. The pressure model gives realistic results even though it was chosen for its simplicity. The viscous shear stress is modeled by assuming a uniform distribution over the entire blade section. The section drag is known since the drag coefficient is given.

The subroutines IUNI and IBI are Lagrangian interpolation subroutines for one- and two-dimensional data, respectively. Second-order interpolation is used. The subroutine CURV1 and functions CURV2 and CURVD are interpolation functions using splines under tension. In subroutine FUNE2, the tabular data are read from a data file and interpolation is done in FUNE2 and FUNE2Q as appropriate for economy in function evaluation. The actual evaluation of pressure and of the time derivative of pressure are completed in the subroutine FUNPSI. A description of the examples follows with a listing of input subroutines, input data, and written output.

EXAMPLE 1

The first example is for a 1/4-scale UH-1 main rotor with a forward speed of 100 knots. The observer location is in the tip path plane of the rotor. The precise flight conditions and computational information are seen in the input data file WOPIN and on the output data sheet. This is a case in which thickness noise is impulsive and dominates the overall noise.

```
      SUBROUTINE FUNE2 (E2,R,AAE2,AAE2P,CH,CHP,LED,LEDP,PCAD,PCADP,
     $                   TRAT,TRATP,CRAT,CRATP)
C
C     THIS SUBROUTINE IS AN INPUT TO THE HELICOPTER PROGRAM WOPWOP.
C     THE VARIABLES IT RETURNS ARE FUNCTIONS OF THE SPANWISE LOCATION
C     (E2) OR THE NORMALIZED SPANWISE LOCATION (ER=E2/R) ONLY.  THESE
C     VARIABLES ARE:
C
C     E2          SPANWISE LOCATION
C     ER          NORMALIZED SPANWISE LOCATION : RE. R
C     AAE2        ANGLE OF ATTACK, RADIANS
C     AAE2P       DERIVATIVE OF AAE2 WRT E2
C     CH          LOCAL CHORD, M.
C     CHP         DERIVATIVE OF CH WRT E2
C     LED         LEADING EDGE DISPLACEMENT, M.  (REAL VARIABLE)
C     LEDP        DERIVATIVE OF LED WRT E2       (REAL VARIABLE)
C     PCAD        PITCH CHANGE AXIS DISPLACEMENT (IN THE THICKNESS DIRECTION)
C     PCADP       DERIVATIVE OF PCAD WRT E2
C     TRAT        THICKNESS RATIO.
C     TRATP       DERIVATIVE OF TRAT WRT E2
C     CRAT        CAMBER RATIO.
C     CRATP       DERIVATIVE OF CRAT WRT E2
C
C     NOTE:  THE VALUE OF LED IS TYPICALLY NEGATIVE.
C
C - START OF FUNE2.
C
      PARAMETER( NPSI=13, NER=18, NPSI2=19 )
      COMMON /PI/ DTR, PI , RTD, TWOPI
      COMMON /FUN/ PSIA(NPSI), ERA(NER), CLPSI(NPSI), CDM(NPSI,2),
     $ PSIA2(NPSI2), CPUPSI(NPSI2), CPLPSI(NPSI2),CPUPP(NPSI2),
     $ CPLO(NPSI2)
      DIMENSION CD(NPSI,NER), CL(NPSI,NER), MACH(NPSI,NER)
      DIMENSION IORDER(2),IPT(2)
      INTEGER STA, PSI1, PSI2
      REAL MACH,MPSI,MACHINT
      REAL LED, LEDP
      LOGICAL FIRST
      DATA FIRST/.TRUE./, IORDER/2,2/, IPT/-1,0/
C
C - UH-1  BASELINE ROTOR
C
      ER= E2/R
C
C - LINEAR TWIST
C
      AAE2P= -10.9*DTR/R
      AAE2 = AAE2P*E2
C
C - CONSTANT CHORD
C
      CH= 0.1334
      CHP= 0.
```

```
C
C - PITCH CHANGE AXIS ON THE QUARTER CHORD
C
      LED= -.25*CH
      LEDP= 0.
      PCAD= 0.
      PCADP= 0.
C
C - 12% THICK AIRFOIL SECTION
C
      TRAT= 0.12
      TRATP= 0.
C
C - SYMMETRIC AIRFOIL
C
      CRAT= 0.
      CRATP= 0.
C
C - END OF FUNE2 GEOMETRY DEFINITIONS
C
C - READ IN DATA FROM C81 DATA FILE  ON FIRST TIME
C
      IF( FIRST ) THEN
C
C READ DATE FOR EXAMPLE CASE 1
C
          OPEN (FILE='C81_CASE1.DAT',STATUS='OLD',UNIT=IN, SHARED)
          DO 10 IPSI1 =1, NPSI-1, 2
              IPSI2 = IPSI1 + 1
C
C - READ AZIMUTH ANGLE
C
              READ( IN, 1000) SPACE
              READ( IN, 1005) PSI1, PSI2
              READ( IN, 1000) SPACE
              PSIA( IPSI1 ) = PSI1*DTR
              PSIA( IPSI2 ) = PSI2*DTR
C
C - READ BLADE ELEMENT DATA
C
              DO 20 I = 1,NER
                  READ(IN,1010) STA, ERA(STA),
     $            MACH(IPSI1,STA), CL(IPSI1,STA), CD(IPSI1,STA),
     $            MACH(IPSI2,STA), CL(IPSI2,STA), CD(IPSI2,STA)
 20           CONTINUE
 10       CONTINUE
C
C - VALUE AT TWOPI = VALUE AT ZERO
C
          DO 30 I = 1,NER
              MACH( 13, I) = MACH( 1, I)
              CL( 13, I) = CL( 1, I)
              CD( 13, I) = CD( 1, I)
 30       CONTINUE
          PSIA(13) = TWOPI
```

```
C
C - DONE READING DATA
C
          FIRST=.FALSE.
          CLOSE( IN )
      ENDIF
C
C - INTERPOLATE TO GET THE CL, CD, AND MACH ARRAYS AS A FUNCTION OF PSI,
C   HOLDING ER FIXED
C
      DO 40 I=1,NPSI
          FPSI = PSIA(I)
C
          CALL IBI(NPSI,PSIA,NER,ERA,NPSI,CL,IORDER,IPT, FPSI, ER,
     $    CLINT,IERR )
          IF( IERR.NE.0 .AND. IERR.NE.-3 ) THEN
              PRINT*,' AN ERROR OCCURRED IN INTERPOLATING CL IN IBI'
              PRINT*,' IERR = ',IERR
          ENDIF
          IF( IERR.EQ.-3 ) PRINT*,' EXTRAPOLATION PERFORMED ON CL'
          CLPSI(I) = CLINT
C
          CALL IBI(NPSI,PSIA,NER,ERA,NPSI,CD,IORDER,IPT, FPSI, ER,
     $    CDINT,IERR )
          IF( IERR.NE.0 .AND. IERR.NE.-3 ) THEN
              PRINT*,' AN ERROR OCCURRED IN INTERPOLATING CD IN IBI'
              PRINT*,' IERR = ',IERR
          ENDIF
          IF( IERR.EQ.-3 ) PRINT*,' EXTRAPOLATION PERFORMED ON CD'
          CDM(I,1) = CDINT
C
          CALL IBI(NPSI,PSIA,NER,ERA,NPSI,MACH,IORDER,IPT, FPSI, ER,
     $    MACHINT,IERR )
          IF( IERR.NE.0 .AND. IERR.NE.-3 ) THEN
              PRINT*,' AN ERROR OCCURRED IN INTERPOLATING MACH IN IBI'
              PRINT*,' IERR = ',IERR
          ENDIF
          IF( IERR.EQ.-3 ) PRINT*,' EXTRAPOLATION PERFORMED ON MACH'
          CDM(I,2) = MACHINT
 40   CONTINUE
C
C - END OF FUNE2
C
 1000 FORMAT (A1)
 1005 FORMAT (20X,I3,40X,I3)
 1010 FORMAT (1X,I2,3X,F5.3,2X,2(F5.3,1X,F8.4,1X,F8.5,20X) )
      RETURN
      END
```

```
      SUBROUTINE FUNE2Q
     $  ( E2, R, Q, CMBR, CMBRP, THK, THKP )
C
C     THIS SUBROUTINE IS AN INPUT TO THE HELICOPTER PROGRAM WOPWOP.
C     THE VARIABLES IT RETURNS ARE FUNCTIONS OF ONLY THE SPANWISE
C     LOCATION (E2) OR THE NORMALIZED SPANWISE LOCATION (ER = E2/R)
C     AND THE NORMALIZED CHORDWISE LOCATION (Q).  THESE VARIABLES ARE:
C
C     E2        SPANWISE LOCATION
C     ER        NORMALIZED SPANWISE LOCATION:  RE. - R
C     Q         NORMALIZED CHORDWISE LOCATION: RE. - CH
C     CMBR      NORMALIZED CAMBER AS MEASURED FROM THE MEAN CHORD LINE
C     CMBRP     DERIVATIVE OF CMBR WRT Q
C     THK       NORMALIZED THICKNESS AS MEASURED FROM THE CAMBER LINE
C     THKP      DERIVATIVE OF THK WRT Q
C
C - START OF FUNE2Q.
C
      PARAMETER( NPSI=13, NER=18, NXOC=19, NPSI2=19 )
      COMMON /PI/ DTR, PI , RTD, TWOPI
      COMMON /FUN/ PSIA(NPSI), ERA(NER), CLPSI(NPSI), CDM(NPSI,2),
     $ PSIA2(NPSI2), CPUPSI(NPSI2), CPLPSI(NPSI2),CPUPP(NPSI2),
     $ CPLO(NPSI2)
      DIMENSION XOC(NXOC),V12(NXOC),V12P(NXOC),DVA12(NXOC),TEMP(NPSI2),
     $  DVA12P(NXOC)
C
C -  THIS SUBROUTINE INTERPOLATES THE CL VALUE AND APPROXIMATES THE
C    SURFACE PRESSURE DISTRIBUTION BY THE METHOD OF VELOCITY ADDITION.
C    SEE ABBOTT AND VON DOENHOFF.
C
C    VELOCITIES FOR AN NACA 0012 AIRFOIL
C
      DATA XOC/0.,.005,.0125,.025,.05,.075,.1,.15,.2,.25,.3,.4,.5,
     $  .6,.7,.8,.9,.95,1./
      DATA V12/0.,.6,1.005,1.114,1.174,1.184,1.188,1.188,1.183,1.174,
     $  1.162,1.135,1.108,1.080,1.053,1.022,.978,.954,.9/
      DATA DVA12/1.988,1.475,1.005,.934,.685,.558,.479,.381,.319,.273,
     $  .239,.187,.149,.118,.092,.068,.044,.029,0./
      DATA IORDER/2/, IPT/-1/, NTAB/1/, ISLPSW/3/, SIGMA/5./
C
C - NACA 0012 AIRFOIL SECTION THICKNESS - UH-1 BASELINE ROTOR
C
      CMBR= 0.
      CMBRP= 0.
      THK= (.2969*SQRT(Q)+Q*(-.126+Q*(-.3516+Q*(.2843 -.1015*Q))))/.2
      IF( Q.GT.0 ) THEN
          THKP=(.1485/SQRT(Q)+(-.126+Q*(-.7032+Q*(.8529 -.4060*Q))))/.2
      ENDIF
C
C - ESTIMATE THE PRESSURE AS A FUNCTION OF PSI
C
C - VELOCITY DUE TO THICKNESS
C
      CALL IUNI(NXOC,NXOC,XOC,NTAB,V12,IORDER,Q,V1,IPT,IERR)
```

```
      IF( IERR.NE.0 .AND. IERR.NE.-4) THEN
          PRINT*,' INTERPOLATION ERROR IN IUNI FOR V12'
          PRINT*,' IERR = ',IERR
      ENDIF
      IF( IERR.EQ.-4 ) PRINT*,' EXTRAPOLATION FOR V12'
C
C - VELOCITY DUE TO ANGLE OF ATTACK
C
      CALL IUNI(NXOC,NXOC,XOC,NTAB,DVA12,IORDER,Q,V2,IPT,IERR)
      IF( IERR.NE.0 .AND. IERR.NE.-4) THEN
          PRINT*,' INTERPOLATION ERROR IN IUNI FOR DVA12'
          PRINT*,' IERR = ',IERR
      ENDIF
      IF( IERR.EQ.-4 ) PRINT*,' EXTRAPOLATION FOR DVA12'
C
C - CALCULATION OF PRESSURE COEFFICIENT
C   THE PERIODICITY OF PRESSURE IS USED TO INSURE SMOOTH DERIVATIVES NEAR
C   THE PSI=0 AND PSI =TWOPI.
C
      DO 10 I=1,NPSI+6
           IF( I.LE.3 )THEN
              K= 9+I
              PSIA2(I) = PSIA(K)- TWOPI
           ELSEIF( I.GT.16 ) THEN
              K= I-15
              PSIA2(I) = PSIA(K) + TWOPI
           ELSE
              K= I-3
              PSIA2(I) = PSIA(K)
           ENDIF
           CPUPSI(I) = 1. - ( V1 + V2*CLPSI(K) ) **2
           CPLPSI(I) = 1. - ( V1 - V2*CLPSI(K) ) **2
 10   CONTINUE
C
C - THESE CALLS ARE FOR INTERPOLATION PURPOSES - THIS IS ONLY NEEDED ONCE FOR
C   EACH ER AND Q VALUE.
C
      CALL CURV1(NPSI2,PSIA2,CPUPSI,SLP1,SLPN,ISLPSW,CPUPP,TEMP,
     $ SIGMA,IERR)
      IF( IERR.NE.0 ) PRINT*,' ERROR IN CURV1 FOR CPUPSI; IERR=',IERR
      CALL CURV1(NPSI2,PSIA2,CPLPSI,SLP1,SLPN,ISLSW,CPLO,TEMP,
     $ SIGMA,IERR)
      IF( IERR.NE.0 ) PRINT*,' ERROR IN CURV1 FOR CPLPSI; IERR=',IERR
C
C - END OF FUNE2Q.
C
      RETURN
      END
```

```
      SUBROUTINE FUNPSI (E2,RR, Q, PSI, SURFP, DP, SPU, SPL, SIGMAU,
     $   SIGMAL, DPCP, SPUP, SPLP, SIGUP, SIGLP )
C
C - THIS SUBROUTINE GIVES THE PRESSURE ON THE UPPER AND LOWER SURFACE AS A
C   FUNCTION OF SPANWISE POSITION (E2), CHORDWISE POSITION (Q), AND AZIMUTHAL
C   POSITION (PSI). IT RETURNS THE TIME DERIVATIVE OF PRESSURE ON THE UPPER AND
C   LOWER SURFACES.  A MEAN PRESSURE AND MEAN PRESSURE DERIVATIVE ARE ALSO
C   CALCULATED.  IF SURFP = .FALSE.  THE MEAN SURFACE IS USED.
C
C   SURFACE STRESSES AND THEIR DERIVATIVES MAY ALSO BE INPUT FOR THE UPPER AND
C   LOWER SURFACES IN SIGMAU, SIGMAL.
C
C   VARIABLES -
C
C    E2 -        SPANWISE LOCATION
C    ER -        NORMALIZED SPANWISE LOCATION - RE. - R
C    Q -         NORMALIZED CHORDWISE LOCATION - RE.- CH
C    PSI -       AZIMUTHAL ANGLE (RADIANS)
C    SURFP -     FLAG FOR MEAN SURFACE CALCULATION ( .TRUE. - FULL SURFACE)
C                                                  ( .FALSE.- MEAN SURFACE)
C    SPU -       UPPER SURFACE PRESSURE
C    SPL -       LOWER SURFACE PRESSURE
C    DP -        SPL - SPU
C    SPUP -      TIME DERIVATIVE OF SPU
C    SPLP -      TIME DERIVATIVE OF SPL
C    DPCP -      SPLP - SPUP
C    SIGMAU -    UPPER SURFACE STRESS TERM
C    SIGMAL -    LOWER SURFACE STRESS TERM
C    SIGUP -     TIME DERIVATIVE OF SIGMAU
C    SIGLP -     TIME DERIVATIVE OF SIGMAL
C
C - START OF COMMON BLOCK.
C
      PARAMETER( NPSI=13, NER=18, NPSI2=19 )
      COMMON /PI/ DTR, PI, RTD, TWOPI
      COMMON /ETC/ C, RHO, ALPHAF, REV, PTIP, VH(3), OBS(3), RINNER,
     $ R, DOQUAD, CINV, OMEGA
      COMMON /BYFUN/ AAE2, AAE2P,  CH,  CHP, CMBR, CMBRP,  LED, LEDP,
     $                PCAD, PCADP, THK, THKP, TRAT, TRATP, CRAT, CRATP
      COMMON /FUN/ PSIA(NPSI), ERA(NER), CLPSI(NPSI), CDM(NPSI,2),
     $ PSIA2(NPSI2), CPUPSI(NPSI2), CPLPSI(NPSI2),CPUPP(NPSI2),
     $ CPLO(NPSI2)
C
C - END OF COMMON BLOCK.
C
      DIMENSION CDMI(2)
      DATA IORDER/2/,NTAB/2/,IPT/-1/,SIGMA/5./
C
C - START OF FUNPSI.
C
      REAL MACH
      LOGICAL SURFP
      SURFP=.TRUE.
```

```
C
C - INTERPOLATE TO ESTIMATE SURFACE PRESSURE AND TIME DERIVATIVE
C
      CPU = CURV2(PSI,NPSI2,PSIA2,CPUPSI,CPUPP,SIGMA)
      CPL = CURV2(PSI,NPSI2,PSIA2,CPLPSI,CPLO,SIGMA)
      CPUP = CURVD(PSI,NPSI2,PSIA2,CPUPSI,CPUPP,SIGMA)*OMEGA
      CPLP = CURVD(PSI,NPSI2,PSIA2,CPLPSI,CPLO,SIGMA)*OMEGA
C
C - INTERPOLATE TO ESTIMATE MACH NO. AND DRAG COEFFICIENT
C
      CALL IUNI(NPSI,NPSI,PSIA,NTAB,CDM,IORDER,PSI,CDMI,IPT,IERR)
      IF( IERR.NE.0 .AND. IERR.NE.-4 ) THEN
          PRINT*,' ERROR IN IUNI FOR MPSI'
          PRINT*,' IERR =',IERR
      ENDIF
      IF( IERR.EQ.-4 ) PRINT*,' EXTRAPOLATION ON MPSI'
      CD = CDMI(1)
      MACH=CDMI(2)
C
C - CALCULATE DYNAMIC PRESSURE
C
      QDYN = .5*RHO*(C*MACH)**2
C
C - SPU = UPPER SURFACE PRESSURE - PO (GAUGE PRESSURE)
C - SPL = LOWER SURFACE PRESSURE - PO (GAUGE PRESSURE)
C
      SPU = CPU*QDYN
      SPL = CPL*QDYN
      DP = SPL - SPU
C
C - AND TIME DERIVATIVES
C
      SPUP= CPUP*QDYN
      SPLP= CPLP*QDYN
      DPCP= SPLP - SPUP
C
C - SURFACE STRESS ( APPROXIMATE USING DRAG COEFFICIENT )
C
      SIGMAU = .5*QDYN*CD
      SIGMAL = SIGMAU
      SIGUP = 0.
      SIGLP = 0.
C
C - END OF FUNPSI.
C
      RETURN
      END
```

Input from C81 Analysis

>>> PSI = 0 <<<

STA	ER	MACH	CL	CD
18	1.000	0.705	0.0000	0.00845
17	0.960	0.677	0.3507	0.00904
16	0.940	0.663	0.3717	0.00937
15	0.880	0.621	0.4337	0.00857
14	0.840	0.593	0.4743	0.00726
13	0.800	0.564	0.5117	0.00731
12	0.760	0.536	0.5422	0.00739
11	0.720	0.508	0.5653	0.00743
10	0.680	0.480	0.5957	0.00746
9	0.640	0.452	0.6268	0.00761
8	0.600	0.424	0.6553	0.00780
7	0.560	0.396	0.6808	0.00796
6	0.520	0.367	0.7041	0.00814
5	0.500	0.353	0.7146	0.00822
4	0.440	0.311	0.7341	0.00840
3	0.400	0.283	0.7446	0.00848
2	0.360	0.255	0.7519	0.00853
1	0.320	0.227	0.7508	0.00852

>>> PSI = 30 <<<

STA	ER	MACH	CL	CD
18	1.000	0.778	0.0000	0.01019
17	0.960	0.750	0.1716	0.00802
16	0.940	0.736	0.2027	0.00843
15	0.880	0.694	0.2881	0.00791
14	0.840	0.665	0.3337	0.00842
13	0.800	0.637	0.3769	0.00865
12	0.760	0.609	0.4194	0.00769
11	0.720	0.581	0.4620	0.00719
10	0.680	0.553	0.5004	0.00724
9	0.640	0.525	0.5324	0.00729
8	0.600	0.496	0.5587	0.00730
7	0.560	0.468	0.5938	0.00745
6	0.520	0.440	0.6266	0.00761
5	0.500	0.426	0.6421	0.00771
4	0.440	0.384	0.6846	0.00800
3	0.400	0.356	0.7109	0.00819
2	0.360	0.327	0.7299	0.00834
1	0.320	0.299	0.7435	0.00847

>>> PSI = 60 <<<

STA	ER	MACH	CL	CD
18	1.000	0.831	0.0000	0.02356
17	0.960	0.803	0.0013	0.01036
16	0.940	0.789	0.0384	0.00968
15	0.880	0.747	0.1406	0.00788
14	0.840	0.718	0.2037	0.00799
13	0.800	0.690	0.2610	0.00772
12	0.760	0.662	0.3096	0.00777
11	0.720	0.634	0.3546	0.00819
10	0.680	0.606	0.3991	0.00738
9	0.640	0.578	0.4445	0.00713
8	0.600	0.549	0.4855	0.00719
7	0.560	0.521	0.5211	0.00720
6	0.520	0.493	0.5514	0.00728
5	0.500	0.479	0.5705	0.00736
4	0.440	0.437	0.6247	0.00760
3	0.400	0.409	0.6582	0.00781
2	0.360	0.380	0.6896	0.00804
1	0.320	0.352	0.7193	0.00824

>>> PSI = 90 <<<

STA	ER	MACH	CL	CD
18	1.000	0.850	0.0000	0.03597
17	0.960	0.822	-0.0646	0.02011
16	0.940	0.808	-0.0363	0.01329
15	0.880	0.766	0.0712	0.00882
14	0.840	0.738	0.1388	0.00774
13	0.800	0.709	0.2027	0.00772
12	0.760	0.681	0.2593	0.00763
11	0.720	0.653	0.3083	0.00769
10	0.680	0.625	0.3548	0.00790
9	0.640	0.597	0.4015	0.00704
8	0.600	0.569	0.4486	0.00713
7	0.560	0.540	0.4903	0.00718
6	0.520	0.512	0.5259	0.00722
5	0.500	0.498	0.5413	0.00723
4	0.440	0.456	0.6013	0.00748
3	0.400	0.428	0.6391	0.00769
2	0.360	0.400	0.6749	0.00791
1	0.320	0.371	0.7099	0.00817

```
          >>> PSI = 120 <<<                               >>> PSI = 150 <<<
STA     ER     MACH      CL         CD          STA     ER     MACH      CL         CD
18    1.000   0.830    0.0000    0.02423        18    1.000   0.776    0.0000    0.00984
17    0.960   0.802   -0.0183    0.01051        17    0.960   0.748    0.1623    0.00795
16    0.940   0.788    0.0190    0.00926        16    0.940   0.734    0.1960    0.00826
15    0.880   0.746    0.1259    0.00783        15    0.880   0.692    0.2891    0.00790
14    0.840   0.718    0.1920    0.00782        14    0.840   0.664    0.3400    0.00856
13    0.800   0.689    0.2522    0.00766        13    0.800   0.636    0.3891    0.00878
12    0.760   0.661    0.3040    0.00762        12    0.760   0.607    0.4382    0.00773
11    0.720   0.633    0.3519    0.00813        11    0.720   0.579    0.4872    0.00727
10    0.680   0.605    0.3998    0.00733        10    0.680   0.551    0.5317    0.00733
 9    0.640   0.577    0.4487    0.00714         9    0.640   0.523    0.5652    0.00758
 8    0.600   0.549    0.4932    0.00721         8    0.600   0.495    0.6004    0.00748
 7    0.560   0.520    0.5312    0.00727         7    0.560   0.467    0.6435    0.00772
 6    0.520   0.492    0.5656    0.00733         6    0.520   0.438    0.6852    0.00800
 5    0.500   0.478    0.5868    0.00742         5    0.500   0.424    0.7056    0.00812
 4    0.440   0.436    0.6478    0.00775         4    0.440   0.382    0.7621    0.00845
 3    0.400   0.408    0.6865    0.00799         3    0.400   0.354    0.7955    0.00869
 2    0.360   0.380    0.7240    0.00823         2    0.360   0.326    0.8249    0.00903
 1    0.320   0.351    0.7563    0.00846         1    0.320   0.298    0.8514    0.00933

          >>> PSI = 180 <<<                               >>> PSI = 210 <<<
STA     ER     MACH      CL         CD          STA     ER     MACH      CL         CD
18    1.000   0.703    0.0000    0.00869        18    1.000   0.631    0.0000    0.01128
17    0.960   0.675    0.3810    0.00993        17    0.960   0.602    0.5652    0.00799
16    0.940   0.661    0.4058    0.01017        16    0.940   0.588    0.5827    0.00794
15    0.880   0.619    0.4803    0.00926        15    0.880   0.546    0.6299    0.00859
14    0.840   0.591    0.5295    0.00743        14    0.840   0.518    0.6635    0.00863
13    0.800   0.563    0.5693    0.00776        13    0.800   0.490    0.7013    0.00813
12    0.760   0.534    0.6018    0.00806        12    0.760   0.462    0.7420    0.00845
11    0.720   0.506    0.6360    0.00781        11    0.720   0.433    0.7742    0.00892
10    0.680   0.478    0.6778    0.00796        10    0.680   0.405    0.8152    0.00883
 9    0.640   0.450    0.7203    0.00824         9    0.640   0.377    0.8504    0.00920
 8    0.600   0.422    0.7570    0.00858         8    0.600   0.349    0.8797    0.00967
 7    0.560   0.394    0.7970    0.00862         7    0.560   0.321    0.9044    0.00993
 6    0.520   0.365    0.8310    0.00897         6    0.520   0.293    0.9305    0.00991
 5    0.500   0.351    0.8466    0.00923         5    0.500   0.279    0.9483    0.01001
 4    0.440   0.309    0.8876    0.00971         4    0.440   0.236    0.9997    0.01094
 3    0.400   0.281    0.9208    0.00986         3    0.400   0.208    1.0315    0.01255
 2    0.360   0.253    0.9579    0.01006         2    0.360   0.180    1.0604    0.01401
 1    0.320   0.225    0.9938    0.01064         1    0.320   0.152    1.0839    0.01522
```

>>> PSI = 240 <<<

STA	ER	MACH	CL	CD
18	1.000	0.578	0.0000	0.00859
17	0.960	0.549	0.6419	0.00881
16	0.940	0.535	0.6575	0.00891
15	0.880	0.493	0.7080	0.00818
14	0.840	0.465	0.7451	0.00852
13	0.800	0.437	0.7746	0.00897
12	0.760	0.409	0.8119	0.00889
11	0.720	0.380	0.8451	0.00911
10	0.680	0.352	0.8709	0.00955
9	0.640	0.324	0.8923	0.00980
8	0.600	0.296	0.9115	0.00981
7	0.560	0.268	0.9406	0.00997
6	0.520	0.240	0.9669	0.01010
5	0.500	0.226	0.9786	0.01017
4	0.440	0.183	1.0055	0.01124
3	0.400	0.155	1.0128	0.01160
2	0.360	0.127	1.0049	0.01121
1	0.320	0.099	0.9691	0.01012

>>> PSI = 270 <<<

STA	ER	MACH	CL	CD
18	1.000	0.559	0.0000	0.00858
17	0.960	0.530	0.6465	0.00848
16	0.940	0.516	0.6608	0.00851
15	0.880	0.474	0.7107	0.00819
14	0.840	0.446	0.7425	0.00848
13	0.800	0.418	0.7706	0.00869
12	0.760	0.390	0.8011	0.00865
11	0.720	0.362	0.8240	0.00889
10	0.680	0.333	0.8422	0.00922
9	0.640	0.305	0.8554	0.00938
8	0.600	0.277	0.8745	0.00955
7	0.560	0.249	0.8915	0.00971
6	0.520	0.221	0.9023	0.00976
5	0.500	0.207	0.9046	0.00978
4	0.440	0.165	0.8925	0.00971
3	0.400	0.136	0.8590	0.00941
2	0.360	0.108	0.7866	0.00875
1	0.320	0.080	0.6143	0.00779

>>> PSI = 300 <<<

STA	ER	MACH	CL	CD
18	1.000	0.579	0.0000	0.00770
17	0.960	0.551	0.5936	0.00812
16	0.940	0.536	0.6059	0.00814
15	0.880	0.494	0.6454	0.00772
14	0.840	0.466	0.6778	0.00796
13	0.800	0.438	0.7079	0.00815
12	0.760	0.410	0.7343	0.00830
11	0.720	0.382	0.7575	0.00842
10	0.680	0.353	0.7760	0.00857
9	0.640	0.325	0.7892	0.00871
8	0.600	0.297	0.7979	0.00883
7	0.560	0.269	0.8104	0.00895
6	0.520	0.241	0.8161	0.00900
5	0.500	0.227	0.8156	0.00900
4	0.440	0.185	0.7949	0.00880
3	0.400	0.157	0.7564	0.00856
2	0.360	0.129	0.6776	0.00809
1	0.320	0.101	0.4970	0.00729

>>> PSI = 330 <<<

STA	ER	MACH	CL	CD
18	1.000	0.632	0.0000	0.00980
17	0.960	0.604	0.4952	0.00785
16	0.940	0.590	0.5146	0.00738
15	0.880	0.548	0.5607	0.00763
14	0.840	0.520	0.5836	0.00770
13	0.800	0.492	0.6095	0.00752
12	0.760	0.463	0.6407	0.00770
11	0.720	0.435	0.6691	0.00789
10	0.680	0.407	0.6947	0.00804
9	0.640	0.379	0.7179	0.00820
8	0.600	0.351	0.7352	0.00834
7	0.560	0.323	0.7471	0.00846
6	0.520	0.295	0.7547	0.00855
5	0.500	0.280	0.7596	0.00858
4	0.440	0.238	0.7635	0.00860
3	0.400	0.210	0.7531	0.00854
2	0.360	0.182	0.7266	0.00837
1	0.320	0.154	0.6678	0.00805

Data File WOPIN

```
$INPUT
 NPTS=200,
 NSPEC=50,
 NSPAN=13,
 NLE=16,
 NTE=12,
 DOQUAD= .25,
 NBLADE= 2,
 R= 1.829, RINNER= 0.1554,
 A0=2.75,
 CENTER=.TRUE.,
 EPSLON=.5,
 FULL=.TRUE.,
 MOTION= .TRUE.,
 DOTIP= .FALSE.,
 A1=1.50, B1=-1.18,
 AA0=13.825, AA1=-2.20, BB1=1.47,
 ALPHAF=-8.85,
 REV= 1296.,
 VH= 51.5, 0., 0.,
 OBS= 3.213, -2.16, -0.3032 $
 Example 1
1/4 Scale UH-1 rotor; High speed impulsive noise; Loading from C81 (AGAJ77)
```

```
                          HELICOPTER DATA SHEET
                          ---------------------

29-JAN-86                                                         07:51:56

                                Example 1
1/4 Scale UH-1 rotor; High speed impulsive noise; Loading from C81 (AGAJ77)

INPUT PARAMETERS
----------------

    - OPERATING CONDITIONS                    - COMPUTATION INFORMATION

      C......... 340.00   M/SEC                 NPTS.............200
      RHO.......   1.2340 KG/M**3               NSPEC............ 50
      ALPHAF....  -8.85   DEG                   NSPAN............ 13
      REV.......1296.00   RPM                   NLE.............. 16
      PTIP......     0.00 PA                    NTE.............. 12
      TZERO.....0.0000000 SEC                   DOQUAD...........  0.2500
      VH...(   51.5,    0.0,    0.0 ) M/SEC     EPSLON...........  0.5000 %

      OBS..(    3.21,   -2.16,   -0.30 ) M  ( IN MOTION  )

    - BLADE GEOMETRY                            COEFFICIENTS ( DEG )
                                       -FLAPPING    -FEATHERING      -LAGGING
      RINNER...  0.155 M              A0...  2.75  AA0... 13.82   EE0...  0.00
      R........  1.829 M              A1...  1.50  AA1... -2.20   EE1...  0.00
      E........  0.000 M              B1... -1.18  BB1...  1.47   FF1...  0.00
      NBLADE...  2                    A2...  0.00  AA2...  0.00   EE2...  0.00
                                      B2...  0.00  BB2...  0.00   FF2...  0.00

OUTPUT PARAMETERS
-----------------

    - FORCES PER BLADE                        - TIME QUANTITIES
       (TIME AVERAGED)

      THRUST.......  1385.302 N                DT........  0.116 MSEC
      TORQUE.......    71.686 N-M              PERIOD.... 23.148 MSEC
      POWER........     9.729 KW               BPF....... 43.200 HZ
      POWER........    13.042 HP

    - OASPL   ( dB re 20 MICROPA )            - VELOCITIES

      THICKNESS...... 121.91 dB                RMNO..... 0.730
      LOADING........ 100.73 dB                VMNO..... 0.151
      OVERALL........ 121.74 dB                HMNO..... 0.880

EXECUTION TIME FOR NOISE CALCULATION -    1655.72 CPU SECONDS
```

PRESSURE SIGNATURES OF NOISE COMPONENTS

29-JAN-86 07:51:56

Example 1

POINT	-- THICKNESS NOISE --			-- LOADING NOISE --			-- OVERALL --
NUMBER	FAR	NEAR	COMBINED	FAR	NEAR	COMBINED	NOISE
		(PA)			(PA)		(PA)
1	0.87	0.15	1.025	-0.41	-0.28	-0.688	0.337
2	0.87	0.15	1.022	-0.39	-0.29	-0.678	0.345
3	0.87	0.15	1.020	-0.38	-0.29	-0.667	0.353
4	0.86	0.16	1.019	-0.36	-0.29	-0.657	0.362
5	0.86	0.16	1.018	-0.35	-0.30	-0.647	0.371
6	0.86	0.16	1.018	-0.34	-0.30	-0.637	0.381
7	0.86	0.16	1.019	-0.32	-0.30	-0.626	0.393
8	0.86	0.16	1.020	-0.31	-0.31	-0.615	0.405
9	0.86	0.16	1.022	-0.29	-0.31	-0.604	0.418
10	0.86	0.16	1.024	-0.28	-0.31	-0.592	0.432
11	0.86	0.16	1.028	-0.26	-0.32	-0.581	0.447
12	0.87	0.16	1.032	-0.25	-0.32	-0.568	0.464
13	0.87	0.17	1.037	-0.23	-0.32	-0.556	0.481
14	0.87	0.17	1.042	-0.21	-0.33	-0.542	0.500
15	0.88	0.17	1.049	-0.20	-0.33	-0.529	0.519
16	0.88	0.17	1.056	-0.18	-0.33	-0.515	0.541
17	0.89	0.17	1.064	-0.16	-0.34	-0.500	0.564
18	0.90	0.18	1.073	-0.15	-0.34	-0.486	0.587
19	0.90	0.18	1.083	-0.13	-0.34	-0.470	0.612
20	0.91	0.18	1.093	-0.11	-0.35	-0.453	0.640
21	0.92	0.18	1.105	-0.09	-0.35	-0.438	0.667
22	0.93	0.19	1.117	-0.07	-0.35	-0.421	0.696
23	0.94	0.19	1.131	-0.05	-0.35	-0.404	0.727
24	0.95	0.19	1.145	-0.03	-0.36	-0.385	0.760
25	0.96	0.20	1.161	-0.01	-0.36	-0.364	0.796
26	0.98	0.20	1.177	0.02	-0.36	-0.345	0.832
27	0.99	0.21	1.195	0.04	-0.36	-0.325	0.870
28	1.00	0.21	1.214	0.06	-0.37	-0.305	0.909
29	1.02	0.22	1.234	0.08	-0.37	-0.284	0.950
30	1.04	0.22	1.256	0.11	-0.37	-0.263	0.992
31	1.05	0.23	1.278	0.13	-0.37	-0.241	1.037
32	1.07	0.23	1.303	0.16	-0.38	-0.219	1.084
33	1.09	0.24	1.328	0.18	-0.38	-0.197	1.132
34	1.11	0.24	1.356	0.20	-0.38	-0.174	1.181
35	1.13	0.25	1.385	0.23	-0.38	-0.152	1.233
36	1.16	0.26	1.415	0.25	-0.38	-0.129	1.286
37	1.18	0.27	1.448	0.28	-0.38	-0.106	1.342
38	1.21	0.27	1.482	0.30	-0.39	-0.083	1.399
39	1.24	0.28	1.519	0.33	-0.39	-0.059	1.459
40	1.27	0.29	1.557	0.35	-0.39	-0.035	1.522
41	1.30	0.30	1.598	0.38	-0.39	-0.011	1.587
42	1.33	0.31	1.642	0.41	-0.39	0.014	1.655
43	1.36	0.32	1.687	0.43	-0.39	0.039	1.726
44	1.40	0.34	1.736	0.46	-0.40	0.064	1.800
45	1.44	0.35	1.788	0.49	-0.40	0.090	1.878

46	1.48	0.36	1.843	0.51	-0.40	0.116	1.959
47	1.52	0.38	1.901	0.54	-0.40	0.143	2.044
48	1.57	0.39	1.962	0.57	-0.40	0.170	2.133
49	1.62	0.41	2.028	0.60	-0.40	0.199	2.227
50	1.67	0.43	2.098	0.63	-0.40	0.227	2.325
51	1.73	0.45	2.172	0.66	-0.40	0.257	2.429
52	1.79	0.47	2.251	0.69	-0.40	0.288	2.539
53	1.85	0.49	2.335	0.72	-0.40	0.321	2.656
54	1.91	0.51	2.425	0.76	-0.40	0.354	2.780
55	1.99	0.54	2.521	0.80	-0.41	0.390	2.911
56	2.06	0.56	2.624	0.83	-0.41	0.428	3.052
57	2.14	0.59	2.734	0.87	-0.41	0.467	3.201
58	2.23	0.62	2.851	0.91	-0.41	0.509	3.360
59	2.32	0.66	2.978	0.96	-0.40	0.553	3.530
60	2.42	0.70	3.113	1.00	-0.40	0.599	3.712
61	2.52	0.74	3.259	1.05	-0.40	0.649	3.908
62	2.64	0.78	3.416	1.10	-0.40	0.698	4.114
63	2.76	0.83	3.586	1.15	-0.40	0.748	4.334
64	2.89	0.88	3.769	1.20	-0.40	0.802	4.570
65	3.03	0.94	3.967	1.25	-0.39	0.857	4.824
66	3.18	1.00	4.182	1.31	-0.39	0.915	5.097
67	3.35	1.07	4.416	1.36	-0.39	0.976	5.392
68	3.53	1.14	4.670	1.43	-0.39	1.040	5.710
69	3.72	1.23	4.948	1.49	-0.38	1.115	6.063
70	3.93	1.32	5.251	1.57	-0.37	1.195	6.446
71	4.16	1.42	5.584	1.65	-0.37	1.279	6.863
72	4.41	1.53	5.949	1.73	-0.36	1.371	7.321
73	4.69	1.66	6.352	1.82	-0.35	1.469	7.821
74	4.99	1.81	6.796	1.92	-0.34	1.574	8.370
75	5.32	1.97	7.288	2.02	-0.33	1.686	8.974
76	5.68	2.15	7.834	2.13	-0.32	1.807	9.641
77	6.08	2.36	8.443	2.24	-0.31	1.937	10.380
78	6.52	2.60	9.123	2.37	-0.29	2.082	11.205
79	7.01	2.88	9.885	2.51	-0.27	2.238	12.123
80	7.55	3.19	10.741	2.66	-0.25	2.412	13.153
81	8.14	3.57	11.706	2.82	-0.22	2.603	14.309
82	8.80	4.00	12.798	3.01	-0.19	2.820	15.618
83	9.52	4.52	14.034	3.21	-0.15	3.067	17.100
84	10.31	5.13	15.436	3.44	-0.10	3.346	18.783
85	11.16	5.87	17.028	3.70	-0.04	3.656	20.684
86	12.06	6.77	18.829	3.98	0.03	4.010	22.839
87	12.98	7.87	20.856	4.29	0.11	4.405	25.260
88	13.86	9.25	23.104	4.62	0.22	4.839	27.942
89	14.55	10.98	25.528	4.95	0.35	5.303	30.832
90	14.82	13.18	27.995	5.27	0.52	5.787	33.782
91	14.18	16.00	30.178	5.54	0.72	6.265	36.443
92	11.72	19.63	31.354	5.77	0.99	6.761	38.115
93	5.77	24.24	30.008	6.02	1.33	7.353	37.360
94	-6.67	29.82	23.143	6.29	1.77	8.059	31.202
95	-30.03	35.63	5.606	6.46	2.34	8.796	14.402
96	-68.14	39.29	-28.847	6.47	3.13	9.599	-19.249
97	-117.28	36.24	-81.045	6.03	4.09	10.113	-70.932
98	-159.41	22.50	-136.903	4.78	5.14	9.919	-126.984
99	-171.40	-0.03	-171.426	2.16	6.14	8.291	-163.135

100	-145.84	-23.52	-169.360	-1.76	6.61	4.842	-164.519
101	-95.83	-40.01	-135.842	-5.45	6.32	0.871	-134.971
102	-43.24	-46.25	-89.499	-7.41	5.42	-1.994	-91.493
103	-3.76	-44.28	-48.040	-7.66	4.34	-3.321	-51.360
104	18.92	-38.34	-19.421	-6.85	3.40	-3.444	-22.865
105	29.23	-31.69	-2.455	-5.70	2.72	-2.980	-5.434
106	32.47	-25.76	6.712	-4.78	2.28	-2.499	4.213
107	32.20	-20.90	11.303	-4.02	1.99	-2.038	9.266
108	30.40	-17.04	13.354	-3.41	1.78	-1.629	11.726
109	28.03	-14.00	14.027	-2.91	1.63	-1.280	12.747
110	25.56	-11.60	13.964	-2.51	1.52	-0.992	12.972
111	23.21	-9.68	13.523	-2.19	1.43	-0.759	12.765
112	21.05	-8.15	12.899	-1.92	1.35	-0.571	12.328
113	19.10	-6.90	12.201	-1.71	1.28	-0.424	11.778
114	17.37	-5.88	11.489	-1.53	1.22	-0.308	11.181
115	15.83	-5.03	10.794	-1.39	1.17	-0.219	10.575
116	14.47	-4.33	10.134	-1.27	1.12	-0.145	9.989
117	13.26	-3.74	9.515	-1.16	1.08	-0.088	9.427
118	12.19	-3.25	8.940	-1.08	1.03	-0.055	8.886
119	11.24	-2.83	8.409	-1.02	0.99	-0.031	8.378
120	10.39	-2.47	7.920	-0.96	0.94	-0.018	7.902
121	9.63	-2.16	7.469	-0.91	0.90	-0.010	7.460
122	8.94	-1.89	7.055	-0.88	0.86	-0.014	7.041
123	8.33	-1.66	6.673	-0.85	0.83	-0.022	6.652
124	7.78	-1.46	6.322	-0.82	0.79	-0.035	6.287
125	7.28	-1.28	5.998	-0.81	0.75	-0.053	5.945
126	6.83	-1.13	5.699	-0.79	0.72	-0.070	5.629
127	6.41	-0.99	5.423	-0.77	0.68	-0.088	5.334
128	6.04	-0.87	5.166	-0.76	0.65	-0.107	5.060
129	5.69	-0.77	4.929	-0.75	0.62	-0.127	4.802
130	5.38	-0.67	4.708	-0.73	0.59	-0.143	4.565
131	5.09	-0.59	4.503	-0.72	0.56	-0.163	4.340
132	4.83	-0.51	4.312	-0.72	0.53	-0.184	4.128
133	4.58	-0.45	4.133	-0.71	0.51	-0.203	3.930
134	4.35	-0.39	3.967	-0.70	0.48	-0.222	3.744
135	4.15	-0.34	3.811	-0.70	0.45	-0.243	3.568
136	3.95	-0.29	3.664	-0.69	0.43	-0.260	3.405
137	3.77	-0.24	3.527	-0.68	0.40	-0.279	3.249
138	3.60	-0.21	3.398	-0.68	0.38	-0.297	3.101
139	3.45	-0.17	3.277	-0.68	0.36	-0.316	2.961
140	3.30	-0.14	3.163	-0.67	0.34	-0.335	2.828
141	3.17	-0.11	3.055	-0.67	0.32	-0.353	2.702
142	3.04	-0.09	2.953	-0.67	0.30	-0.371	2.582
143	2.92	-0.06	2.857	-0.67	0.28	-0.389	2.468
144	2.81	-0.04	2.766	-0.66	0.26	-0.406	2.360
145	2.70	-0.02	2.679	-0.66	0.24	-0.424	2.256
146	2.60	-0.01	2.598	-0.66	0.22	-0.441	2.156
147	2.51	0.01	2.520	-0.66	0.20	-0.459	2.061
148	2.42	0.02	2.446	-0.66	0.19	-0.476	1.970
149	2.34	0.04	2.376	-0.66	0.17	-0.495	1.882
150	2.26	0.05	2.310	-0.66	0.15	-0.515	1.795
151	2.19	0.06	2.246	-0.67	0.13	-0.532	1.714
152	2.12	0.07	2.186	-0.67	0.12	-0.550	1.635
153	2.05	0.08	2.128	-0.67	0.10	-0.567	1.561
154	1.99	0.08	2.073	-0.67	0.09	-0.584	1.489

155	1.93	0.09	2.021	-0.67	0.07	-0.598	1.423
156	1.87	0.10	1.970	-0.67	0.06	-0.611	1.359
157	1.82	0.10	1.922	-0.67	0.05	-0.625	1.297
158	1.77	0.11	1.877	-0.67	0.04	-0.637	1.240
159	1.72	0.11	1.833	-0.68	0.02	-0.651	1.182
160	1.67	0.12	1.791	-0.68	0.01	-0.664	1.127
161	1.63	0.12	1.750	-0.68	0.00	-0.677	1.073
162	1.59	0.12	1.712	-0.68	-0.01	-0.690	1.022
163	1.55	0.13	1.675	-0.68	-0.02	-0.702	0.973
164	1.51	0.13	1.640	-0.68	-0.03	-0.713	0.926
165	1.47	0.13	1.606	-0.68	-0.04	-0.724	0.882
166	1.44	0.13	1.573	-0.68	-0.05	-0.735	0.839
167	1.41	0.14	1.542	-0.68	-0.06	-0.745	0.797
168	1.37	0.14	1.512	-0.68	-0.07	-0.754	0.758
169	1.34	0.14	1.483	-0.68	-0.08	-0.762	0.721
170	1.31	0.14	1.456	-0.68	-0.09	-0.770	0.685
171	1.29	0.14	1.429	-0.68	-0.10	-0.778	0.652
172	1.26	0.14	1.404	-0.67	-0.11	-0.782	0.622
173	1.24	0.14	1.380	-0.67	-0.12	-0.789	0.591
174	1.21	0.14	1.356	-0.67	-0.13	-0.794	0.563
175	1.19	0.15	1.334	-0.66	-0.13	-0.798	0.536
176	1.17	0.15	1.312	-0.66	-0.14	-0.800	0.512
177	1.15	0.15	1.292	-0.65	-0.15	-0.804	0.488
178	1.13	0.15	1.272	-0.65	-0.16	-0.806	0.467
179	1.11	0.15	1.254	-0.64	-0.16	-0.807	0.447
180	1.09	0.15	1.236	-0.64	-0.17	-0.807	0.428
181	1.07	0.15	1.219	-0.63	-0.18	-0.804	0.415
182	1.05	0.15	1.202	-0.62	-0.18	-0.805	0.398
183	1.04	0.15	1.187	-0.61	-0.19	-0.803	0.383
184	1.02	0.15	1.172	-0.60	-0.20	-0.801	0.371
185	1.01	0.15	1.158	-0.60	-0.20	-0.799	0.359
186	1.00	0.15	1.144	-0.59	-0.21	-0.795	0.349
187	0.98	0.15	1.132	-0.58	-0.21	-0.791	0.340
188	0.97	0.15	1.120	-0.57	-0.22	-0.787	0.333
189	0.96	0.15	1.109	-0.55	-0.22	-0.777	0.332
190	0.95	0.15	1.098	-0.54	-0.23	-0.773	0.325
191	0.94	0.15	1.088	-0.53	-0.24	-0.767	0.321
192	0.93	0.15	1.079	-0.52	-0.24	-0.760	0.319
193	0.92	0.15	1.070	-0.51	-0.25	-0.753	0.317
194	0.91	0.15	1.062	-0.49	-0.25	-0.746	0.317
195	0.90	0.15	1.055	-0.48	-0.26	-0.738	0.317
196	0.90	0.15	1.049	-0.47	-0.26	-0.730	0.318
197	0.89	0.15	1.043	-0.46	-0.27	-0.722	0.320
198	0.89	0.15	1.037	-0.44	-0.27	-0.714	0.323
199	0.88	0.15.	1.033	-0.43	-0.27	-0.705	0.327
200	0.88	0.15	1.028	-0.42	-0.28	-0.697	0.332
201	0.87	0.15	1.025	-0.41	-0.28	-0.688	0.337

END POINT

102	-43.16	-46.25	-89.414	-7.41	5.41	-1.998	-91.412

```
                    PRESSURE SPECTRA OF NOISE COMPONENTS
                    ------------------------------------
29-JAN-86                                                       07:51:56

                                 Example 1

--- HARMONIC -----   ------ OVERALL ------  THICKNESS    LOADING
NUMBER  FREQUENCY        LEVEL      PHASE  LEVEL  PHASE  LEVEL  PHASE
          (HZ)     (DB RE 20 UPA)   (DEG)   (DB)  (DEG)   (DB)  (DEG)

   1       43.20         99.2        63.5  102.5   85.2   95.5  -60.1
   2       86.40        106.6      -102.8  107.3  -94.7   91.2  141.8
   3      129.60        109.0        81.6  109.3   88.0   90.5  -21.1
   4      172.80        110.2       -94.3  110.3  -88.9   89.9  168.7
   5      216.00        110.8        89.6  110.8   94.4   89.3   -3.8
   6      259.20        111.0       -86.6  111.0  -82.2   88.6 -179.2
   7      302.40        111.0        97.2  111.0  101.2   87.9    4.4
   8      345.60        110.8       -79.1  110.8  -75.4   87.0 -172.9
   9      388.80        110.5       104.6  110.5  108.0   86.1    9.1
  10      432.00        110.0       -71.8  110.1  -68.5   85.2 -169.3
  11      475.20        109.5       111.9  109.6  114.9   84.3   12.2
  12      518.40        108.9       -64.5  109.1  -61.6   83.3 -166.6
  13      561.60        108.3       119.0  108.4  121.8   82.4   14.4
  14      604.80        107.6       -57.4  107.8  -54.7   81.5 -164.7
  15      648.00        106.9       126.2  107.0  128.8   80.7   16.2
  16      691.20        106.1       -50.3  106.3  -47.7   79.9 -162.9
  17      734.40        105.3       133.2  105.5  135.7   79.1   18.2
  18      777.60        104.4       -43.2  104.6  -40.8   78.3 -160.3
  19      820.80        103.6       140.3  103.8  142.8   77.5   21.1
  20      864.00        102.6       -36.1  102.9  -33.7   76.6 -157.5
  21      907.20        101.7       147.5  101.9  149.8   75.8   24.1
  22      950.40        100.7       -28.9  101.0  -26.6   74.9 -154.2
  23      993.60         99.7       154.7  100.0  157.0   74.0   27.7
  24     1036.80         98.7       -21.7   99.0  -19.4   73.1 -150.7
  25     1080.00         97.7       162.0   98.0  164.2   72.1   30.9
  26     1123.20         96.6       -14.3   96.9  -12.1   71.2 -147.5
  27     1166.40         95.5       169.5   95.8  171.6   70.2   33.8
  28     1209.60         94.3        -6.7   94.7   -4.7   69.2 -144.7
  29     1252.80         93.2       177.1   93.5  179.1   68.2   36.5
  30     1296.00         92.0         1.0   92.4    2.9   67.1 -142.3
  31     1339.20         90.8      -175.0   91.2 -173.3   66.1   38.7
  32     1382.40         89.5         9.0   90.0   10.6   65.1 -140.6
  33     1425.60         88.3      -166.9   88.7 -165.4   64.0   39.9
  34     1468.80         87.0        17.3   87.5   18.7   63.0 -139.6
  35     1512.00         85.7      -158.4   86.2 -157.2   61.9   40.9
  36     1555.20         84.3        26.0   84.8   27.0   61.0 -138.4
  37     1598.40         82.9      -149.4   83.5 -148.6   59.9   42.4
  38     1641.60         81.5        35.3   82.1   35.8   58.9 -136.6
  39     1684.80         80.0      -139.9   80.7 -139.5   57.8   44.6
  40     1728.00         78.6        45.2   79.2   45.3   56.8 -134.0
```

41	1771.20	77.0	-129.5	77.8	-129.7	55.8	47.9
42	1814.40	75.5	56.1	76.2	55.5	54.7	-130.3
43	1857.60	73.9	-118.1	74.6	-118.9	53.5	52.1
44	1900.80	72.2	68.2	73.0	67.0	52.4	-125.7
45	1944.00	70.5	-104.8	71.3	-106.7	51.0	55.3
46	1987.20	68.7	82.7	69.5	80.2	49.7	-122.3
47	2030.40	66.8	-88.8	67.6	-92.1	48.2	58.7
48	2073.60	64.8	100.8	65.6	96.7	46.6	-118.1
49	2116.80	62.6	-67.5	63.4	-72.7	45.0	63.9
50	2160.00	60.3	127.1	60.9	120.7	42.8	-117.0

EXAMPLE 2

The second example uses the same input subroutines as example 1. This case is different in that the forward speed is 60 knots and the observer location is located below the rotor just outside the right side of the helicopter in the tip path plane (TPP). This case is used to illustrate a near-field observer that is dominated by loading noise. (Note: The input subroutines will not be repeated here since they are the same as in example 1.)

Input from C81 Analysis

\>>> PSI = 0 <<<

STA	ER	MACH	CL	CD
18	1.000	0.705	0.0000	0.00742
17	0.960	0.677	0.2369	0.00747
16	0.940	0.663	0.2627	0.00746
15	0.880	0.621	0.3336	0.00753
14	0.840	0.592	0.3816	0.00698
13	0.800	0.564	0.4295	0.00706
12	0.760	0.536	0.4722	0.00712
11	0.720	0.508	0.5095	0.00713
10	0.680	0.480	0.5484	0.00727
9	0.640	0.451	0.5887	0.00744
8	0.600	0.423	0.6272	0.00762
7	0.560	0.395	0.6638	0.00786
6	0.520	0.367	0.6996	0.00811
5	0.500	0.353	0.7169	0.00823
4	0.440	0.310	0.7570	0.00854
3	0.400	0.282	0.7844	0.00873
2	0.360	0.254	0.8126	0.00897
1	0.320	0.226	0.8374	0.00920

\>>> PSI = 30 <<<

STA	ER	MACH	CL	CD
18	1.000	0.749	0.0000	0.00776
17	0.960	0.721	0.1434	0.00750
16	0.940	0.706	0.1760	0.00741
15	0.880	0.664	0.2613	0.00747
14	0.840	0.636	0.3104	0.00756
13	0.800	0.608	0.3588	0.00728
12	0.760	0.580	0.4094	0.00703
11	0.720	0.551	0.4565	0.00711
10	0.680	0.523	0.4983	0.00715
9	0.640	0.495	0.5351	0.00721
8	0.600	0.467	0.5782	0.00739
7	0.560	0.439	0.6198	0.00756
6	0.520	0.410	0.6599	0.00782
5	0.500	0.396	0.6793	0.00795
4	0.440	0.354	0.7352	0.00833
3	0.400	0.326	0.7658	0.00856
2	0.360	0.298	0.7932	0.00879
1	0.320	0.270	0.8274	0.00911

\>>> PSI = 60 <<<

STA	ER	MACH	CL	CD
18	1.000	0.781	0.0000	0.00887
17	0.960	0.752	0.0604	0.00789
16	0.940	0.738	0.0959	0.00767
15	0.880	0.696	0.1958	0.00738
14	0.840	0.668	0.2528	0.00747
13	0.800	0.640	0.3036	0.00749
12	0.760	0.611	0.3534	0.00739
11	0.720	0.583	0.4053	0.00703
10	0.680	0.555	0.4545	0.00711
9	0.640	0.527	0.4985	0.00716
8	0.600	0.499	0.5358	0.00721
7	0.560	0.471	0.5808	0.00740
6	0.520	0.442	0.6245	0.00759
5	0.500	0.428	0.6459	0.00774
4	0.440	0.386	0.7087	0.00814
3	0.400	0.358	0.7468	0.00840
2	0.360	0.330	0.7804	0.00865
1	0.320	0.301	0.8102	0.00894

\>>> PSI = 90 <<<

STA	ER	MACH	CL	CD
18	1.000	0.792	0.0000	0.01018
17	0.960	0.764	0.0235	0.00828
16	0.940	0.750	0.0602	0.00774
15	0.880	0.707	0.1645	0.00733
14	0.840	0.679	0.2259	0.00743
13	0.800	0.651	0.2800	0.00740
12	0.760	0.623	0.3304	0.00756
11	0.720	0.595	0.3821	0.00699
10	0.680	0.567	0.4344	0.00708
9	0.640	0.538	0.4816	0.00715
8	0.600	0.510	0.5229	0.00719
7	0.560	0.482	0.5650	0.00734
6	0.520	0.454	0.6105	0.00752
5	0.500	0.440	0.6328	0.00765
4	0.440	0.398	0.6980	0.00806
3	0.400	0.369	0.7396	0.00834
2	0.360	0.341	0.7762	0.00860
1	0.320	0.313	0.8093	0.00890

```
          >>> PSI = 120 <<<                              >>> PSI = 150 <<<
STA     ER     MACH      CL       CD           STA     ER     MACH      CL       CD
18   1.000   0.780   0.0000   0.00891         18   1.000   0.748   0.0000   0.00778
17   0.960   0.752   0.0575   0.00785         17   0.960   0.720   0.1590   0.00750
16   0.940   0.738   0.0936   0.00766         16   0.940   0.705   0.1927   0.00753
15   0.880   0.695   0.1953   0.00738         15   0.880   0.663   0.2809   0.00754
14   0.840   0.667   0.2535   0.00746         14   0.840   0.635   0.3328   0.00789
13   0.800   0.639   0.3055   0.00752         13   0.800   0.607   0.3847   0.00737
12   0.760   0.611   0.3568   0.00740         12   0.760   0.579   0.4383   0.00711
11   0.720   0.583   0.4103   0.00704         11   0.720   0.551   0.4879   0.00720
10   0.680   0.555   0.4608   0.00713         10   0.680   0.522   0.5314   0.00728
 9   0.640   0.526   0.5063   0.00718          9   0.640   0.494   0.5697   0.00735
 8   0.600   0.498   0.5445   0.00724          8   0.600   0.466   0.6169   0.00755
 7   0.560   0.470   0.5913   0.00744          7   0.560   0.438   0.6631   0.00785
 6   0.520   0.442   0.6370   0.00768          6   0.520   0.410   0.7083   0.00812
 5   0.500   0.428   0.6595   0.00783          5   0.500   0.396   0.7303   0.00825
 4   0.440   0.386   0.7257   0.00824          4   0.440   0.354   0.7904   0.00866
 3   0.400   0.358   0.7652   0.00850          3   0.400   0.325   0.8263   0.00905
 2   0.360   0.329   0.8011   0.00877          2   0.360   0.297   0.8601   0.00942
 1   0.320   0.301   0.8336   0.00917          1   0.320   0.269   0.9047   0.00978

          >>> PSI = 180 <<<                              >>> PSI = 210 <<<
STA     ER     MACH      CL       CD           STA     ER     MACH      CL       CD
18   1.000   0.704   0.0000   0.00776         18   1.000   0.660   0.0000   0.00850
17   0.960   0.676   0.2872   0.00771         17   0.960   0.632   0.3916   0.00866
16   0.940   0.662   0.3140   0.00788         16   0.940   0.618   0.4175   0.00822
15   0.880   0.619   0.3920   0.00807         15   0.880   0.576   0.4954   0.00729
14   0.840   0.591   0.4451   0.00716         14   0.840   0.547   0.5420   0.00737
13   0.800   0.563   0.4962   0.00726         13   0.800   0.519   0.5770   0.00764
12   0.760   0.535   0.5407   0.00737         12   0.760   0.491   0.6172   0.00755
11   0.720   0.507   0.5767   0.00748         11   0.720   0.463   0.6638   0.00786
10   0.680   0.479   0.6219   0.00757         10   0.680   0.435   0.7094   0.00816
 9   0.640   0.450   0.6688   0.00789          9   0.640   0.407   0.7518   0.00842
 8   0.600   0.422   0.7147   0.00818          8   0.600   0.378   0.7933   0.00863
 7   0.560   0.394   0.7579   0.00840          7   0.560   0.350   0.8308   0.00903
 6   0.520   0.366   0.7984   0.00868          6   0.520   0.322   0.8649   0.00949
 5   0.500   0.352   0.8174   0.00884          5   0.500   0.308   0.8807   0.00964
 4   0.440   0.310   0.8694   0.00952          4   0.440   0.266   0.9435   0.00998
 3   0.400   0.282   0.9101   0.00981          3   0.400   0.238   0.9889   0.01040
 2   0.360   0.253   0.9562   0.01005          2   0.360   0.210   1.0355   0.01275
 1   0.320   0.225   1.0036   0.01114          1   0.320   0.181   1.0831   0.01518
```

```
           >>> PSI = 240 <<<
STA    ER     MACH     CL        CD
18   1.000   0.628   0.0000   0.00857
17   0.960   0.600   0.4488   0.00719
16   0.940   0.586   0.4745   0.00724
15   0.880   0.544   0.5427   0.00739
14   0.840   0.515   0.5764   0.00759
13   0.800   0.487   0.6163   0.00754
12   0.760   0.459   0.6609   0.00784
11   0.720   0.431   0.7044   0.00812
10   0.680   0.403   0.7453   0.00834
 9   0.640   0.375   0.7839   0.00858
 8   0.600   0.347   0.8187   0.00888
 7   0.560   0.318   0.8498   0.00932
 6   0.520   0.290   0.8822   0.00963
 5   0.500   0.276   0.9024   0.00977
 4   0.440   0.234   0.9626   0.01008
 3   0.400   0.206   1.0023   0.01107
 2   0.360   0.178   1.0414   0.01305
 1   0.320   0.149   1.0797   0.01498
```

```
           >>> PSI = 270 <<<
STA    ER     MACH     CL        CD
18   1.000   0.617   0.0000   0.00795
17   0.960   0.589   0.4440   0.00715
16   0.940   0.574   0.4680   0.00720
15   0.880   0.532   0.5318   0.00728
14   0.840   0.504   0.5635   0.00737
13   0.800   0.476   0.6049   0.00750
12   0.760   0.448   0.6465   0.00774
11   0.720   0.420   0.6866   0.00800
10   0.680   0.391   0.7252   0.00823
 9   0.640   0.363   0.7596   0.00846
 8   0.600   0.335   0.7901   0.00869
 7   0.560   0.307   0.8165   0.00899
 6   0.520   0.279   0.8483   0.00930
 5   0.500   0.265   0.8650   0.00946
 4   0.440   0.222   0.9121   0.00982
 3   0.400   0.194   0.9399   0.00996
 2   0.360   0.166   0.9631   0.01008
 1   0.320   0.138   0.9788   0.01017
```

```
           >>> PSI = 300 <<<
STA    ER     MACH     CL        CD
18   1.000   0.629   0.0000   0.00789
17   0.960   0.601   0.3905   0.00705
16   0.940   0.587   0.4152   0.00706
15   0.880   0.544   0.4816   0.00716
14   0.840   0.516   0.5192   0.00718
13   0.800   0.488   0.5539   0.00729
12   0.760   0.460   0.5941   0.00746
11   0.720   0.432   0.6326   0.00765
10   0.680   0.403   0.6692   0.00788
 9   0.640   0.375   0.7046   0.00813
 8   0.600   0.347   0.7360   0.00835
 7   0.560   0.319   0.7618   0.00855
 6   0.520   0.291   0.7864   0.00875
 5   0.500   0.277   0.8008   0.00885
 4   0.440   0.234   0.8394   0.00922
 3   0.400   0.206   0.8597   0.00941
 2   0.360   0.178   0.8734   0.00954
 1   0.320   0.150   0.8767   0.00957
```

```
           >>> PSI = 330 <<<
STA    ER     MACH     CL        CD
18   1.000   0.661   0.0000   0.00748
17   0.960   0.633   0.3173   0.00762
16   0.940   0.619   0.3403   0.00755
15   0.880   0.577   0.4116   0.00703
14   0.840   0.548   0.4555   0.00710
13   0.800   0.520   0.4942   0.00713
12   0.760   0.492   0.5295   0.00719
11   0.720   0.464   0.5694   0.00736
10   0.680   0.436   0.6075   0.00751
 9   0.640   0.408   0.6437   0.00772
 8   0.600   0.379   0.6778   0.00797
 7   0.560   0.351   0.7119   0.00820
 6   0.520   0.323   0.7380   0.00840
 5   0.500   0.309   0.7493   0.00849
 4   0.440   0.267   0.7878   0.00875
 3   0.400   0.238   0.8111   0.00895
 2   0.360   0.210   0.8296   0.00913
 1   0.320   0.182   0.8410   0.00924
```

Data File WOPIN

```
$INPUT
 NPTS=80,
 NSPEC=20,
 NSPAN=13,
 NLE=16,
 NTE=12,
 DOQUAD= .25,
 NBLADE= 2,
 R= 1.829, RINNER= 0.1554,
 A0=2.75,
 CENTER=.TRUE.,
 EPSLON=.5,
 FULL=.TRUE.,
 MOTION= .TRUE.,
 DOTIP= .FALSE.,
 A1=-.266, B1=-.013,
 AA0=13.529, AA1=-1.607, BB1=1.440,
 ALPHAF=-8.0,
 REV= 1296.,
 VH= 30.9, 0., 0.,
 OBS= .4070, -.675, -.716  $
 Example 2
1/4 Scale UH-1 rotor; Near-field, out of TPP ; Loading from C81 (AGAJ77)
```

```
                              HELICOPTER DATA SHEET
                              ---------------------

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                                    Example 2
1/4 Scale UH-1 rotor; Near-field, out of TPP ; Loading from C81 (AGAJ77)

INPUT PARAMETERS
----------------

   - OPERATING CONDITIONS                      - COMPUTATION INFORMATION

     C......... 340.00   M/SEC                   NPTS............. 80
     RHO.......   1.2340 KG/M**3                 NSPEC............ 20
     ALPHAF....  -8.00   DEG                     NSPAN............ 13
     REV.......1296.00   RPM                     NLE.............. 16
     PTIP......     0.00 PA                      NTE.............. 12
     TZERO.....0.0000000 SEC                     DOQUAD...........  0.2500
     VH...(   30.9,    0.0,    0.0 ) M/SEC       EPSLON...........  0.5000 %

     OBS..(    0.41,   -0.68,   -0.72 ) M   ( IN MOTION   )


   - BLADE GEOMETRY                              COEFFICIENTS ( DEG )
                                          -FLAPPING     -FEATHERING      -LAGGING
     RINNER...  0.155 M                  A0...  2.75   AA0... 13.53   EE0...  0.00
     R........  1.829 M                  A1... -0.27   AA1... -1.61   EE1...  0.00
     E........  0.000 M                  B1... -0.01   BB1...  1.44   FF1...  0.00
     NBLADE...  2                        A2...  0.00   AA2...  0.00   EE2...  0.00
                                         B2...  0.00   BB2...  0.00   FF2...  0.00


OUTPUT PARAMETERS
-----------------

   - FORCES PER BLADE                          - TIME QUANTITIES
     (TIME AVERAGED)

     THRUST.......  1318.491 N                   DT........  0.289 MSEC
     TORQUE.......    80.618 N-M                 PERIOD.... 23.148 MSEC
     POWER........    10.941 KW                  BPF....... 43.200 HZ
     POWER........    14.666 HP

   - OASPL  ( dB re 20 MICROPA )               - VELOCITIES

     THICKNESS...... 109.56 dB                   RMNO..... 0.730
     LOADING........ 128.36 dB                   VMNO..... 0.091
     OVERALL........ 127.45 dB                   HMNO..... 0.820

EXECUTION TIME FOR NOISE CALCULATION -     692.55 CPU SECONDS
```

```
                   PRESSURE SIGNATURES OF NOISE COMPONENTS
                   ---------------------------------------
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                                  Example 2

POINT     -- THICKNESS NOISE --          -- LOADING NOISE --         -- OVERALL -

NUMBER    FAR      NEAR     COMBINED       FAR      NEAR     COMBINED       NOISE
          ----------------------------      ----------------------------     -----
                   (PA)                              (PA)                     (PA)

   1      1.22     2.15       3.372        9.81    24.50      34.311       37.682
   2      1.24     2.12       3.353        9.88    24.74      34.612       37.965
   3      1.25     2.09       3.341        9.96    25.13      35.087       38.428
   4      1.27     2.06       3.334       10.05    25.67      35.716       39.050
   5      1.29     2.04       3.331       10.14    26.36      36.497       39.828
   6      1.30     2.03       3.331       10.22    27.20      37.419       40.750
   7      1.31     2.02       3.333       10.26    28.20      38.458       41.792
   8      1.32     2.01       3.336       10.25    29.35      39.599       42.935
   9      1.33     2.01       3.339       10.17    30.65      40.815       44.153
  10      1.33     2.01       3.338       10.07    32.11      42.181       45.518
  11      1.32     2.01       3.332       10.03    33.74      43.763       47.095
  12      1.31     2.01       3.318       10.02    35.55      45.571       48.889
  13      1.29     2.01       3.292       10.06    37.56      47.618       50.910
  14      1.25     2.00       3.251       10.13    39.79      49.922       53.173
  15      1.21     1.98       3.188       10.25    42.06      52.310       55.499
  16      1.15     1.95       3.099       10.39    44.79      55.176       58.275
  17      1.07     1.91       2.976       10.56    47.85      58.413       61.390
  18      0.97     1.84       2.812       10.78    51.23      62.010       64.822
  19      0.84     1.75       2.597       11.02    54.96      65.985       68.582
  20      0.69     1.63       2.321       11.32    59.05      70.372       72.693
  21      0.51     1.46       1.973       11.70    63.53      75.229       77.202
  22      0.29     1.25       1.539       12.07    68.42      80.488       82.027
  23      0.04     0.97       1.008       12.40    73.75      86.149       87.157
  24     -0.25     0.62       0.365       12.73    79.50      92.228       92.593
  25     -0.58     0.18      -0.400       13.04    85.68      98.713       98.313
  26     -0.95    -0.35      -1.298       13.35    92.26     105.613      104.315
  27     -1.36    -0.98      -2.334       13.67    99.68     113.351      111.017
  28     -1.79    -1.71      -3.506       14.00   107.04     121.031      117.526
  29     -2.25    -2.55      -4.804       14.31   114.54     128.848      124.044
  30     -2.72    -3.49      -6.207       14.56   122.14     136.690      130.483
  31     -3.18    -4.50      -7.681       14.75   129.67     144.421      136.740
  32     -3.61    -5.56      -9.176       15.07   136.98     152.055      142.879
  33     -4.00    -6.63     -10.630       15.65   143.95     159.598      148.968
  34     -4.33    -7.64     -11.968       16.45   150.38     166.827      154.859
  35     -4.57    -8.54     -13.109       17.40   156.09     173.490      160.381
  36     -4.72    -9.25     -13.974       18.40   160.88     179.279      165.305
  37     -4.77    -9.73     -14.494       19.38   164.53     183.914      169.419
  38     -4.71    -9.92     -14.621       20.15   166.68     186.830      172.208
  39     -4.54    -9.79     -14.332       20.49   167.68     188.176      173.843
  40     -4.29    -9.34     -13.636       20.55   167.13     187.676      174.040
  41     -3.97    -8.60     -12.572       20.51   165.16     185.674      173.102
  42     -3.59    -7.61     -11.206       20.56   161.88     182.444      171.237
  43     -3.18    -6.44      -9.621       20.86   157.47     178.337      168.716
  44     -2.76    -5.15      -7.905       21.58   152.15     173.723      165.819
  45     -2.34    -3.81      -6.146       22.45   146.15     168.592      162.446
```

46	-1.93	-2.49	-4.422	23.19	139.66	162.850	158.428
47	-1.55	-1.25	-2.794	23.56	132.85	156.403	153.609
48	-1.19	-0.11	-1.307	23.56	125.83	149.394	148.087
49	-0.88	0.89	0.013	23.18	118.75	141.925	141.938
50	-0.59	1.75	1.151	22.50	111.64	134.132	135.283
51	-0.35	2.45	2.109	21.63	104.42	126.052	128.161
52	-0.13	3.02	2.895	20.65	97.16	117.810	120.704
53	0.06	3.47	3.522	19.73	90.77	110.495	114.016
54	0.21	3.79	4.008	18.83	84.73	103.563	107.571
55	0.35	4.02	4.371	17.98	79.05	97.034	101.406
56	0.46	4.17	4.631	17.20	73.74	90.942	95.573
57	0.56	4.24	4.803	16.49	68.80	85.286	90.090
58	0.64	4.26	4.905	15.84	64.22	80.055	84.960
59	0.71	4.24	4.950	15.17	59.97	75.145	80.094
60	0.77	4.18	4.949	14.59	56.05	70.640	75.589
61	0.81	4.10	4.913	14.07	52.45	66.522	71.435
62	0.86	4.00	4.852	13.58	49.14	62.724	67.576
63	0.89	3.88	4.771	13.11	46.12	59.232	64.003
64	0.92	3.76	4.677	12.67	43.35	56.016	60.692
65	0.94	3.63	4.574	12.24	40.76	53.006	57.580
66	0.97	3.50	4.466	11.83	38.58	50.405	54.871
67	0.99	3.37	4.357	11.47	36.47	47.947	52.304
68	1.00	3.24	4.249	11.16	34.58	45.739	49.988
69	1.02	3.12	4.143	10.88	32.88	43.763	47.906
70	1.04	3.00	4.040	10.64	31.37	42.009	46.049
71	1.05	2.89	3.945	10.44	30.02	40.462	44.406
72	1.07	2.79	3.856	10.27	28.84	39.104	42.961
73	1.08	2.69	3.774	10.12	27.81	37.930	41.703
74	1.10	2.60	3.697	10.00	26.92	36.922	40.620
75	1.12	2.51	3.627	9.89	26.19	36.078	39.706
76	1.13	2.43	3.565	9.81	25.59	35.399	38.964
77	1.15	2.36	3.512	9.75	25.14	34.893	38.406
78	1.17	2.30	3.466	9.73	24.83	34.564	38.030
79	1.18	2.24	3.428	9.73	24.66	34.394	37.822
80	1.20	2.19	3.396	9.76	24.59	34.352	37.748
81	1.22	2.15	3.372	9.81	24.50	34.311	37.682
END POINT							
63	0.89	3.88	4.771	13.11	46.12	59.230	64.001

```
                    PRESSURE SPECTRA OF NOISE COMPONENTS
                    ------------------------------------
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                               Example 2

--- HARMONIC -----  ------ OVERALL ------   THICKNESS    LOADING
NUMBER  FREQUENCY       LEVEL      PHASE  LEVEL  PHASE  LEVEL  PHASE
          (HZ)    (DB RE 20 UPA)   (DEG)   (DB)  (DEG)   (DB)  (DEG)

   1      43.20         127.2      -86.8  107.6  112.6  128.0  -85.0
   2      86.40         115.0       96.1  104.3  -59.3  117.1  101.6
   3     129.60         101.4      -77.8   97.3  130.2  105.3  -67.1
   4     172.80          82.8       84.1   88.8  -40.2   91.4  121.9
   5     216.00          72.9       13.7   79.5  149.3   82.3  -16.9
   6     259.20          81.4     -147.7   69.7  -21.5   82.8 -158.0
   7     302.40          80.8       14.6   59.4  168.0   81.4   12.6
   8     345.60          80.5     -169.8   49.2   -3.9   80.7 -170.2
   9     388.80          76.8        6.3   38.0 -174.5   76.9    6.3
  10     432.00          71.5     -166.1   28.1   24.6   71.5 -166.1
  11     475.20          55.8      162.0   19.6  164.9   55.7  162.0
  12     518.40          56.4       41.0   14.7  139.9   56.4   40.6
  13     561.60          52.0      179.0   16.1 -166.3   51.9  178.8
  14     604.80          57.8     -169.6   14.5 -120.1   57.7 -169.9
  15     648.00          61.1       14.2   16.3  -87.2   61.1   14.5
  16     691.20          57.7     -141.3   13.4  -53.7   57.7 -141.7
  17     734.40          57.3      -95.6   12.2   -4.2   57.3  -95.9
  18     777.60          59.6      102.6   11.2   35.7   59.6  102.8
  19     820.80          58.3     -127.3    8.3   64.2   58.3 -127.3
  20     864.00          54.5      -14.6    0.1  111.0   54.5  -14.7
```

EXAMPLE 3

The third example shows the usage of functional form of loading. In this hovering case, the section lift coefficient is calculated based upon a thrust coefficient $C_T = 0.0028$. The drag coefficient is approximated using a parabolic relationship between lift and drag. These models can be seen as they are implemented in the subroutine FUNPSI. This case also illustrates the program options FULL = .FALSE. and MOTION = .FALSE.

```
      SUBROUTINE FUNE2 (E2,R,AAE2,AAE2P,CH,CHP,LED,LEDP,PCAD,PCADP,
     $                  TRAT,TRATP,CRAT,CRATP)
C
C     THIS SUBROUTINE IS AN INPUT TO THE HELICOPTER PROGRAM WOPWOP.
C     THE VARIABLES IT RETURNS ARE FUNCTIONS OF THE SPANWISE LOCATION
C     (E2) OR THE NORMALIZED SPANWISE LOCATION (ER=E2/R) ONLY.  THESE
C     VARIABLES ARE:
C
C
C     E2         SPANWISE LOCATION
C     ER         NONDIMENSIONAL SPANWISE LOCATION - RE. - R
C     AAE2       ANGLE OF ATTACK, RADIANS
C     AAE2P      DERIVATIVE OF AAE2 WRT E2
C     CH         LOCAL CHORD, M.
C     CHP        DERIVATIVE OF CH WRT E2
C     LED        LEADING EDGE DISPLACEMENT, M.  (REAL VARIABLE)
C     LEDP       DERIVATIVE OF LED WRT E2       (REAL VARIABLE)
C     PCAD       PITCH CHANGE AXIS DISPLACEMENT (IN THE THICKNESS DIRECTION)
C     PCADP      DERIVATIVE OF PCAD WRT E2
C     TRAT       THICKNESS RATIO.
C     TRATP      DERIVATIVE OF TRAT WRT E2
C     CRAT       CAMBER RATIO.
C     CRATP      DERIVATIVE OF CRAT WRT E2
C
C     NOTE:  THE VALUE OF LED IS TYPICALLY NEGATIVE.
C
C - START OF FUNE2.
      REAL LED, LEDP
C
C - UH-1  BASELINE ROTOR
C
C - LINEAR TWIST
C
      DTR=.017453293
      AAE2P= -10.9*DTR/R
      AAE2 = AAE2P*E2
C
C - CONSTANT CHORD
C
      CH= 0.1334
      CHP= 0.
```

```
C
C - PITCH CHANGE AXIS ON THE QUARTER CHORD
C
      LED= -.25*CH
      LEDP= 0.
      PCAD= 0.
      PCADP= 0.
C
C - 12% THICK
C
      TRAT= 0.12
      TRATP= 0.
C
C - SYMMETRIC AIRFOIL
C
      CRAT= 0.
      CRATP= 0.
C - END OF FUNE2.
      RETURN
      END
```

```
      SUBROUTINE FUNE2Q
     $  ( E2, R, Q, CMBR, CMBRP, THK, THKP )
C
C     THIS SUBROUTINE IS AN INPUT TO THE HELICOPTER PROGRAM WOPWOP.
C     THE VARIABLES IT RETURNS ARE FUNCTIONS OF ONLY THE SPANWISE
C     LOCATION (E2) OR THE NORMALIZED SPANWISE LOCATION (ER = E2/R)
C     AND THE NORMALIZED CHORDWISE LOCATION (Q).  THESE VARIABLES ARE:
C
C     E2          SPANWISE LOCATION
C     ER          NONDIMENSIONAL SPANWISE LOCATION - RE. - R
C     Q           NONDIMENSIONAL CHORDWISE LOCATION - RE.- CH
C     CMBR        NORMALIZED CAMBER AS MEASURED FROM THE MEAN CHORD LINE.
C     CMBRP       DERIVATIVE OF CMBR WRT Q.
C     THK         NORMALIZED THICKNESS AS MEASURED FROM THE CAMBER LINE.
C     THKP        DERIVATIVE OF THK WRT Q.
C
C     NOTE: ALL OF THE ABOVE TERMS ARE NORMALIZED WITH RESPECT TO THE
C     THICKNESS RATIO TIMES THE CHORD (TRAT*CH).
C
C - START OF FUNE2Q.
C
C - NACA 0012 AIRFOIL SECTION - UH-1 BASELINE ROTOR
C
      CMBRP= 0.
      THK= (.2969*SQRT(Q)+Q*(-.126+Q*(-.3516+Q*(.2843 -.1015*Q))))/.2
      IF( Q.GT.0 ) THEN
          THKP=(.1485/SQRT(Q)+(-.126+Q*(-.7032+Q*(.8529 -.4060*Q))))/.2
      ENDIF
C - END OF FUNE2Q.
      RETURN
      END
```

```
      SUBROUTINE FUNPSI (E2,RR, Q, PSII, SURFP, DP, SPU, SPL, SIGMAU,
     $   SIGMAL, DPCP, SPUP, SPLP, SIGUP, SIGLP )
      PARAMETER( NXOC=19 )
C
C - THIS SUBROUTINE GIVES THE PRESSURE ON THE UPPER AND LOWER SURFACE AS A
C   FUNCTION OF SPANWISE POSITION (E2), CHORDWISE POSITION (Q), AND AZIMUTHAL
C   POSITION (PSI). IT RETURNS THE TIME DERIVATIVE OF PRESSURE ON THE UPPER
C   AND LOWER SURFACES.  A MEAN PRESSURE AND MEAN PRESSURE DERIVATIVE ARE ALSO
C   CALCULATED.  IF SURFP = .FALSE.  THE MEAN SURFACE IS USED.
C
C   SURFACE STRESSES AND THEIR DERIVATIVES ARE ALSO INPUT FOR THE UPPER AND
C   LOWER SURFACES IN SIGMAU, SIGMAL.
C
C   VARIABLES -
C
C    E2 -        SPANWISE LOCATION
C    ER -        NONDIMENSIONAL SPANWISE LOCATION - RE. - R
C    Q -         NONDIMENSIONAL CHORDWISE LOCATION - RE.- CH
C    PSI -       AZIMUTHAL ANGLE (RADIANS)
C    SURFP -     FLAG FOR MEAN SURFACE CALCULATION ( .TRUE. - FULL SURFACE)
C                                                  ( .FALSE.- MEAN SURFACE)
C    SPU -       UPPER SURFACE PRESSURE
C    SPL -       LOWER SURFACE PRESSURE
C    DP -        SPL - SPU
C    SPUP -      TIME DERIVATIVE OF SPU
C    SPLP -      TIME DERIVATIVE OF SPL
C    DPCP -      SPLP - SPUP
C    SIGMAU -    UPPER SURFACE STRESS TERM
C    SIGMAL -    LOWER SURFACE STRESS TERM
C    SIGUP -     TIME DERIVATIVE OF SIGMAU
C    SIGLP -     TIME DERIVATIVE OF SIGMAL
C
C - START OF COMMON BLOCK.
C
      COMMON /PI/ DTR, PI, RTD, TWOPI
      COMMON /ETC/ C, RHO, ALPHAF, REV, PTIP, VH(3), OBS(3), RINNER,
     $ R, DOQUAD, CINV, OMEGA
      COMMON /BYFUN/ AAE2, AAE2P,  CH,  CHP, CMBR, CMBRP,  LED, LEDP,
     $               PCAD, PCADP, THK, THKP, TRAT, TRATP, CRAT, CRATP
      COMMON /ANGLES/ PSI, PSIP, CPSI, SPSI, C2PSI, S2PSI,
     $   A0, A1, B1, A2, B2, BETA, BETAP, BETAPP, CBETA, SBETA, CONB,
     $  EE0,EE1,FF1,EE2,FF2, ZETA, ZETAP, ZETAPP, CZETA, SZETA, CONZ,
     $  AA0,AA1,BB1,AA2,BB2,THETA,THETAP, THETPP,CTHETA,STHETA, CONT
C
C - END OF COMMON BLOCK.
C
C - START OF FUNPSI.
      REAL M2,MU,LAMDA,LMDAI
      DIMENSION XOC(NXOC),V12(NXOC),V12P(NXOC),DVA12(NXOC),TEMP(NXOC),
     $  DVA12P(NXOC)
      LOGICAL FIRST,SURFP
C
C -  THIS SUBROUTINE ROUGHLY CALCULATES THE CL VALUE AND APPROXIMATES THE
C    SURFACE PRESSURE DISTRIBUTION BY THE METHOD OF VELOCITY ADDITION.
C    SEE ABBOTT AND VON DOENHOFF.
```

```
C
C    VELOCITIES FOR AN NACA 0012 AIRFOIL
C
      DATA FIRST/.TRUE./,SIGMA/5.0/,SLP/0./,ISLPSW/3/,P0/10.132E4/
      DATA XOC/0.,.5,1.25,2.5,5.0,7.5,10.0,15.,20.,25.,30.,40.,50.,
     $  60.,70.,80.,90.,95.,100./
      DATA V12/0.,.8,1.005,1.114,1.174,1.184,1.188,1.188,1.183,1.174,
     $  1.162,1.135,1.108,1.080,1.053,1.022,.978,.954,0./
      DATA DVA12/1.988,1.475,1.005,.934,.685,.558,.479,.381,.319,.273,
     $  .239,.187,.149,.118,.092,.068,.044,.029,0./
      DATA INTORD/1/, IIO/-1/, NTAB/1/
      SURFP=.TRUE.
      ER = E2/RR
      IF( FIRST ) THEN
C
C - EXECUTE ON THE FIRST CALL OF FUNPSI TO INITIALIZE
C
          DO 10 I=1,NXOC
              XOC(I) = XOC(I)/100.
 10       CONTINUE
          FIRST=.FALSE.
      ENDIF
C
C - ESTIMATE SECTION ANGLE OF ATTACK ( IN RADIANS ) AND ALPHA DOT
C
      CT = .0028
      UT = ER
      UP = SQRT( CT/2 )
      PHI = ATAN2( UP, UT )
      ALPHA = THETA + AAE2 - PHI
C
C - APPROXIMATE VELOCITY OF THE SECTION
      VEL = UT*OMEGA*RR
      M2 = (VEL*CINV)**2
C
C - ESTIMATE THE PRESSURE
C
C - VELOCITY DUE TO THICKNESS
C
      CALL IUNI(NXOC,NXOC,XOC,NTAB,V12,INTORD,Q,V1,IIO,IERR)
C
C - VELOCITY DUE TO ANGLE OF ATTACK
C
      CALL IUNI(NXOC,NXOC,XOC,NTAB,DVA12,INTORD,Q,V2,IIO,IERR)
C
C - LIFT COEFFICIENT CALCULATION AND COMPRESSIBILITY CORRECTION
C - APPROXIMATE TIP LOSS CORRECTION INCLUDED
C
      CLCORR = 1.
      IF( ER .GT. .9) CLCORR = (10.*(1-ER))**2
      SQRTM2= 1/SQRT(1-M2)
      CL = 5.7*ALPHA*SQRTM2
      FALPHA = CL*CLCORR
C
      CPU = 1. - ( V1 + V2*FALPHA ) **2
      CPL = 1. - ( V1 - V2*FALPHA ) **2
```

```
C
C - CALCULATE DYNAMIC PRESSURE
      QDYN = .5*RHO*VEL*VEL
C
C - SPU = UPPER SURFACE PRESSURE - PO (GAUGE PRESSURE)
C - SPL = LOWER SURFACE PRESSURE - PO (GAUGE PRESSURE)
C
      SPU = QDYN*CPU
      SPL = QDYN*CPL
      DP = SPL - SPU
C
C - SIMPLE DRAG LOADING USED
C
      CDO = .006
      CD1 = .004
      SGMA = (CDO + CD1*CL*CL)*QDYN
      SIGMAU= SGMA*.5
      SIGMAL= SGMA*.5
C
C - TIME DERIVATIVES
C
      SPUP= 0.
      SPLP= 0.
      SIGUP=0.
      SIGLP=0.
      DPCP= 0.
C
C - END OF FUNPSI.
      RETURN
      END
```

Data File WOPIN

```
 $INPUT
 NPTS=200,
 NSPEC=30,
 NSPAN=13,
 NLE=16,
 NTE=12,
 DOQUAD= .25,
 NBLADE= 2,
 R= 1.829, RINNER= 0.1554,
 A0=2.75,
 CENTER=.TRUE.,
 EPSLON=.5,
 FULL=.FALSE.,
 MOTION= .FALSE.,
 DOTIP= .FALSE.,
 A1=0., B1=0.,
 AA0=15.0, AA1=0., BB1=0.,
 ALPHAF=0.,
 REV= 1296.,
 VH= 0., 0., 0.,
 OBS= 3., 0. , 0. $
 Example 3
1/4 Scale UH-1 rotor; Functional form of loading for hovering rotor
```

```
                              HELICOPTER DATA SHEET
                              ---------------------

29-JAN-86                                                               07:51:24

                                   Example 3
1/4 Scale UH-1 rotor; Functional form of loading for hovering rotor

INPUT PARAMETERS
----------------

   - OPERATING CONDITIONS                       - COMPUTATION INFORMATION

     C......... 340.00   M/SEC                    NPTS.............200
     RHO.......    1.2340 KG/M**3                 NSPEC............ 30
     ALPHAF....   0.00   DEG                      NSPAN............ 13
     REV.......1296.00   RPM                      NLE.............. 16
     PTIP......       0.00 PA                     NTE.............. 12
     TZERO.....0.0000000 SEC                      DOQUAD...........  0.2500
     VH...(    0.0,    0.0,    0.0 ) M/SEC        EPSLON...........  0.5000 %

     OBS..(    3.00,    0.00,    0.00 ) M  ( STATIONARY )


   - BLADE GEOMETRY                            COEFFICIENTS ( DEG )
                                       -FLAPPING    -FEATHERING     -LAGGING
     RINNER...  0.155 M                A0...  2.75  AA0... 15.00  EE0...  0.00
     R........  1.829 M                A1...  0.00  AA1...  0.00  EE1...  0.00
     E........  0.000 M                B1...  0.00  BB1...  0.00  FF1...  0.00
     NBLADE...  2                      A2...  0.00  AA2...  0.00  EE2...  0.00
                                       B2...  0.00  BB2...  0.00  FF2...  0.00


OUTPUT PARAMETERS
-----------------

   - FORCES PER BLADE                           - TIME QUANTITIES
      (TIME AVERAGED)

     THRUST.......  1132.976 N                    DT........  0.116 MSEC
     TORQUE.......    89.876 N-M                  PERIOD.... 23.148 MSEC
     POWER........    12.198 KW                   BPF....... 43.200 HZ
     POWER........    16.351 HP

   - OASPL   ( dB re 20 MICROPA )               - VELOCITIES

     THICKNESS...... 110.26 dB                    RMNO..... 0.730
     LOADING........ 107.03 dB                    VMNO..... 0.000
     OVERALL........ 107.73 dB                    HMNO..... 0.730

EXECUTION TIME FOR NOISE CALCULATION -     789.79 CPU SECONDS
```

```
                          OVERALL PRESSURE SIGNATURE
                          --------------------------

29-JAN-86                                                           07:51:24

                                  Example 3

POINT   ------------------------ OVERALL NOISE -----------------------
NUMBER                               (PA)

   0       -1.1143      -1.1471      -1.1790      -1.2099      -1.2398
   5       -1.2688      -1.2968      -1.3239      -1.3501      -1.3752
  10       -1.3995      -1.4227      -1.4449      -1.4662      -1.4864
  15       -1.5056      -1.5237      -1.5407      -1.5566      -1.5714
  20       -1.5850      -1.5974      -1.6085      -1.6183      -1.6267
  25       -1.6337      -1.6393      -1.6433      -1.6457      -1.6464
  30       -1.6454      -1.6425      -1.6377      -1.6308      -1.6217
  35       -1.6104      -1.5966      -1.5803      -1.5614      -1.5395
  40       -1.5146      -1.4864      -1.4549      -1.4196      -1.3805
  45       -1.3372      -1.2894      -1.2369      -1.1794      -1.1164
  50       -1.0477      -0.9727      -0.8910      -0.8022      -0.7058
  55       -0.6011      -0.4876      -0.3646      -0.2314      -0.0871
  60        0.0689       0.2375       0.4198       0.6168       0.8295
  65        1.0590       1.3066       1.5734       1.8608       2.1701
  70        2.5025       2.8592       3.2412       3.6494       4.0843
  75        4.5456       5.0326       5.5432       6.0740       6.6192
  80        7.1703       7.7148       8.2350       8.7065       9.0963
  85        9.3609       9.4441       9.2765       8.7753       7.8493
  90        6.4077       4.3785       1.7384      -1.4672      -5.0841
  95       -8.8245     -12.3143     -15.1421     -16.9477     -17.5254
 100      -16.8547     -15.1026     -12.5623      -9.5726      -6.4474
 105       -3.4313      -0.6859       1.7025       3.7056       5.3333
 110        6.6177       7.6009       8.3276       8.8405       9.1778
 115        9.3731       9.4546       9.4458       9.3662       9.2316
 120        9.0548       8.8463       8.6144       8.3658       8.1058
 125        7.8387       7.5679       7.2961       7.0252       6.7570
 130        6.4927       6.2331       5.9792       5.7313       5.4898
 135        5.2549       5.0268       4.8056       4.5911       4.3834
 140        4.1824       3.9878       3.7997       3.6178       3.4419
 145        3.2719       3.1076       2.9488       2.7953       2.6469
 150        2.5034       2.3647       2.2305       2.1007       1.9752
 155        1.8537       1.7361       1.6223       1.5121       1.4054
 160        1.3020       1.2018       1.1047       1.0106       0.9193
 165        0.8307       0.7448       0.6614       0.5804       0.5018
 170        0.4255       0.3513       0.2792       0.2092       0.1411
 175        0.0749       0.0105      -0.0522      -0.1132      -0.1725
 180       -0.2302      -0.2864      -0.3412      -0.3945      -0.4463
 185       -0.4969      -0.5461      -0.5941      -0.6408      -0.6863
 190       -0.7306      -0.7738      -0.8159      -0.8568      -0.8967
 195       -0.9355      -0.9733      -1.0100      -1.0458      -1.0806
 200       -1.1143

END POINT NOW AT POINT NUMBER =  93 FORMER LEVEL =       1.7344  PA
```

```
                         OVERALL PRESSURE SPECTRA
                         ------------------------
29-JAN-86                                                          07:51:24

                                Example 3


         ---- HARMONIC -----      ---- OVERALL NOISE -----
         NUMBER    FREQUENCY          LEVEL          PHASE
                     (HZ)         (DB RE 20 UPA)     (DEG)

            1          43.2             99.8        -129.4
            2          86.4             92.2         -72.9
            3         129.6             98.8          87.5
            4         172.8            100.0         -92.6
            5         216.0             99.7          89.9
            6         259.2             98.6         -86.8
            7         302.4             97.1          96.8
            8         345.6             95.3         -79.4
            9         388.8             93.4         104.6
           10         432.0             91.3         -71.4
           11         475.2             89.1         112.7
           12         518.4             86.8         -63.2
           13         561.6             84.5         120.9
           14         604.8             82.1         -55.0
           15         648.0             79.6         129.2
           16         691.2             77.1         -46.6
           17         734.4             74.6         137.6
           18         777.6             72.0         -38.2
           19         820.8             69.4         146.0
           20         864.0             66.7         -29.7
           21         907.2             64.0         154.6
           22         950.4             61.3         -21.1
           23         993.6             58.6         163.3
           24        1036.8             55.8         -12.3
           25        1080.0             53.0         172.2
           26        1123.2             50.2          -3.2
           27        1166.4             47.3        -178.5
           28        1209.6             44.4           6.3
           29        1252.8             41.5        -168.6
           30        1296.0             38.5          16.7
```

EXAMPLE 4

The fourth example is the same as example 2 but with a stationary observer in the far-field. This example simulates a helicopter flying over an observer. Note in this example that the near-field pressure does not contribute to the noise, but the program does predict a steady pressure from these terms. One should remember that a microphone does not measure the steady pressure field. (Note that the input subroutines may be found in example 1 and the input data from the C81 analysis are found in example 2; therefore, these will not be repeated here.)

Data File WOPIN

```
$INPUT
 NPTS=80,
 NSPEC=20,
 NSPAN=13,
 NLE=16,
 NTE=12,
 DOQUAD= .25,
 NBLADE= 2,
 R= 1.829, RINNER= 0.1554,
 A0=2.75,
 CENTER=.TRUE.,
 EPSLON=.5,
 FULL=.TRUE.,
 MOTION= .TRUE.,
 DOTIP= .FALSE.,
 A1=-.266, B1=-.013,
 AA0=13.529, AA1=-1.607, BB1=1.440,
 ALPHAF=-8.0,
 REV= 1296.,
 VH= 30.9, 0., 0.,
 OBS= 0., 0., 17. $
 Example 4
1/4 Scale UH-1 rotor; Stationary Observer ; Loading from C81 (AGAJ77)
```

```
                        HELICOPTER DATA SHEET
                        ---------------------

 5-MAR-86                                                   13:55:42

                             Example 4
1/4 Scale UH-1 rotor; Stationary Observer ; Loading from C81 (AGAJ77)

INPUT PARAMETERS
----------------

    - OPERATING CONDITIONS                    - COMPUTATION INFORMATION

      C......... 340.00   M/SEC                 NPTS............. 80
      RHO.......    1.2340 KG/M**3              NSPEC............ 20
      ALPHAF....  -8.00   DEG                   NSPAN............ 13
      REV.......1296.00   RPM                   NLE.............. 16
      PTIP......       0.00 PA                  NTE.............. 12
      TZERO.....0.0000000 SEC                   DOQUAD...........  0.2500
      VH...(   30.9,    0.0,     0.0 ) M/SEC    EPSLON...........  0.5000 %

      OBS..(    0.00,    0.00,   17.00 ) M  ( IN MOTION  )

    - BLADE GEOMETRY                            COEFFICIENTS ( DEG )
                                     -FLAPPING    -FEATHERING    -LAGGING
      RINNER...  0.155 M           A0...  2.75   AA0... 13.53   EE0...  0.00
      R........  1.829 M           A1... -0.27   AA1... -1.61   EE1...  0.00
      E........  0.000 M           B1... -0.01   BB1...  1.44   FF1...  0.00
      NBLADE...  2                 A2...  0.00   AA2...  0.00   EE2...  0.00
                                   B2...  0.00   BB2...  0.00   FF2...  0.00


OUTPUT PARAMETERS
-----------------

    - FORCES PER BLADE                        - TIME QUANTITIES
       (TIME AVERAGED)

      THRUST.......  1311.340 N                 DT........  0.289 MSEC
      TORQUE.......    86.125 N-M               PERIOD.... 23.148 MSEC
      POWER........    11.689 KW                BPF....... 43.200 HZ
      POWER........    15.668 HP

    - OASPL  ( dB re 20 MICROPA )             - VELOCITIES

      THICKNESS......  46.55 dB                 RMNO..... 0.730
      LOADING........  85.55 dB                 VMNO..... 0.091
      OVERALL........  85.60 dB                 HMNO..... 0.820

EXECUTION TIME FOR NOISE CALCULATION -     650.68 CPU SECONDS
```

```
                    PRESSURE SIGNATURES OF NOISE COMPONENTS
                    ---------------------------------------
 5-MAR-86                                                            13:55:42

                                  Example 4

POINT      -- THICKNESS NOISE --          -- LOADING NOISE --        -- OVERALL -

NUMBER     FAR      NEAR    COMBINED       FAR      NEAR   COMBINED      NOISE

   1       0.00     0.00     0.004        0.27     -0.55    -0.281       -0.277
   2       0.00     0.00     0.004        0.27     -0.55    -0.281       -0.277
   3       0.00     0.00     0.005        0.26     -0.55    -0.285       -0.281
   4       0.00     0.00     0.005        0.26     -0.55    -0.291       -0.286
   5       0.00     0.00     0.005        0.25     -0.55    -0.301       -0.295
   6       0.00     0.00     0.005        0.23     -0.55    -0.316       -0.310
   7       0.00     0.00     0.006        0.21     -0.54    -0.338       -0.333
   8       0.00     0.00     0.006        0.17     -0.54    -0.371       -0.365
   9       0.00     0.00     0.006        0.12     -0.54    -0.418       -0.413
  10       0.00     0.00     0.006        0.06     -0.54    -0.479       -0.473
  11       0.00     0.00     0.006        0.02     -0.54    -0.525       -0.519
  12       0.00     0.00     0.006       -0.02     -0.54    -0.557       -0.551
  13       0.00     0.00     0.006       -0.04     -0.54    -0.580       -0.574
  14       0.00     0.00     0.006       -0.06     -0.54    -0.598       -0.592
  15       0.00     0.00     0.006       -0.07     -0.54    -0.612       -0.606
  16       0.00     0.00     0.006       -0.09     -0.54    -0.625       -0.620
  17       0.00     0.00     0.005       -0.10     -0.54    -0.639       -0.634
  18       0.00     0.00     0.005       -0.12     -0.54    -0.657       -0.652
  19       0.00     0.00     0.005       -0.14     -0.54    -0.682       -0.677
  20       0.00     0.00     0.005       -0.18     -0.54    -0.717       -0.712
  21       0.00     0.00     0.004       -0.23     -0.54    -0.768       -0.763
  22       0.00     0.00     0.004       -0.30     -0.54    -0.841       -0.837
  23       0.00     0.00     0.004       -0.41     -0.54    -0.948       -0.945
  24       0.00     0.00     0.003       -0.52     -0.54    -1.062       -1.059
  25       0.00     0.00     0.003       -0.60     -0.54    -1.140       -1.137
  26       0.00     0.00     0.002       -0.65     -0.54    -1.190       -1.188
  27       0.00     0.00     0.002       -0.68     -0.54    -1.222       -1.220
  28       0.00     0.00     0.001       -0.70     -0.54    -1.240       -1.239
  29       0.00     0.00     0.001       -0.70     -0.54    -1.249       -1.248
  30       0.00     0.00     0.000       -0.70     -0.54    -1.242       -1.241
  31       0.00     0.00     0.000       -0.70     -0.54    -1.240       -1.240
  32       0.00     0.00     0.000       -0.69     -0.55    -1.239       -1.239
  33      -0.01     0.00    -0.001       -0.69     -0.55    -1.238       -1.239
  34      -0.01     0.00    -0.001       -0.69     -0.55    -1.239       -1.240
  35      -0.01     0.00    -0.002       -0.69     -0.55    -1.243       -1.245
  36      -0.01     0.00    -0.002       -0.70     -0.55    -1.254       -1.257
  37      -0.01     0.00    -0.003       -0.72     -0.55    -1.276       -1.278
  38      -0.01     0.00    -0.003       -0.74     -0.55    -1.294       -1.298
  39      -0.01     0.00    -0.004       -0.75     -0.56    -1.304       -1.307
  40      -0.01     0.00    -0.004       -0.75     -0.56    -1.306       -1.310
  41      -0.01     0.00    -0.004       -0.74     -0.56    -1.303       -1.307
  42      -0.01     0.00    -0.005       -0.74     -0.56    -1.296       -1.301
  43      -0.01     0.00    -0.005       -0.72     -0.56    -1.287       -1.292
  44      -0.01     0.00    -0.005       -0.70     -0.56    -1.267       -1.272
  45      -0.01     0.00    -0.005       -0.69     -0.56    -1.252       -1.258
```

46	-0.01	0.00	-0.006	-0.67	-0.57	-1.235	-1.241
47	-0.01	0.00	-0.006	-0.65	-0.57	-1.216	-1.222
48	-0.01	0.00	-0.006	-0.62	-0.57	-1.192	-1.198
49	-0.01	0.00	-0.006	-0.59	-0.57	-1.164	-1.170
50	-0.01	0.00	-0.006	-0.56	-0.57	-1.131	-1.137
51	-0.01	0.00	-0.006	-0.52	-0.57	-1.094	-1.100
52	-0.01	0.00	-0.006	-0.49	-0.57	-1.063	-1.069
53	-0.01	0.00	-0.006	-0.46	-0.58	-1.037	-1.043
54	-0.01	0.00	-0.006	-0.44	-0.58	-1.013	-1.019
55	-0.01	0.00	-0.006	-0.41	-0.58	-0.991	-0.997
56	-0.01	0.00	-0.006	-0.39	-0.58	-0.969	-0.975
57	-0.01	0.00	-0.006	-0.36	-0.57	-0.937	-0.943
58	-0.01	0.00	-0.005	-0.34	-0.57	-0.910	-0.916
59	-0.01	0.00	-0.005	-0.31	-0.57	-0.882	-0.887
60	-0.01	0.00	-0.005	-0.27	-0.58	-0.847	-0.852
61	-0.01	0.00	-0.004	-0.23	-0.58	-0.804	-0.808
62	-0.01	0.00	-0.004	-0.17	-0.58	-0.746	-0.751
63	-0.01	0.00	-0.004	-0.09	-0.57	-0.667	-0.670
64	-0.01	0.00	-0.003	0.00	-0.57	-0.574	-0.577
65	-0.01	0.00	-0.003	0.07	-0.57	-0.503	-0.506
66	-0.01	0.00	-0.003	0.12	-0.57	-0.451	-0.454
67	-0.01	0.00	-0.002	0.16	-0.57	-0.413	-0.415
68	-0.01	0.00	-0.002	0.18	-0.57	-0.385	-0.387
69	-0.01	0.00	-0.001	0.21	-0.57	-0.362	-0.363
70	-0.01	0.00	-0.001	0.22	-0.57	-0.345	-0.345
71	-0.01	0.00	0.000	0.23	-0.56	-0.331	-0.331
72	0.00	0.00	0.000	0.24	-0.56	-0.323	-0.322
73	0.00	0.00	0.001	0.24	-0.56	-0.318	-0.317
74	0.00	0.00	0.001	0.24	-0.56	-0.317	-0.316
75	0.00	0.00	0.002	0.24	-0.56	-0.322	-0.321
76	0.00	0.00	0.002	0.22	-0.56	-0.332	-0.330
77	0.00	0.00	0.002	0.24	-0.55	-0.316	-0.314
78	0.00	0.00	0.003	0.25	-0.55	-0.300	-0.297
79	0.00	0.00	0.003	0.26	-0.55	-0.290	-0.287
80	0.00	0.00	0.004	0.27	-0.55	-0.284	-0.281
81	0.00	0.00	0.004	0.27	-0.55	-0.281	-0.277
END POINT							
36	-0.01	0.00	-0.002	-0.70	-0.55	-1.255	-1.257

```
                       PRESSURE SPECTRA OF NOISE COMPONENTS
                       ------------------------------------
5-MAR-86                                                                13:55:42

                                    Example 4

--- HARMONIC -----     ------ OVERALL ------  THICKNESS     LOADING
NUMBER   FREQUENCY        LEVEL       PHASE  LEVEL  PHASE  LEVEL  PHASE
            (HZ)       (DB RE 20 UPA)  (DEG)  (DB)  (DEG)   (DB)  (DEG)

   1        43.20          85.5        97.4   46.6   43.4   85.5   97.9
   2        86.40          49.1        76.5   -2.0  -33.1   49.1   76.7
   3       129.60          63.2      -110.5  -26.4 -164.1   63.2 -110.5
   4       172.80          43.5       140.8  -22.4  167.6   43.5  140.8
   5       216.00          65.6        33.1  -38.6  141.3   65.6   33.1
   6       259.20          55.1       -40.4  -26.7  171.9   55.1  -40.4
   7       302.40          56.8      -156.1  -27.9  136.2   56.8 -156.1
   8       345.60          33.8       110.1  -28.8 -133.0   33.8  110.1
   9       388.80          43.3        15.0  -28.6  134.0   43.3   15.0
  10       432.00          31.2      -163.1  -39.3  -79.9   31.2 -163.2
  11       475.20          50.3       149.8  -26.9  153.6   50.3  149.8
  12       518.40          37.2       125.3  -44.9   92.9   37.2  125.3
  13       561.60          41.9       -36.9  -27.2 -158.6   41.9  -36.9
  14       604.80          11.9       -92.6  -34.4   53.7   11.9  -92.7
  15       648.00          32.8       167.2  -31.2 -126.4   32.8  167.2
  16       691.20          24.8       -41.2  -30.1  104.1   24.8  -41.2
  17       734.40          41.0       -68.9  -33.8 -119.5   41.0  -68.8
  18       777.60          33.3      -133.4  -31.6  172.2   33.3 -133.3
  19       820.80          32.6        60.4  -29.2  -42.7   32.6   60.5
  20       864.00          25.8        12.3  -38.6 -171.0   25.8   12.3
```

APPENDIX C

DESCRIPTION OF WOPPLT PROGRAM

The separate program, called WOPPLT, written at the Langley Research Center is an interactive plotting program used to plot the output from the helicopter noise program WOPWOP. WOPPLT used in conjunction with WOPWOP forms a valuable system used to examine the noise from a helicopter rotor.

The plotting program WOPPLT has capabilities to do the following:

1. Plot acoustic signature as a function of time
2. Plot sound pressure level (SPL) as a function of harmonic number
3. Plot phase as a function of harmonic number
4. Plot both acoustic signature and SPL on one frame

These capabilities are multiplied by the additional capability to plot various types of data in each of the above representations. The following types of data can be plotted:

1. Overall noise
2. Thickness noise
3. Loading noise

The near-field and far-field components of these are also available. Three lines of data may be plotted on any one frame. (This limitation may be changed.) Using multiple lines of data makes comparisons very easy indeed. If data from sources other than WOPWOP are put into the same format as the data file WOPPLT, written by WOPWOP, these data could be plotted too. The format of the data file WOPPLT.DAT follows:

Line	Format	Variable Definition
1	A79	TEXT - 79-character case identifier
2	2A10,1X,A10,1X,E10.4	DAY, TIME, IDENT, CSEC DAY - Date TIME - Time of day IDENT - 10-character case identifier CSEC - Execution time on computer
3	6(1X,E10.4)	C, RHO, ALPHAF, REV, PTIP, TZERO (See "Input Data" for description.)

4	6(1X,E10.4)	VH(1), VH(2), VH(3), OBS(1), OBS(2), OBS(3) (See "Input Data" for description.)
5	5(1X,I5),2(1X,E10.4)	NPTS, NSPEC, NSPAN, NLE, NTE, DOQUAD, EPSLON (See "Input Data" for description.)
6	3(1X,E10.4),1X,I5	RINNER, R, E, NBLADE (See "Input Data" for description.)
7	5(1X,E10.4)	A0, A1, B1, A2, B2 (See "Input Data" for description.)
8	5(1X,E10.4)	AA0, AA1, BB1, AA2, BB2 (See "Input Data" for description.)
9	5(1X,E10.4)	EE0, EE1, FF1, EE2, FF2 (See "Input Data" for description.)
10	4(1X,E10.4)	THRUST, TORQUE, POWER, BPOWER THRUST - Thrust per blade TORQUE - Torque per blade POWER - Power per blade in kilowatts BPOWER - Power per blade in horsepower
11	3(1X,E10.4)	DT, PERIOD, BPF DT - Time increment between calculations in time history PERIOD - Blade passage period BPF - Blade passage frequency
12	7(1X,E10.4)	OSPLTF, OSPLTN, OASPLT, OSPLDF, OSPLDN, OASPLD, OASPLO OSPLTF - Overall sound pressure for far-field thickness noise OSPLTN - Overall sound pressure for near-field thickness noise OASPLT - Overall sound pressure for total thickness noise OSPLDF - Overall sound pressure for far-field loading noise OSPLDN - Overall sound pressure for near-field loading noise OASPLD - Overall sound pressure for total loading noise OASPLO - Overall sound pressure

13 3(1X,E10.4) RMNO, VMNO, HMNO

RMNO - Rotational Mach number
VMNO - Forward Mach number
HMNO - Helical-tip Mach number

14 6L5 CENTER, DONE, DOTIP, FULL, MOTION, SAVE

(See "Input Data" for description.)

15 7(1X,E10.4) THF(I), THN(I), TH(I), DPF(I), DPN(I), DP(I), O(I)

THF - Far-field thickness pressure at time I
THN - Near-field thickness pressure at time I
TH - Total thickness pressure at time I
DPF - Far-field loading pressure at time I
DPN - Near-field loading pressure at time I
DP - Total loading pressure at time I
O - Total pressure at time I

This line is repeated NPTS times.

15A I5,6(1X,E10.4) IOEP, OEPTHF, OEPTHN, OEPTH, OEPDPF, OEPDPN, OEPDP

IOEP - Original end point value of I
OEPTHF - THF at original end point
OEPTHN - THN at original end point
OEPTH - TH at original end point
OEPDPF - DPF at original end point
OEPDPN - DPN at original end point
OEPDP - DP at original end point

This line is present only if CENTER = .TRUE.

16 7(1X,E10.4) THFA(I), THNA(I), THA(I), DPFA(I), DPNA(I), DPA(I), OA(I)

THFA - Amplitude of Ith harmonic of far-field thickness noise
THNA - Amplitude of Ith harmonic of near-field thickness noise
THA - Amplitude of Ith harmonic of total thickness noise
DPFA - Amplitude of Ith harmonic of far-field loading noise
DPNA - Amplitude of Ith harmonic of near-field loading noise
DPA - Amplitude of Ith harmonic of total loading noise
OA - Amplitude of Ith harmonic of overall noise

This line is repeated NPSEC times.

17	7(1X,E10.4)	THFP(I), THNP(I), THP(I), DPFP(I), DPNP(I), DPP(I), OP(I) THFA - Phase of Ith harmonic of far-field thickness noise THNA - Phase of Ith harmonic of near-field thickness noise THA - Phase of Ith harmonic of total thickness noise DPFA - Phase of Ith harmonic of far-field loading noise DPNA - Phase of Ith harmonic of near-field loading noise DPA - Phase of Ith harmonic of total loading noise OA - Phase of Ith harmonic of overall noise

This line is repeated NPSEC times.

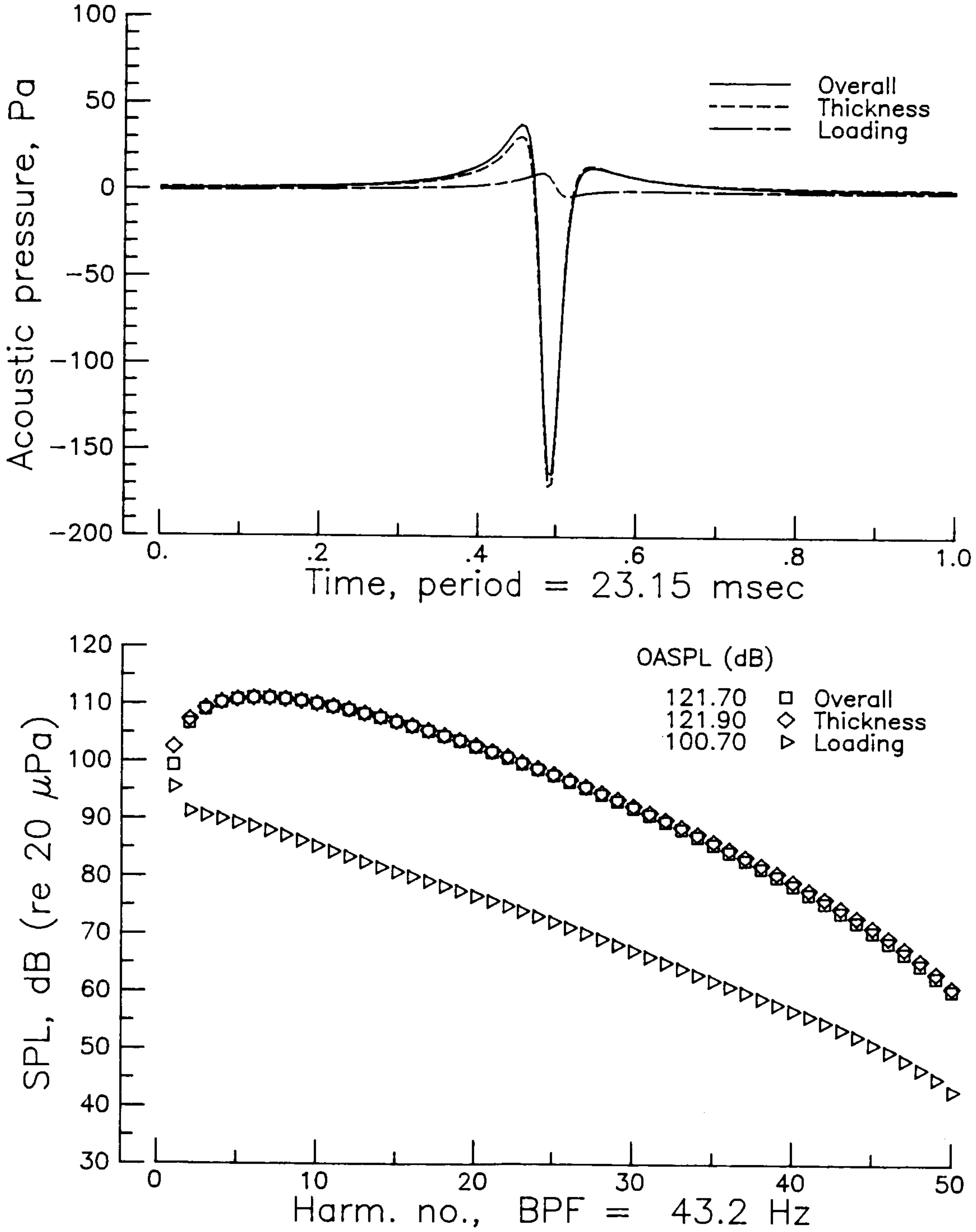
WOPPLT organizes the data by using the same case identifiers used in WOPWOP and also prints the same summary data sheet. This data sheet contains all the WOPWOP program inputs and the calculated values of rotor thrust, torque, and power. It also contains the overall sound pressure level (OASPL), related blade Mach numbers (rotational - RMNO, forward - VMNO, and helical - HMNO), blade passage frequency, and data and time of program execution. This data sheet provides all the information necessary to identify the case and aid in the evaluation of the data.

WOPPLT is written to work in an interactive environment. The user is queried to determine the number of data files to be used, the types of plots, etc. The queries are straightforward and logical. They appear as various menus.

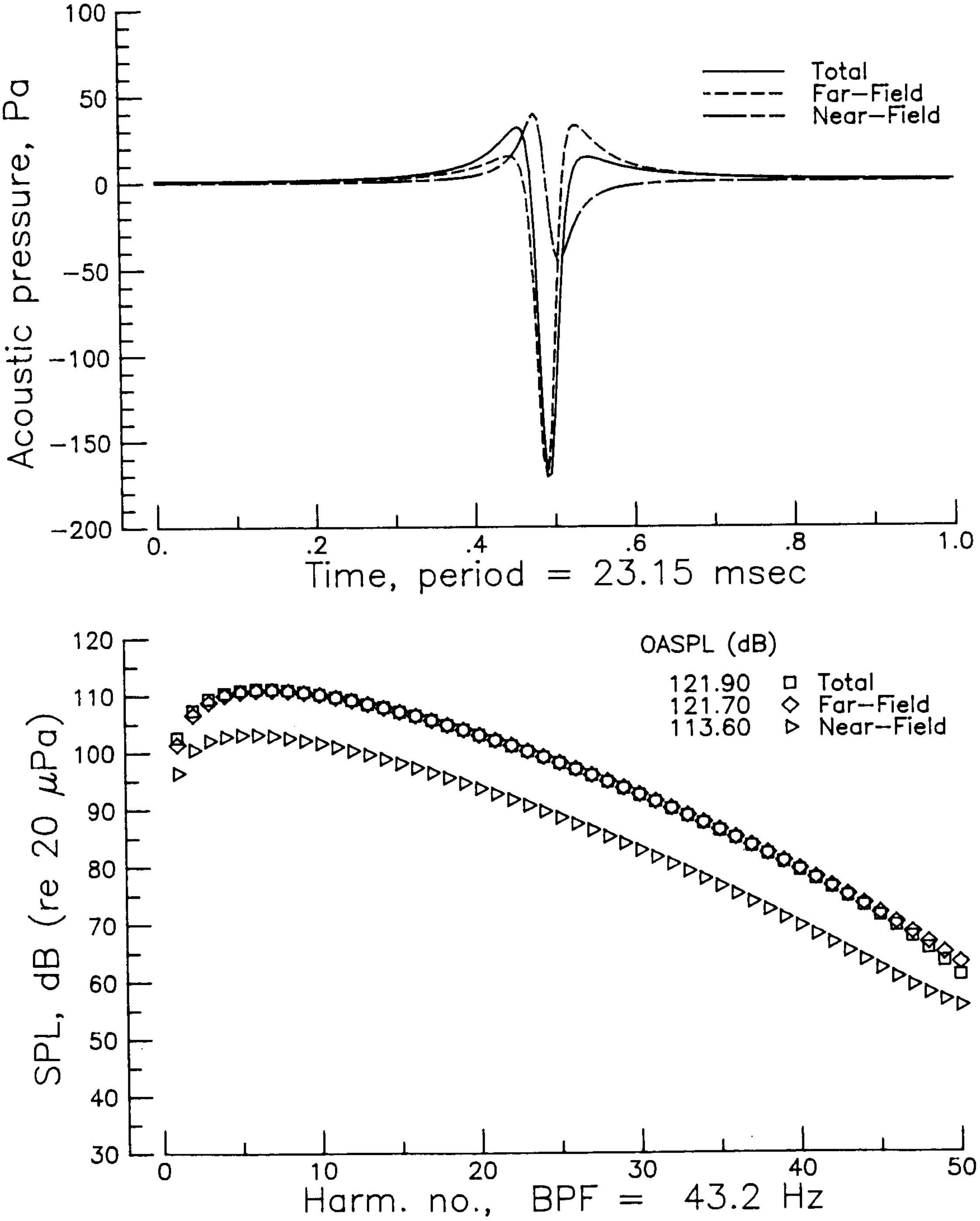
APPENDIX D

GRAPHICAL OUTPUT FROM WOPPLT PROGRAM

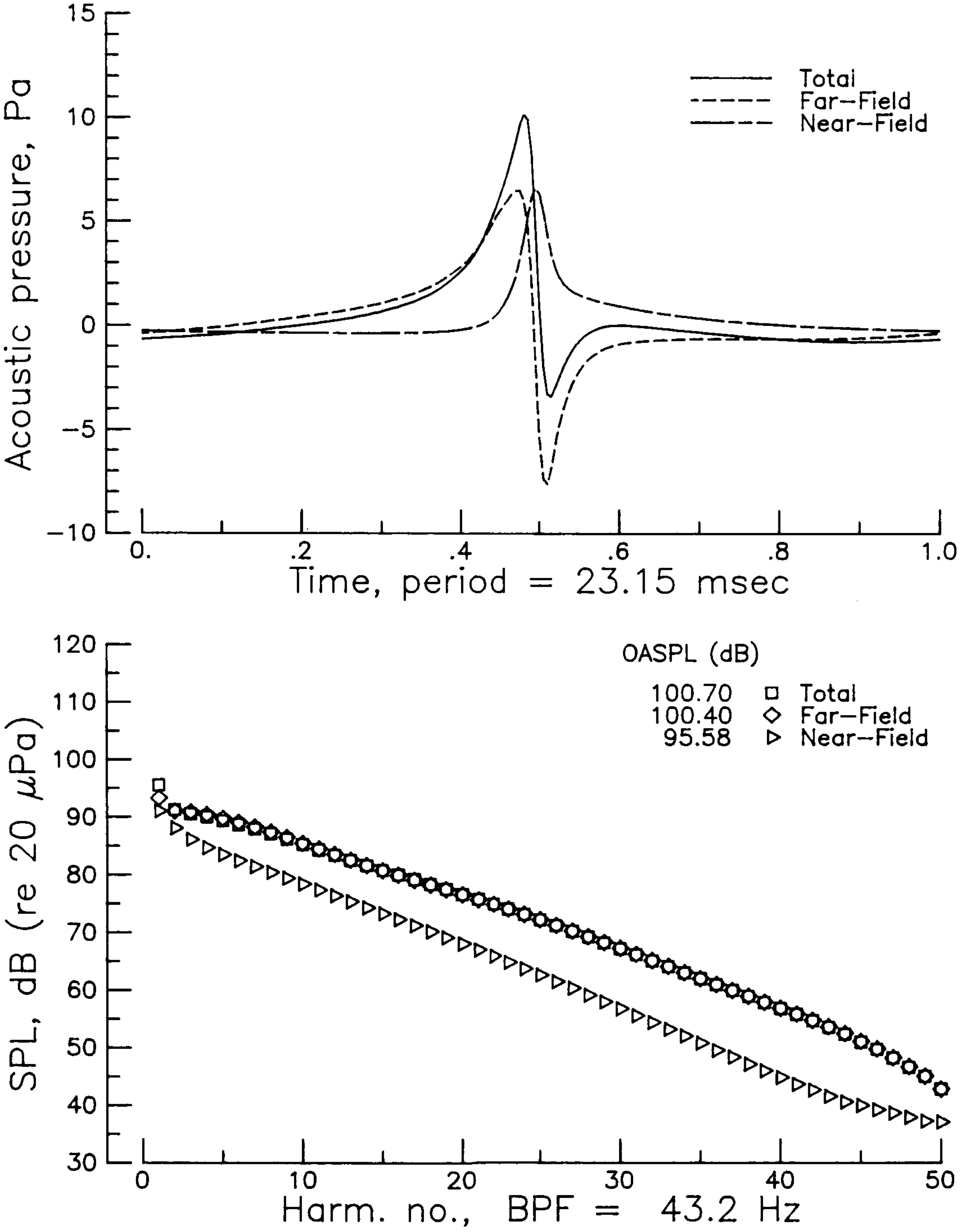
In this appendix the graphical output from the plotting program WOPPLT is shown for the four examples given in appendix B. Each graph is clearly labeled at the bottom of each page. For each example, three graphs are shown. These graphs show the acoustic-pressure time history and sound pressure level of the overall noise, thickness noise, and loading noise in the first frame. The thickness and loading noise are broken into their far-field and near-field components in the subsequent two frames.



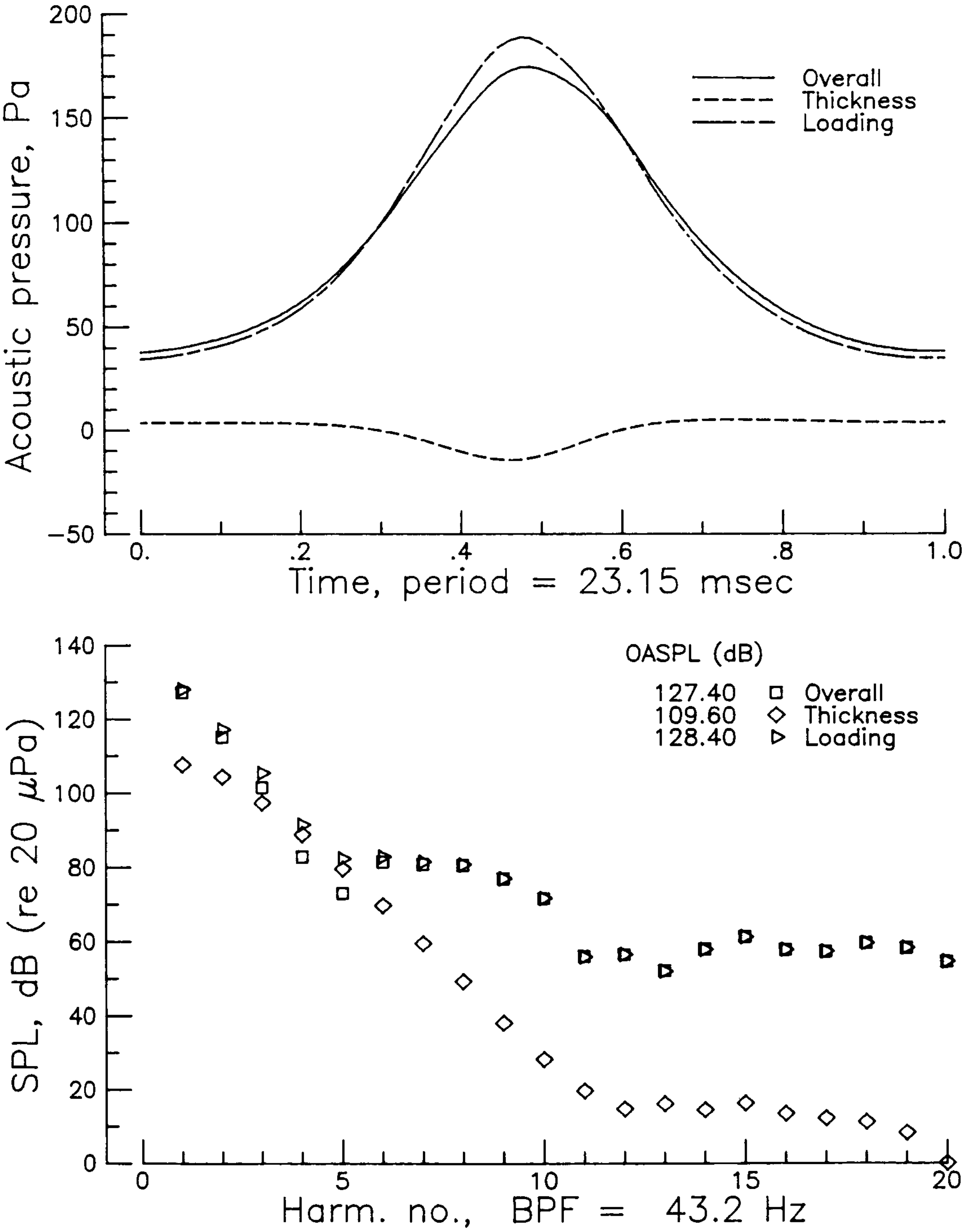
Example 1 Noise



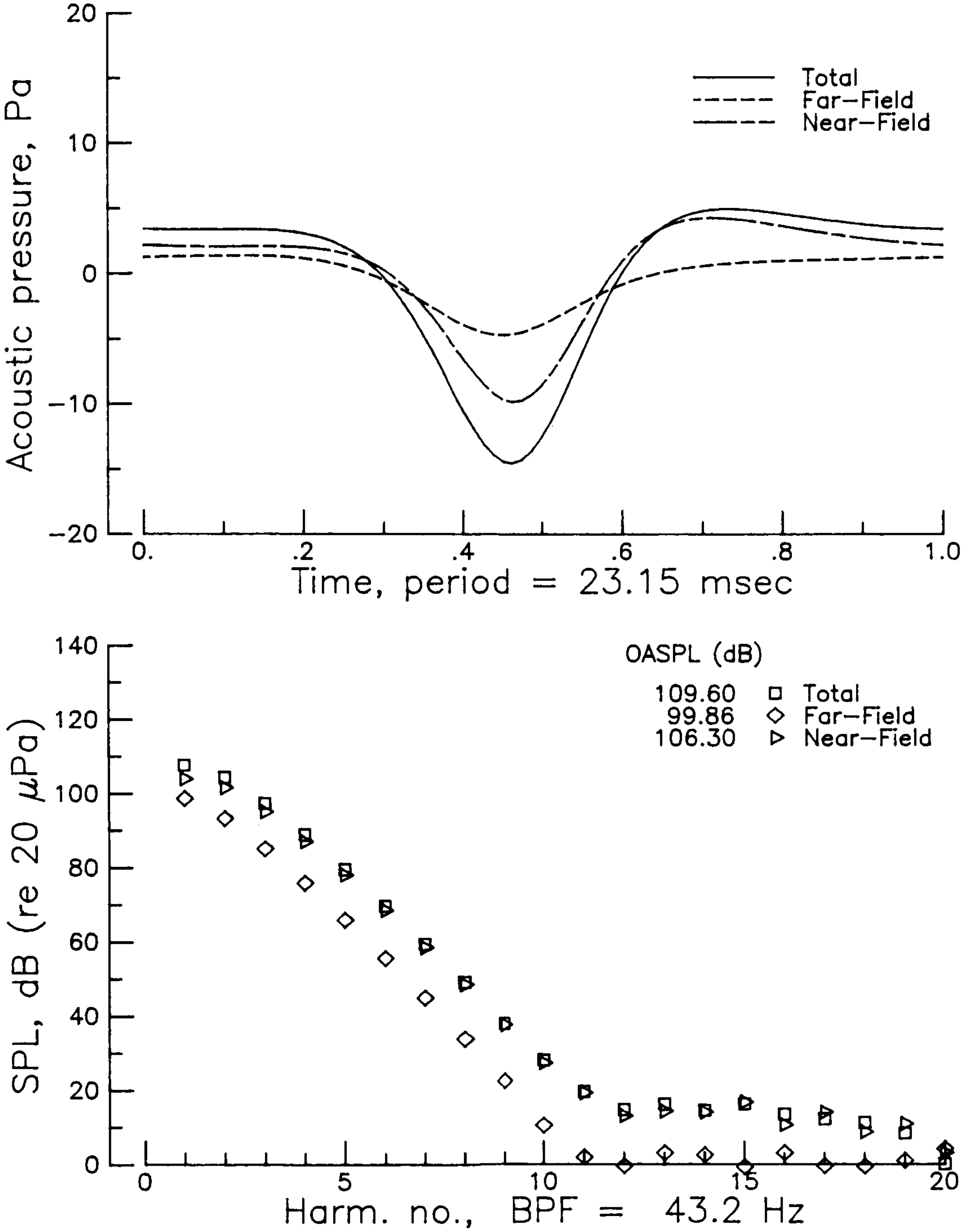
Example 1 Thickness Noise



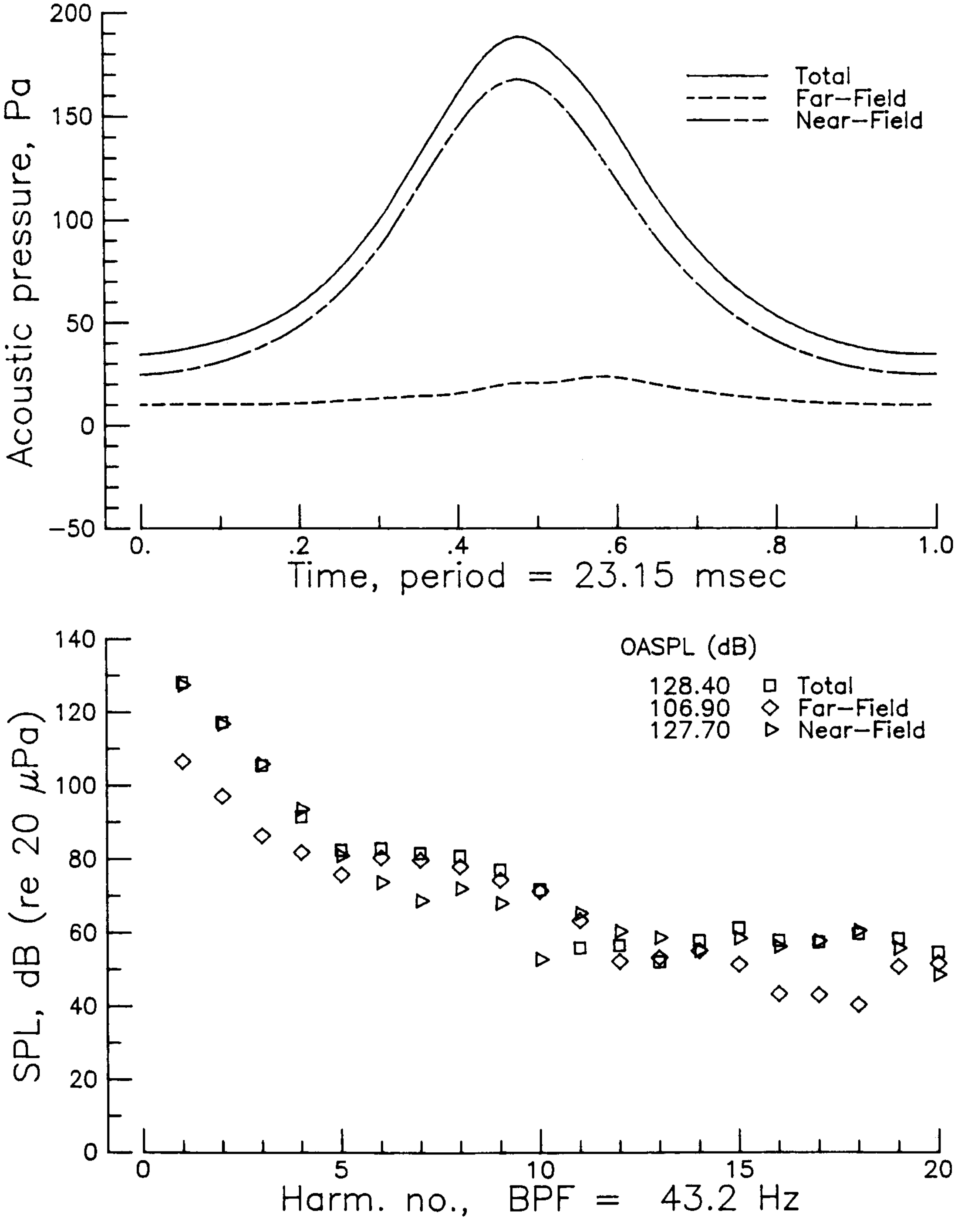
Example 1 Loading Noise



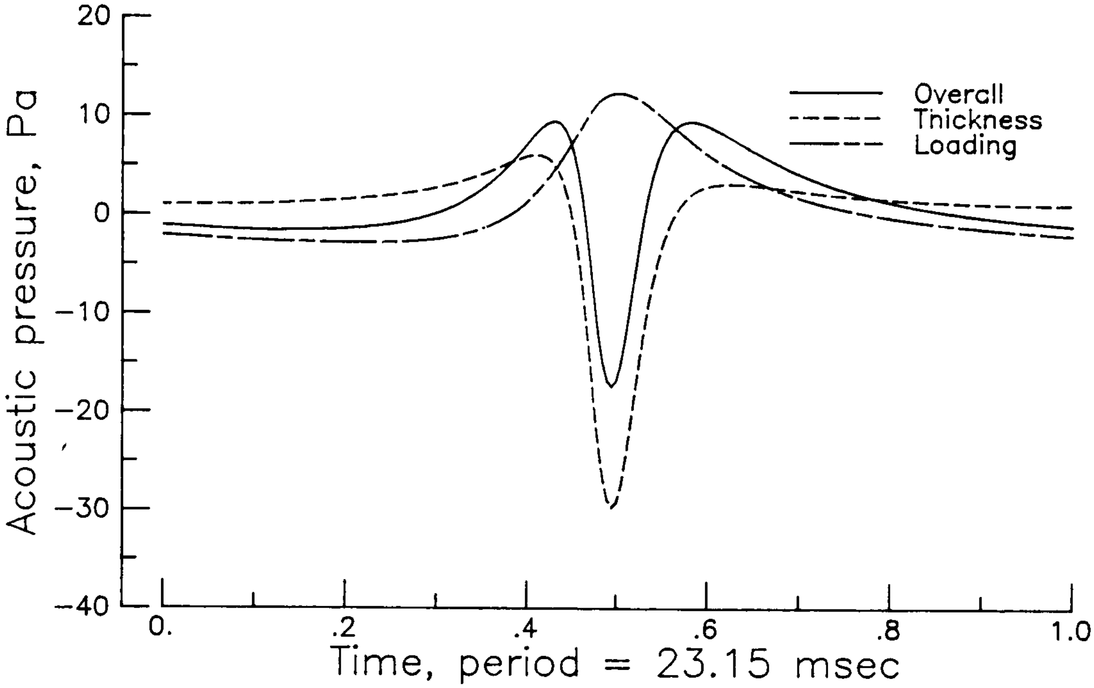
Example 2 Noise

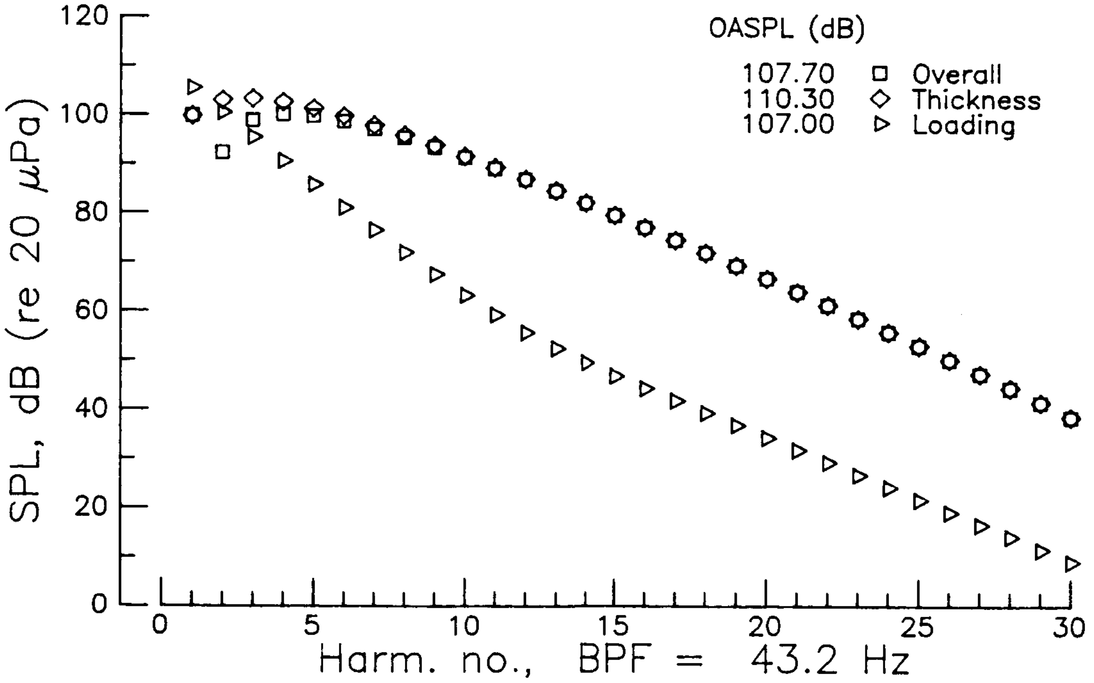


Example 2 Thickness Noise

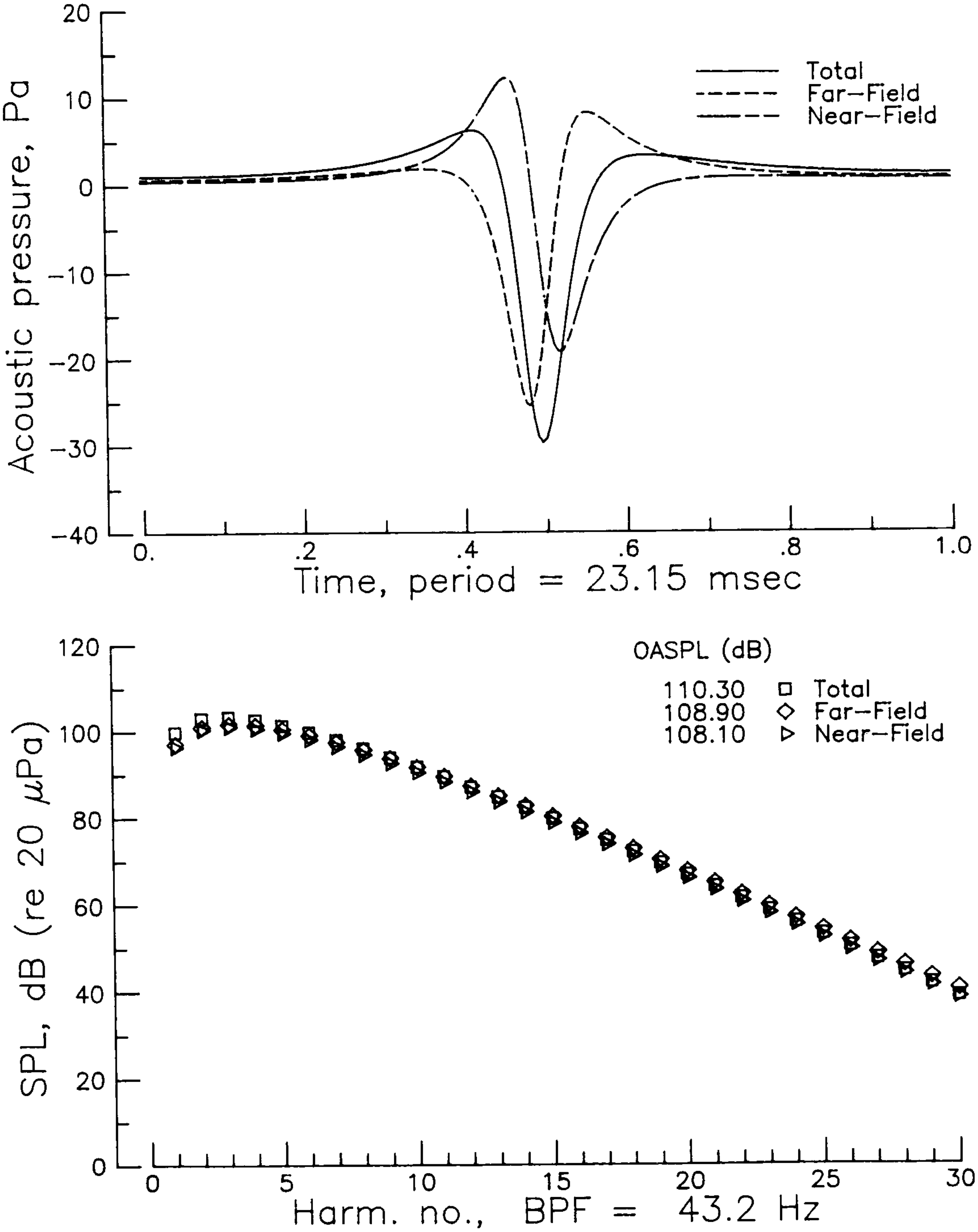


Example 2 Loading Noise

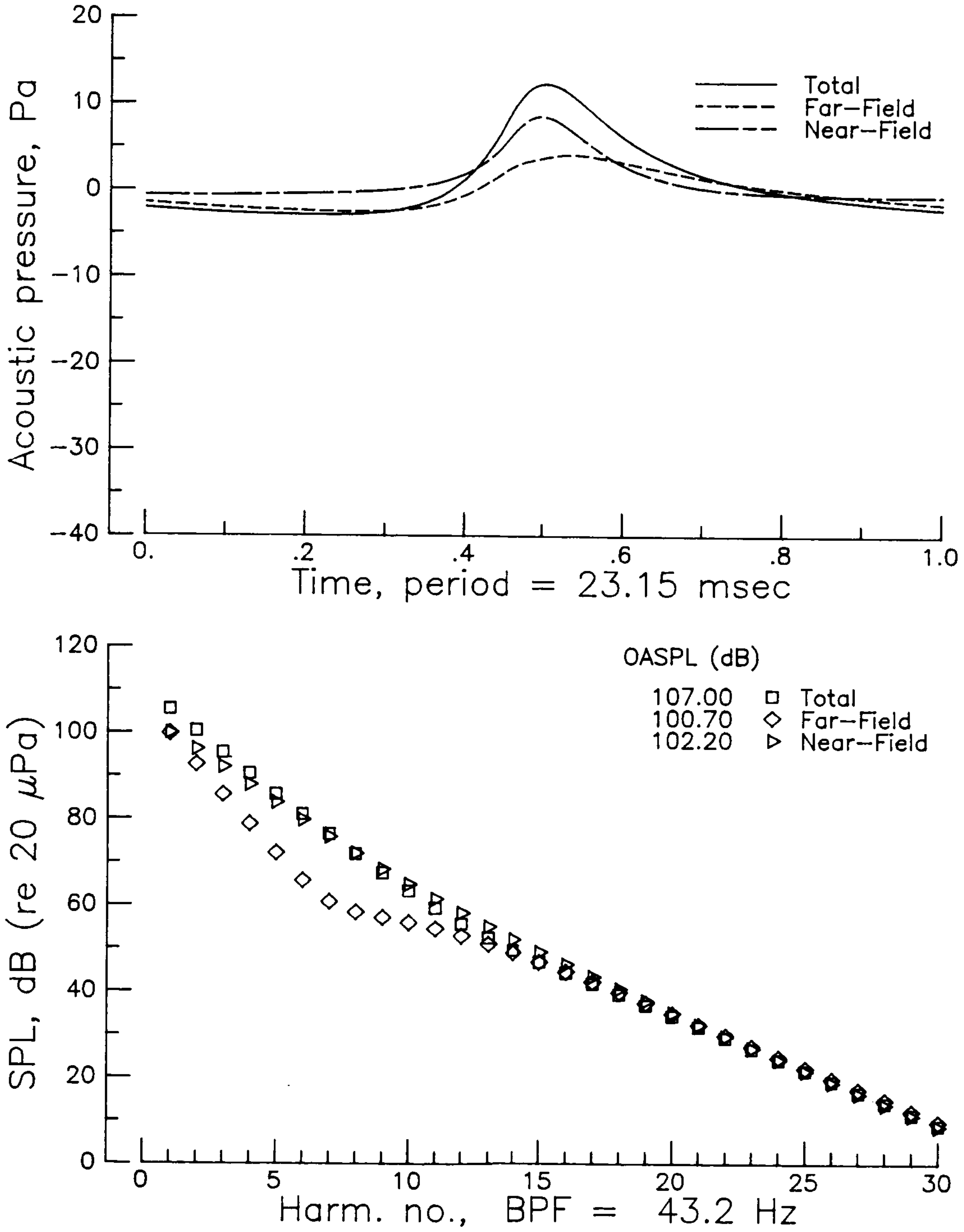




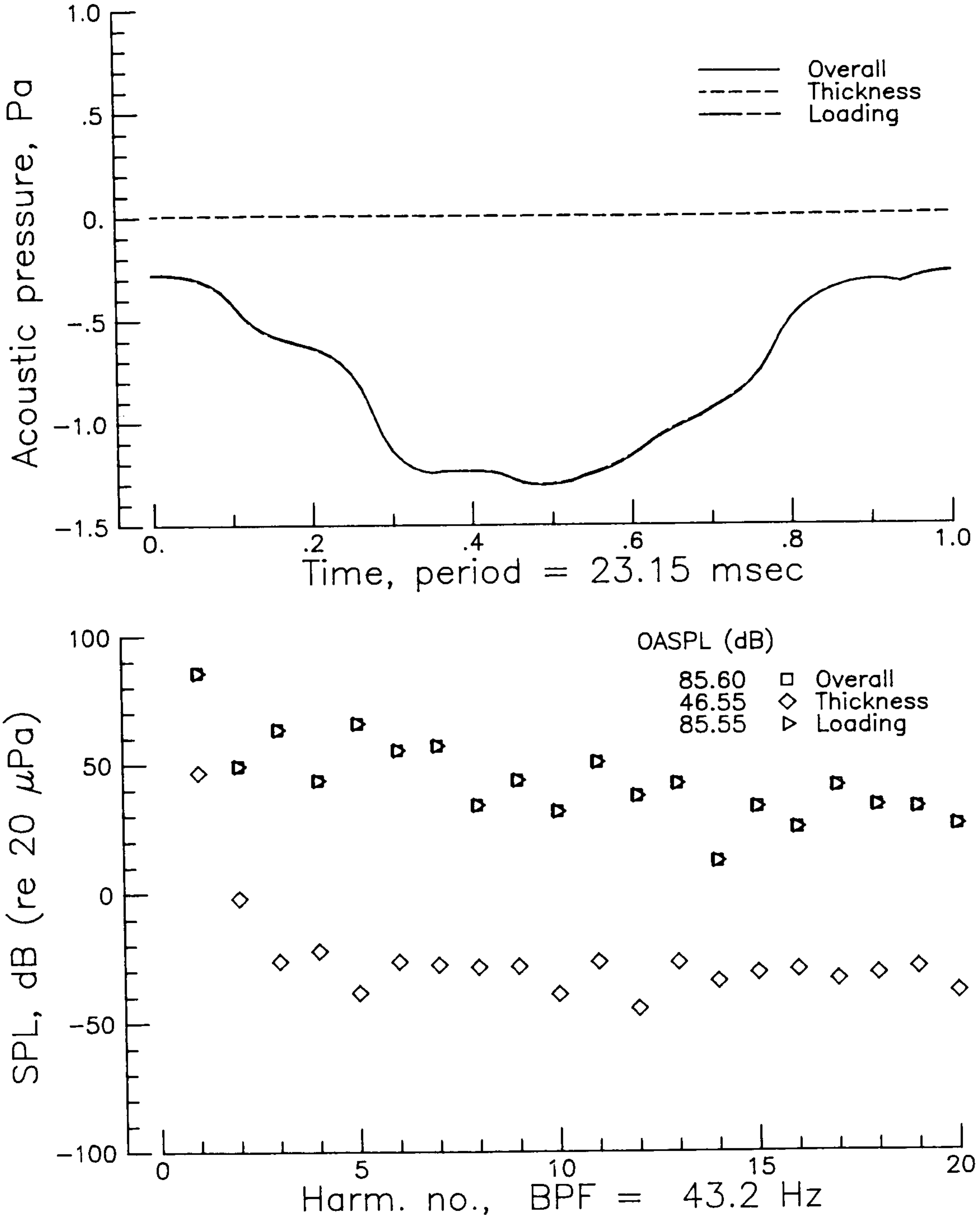
Example 3 Noise



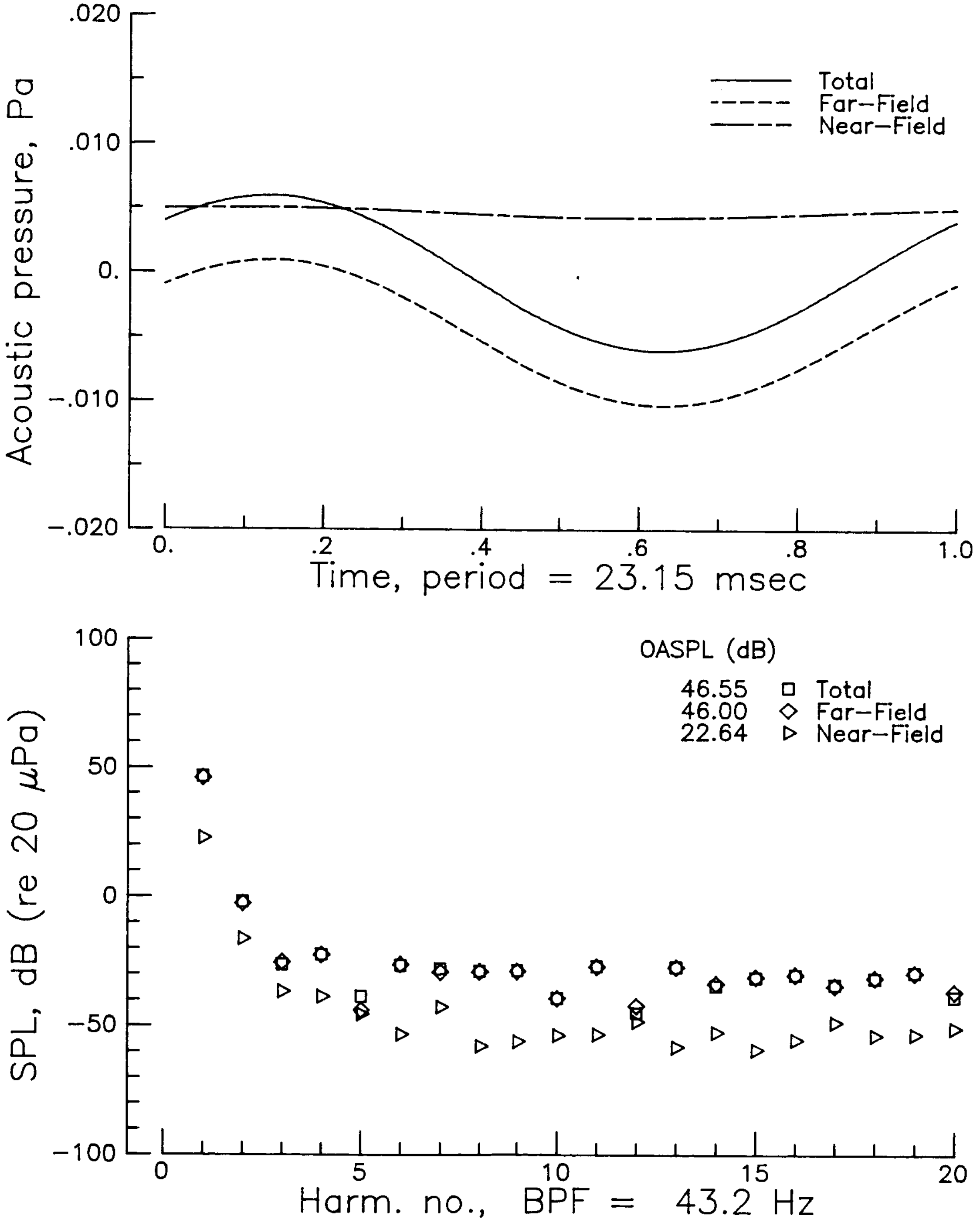
Example 3 Thickness Noise



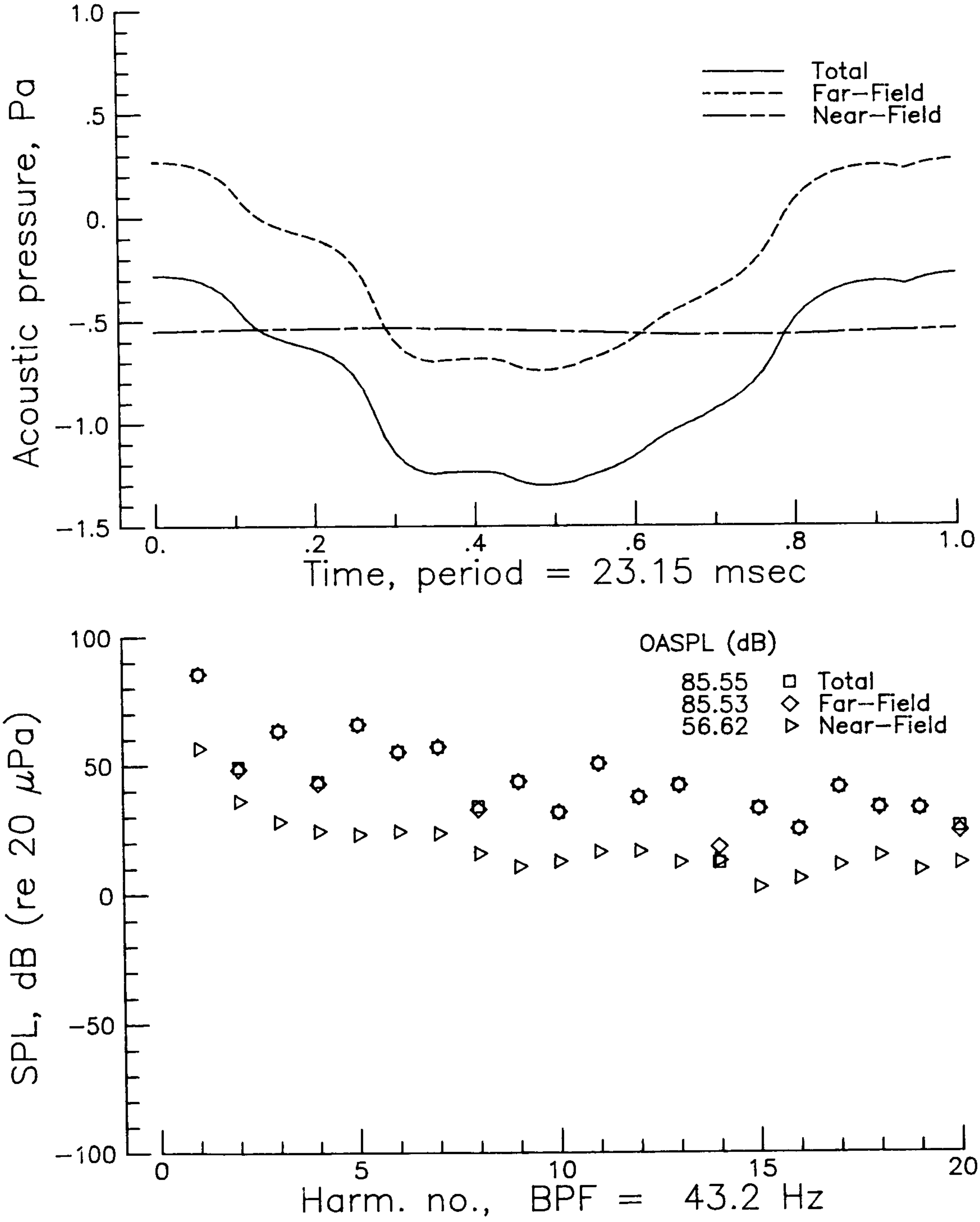
Example 3 Loading Noise



Example 4 Noise



Example 4 Thickness Noise



Example 4 Loading Noise

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15. Supplementary Notes

16. Abstract

A computer program has been developed at the Langley Research Center to predict the discrete frequency noise of conventional and advanced helicopter rotors. The program, called WOPWOP, uses the most advanced subsonic formulation of Farassat that is less sensitive to errors and is valid for nearly all helicopter rotor geometries and flight conditions. A brief derivation of the acoustic formulation is presented along with a discussion of the numerical implementation of the formulation. The computer program uses realistic helicopter blade motion and aerodynamic loadings, input by the user, for noise calculation in the time domain. A detailed definition of all the input variables, default values, and output data is included. A comparison with experimental data shows good agreement between prediction and experiment; however, accurate aerodynamic loading is needed.

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