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# USER'S MANUAL FOR XTRAN2L (VERSION 1.2): A PROGRAM FOR SOLVING THE GENERAL-FREQUENCY UNSTEADY TRANSONIC SMALL-DISTURBANCE EQUATION

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## Summary

The development, use, and operation of the XTRAN2L program that solves the two-dimensional unsteady transonic small-disturbance potential equation are described. The XTRAN2L program is used to calculate steady and unsteady transonic flow fields about airfoils and is capable of performing self-contained transonic flutter calculations. Operation of the XTRAN2L code is described, and tables defining all input variables, including default values, are presented. Sample cases that use various program options are shown to illustrate operation of XTRAN2L. Computer listings containing input and selected output are included as an aid to the user.

## Introduction

Considerable research is presently being conducted to develop computational methods for calculating transonic unsteady aerodynamics for aeroelastic applications. The methods are being developed to provide accurate yet cost efficient means for calculating unsteady transonic airloads for the prediction of aeroelastic characteristics such as flutter and divergence. Computational developments and advances that are possible because of improvements made in computer technology and numerical solution techniques are described in Ref. 1.

Solutions for unsteady transonic flows about oscillating airfoils have been made possible using computer codes such as LTRAN2.[2] The original

LTRAN2 code was developed to compute time-accurate solutions of the low-frequency approximation of the transonic small-disturbance (TSD) equation. Houwink and Van der Vooren[3] extended the range of applicability of the LTRAN2 code by incorporating the time-derivative terms in the airfoil and wake boundary conditions. The resulting code was termed LTRAN2-NLR. The XTRAN2L code,[4] developed at NASA Langley Research Center, is an extensive modification of LTRAN2-NLR that includes monotone differencing, nonreflecting farfield boundary conditions, an improved computational grid, a pulse transient capability, and an aeroelastic transient capability. Details of the algorithm used in XTRAN2L and the modifications made to LTRAN2-NLR are given by Whitlow.[4] Details of the grid development and pulse transient capability are given by Seidel, Bennett, and Whitlow.[5] The development of the aeroelastic transient capability was reported by Edwards, Bennett, Whitlow, and Seidel.[6]

The XTRAN2L program is operational at the NASA Langley Research Center on a CYBER-175 computer using FORTRAN IV. The program uses the OVERLAY capability to segment the program into 3 parts and reduce the field length required to load and run the program. The program requires 120 kbytes to load and run in overlayed form. On the CYBER-175, the program requires 0.25 CPU seconds per time step.

The purpose of the present report is: (1) to summarize the XTRAN2L developments of Refs. 4-6, and (2) to describe the operation of the XTRAN2L (Version 1.2) code. The report reiterates the governing equations and program input descriptions given in the LTRAN2-NLR user's manual,[7] and extends the information to include the XTRAN2L modifications and improvements. A brief description of XTRAN2L is presented first, highlighting the relevant equations and computational procedures. Operation of XTRAN2L is described next, along with tables defining all input variables, including default values. Finally, application of XTRAN2L is illustrated by sample calculations for the NACA 64A010A airfoil at a freestream Mach number of 0.78 and a mean angle of attack of 1.0°. In these calculations, various program options are used. Computer listings containing input and selected output are included as an aid to the user.

## Symbols

| | |
|---|---|
| $a$ | pulse amplitude in Eqs. (8a), (8b) and (8c) |
| $a_h$ | distance in semichords from midchord to elastic axis |
| $a_n$ | harmonic coefficient in Eq. (7) |
| $A$ | coefficient defined in Eq. (2a) |
| $b$ | semichord, c/2 |
| $b_n$ | harmonic coefficient in Eqs. (6a) and (6b) |
| $B$ | coefficient defined in Eq. (2b) |
| $c$ | chordlength |
| $c_a$ | axial force coefficient |
| $c_n$ | normal force coefficient, positive up |
| $c_{n_f}$ | control surface normal force coefficient, positive up |
| $c_m$ | pitching moment coefficient about pitch axis $x_r$, positive nose down |
| $c_{m_f}$ | control surface moment coefficient about hinge line $x_h$, positive trailing-edge up |
| $c_\beta$ | distance in semichords from midchord to hinge axis |
| $C$ | coefficient defined in Eq. (2c) |
| $C_p$ | pressure coefficient |
| $C_{p_u}$ | upper surface pressure coefficient |
| $C_{p_\ell}$ | lower surface pressure coefficient |
| $C_p^*$ | critical pressure coefficient |

| | |
|---|---|
| $f$ | instantaneous position of airfoil, defined in Eqs. (4a) and (4b) |
| $f_o(x)$ | airfoil contour |
| $g(x,t)$ | chord deformation |
| $g_1(x)$ | amplitude of harmonic chord deformation |
| $h(t)$ | plunge displacement of elastic axis nondimensionalized by semichord, positive down (used for aeroelastic motion) |
| $H(t)$ | function for forced harmonic motion |
| $k$ | reduced frequency, $\omega b/U$ |
| $[K]$ | stiffness matrix, defined in Eq. (10b) |
| $m$ | airfoil mass per unit span |
| $M$ | local Mach number |
| $M_\infty$ | freestream Mach number |
| $[M]$ | mass matrix, defined in Eq. (10a) |
| $p(x,t)$ | arbitrary motion specified by the user |
| $r_\alpha$ | radius of gyration of airfoil about elastic axis |
| $r_\beta$ | radius of gyration of control surface about hinge line |
| $r_1$ | parameter to turn on/off time dependent term in airfoil boundary condition, defined in Eq. (3) |
| $r_2$ | parameter to turn on/off time dependent term in airfoil wake condition, defined in Eq. (12) |
| $r_3$ | parameter to turn on/off time dependent term in $C_p$ and Mach number formulas, defined in Eqs. (14) and (16) |
| $t$ | scaled time, $kT$ |
| $\bar{t}$ | nondimensional time for print and plot output, $k\tau$ |
| $T$ | time, (sec.) |
| $T_c$ | time at pulse center in Eqs. (8a), (8b) and (8c) |
| $U$ | freestream speed |
| $U_F$ | flutter speed |
| $\{u\}$ | aerodynamic load vector for aeroelastic motion, defined in Eq. (10d) |

| | |
|---|---|
| $w$ | parameter that controls pulse width in Eqs. (8a), (8b) and (8c) |
| $x$ | streamwise coordinate relative to leading edge, measured in chordlength |
| $x_f$ | control surface leading edge location |
| $x_h$ | control surface hinge axis location |
| $x_r$ | pitch axis location |
| $x_\alpha$ | distance in semichords from elastic axis to center of mass |
| $x_\beta$ | distance in semichords from hinge axis to control surface center of mass |
| $\{x\}$ | displacement vector for aeroelastic motion, defined in Eq. (10c) |
| $z$ | coordinate normal to freestream, measured in chordlength, positive up |
| $Z(t)$ | nondimensional plunge displacement, positive up (used for forced harmonic and pulse motions) |
| $Z_1$ | harmonic plunge amplitude |
| $\alpha(t)$ | pitch motion, positive nose up |
| $\alpha_0$ | mean angle of attack |
| $\alpha_1$ | harmonic pitch amplitude |
| $\beta(t)$ | control surface motion, positive trailing edge down |
| $\beta_0$ | control surface mean deflection angle |
| $\beta_1$ | control surface harmonic amplitude |
| $\gamma$ | ratio of specific heats |
| $\Delta C_p$ | lifting pressure coefficient |
| $\Delta T$ | time step size |
| $\delta$ | airfoil maximum thickness-to-chord ratio |
| $\lfloor\theta\rfloor$ | integral of state-transition matrix, used for aeroelastic motion |
| $\mu$ | airfoil mass ratio, $m/\pi\rho_\infty b^2$ |
| $\rho$ | density |
| $\rho_\infty$ | freestream density |

| | |
|---|---|
| $\tau$ | nondimensional time, UT/b |
| $\phi$ | disturbance velocity potential |
| $[\Phi]$ | state-transition matrix, used for aeroelastic motion |
| $\omega$ | angular frequency |
| $\omega_h$ | uncoupled natural frequency of plunge, rad/sec |
| $\omega_\alpha$ | uncoupled natural frequency of pitch, rad/sec |
| $\omega_\beta$ | uncoupled natural frequency of control surface deflection, rad/sec |

## Description of XTRAN2L

The XTRAN2L code is used to calculate time-accurate, finite-difference solutions of the nonlinear, small-disturbance, potential equation for two-dimensional transonic flow. The code can be used to calculate steady and unsteady transonic flow fields about airfoils and is capable of treating forced harmonic, pulse, or aeroelastic transient type motions. In this section, the XTRAN2L code is described including the relevant equations and computational procedures.

### Transonic Small-Disturbance Equation

The flow field is described by the complete unsteady transonic small-disturbance equation

$$A\phi_{tt} + B\phi_{xt} = C\phi_{xx} + \phi_{zz} \tag{1}$$

where $\phi$ is a disturbance velocity potential scaled by $c[\delta M_\infty^2 (\gamma^* + 1)]^{2/3}$, $\gamma^* = 2 - (2 - \gamma)M_\infty^2$, and the spatial coordinates x and z and time t are normalized from the physical quantities by c, $c/[\delta M_\infty^2 (\gamma^* + 1)]^{1/3}$ and $k^{-1}$, respectively. The coefficients A, B, and C are defined as

$$A = c^2 k^2 M_\infty^2/U^2 \left[\delta M_\infty^2 (\gamma^* + 1)\right]^{2/3} \tag{2a}$$

$$B = 2 c k M_\infty^2/U \left[\delta M_\infty^2 (\gamma^* + 1)\right]^{2/3} \tag{2b}$$

$$C = (1 - M_\infty^2)/\left[\delta M_\infty^2 (\gamma^* + 1)\right]^{2/3} - M_\infty^2 (\gamma^* + 1)\phi_x \tag{2c}$$

A time-accurate alternating-direction implicit (ADI) finite-difference scheme is used to solve Eq. (1). Details of the ADI algorithm are given by Whitlow.[4]

## Airfoil Boundary Condition

The airfoil flow tangency boundary condition[7] is

$$\varphi_z^\pm = f_x^\pm + r_1 f_t \tag{3}$$

where

$$f = f_o(x) + g(x,t) + Z(t) - \alpha(t) \left[x - x_r\right] + p(x,t) \quad ; x < x_f \tag{4a}$$

and

$$f = f_o(x) + g(x,t) + Z(t) - \alpha(t) \left[x - x_r\right] + p(x,t) - \beta(t) \left[x - x_h\right] \quad ; \quad x \geq x_f \tag{4b}$$

In Eq. (3), $r_1$ is a parameter specified by the user to be either 0 or 1. The low frequency airfoil boundary condition is selected by setting $r_1$ to be equal to zero. In Eqs. (4a) and (4b), $f_o(x)$ describes the airfoil contour, $g(x,t)$ is the chord deformation, and $Z(t)$, $\alpha(t)$, and $\beta(t)$ are the nondimensional plunge displacement, pitch, and trailing edge control surface deflection, respectively. Three types of motion may be analyzed using XTRAN2L as described below. The motion types are forced harmonic, pulse, and aeroelastic. The capability for specifying an arbitrary motion is provided through the use of the function $p(x,t)$.

Forced Harmonic Motion. - Typically, unsteady aerodynamic forces are determined by calculating several cycles of forced harmonic oscillation with the last cycle providing the estimate of the forces. Following Ref. 7, the equations describing forced harmonic motion are

$$g(x,t) = g_1(x)\ H(t) \tag{5a}$$

$$Z(t) = Z_1\ H(t) \tag{5b}$$

$$\alpha(t) = \alpha_o + \alpha_1\ H(t) \tag{5c}$$

$$\beta(t) = \beta_o + \beta_1\ H(t) \tag{5d}$$

where $\alpha_0$ and $\beta_0$ are the airfoil mean angle of attack and control surface mean deflection angle, respectively; $g_1(x)$ is the amplitude of harmonic chord deformation, and $Z_1$, $\alpha_1$, and $\beta_1$ are the amplitudes of harmonic plunge, pitch, and control surface motions, respectively. Two alternatives exist for the definition of the harmonic function H(t). The first definition is

$$H(t) = \sum_{n=1}^{N} b_n \sin^2 nk\tau \quad ; \; 0 \leq \tau \leq \frac{\pi}{2nk} \tag{6a}$$

$$H(t) = \sum_{n=1}^{N} b_n \sin nk\tau \quad ; \; \tau > \frac{\pi}{2nk} \tag{6b}$$

where N is the number of harmonics to be selected by the user. Equation (6a) is used to provide a smooth start over the first quarter period of each harmonic which reduces the starting transient. The second definition for H(t) is

$$H(t) = \sum_{n=1}^{N} a_n \cos nk\tau \quad ; \; \tau \geq 0 \tag{7}$$

Real and imaginary parts of the unsteady aerodynamic forces in the frequency domain may be determined two ways. First, the method used in the LTRAN2-NLR code was retained. This method calculates the coefficients of the first harmonics of the airloads based on information from each quarter period of the last cycle of harmonic motion. The procedure assumes that the time histories of the normal force and moment coefficients are periodic and simple harmonic. The relevant equations are presented in Ref. 7. In the second procedure, Fourier analyses of the last cycle of motion are performed to determine all relevant harmonic components. This procedure is the preferred method since the only assumption is that of periodicity.

Pulse Motion. - As an alternative to calculating unsteady aerodynamic forces by forced harmonic oscillation, the unsteady forces may be obtained indirectly from the response due to a smoothly varying, exponentially shaped pulse.[5] In this procedure, the airfoil is given a small prescribed pulse in a given mode of motion and the aerodynamic transients are calculated. For plunge motion, the input pulse is given by

$$Z(t) = ae^{-w\,(T - T_c)^2} \tag{8a}$$

for pitch motion, the input pulse is given by

$$\alpha(t) = \alpha_0 + ae^{-w\,(T - T_c)^2} \tag{8b}$$

and for control surface motion, the input pulse is given by

$$\beta(t) = \beta_0 + ae^{-w\,(T - T_c)^2} \tag{8c}$$

where a is the pulse amplitude, w is a parameter that controls the pulse width, and $T_c$ is the time at the pulse center. The pulse width is inversely proportional to w, such that as the value of w increases, the width of the pulse decreases. To ensure adequate resolution of harmonic components up to a reduced frequency of k = 2.0, the product of the chosen values of w and $\Delta T^2$ should be near the product of the default values. The harmonic response is obtained by a transfer-function analysis using fast Fourier transforms (FFT). Specifically, the aerodynamic forces in the frequency domain are determined by dividing the FFT of the time histories of the output normal force and moment coefficients by the FFT of the input airfoil pulse motion. The calculation is performed external to the XTRAN2L code as a separate job step and thus the post-processing program is not included within XTRAN2L. Use of the pulse transfer-function analysis gives considerable detail in the frequency domain with a significant reduction in cost over the alternative method of calculating multiple oscillatory responses, as shown in Fig. 13 of Ref. 5. As an example, Fig. 1 shows a pitch pulse input (Fig. 1(a)), a typical normal force coefficient output (Fig. 1(b)), and the resulting unsteady forces (Fig. 1(c)).

Aeroelastic Motion. - An aeroelastic transient capability is available within XTRAN2L wherein the structural equations of motion are coupled with the aerodynamic solution procedure for simultaneous time-integration. The equations of motion for a three degree-of-freedom (plunge, pitch, and control surface motions) aeroelastic system may be written as

$$[M]\,\{\ddot{x}\} + [K]\,\{x\} = \frac{1}{\pi\mu}\left(\frac{U}{b}\right)^2 \{u\} \qquad (9)$$

where $[M]$, the mass matrix, $[K]$, the stiffness matrix, $\{x\}$, the displacement vector, and $\{u\}$, the aerodynamic load vector, are defined as

$$[M] = \begin{bmatrix} 1 & x_\alpha & x_\beta \\ x_\alpha & r_\alpha^2 & (c_\beta - a_h)x_\beta + r_\beta^2 \\ x_\beta & (c_\beta - a_h)x_\beta + r_\beta^2 & r_\beta^2 \end{bmatrix} \tag{10a}$$

$$[K] = \begin{bmatrix} \omega_h^2 & 0 & 0 \\ 0 & r_\alpha^2\ \omega_\alpha^2 & 0 \\ 0 & 0 & r_\beta^2\ \omega_\beta^2 \end{bmatrix} \tag{10b}$$

$$\{x\} = \begin{Bmatrix} h \\ \alpha \\ \beta \end{Bmatrix} \tag{10c}$$

$$\{u\} = \begin{Bmatrix} -(c_n - c_{n_o}) \\ 2(c_m - c_{m_o}) \\ 2(c_{m_f} - c_{m_{f_o}}) \end{Bmatrix} \tag{10d}$$

The dot (•) above a variable denotes differentiation with respect to time T, and the structural parameters appearing in Eqs. (9) and (10) are defined in Fig. 2. In the aerodynamic load vector, the steady-state coefficients $c_{n_o}$, $c_{m_o}$, and $c_{m_{f_o}}$ are subtracted from the total coefficients. Thus the aeroelastic response (i.e., $h(t)$, $\alpha(t)$, and $\beta(t)$) represents motion about the steady-state condition. Aeroelastic equations of motion for any of the three possible two degree-of-freedom systems are determined by deleting the appropriate rows and columns in Eqs. (9) and (10).

The aeroelastic response is determined by numerically integrating the equations of motion in time using a structural integrator based on the state-transition matrix.[6] More specifically, the time-integration of Eq. (9) is performed by advancing the aeroelastic solution from time level n to time level n+1 using an algorithm described by

$$\left\{\frac{\{x\}}{\{\dot{x}\}}\right\}^{n+1} = [\Phi] \left\{\frac{\{x\}}{\{\dot{x}\}}\right\}^{n} + \frac{1}{\pi\mu}\left(\frac{U}{b}\right)^2 [\theta] \left\{\frac{[0]}{[M]^{-1}}\right\}\left[\frac{3}{2}\{u\}^n - \frac{1}{2}\{u\}^{n-1}\right] \quad (11)$$

where $[\Phi]$ and $[\theta]$ are the state-transition matrix and its integral matrix, respectively. These matrices are functions of the aeroelastic parameters and are computed within the XTRAN2L code. Details of the aeroelastic solution procedure may be found in Ref. 6. In general, several aeroelastic responses are calculated for a range of freestream speeds, U, at a given Mach number. The values for U are selected such that stable (converging) and unstable (diverging) responses result. The flutter speed $U_F$, where the damping is zero, is calculated by interpolating the critical damping of the responses. Damping of the aeroelastic transients is typically determined using the modal identification program of Bennett and Desmarais.[8] The program uses complex exponential functions and a least-squares curve-fitting technique to estimate damping, frequency, magnitude, and phase of the aeroelastic modes from the transient responses. This calculation is performed as a separate post-processing job step and thus the program of Ref. 8 is not included within the XTRAN2L code.

## Wake Condition

The wake is represented as a slit downstream of the airfoil trailing edge. Along the slit the condition[7]

$$[\phi_x] + r_2[\phi_t] = 0 \quad ; \; z = 0, \; x > 1 \tag{12}$$

is imposed, where [ ] denotes the jump in the indicated quantity across the wake. The parameter $r_2$ is specified by the user to be either 0 or 1. The low frequency version of the wake condition is specified by setting $r_2$ to be equal to zero.

## Nonreflecting Farfield Boundary Conditions

The LTRAN2 and LTRAN2-NLR codes use steady-state farfield boundary conditions which cause disturbances to be reflected from the computational boundaries. The boundaries were subsequently located far away to minimize the possibility of disturbances reflecting back into the flow field and contaminating the solution. Therefore, nonreflecting farfield boundary conditions were developed and implemented in XTRAN2L by Whitlow.[4] These boundary conditions, consistent with the TSD equation (Eq. (1)), are summarized in Fig. 3, taken from Ref. 4.

## Pressure Coefficient and Mach Number

The pressure coefficient $C_p$, may be calculated using either of two formulae.[7] The exact expression is given by

$$C_p = \frac{2}{\gamma M_\infty^2} (\rho^\gamma - 1) \tag{13a}$$

where

$$\rho = \left[1 - \frac{\gamma-1}{2} M_\infty^2 (2\phi_x + \phi_x^2 + \phi_z^2 + 2\phi_t)\right]^{\frac{1}{\gamma-1}} \tag{13b}$$

The linearized TSD approximation is given by

$$C_p = -2(\varphi_x + r_1 r_3 \phi_t) \tag{14}$$

The local Mach number M, may also be calculated by either of two formulae.[7] The exact expression is

$$M^2 = M_\infty^2 \frac{(1+\phi_x)^2 + \phi_z^2}{\rho^{\gamma-1}} \tag{15}$$

and the linearized TSD approximation is

$$M^2 = M_\infty^2 \left[1 + (\gamma^* + 1)\phi_x + r_1 r_3 (\gamma - 1) M_\infty^2 \phi_t\right] \tag{16}$$

The user may also select low-frequency versions of the linearized equations, Eq. (14) and Eq. (16), whereby the time-derivative terms are omitted. This is done by defining the product $r_1 r_3$ to be equal to zero. Otherwise the product $r_1 r_3$ is set equal to unity.

## Normal Force, Axial Force, and Pitching Moment Coefficients

For the airfoil, the normal force coefficient $c_n$, axial force coefficient $c_a$, and pitching moment coefficient $c_m$, are defined as

$$c_n = -\int_0^1 \Delta C_p \, dx \tag{17a}$$

$$c_a = \int_0^1 (C_{p_u} f_{x_u} - C_{p_\ell} f_{x_\ell}) \, dx \tag{17b}$$

$$c_m = -\int_0^1 \Delta C_p \, (x - x_r) \, dx \tag{17c}$$

where $\Delta C_p = C_{p_u} - C_{p_\ell}$, and the subscripts u and $\ell$ denote the upper and lower airfoil surfaces, respectively.

For the control surface, the normal force coefficient $c_{n_f}$, and pitching moment coefficient $c_{m_f}$ are defined as

$$c_{n_f} = - \int_{x_f}^{1} \Delta C_p \, dx \tag{18a}$$

$$c_{m_f} = \int_{x_f}^{1} \Delta C_p \, (x - x_h) \, dx \tag{18b}$$

By substituting Eq. (14) for the pressure coefficients appearing in Eqs. (17) and (18), and evaluating several of the integrals by parts leads to

$$c_n = 2 \, \Delta\phi_{TE} + 2r_1 r_3 \int_0^1 \Delta\phi_t \, dx \tag{19a}$$

$$c_a = \int_0^1 (C_{p_u} \, f_{x_u} - C_{p_\ell} \, f_{x_\ell}) \, dx \tag{19b}$$

$$c_m = 2 \, (1 - x_r) \, \Delta\phi_{TE} + 2 \int_0^1 \Delta\phi \, dx + 2r_1 r_3 \int_0^1 \Delta\phi_t \, (x - x_r) \, dx \tag{19c}$$

for the airfoil, and

$$c_{n_f} = 2 \, \Delta\phi_{TE} - 2 \, \Delta\phi_{x_f} + 2r_1 r_3 \int_{x_f}^{1} \Delta\phi_t \, dx \tag{20a}$$

$$c_{m_f} = 2 \, (1 - x_h) \, \Delta\phi_{TE} - 2 \, (x_f - x_h) \, \Delta\phi_{x_f} + 2 \int_{x_f}^{1} \Delta\phi \, dx$$

$$+ 2r_1 r_3 \int_{x_f}^{1} \Delta\phi_t \, (x - x_h) \, dx \tag{20b}$$

for the control surface. In Eqs. (19) and (20), $\Delta\phi = \phi_u - \phi_\ell$, and $\Delta\phi_{TE}$ and $\Delta\phi_{x_f}$ are the values of $\Delta\phi$ at the airfoil trailing edge and control surface leading edge, respectively. In XTRAN2L, the normal force, axial force, and pitching moment coefficients are calculated using Eqs. (19) and (20) when the linearized equation is selected for the pressure coefficient (Eq. (14)). This is computationally more accurate than integrating the lifting pressure coefficients as indicated in Eqs. (17) and (18). Note that if a particular case has no control surface then $x_f = x_h = 1$ leads to $c_{n_f} = 0$ and $c_{m_f} = 0$.

## Operation of XTRAN2L

### General Information and Input Data

In this section, general information is given on the operation of XTRAN2L including input data and recommended operating procedures. Data to define the problem and control program execution are defined using six namelists. The input data consists of a single TITLE card followed by the six namelists in the following order:

AEROEL - Definition of airfoil motion and aeroelastic parameters
INPUT - Definition of program solution parameters and constants
MESH - Definition of user-input extended fine grid
AMPLI - Definition of periodic time-dependent airfoil motion
ORD - Definition of airfoil geometry
COND - Definition of airfoil chord deformation

Namelists INPUT, MESH, AMPLI, ORD, and COND have been retained from the LTRAN2-NLR code. A new namelist, AEROEL, has been added to allow for specification of the type of airfoil motion (forced harmonic, pulse, aeroelastic, or no motion) and for input of pulse or aeroelastic parameter values. Tables 1-6 list the parameters input in each namelist and give a short description of each parameter including its default value. The tables are presented in the same format as that of the LTRAN2-NLR user's manual.[7] Any parameter not explicitly defined in a NAMELIST statement assumes its default value.

To start the solution of the unsteady flow equation, the program requires an initial, steady-state solution for the flow field at T = 0. The steady-state solution can be calculated in one of three ways which are selected using the IREAD parameter in namelist INPUT. The first method is to define the initial flow field as an undisturbed stream (IREAD = 0). The second method is to solve for a steady-state solution using a successive line-overrelaxation (SLOR) scheme (IREAD = 1). The third method is to solve for a steady-state solution using the unsteady TSD scheme, termed the "unsteady solver", with no airfoil motion (IREAD = 0 and IRESP = 5). Once a converged steady-state solution has been achieved, the program is then restarted using the converged solution as the initial condition (IREAD = 5). The SLOR solution procedure normally involves using a sequence of three default grids defined as coarse, fine, and extended fine, to accelerate convergence. The default extended fine grid used in XTRAN2L was developed to increase the accuracy of the unsteady solution while decreasing the number of grid points used in the LTRAN2-NLR code.[5] Grid point locations for the default extended fine grid are listed in Table 7. The grid distribution in the vicinity of the airfoil is shown in Fig. 4. The coarse and fine grids were defined to be subsets of the extended fine grid. The user may choose to use the default extended fine grid or input a new extended fine grid using namelist MESH.

Calculating steady solutions using the unsteady solver requires starting from an initial undisturbed stream and solving the unsteady TSD equation for no airfoil motion until a converged steady-state solution is reached. All computations using the unsteady solver are performed on the extended fine grid only. Experience has shown that for most cases the unsteady solver converges to a steady-state solution as fast or faster than the SLOR algorithm. Use of the unsteady solver is the preferred approach since for lifting cases the two algorithms converge to slightly different steady-state solutions.[5] For consistency with the unsteady solution it is therefore recommended that the steady-state starting solution be calculated using the unsteady solver.

The unsteady solver can solve three combinations of the TSD equation and boundary conditions. These are denoted as the LTRAN, HYTRAN, and EXTRAN options. The equation set to be solved is chosen using the IEQFLAG parameter in namelist AEROEL. Selecting the LTRAN option gives the low-frequency approximation to the complete unsteady TSD equation (Eq. (1)) by defining the coefficient "A" in the equation to be zero. In addition, the time-derivative terms in the airfoil and wake boundary conditions (Eqs. (3) and (12), respectively), and in the pressure and local Mach number equations (Eqs. (14) and (16), respectively), are automatically deleted by the program setting the parameters $r_1$ and $r_2$ (variables IR and IMODFR in namelist INPUT) to be equal to zero. Selecting the HYTRAN option defines the coefficient "A" in Eq. (1) to be zero. The time derivative terms are included in the airfoil and wake boundary condition equations and in the pressure and local Mach number equations by setting $r_1$ and $r_2$ to be equal to unity. This option is the capability implemented in LTRAN2-NLR.[7] In choosing the LTRAN and HYTRAN options, the farfield boundary conditions in Fig. 3 reduce to a set consistent with the low frequency approximation. Selecting the EXTRAN option defines the coefficient "A" in Eq. (1) to be as described in Eq. (2a). The time derivative terms are also included in the associated boundary conditions.

The unsteady solver calculates the time varying flow field by employing a time marching solution procedure. For oscillatory cases, the time step is implicitly defined by the user based upon the reduced frequency k, scaled velocity U/c, and number of time steps per cycle NSPC, as

$$\Delta T = \frac{\pi}{NSPC*k*U/c} \tag{21}$$

For cases other than oscillatory motion, the time step is explicitly defined by the user. In these cases, the reduced frequency k is implicitly defined based on $\Delta T$, U/c, and NSPC, using Eq. (21).

For both steady and unsteady cases, the airfoil contour is defined in terms of the upper and lower surface slopes at the grid points, input in namelist ORD. The program will interpolate airfoil slopes which are not defined at the grid points and thus calculate new slopes, but this approach is not recommended. Before running the XTRAN2L program, a pre-processor is normally used to convert the airfoil geometry into slopes and displacements at the grid points. This allows the user to view the geometry to be input to the program and to take any required corrective action. This is especially true for measured airfoil ordinates where errors or inaccuracies in the ordinates may cause unrealistic airfoil slopes to be calculated.

The program has a restart capability designed for continuing the steady SLOR solution or the unsteady solver from a previously saved flow field solution. The restart capability is typically used to restart the SLOR solution to achieve better steady-state convergence (IREAD = 3 or 4), to start an unsteady computation from a previously calculated steady-state solution (IREAD = 5), or to continue an unsteady computation further in time (IREAD = 5).

## Files and Logical Units

The XTRAN2L program uses the logical units TAPE3, TAPE4, TAPE5, TAPE6, TAPE7, and TAPE8. The logical units TAPE5 and TAPE6 are used for program input and output, respectively. The logical units TAPE3 and TAPE4 are used for restart files. The data to be saved for a restart is written to TAPE4 and a restart reads the required data from TAPE3. The data is in unformatted binary form and is input and output using BUFFER IN and BUFFER OUT statements. The BUFFER IN and BUFFER OUT statements are called in subroutines GETS and PUTS, respectively. The call to GETS and PUTS is of the form:

```
CALL GETS (INDEX, ARRAY, NELEMNT)
```

where,

INDEX - logical unit number

ARRAY - array of data to be input/output

NELEMNT - number of data elements to be input/output

The data is written to TAPE4 using the following FORTRAN statements:

```
CALL PUTS (4,BUF1,2)
CALL PUTS (4,BUF2,40)
CALL PUTS (4,BUF3,5)
CALL PUTS (4,VUO,80)
CALL PUTS (4,VLO,80)
```

```
      CALL PUTS (4,PTU(1,ITM1),JMAX1)
      CALL PUTS (4,POU,JMAX1)
      CALL PUTS (4,PTL(1,ITM1),JMAX1)
      CALL PUTS (4,POL,JMAX1)
      DO 704 J=1, JMAX1
  704 CALL PUTS (4,PO(1,J),LMAX1)
      CALL PUTS (4,PTT(1,1),4880)
      CALL PUTS (4,PTTU(1),80)
      CALL PUTS (4,PTTL(1),80)
```

where,

BUF1 - Array containing circulation value and time from last time step

BUF2 - Array containing array sizes, airfoil aeroelastic response from last time step and calculated forces from last time step

BUF3 - Array containing calculated forces from last time step

VUO/VLO - Array of airfoil upper/lower surface boundary condition values from last time step

PTU/PTL - Array of airfoil upper/lower surface potentials from the next to last time step

JMAX1/LMAX1 - Number of points in extended fine grid in x/z, respectively

POU/POL - Array of airfoil upper/lower surface potentials from last time step

PO - Array of flow field potentials from last time step

PTT - Array of flow field potentials from next to last time step

PTTU/PTTL - Array of airfoil upper/lower surface potentials from next to last time step

The logical units TAPE7 and TAPE8 are used for storing results at each time step for post-processing. If the IBUF parameter in namelist INPUT is set equal to 1, the program outputs time histories of aeroelastic quantities, pressure coefficients, and forces in unformatted binary to TAPE8. For restarts, TAPE7 is provided to allow the merging of previous time histories from a TAPE8 file onto a new file TAPE8. The program copies TAPE7 onto TAPE8 and then proceeds as normal. This option is not recommended due to the large size required to store a TAPE8 file. A blank TAPE7 file causes the program to skip the copying step on restarts and continues with normal execution. The data is written to TAPE8 using the following FORTRAN statements:

```
    CALL PUTS (8,TITLE,8)
    CALL PUTS (8,IINPUT,49)
    CALL PUTS (8,X,NPTSARF)
    CALL PUTS (8,FXU,NPTSARF)
    CALL PUTS (8,FXL,NPTSARF)
    DO 10 IA=1, NITER
    CALL PUTS (8,BUF4,9)
    CALL PUTS (8,CPU,NPTSARF)
    CALL PUTS (8,CPL,NPTSARF)
    CALL PUTS (8,XN,6)
 10 CONTINUE
```

where,

TITLE - array containing 80 character title

IINPUT - array containing program variables and constants

X - array containing x coordinates of grid points on airfoil

NPTSARF - number of x-grid points on airfoil

FXU/FXL - array containing airfoil upper/lower surface displacements at x-grid points

NITER - number of iterations of time history data written
=1 - steady solver solution only
=MAXIT - unsteady solution only, no restart
=MAXIT+1 - unsteady solution started from steady solver or restart file

BUF4 - array containing nondimensional time and calculated force coefficients

CPU/CPL - array containing upper/lower surface pressure coefficients on airfoil

XN - array containing aeroelastic displacements of airfoil

The do-loop illustrated above is executed at every time step. If a restart is performed, the first set of data written by the do-loop is for the data read from the restart file.

## Sample Calculations

Sample calculations were performed for the NACA 64A010A airfoil[9] (NASA Ames model) to illustrate various program options. Four cases were run to demonstrate the program's capabilities. The first case is a steady-state solution using the unsteady solver. The next three cases are a simple harmonic pitching motion of the airfoil, an airfoil pitch pulse which is used to calculate the generalized aerodynamic forces, and a transient aeroelastic response of the airfoil at a condition just above the flutter speed. The last three cases are restarted from the steady-state solution.

### Steady Calculations

Results from the steady calculation are listed in Appendix A. The input file read by the program is listed first, followed by the program output. For brevity, the output included in Appendix A is only a partial listing of the output generated by the program for the case run. The output shown includes the banner page, echo of input parameters, airfoil description, computational grid listing and output of pressure distributions and forces calculated at selected iterations. The unsteady solver was used to converge to a steady flow field solution at $M_\infty = 0.78$ and $\alpha_0 = 1.0°$ starting from freestream initial conditions with no airfoil motion. The calculation was run for 1024 iterations to ensure convergence to a steady-state solution. Airfoil pressures and forces are printed every 128 iterations. The pressure distributions and forces listed in Appendix A are for the first and last iterations for which calculations were performed. The time listed with each set of pressure output is a nondimensional time based on harmonic motion, $\bar{t}$. For harmonic motion, $\bar{t}$ is the measure of the angular position in radians in the harmonic cycle. Also output is the equivalent angular position in degrees. For other than harmonic motion, the time output can be considered as a nondimensional time. The time histories of airfoil force coefficients and the final pressure distributions are shown in Fig. 5. The plots were created by a post-processing program which reads the TAPE8 file and uses the information to generate appropriate plots for the case run.

## Unsteady Calculations

Forced Harmonic Motion. - Results from a forced harmonic oscillation of the airfoil in pitch are listed in Appendix B1. The input file is listed first, followed by selected program output. The airfoil was oscillated for four cycles about the quarter-chord at a reduced frequency of $k = 0.075$ with an amplitude of $\alpha_1 = 0.5°$ about the mean angle of attack $\alpha_0 = 1.0°$. The flow field was calculated in 1° increments of a cycle of motion. Included in the output are the pressure distributions for the first and last iterations and time histories of the airfoil forces for the last cycle of oscillation. In the output, the pitching moment coefficient, normal force coefficient, and control surface moment coefficient are labeled as "CM", "CN", and "CMF", respectively. A Fourier analysis of the forces is performed using the last cycle of airfoil motion and the first nine harmonics are output. The real and imaginary components of the forces, labeled as "RE" and "IM", respectively, are scaled by the amplitude of the motion (in radians for both airfoil pitch and control surface motions). Also included in the harmonic quantities output is a measure of the amount of higher harmonic components in the force time histories, labeled as "ECM", "ECN", and "ECMF". The quantities are defined as the magnitude of the nth harmonic component divided by the magnitude of the fundamental, or first harmonic component. The zeroth harmonic is defined as the mean or average value.

The first five harmonics of the airfoil pressures calculated for the last cycle of motion are included in Appendix B1 for reference. The pressure harmonics are calculated by a post-processing program using the information stored on TAPE8. The time histories of the airfoil motion and corresponding force coefficients are plotted in Figs. 6(a) and 6(b), respectively. Figures 6(c)-6(f) show the mean pressure distribution and the first harmonic pressure distributions calculated by the post-processor.

Pulse Motion. - Results from an airfoil pitch pulse are listed in Appendix B2. The input file is listed first followed by selected program output. The airfoil was pitched about the quarter-chord with maximum amplitude of a = 0.5° from the mean angle of attack of $\alpha_0$ = 1.0°. The exponential pulse was centered at iteration 30, and the unsteady solver was run until the flow field returned to the steady-state condition. It is important to ensure that the flow field returns to steady-state conditions in order to allow accurate calculation of the generalized aerodynamic forces. The pressure distributions for the first and last iteration are listed.

Included in the output are the generalized aerodynamic forces calculated by a post-processing program from the information contained on TAPE8. The time histories of the airfoil motion and resulting force coefficients are plotted in Figs. 7(a) and 7(b), respectively. Figures 7(c) and 7(d) show the generalized aerodynamic forces calculated by the post-processor.

Aeroelastic Motion. - Results from aeroelastic motion of the airfoil are listed in Appendix B3. The input file is listed first followed by selected program output. The aeroelastic parameters used were the program default values: $a_h$ = -2.0, $x_\alpha$ = 1.8, $r_\alpha$ = 1.865, $\mu$ = 60.0, $\omega_h$ = 100.0 rad/sec, and $\omega_\alpha$ = 100.0 rad/sec. The default values are those of Case A of Isogai[10] which were chosen to have normal modes similar to those of a streamwise section near the tip of a sweptback wing. The wind-off coupled plunge and pitch frequencies are 71.3 and 535.7 rad/sec, respectively. The pivotal point for the plunge mode is located 1.44 chordlengths forward of the leading edge; the pivotal point for the pitch mode is located 0.068 chordlengths ahead of midchord. For the sample aeroelastic calculation presented here, the scaled velocity U/c was set equal to 330.0, which is slightly above the flutter speed of the NACA 64A010A airfoil at M = 0.78 and $\alpha_0$ = 1.0°. The program automatically calculates the state-transition matrix $[\Phi]$ and its integral matrix $[\theta]$ in Eq. (11) from the aeroelastic quantities input in namelist AEROEL. The output from this calculation is included in Appendix B3. The $[\Phi]$ matrix is labeled in the output as "PHI" and the "THETA*B-PRIME" matrix is defined as

$$\text{THETA*B-PRIME} = \frac{1}{\pi\mu} \left(\frac{U}{b}\right)^2 [\theta] \begin{Bmatrix} [0] \\ [M]^{-1} \end{Bmatrix} \tag{22}$$

The "I.C. VECTOR" listed in the output contains the initial values used for the aeroelastic displacement vector $\{x\}$. The pressure distributions output for the first and last iterations are included in the Appendix. The time histories of the airfoil motion and corresponding force coefficients are plotted in Fig. 8. As shown, the airfoil motion is slightly divergent for the case selected.

## Acknowledgment

The authors wish to acknowledge the National Aerospace Laboratory, NLR, the Netherlands, for the thorough presentation of equations and detailed input description for the LTRAN2-NLR code reported in their user's manual,[7] the organization and format of which were adopted in the present report.

## References

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[9]Bland, S. R., "AGARD Two-Dimensional Aeroelastic Configurations." AGARD AR-156, August 1979.

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Table 1. Description of input parameters to NAMELIST AEROEL.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| IRESP | | 0 | Selects type of airfoil motion<br>0 - Harmonic oscillation<br>1 - Aeroelastic transient response<br>2 - Plunge pulse transient response<br>3 - Pitch pulse transient response<br>4 - Control surface pulse transient response<br>5 - No airfoil motion allowed |
| NELAST | | 1 | Selects type of aeroelastic motion<br>1 - 2-DOF, plunge and pitch<br>2 - 2-DOF, plunge and control surface<br>3 - 2-DOF, pitch and control surface<br>4 - 3-DOF, plunge pitch and control surface |
| UC | U/c | 100.0 | Scaled freestream velocity, used to define time step $\Delta T$ (IRESP = 0) or reduced frequency k (IRESP $\neq$ 0), Eq.(21) |
| XMU | $\mu$ | 60.0 | Airfoil mass ratio |
| DELT | $\Delta T$ | .002618 | Time step (sec), calculated by program using Eq. (21) if IRESP = 0 |
| IEQFLAG | | 3 | Selects equation set<br>1 - LTRAN option<br>2 - HYTRAN option<br>3 - EXTRAN option |
| AMPLTD | a | .017435 | Amplitude of pulse transient |
| WDTHPLS | w | 10000.0 | Exponential constant for pulse |
| TZEROST | $T_c/\Delta T$ | 17.5 | Center of pulse (iterations) |
| XALPHA | $x_\alpha$ | 1.8 | Nondimensional distance from elastic axis to airfoil center of mass |
| XBETA | $x_\beta$ | .020833 | Nondimensional distance from hinge line to control surface center of mass |
| RALPHA | $r_\alpha$ | 1.865 | Radius of gyration of airfoil about elastic axis |
| RBETA | $r_\beta$ | .027169 | Radius of gyration of control surface about hinge line |

Table 1. Concluded.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| OMEGAH | $\omega_h$ | 100. | Uncoupled natural frequency of plunge |
| OMEGAA | $\omega_\alpha$ | 100. | Uncoupled natural frequency of pitch about elastic axis |
| OMEGAB | $\omega_\beta$ | 500. | Uncoupled natural frequency of control surface deflection about hinge line |
| AH | $a_h$ | -2. | Nondimensional elastic axis location |
| CBETA | $c_\beta$ | .5 | Nondimensional control surface hinge location |
| XIC(1) | $h(0)$ | .01 | Initial plunge displacement |
| XIC(2) | $\alpha(0)$ | 0. | Initial pitch rotation |
| XIC(3) | $\beta(0)$ | 0. | Initial control surface deflection |
| XIC(4) | $\dot{h}(0)$ | 0. | Initial plunge velocity |
| XIC(5) | $\dot{\alpha}(0)$ | 0. | Initial pitch velocity |
| XIC(6) | $\dot{\beta}(0)$ | 0. | Initial control surface velocity |

Table 2. Description of input parameters to NAMELIST INPUT.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| XK | 2k | .2 | Reduced frequency (based on chord), calculated by program using Eq. (21) if IRESP $\neq$ 0 |
| XM | $M_\infty$ | .85 | Freestream Mach number |
| GAM | $\gamma$ | 1.4 | Ratio of specific heats |
| IREAD | | 1 | Starting conditions<br>0 - Unsteady computation starting from zero initial conditions<br>1 - Compute steady-state initial conditions starting from zero, then do the unsteady computation<br>2 - Compute steady-state solution starting from zero and stop<br>3 - Read starting solution, compute steady-state solution and stop<br>4 - Read starting solution and compute steady-state initial conditions, then do the unsteady computation<br>5 - Read initial conditions and do the unsteady computation<br>Options 3, 4, and 5 require a file which has been generated in a previous run |
| ICNVRG | | 1 | Selects method for converging steady-state solution<br>0 - Converge solution on extended fine grid only<br>1 - Converge to approximations to steady-state on coarse and fine spaced grids, then final solution on extended fine grid |
| MAXIT | | 360 | Number of time steps |
| NSPC | | 120 | Number of steps taken per cycle of oscillation (IRESP $\neq$ 0), used to define time step $\Delta$T (IRESP = 0) or reduced frequency k (IRESP $\neq$ 0), Eq. (21) |

Table 2. Continued.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| ITRAN | | 0 | Selects airfoil motion<br>0 - Pitch, plunge and control surface deflection<br>1 - Pitch, plunge, control surface deflection and chord deformation<br>2 - Arbitrary user-specified time-dependent motion only, user specifies p(x,t), Eqs. (4) |
| ISICO | | 0 | Selects method for calculating the time-dependent angle of attack, Eqs.(6) & (7)<br>0 - Sinusoidal variation<br>1 - Cosinusoidal variation |
| ICPRNT | | 60 | Time step print increment for intermediate $C_p$ output |
| JFIRST | | JFWLE | Index of first x-grid point to be included in $C_p$ output, JFWLE is the index of the first x-grid point on the airfoil in the extended fine grid |
| JLAST | | JFWTE | Index of last x-grid point to be include in $C_p$ output, JFWTE is the index of the last x-grid point on the airfoil in the extended fine grid |
| IBUF | | 0 | Storage on logical unit 8<br>0 - No storage<br>1 - Unsteady results are being stored |
| LIN | | 0 | Selects formulas for $C_p$ and local Mach number computations<br>0 - Linearized expressions<br>1 - Exact expressions |
| IR | $r_1$ | 1 | Program selected airfoil boundary condition based on IEQFLAG, Eq. (3)<br>0 - No time-derivative terms (IEQFLAG = 0)<br>1 - Include time-derivative terms (IEQFLAG = 1 or 2) |
| DEL | $\delta$ | .1 | Airfoil maximum thickness to chord ratio |
| XAR | $x_r$ | 0. | Location of airfoil pitch axis |

Table 2. Continued.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| ALFZRO | $\alpha_0$ | 0. | Mean angle of attack of airfoil (in degrees) |
| ALFONE | $\alpha_1$ | 1. | Harmonic pitch amplitude of airfoil (in degrees) |
| XFLAP | $x_f$ | 1. | Control surface leading edge location |
| XFR | $x_h$ | 1. | Control surface hinge location |
| BETZRO | $\beta_0$ | 0. | Mean control surface angle with respect to airfoil (in degrees) |
| BETONE | $\beta_1$ | 0. | Harmonic control surface amplitude (in degrees) |
| Z1 | $Z_1$ | 0. | Plunge amplitude |
| IMODFR | $r_2$ | 1 | Program selected wake condition based on IEQFLAG, Eq. (11)<br>0 - No time-derivative terms (IEQFLAG=0)<br>1 - Include time-derivative terms (IEQFLAG = 1 or 2) |
| RSUB | | 1.4 | Subsonic relaxation factor |
| RSUP | | 1.0 | Supersonic relaxation factor |
| MITC | | 500 | Maximum number of iterations |
| MITM | | 100 | on coarse, fine, and extended fine grids |
| MITEF | | 25 | for steady calculations, respectively |
| TOLC | | .00001 | Convergence tolerance parameters in |
| TOLM | | .000001 | steady calculations on course, fine |
| TOLEF | | .000001 | and extended fine grids, respectively |
| ICPRUN | | 0 | Output request for unsteady pressures<br>0 - No output<br>1 - Output of unsteady pressures, if ISICO = 0 |
| LINDIF | | 0 | Selects differential equation<br>0 - TSD equation<br>1 - TSD equation, nonlinear term omitted |

Table 2. Concluded.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| ICPT | $r_3$ | 1 | Selects time derivative in linearized formulas for $C_p$ and local Mach number<br><br>$r_1 r_3 = 0$ - Time derivative is set equal to zero<br>$r_1 r_3 = 1$ - Time derivative included in calculation of $C_p$ and local Mach number |

Table 3. Description of input parameters to NAMELIST MESH.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| JFMAX | | * 80 | Number of x-grid points in extended fine grid (Maximum value is 80) |
| LFMAX | | 61 | Number of z-grid points in extended fine grid (Maximum value is 61) |
| XFINE | | | Array of increasing x-coordinates specifying the vertical lines in the extended fine grid (JFMAX elements) |
| ZFINE | | | Array of increasing z-coordinates specifying the horizontal lines in the extended fine grid (LFMAX elements) |

*In case the default extended fine grid is used, it is sufficient to input the empty namelist $MESH $

Table 4. Description of input parameters to NAMELIST AMPLI.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| N | N | 1 | Number of terms in Eqs. (6) and (7) |
| AB | $a_n, b_n$ | 1 | Array $a_n$, $b_n$ in Eqs. (6) and (7) (N elements) |

Table 5. Description of input parameters to NAMELIST ORD.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| NINU | | * | Number of points on upper side of airfoil |
| NINL | | | Number of points on lower side of airfoil |
| XINU | | | Array of increasing x-coordinates of points specifying upper side of airfoil (NINU elements) |
| ZINU | | | Array of corresponding z-coordinates specifying upper side of airfoil (NINU elements) |
| VINU | | | Array of corresponding slopes specifying upper side of airfoil (NINU elements) |
| XINL | | | Array of increasing x-coordinates of points specifying lower side of airfoil (NINL elements) |
| ZINL | | | Array of corresponding z-coordinates specifying lower side of airfoil (NINL elements) |
| VINL | | | Array of corresponding slopes specifying lower side of airfoil (NINL elements) |

* Default is the biconvex airfoil, $\delta = .1$

Table 6. Description of input parameters to NAMELIST COND.

| PARAMETER | VARIABLE | DEFAULT | DESCRIPTION |
|---|---|---|---|
| NIN | | | Number of points at which chord deformation $g_1(x)$ is specified, Eq. (5a) |
| XIN | | | Array of increasing x-coordinates of points where the chord deformation is specified (NIN elements) |
| COND1 | $g_1$ | 0 | Array of corresponding $g_1$-values (NIN elements) |
| COND2 | $\frac{dg_1}{dx}$ | 0 | Array of corresponding $dg_1/dx$-values (NIN elements) |

Table 7. XTRAN2L extended fine default grid.

| INDEX | x | z |
|---|---|---|
| 1 | -20.00000 | -25.00000 |
| 2 | -16.30961 | -23.36111 |
| 3 | -13.10054 | -21.77778 |
| 4 | -10.33987 | -20.25000 |
| 5 | -7.99453 | -18.77778 |
| 6 | -6.03136 | -17.36111 |
| 7 | -4.41705 | -16.00000 |
| 8 | -3.11817 | -14.69444 |
| 9 | -2.10110 | -13.44444 |
| 10 | -1.33204 | -12.25000 |
| 11 | -.77699 | -11.11111 |
| 12 | -.40170 | -10.02778 |
| 13 | -.17160 | -9.00000 |
| 14 | -.05175 | -8.02778 |
| 15 | -.00667 | -7.11111 |
| 16 | .00667 | -6.25000 |
| 17 | .02000 | -5.44444 |
| 18 | .04000 | -4.69444 |
| 19 | .06000 | -4.00000 |
| 20 | .08000 | -3.36111 |
| 21 | .10000 | -2.77778 |
| 22 | .12000 | -2.25000 |
| 23 | .14000 | -1.77778 |
| 24 | .16000 | -1.36111 |
| 25 | .18000 | -1.00000 |
| 26 | .20000 | -.69444 |
| 27 | .22000 | -.44444 |
| 28 | .24000 | -.25000 |
| 29 | .26000 | -.11111 |
| 30 | .28000 | -.02778 |
| 31 | .30000 | 0.00000 |
| 32 | .32000 | .02778 |
| 33 | .34000 | .11111 |
| 34 | .36000 | .25000 |
| 35 | .38000 | .44444 |
| 36 | .40000 | .69444 |
| 37 | .42000 | 1.00000 |
| 38 | .44000 | 1.36111 |
| 39 | .46000 | 1.77778 |
| 40 | .48000 | 2.25000 |
| 41 | .50000 | 2.77778 |
| 42 | .52000 | 3.36111 |
| 43 | .54000 | 4.00000 |
| 44 | .56000 | 4.69444 |
| 45 | .58000 | 5.44444 |

Table 7. Concluded.

| INDEX | x | z |
|---|---|---|
| 46 | .60000 | 6.25000 |
| 47 | .62000 | 7.11111 |
| 48 | .64000 | 8.02778 |
| 49 | .66000 | 9.00000 |
| 50 | .68000 | 10.02778 |
| 51 | .70000 | 11.11111 |
| 52 | .72000 | 12.25000 |
| 53 | .74000 | 13.44444 |
| 54 | .76000 | 14.69444 |
| 55 | .78000 | 16.00000 |
| 56 | 80000 | 17.36111 |
| 57 | .82000 | 18.77778 |
| 58 | .84000 | 20.25000 |
| 59 | .86000 | 21.77778 |
| 60 | .88000 | 23.36111 |
| 61 | .90000 | 25.00000 |
| 62 | .92000 | |
| 63 | .94000 | |
| 64 | .96000 | |
| 65 | .98000 | |
| 66 | 1.00000 | |
| 67 | 1.02000 | |
| 68 | 1.12274 | |
| 69 | 1.35473 | |
| 70 | 1.75323 | |
| 71 | 2.35080 | |
| 72 | 3.17695 | |
| 73 | 4.25898 | |
| 74 | 5.62249 | |
| 75 | 7.29170 | |
| 76 | 9.28970 | |
| 77 | 11.63860 | |
| 78 | 14.35968 | |
| 79 | 17.47352 | |
| 80 | 21.00000 | |

# Appendix A - Results from Steady Calculations

## XTRAN2L Input

```
NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   STEADY-STATE CONVERGENCE
$AEROEL INESP=5, DELT=0.002454369, UC=100.0, $END
$INPUT XM=0.780, IREAD=0, MAXIT=1024, NSPC=128, ICPRNT=128, IBUF=1,
 DEL=0.10, XAR=0.25, ALFZRO=1.00, ALFONE=0.00, $END
$MESH $
$AMPLI $
$ORD NINU = 51, NINL = 51,
XINU =
 .006667,  .020000,  .040000,  .060000,  .080000,  .100000,  .120000,  .140000,
 .160000,  .180000,  .200000,  .220000,  .240000,  .260000,  .280000,  .300000,
 .320000,  .340000,  .360000,  .380000,  .400000,  .420000,  .440000,  .460000,
 .480000,  .500000,  .520000,  .540000,  .560000,  .580000,  .600000,  .620000,
 .640000,  .660000,  .680000,  .700000,  .720000,  .740000,  .760000,  .780000,
 .800000,  .820000,  .840000,  .860000,  .880000,  .900000,  .920000,  .940000,
 .960000,  .980000, 1.000000,
ZINU =
 .010144,  .016499,  .022381,  .026732,  .030412,  .033687,  .036532,  .039115,
 .041413,  .043449,  .045258,  .046874,  .048300,  .049535,  .050589,  .051465,
 .052232,  .052792,  .053113,  .053200,  .053113,  .052905,  .052535,  .051921,
 .051053,  .049999,  .048815,  .047508,  .046076,  .044524,  .042865,  .041114,
 .039280,  .037367,  .035365,  .033343,  .031251,  .029124,  .026980,  .024828,
 .022672,  .020513,  .018343,  .016152,  .013956,  .011794,  .009695,  .007538,
 .005196,  .002650, 0.000000,
VINU =
 .666396,  .373066,  .247503,  .201161,  .174588,  .150587,  .135658,  .121236,
 .108089,  .095780,  .085469,  .076080,  .066554,  .057051,  .048547,  .041197,
 .033109,  .022385,  .009743, -.000503, -.007639, -.013740, -.023947, -.037534,
-.048629, -.056247, -.062229, -.068431, -.074733, -.080404, -.085320, -.089694,
-.093739, -.097436, -.100687, -.103473, -.105608, -.106902, -.107439, -.107720,
-.107831, -.108131, -.108983, -.110036, -.109200, -.106129, -.105359, -.111450,
-.122939, -.130770, -.133386,
XINL =
 .006667,  .020000,  .040000,  .060000,  .080000,  .100000,  .120000,  .140000,
 .160000,  .180000,  .200000,  .220000,  .240000,  .260000,  .280000,  .300000,
 .320000,  .340000,  .360000,  .380000,  .400000,  .420000,  .440000,  .460000,
 .480000,  .500000,  .520000,  .540000,  .560000,  .580000,  .600000,  .620000,
 .640000,  .660000,  .680000,  .700000,  .720000,  .740000,  .760000,  .780000,
 .800000,  .820000,  .840000,  .860000,  .880000,  .900000,  .920000,  .940000,
 .960000,  .980000, 1.000000,
ZINL =
-.009941, -.016598, -.022527, -.026839, -.030529, -.033748, -.036542, -.039014,
-.041272, -.043251, -.045019, -.046644, -.048113, -.049395, -.050483, -.051393,
-.052138, -.052706, -.053081, -.053258, -.053246, -.053049, -.052654, -.052038,
-.051206, -.050192, -.049027, -.047730, -.046317, -.044793, -.043155, -.041401,
-.039558, -.037654, -.035699, -.033678, -.031584, -.029437, -.027265, -.025083,
-.022891, -.020688, -.018469, -.016229, -.013974, -.011722, -.009482, -.007215,
-.004875, -.002458, 0.000000,
VINL =
-.755623, -.364001, -.245107, -.199126, -.169990, -.147623, -.134094, -.117215,
-.105643, -.092960, -.084615, -.077614, -.069016, -.059127, -.049812, -.041371,
-.032950, -.023693, -.013753, -.004057,  .005245,  .014597,  .025101,  .036447,
 .046437,  .054702,  .061695,  .067874,  .073371,  .079002,  .084907,  .090180,
 .093908,  .096372,  .099285,  .102933,  .106255,  .108179,  .108874,  .109377,
 .109858,  .110466,  .111425,  .112519,  .112822,  .112177,  .112272,  .114404,
 .119226,  .122218,  .123215,
$END
$COND $
```

Appendix A - Concluded

XTRAN2L Output

```
****************************************************************************
*                                                                          *
*                  PROGRAM XTRAN2L - VERSION 1.2                           *
*                                                                          *
*     IMPLICIT FINITE DIFFERENCE PROGRAM SOLVING THE COMPLETE              *
*          UNSTEADY TRANSONIC SMALL DISTURBANCE EQUATION                   *
*                INCLUDING AEROELASTIC RESPONSE                            *
*                                                                          *
*                                                                          *
*                 UNSTEADY AERODYNAMICS BRANCH                             *
*                                                                          *
*                 NASA LANGLEY RESEARCH CENTER                             *
*                                                                          *
*                     HAMPTON, VA    23665                                 *
*                                                                          *
*                                                                          *
*        CONTACT:  DAVID A. SEIDEL   (804) 865-4236                        *
*                  JOHN T. BATINA    (804) 865-4236                        *
*                                                                          *
****************************************************************************
```

```
                    NACA 64A010 AMES AIRFOIL   M=0,780   ALFZRO=1,0   STEADY-STATE CONVERGENCE

AEROELASTIC SYSTEM

IRESP          5  NO AIRFOIL MOTION                             NELAST          1  2-DOF , PLUNGE AND PITCH
UC     100,00000  NONDIMENSIONAL VELOCITY                       XMU      60,00000  MASS RATIO
DELT      ,00245  TIME STEP, SECONDS                            IEQFLAG         3  EXTRAN EQUATION
AMPLTD    ,01745  AMPLITUDE OF PULSE                            WOTHPLS   10000,0  PULSE EXPONENTIAL FACTOR
TZEROST 17,50000  CENTER OF PULSE


INPUT PARAMETERS

XK        ,20000  REDUCED FREQUENCY BASED ON CHORD              XM         ,78000  MEAN FREE-STREAM MACH NO,
GAM      1,40000  RATIO OF SPECIFIC HEATS
IHEAD          0  INITIAL CONDITIONS                            ICNVRG          1  GET S-S SOL, ON COARS, THEN FINER GRIDS
MAXIT       1024  MAX, NO, TIME STEPS                           NSPC          128  NO, STEPS PER CYCLE
ITRAN          0  PITCH, PLUNGE, FLAP MOTION                    ISICO           0  SINUSOIDAL VARIATION
ICPRNT       128  ITERATION PRINT INCREMENT FOR CP              IOUF            1  OUTPUT TO LU 6
JFIRST        16  FIRST CHORDWISE GRIDPT FOR CP PRINTING        JLAST          66  LAST CHORDWISE GRIDPT FOR CP PRINTING
LIN            0  LINEARIZED CP                                 IR              1  TIME-DERIV, IN AIRFOIL B,C,
DEL       ,10000  AIRFOIL THICKNESS RATIO                       XAR        ,25000  POSITION OF PITCH AXIS
ALFZRO   1,00000  MEAN ANGLE OF ATTACK                          ALFONE    0,00000  PITCHING AMPLITUDE
Z1       0,00000  PLUNGE AMPLITUDE                              IMODFR          1  TIME-DERIVATIVE IN WAKE CONDITION
RSUB     1,40000  SUBSONIC RELAXATION FACTOR                    RSUP      1,00000  SUPERSONIC RELAXATION FACTOR
MITC         500  MAXIMUM NUMBER OF ITERATIONS                  TOLC      ,10E-04  TOLERANCE PARAMETERS IN STEADY
MITM         100  ON COARSE, FINE AND EXT, FINE GRID            TOLM      ,10E-03  CALCULATIONS ON COARSE, FINE
MITEF         25  RESPECTIVELY                                  TOLEF     ,10E-03  AND EXT, FINE GRID RESPECTIVELY
ICPRUN         0  NO REQUEST FOR OUTPUT OF UNSTEADY PRESSURES   LINDIF          0  NLR-TSP EQUATION (WITH NON-LINEAR TERM)
ICPT           1  TIME-DER, CONTRIBUTES TO CP AND MACH, IF IR=1

N              1  NUMBER OF (CO)SIN HARMONICS
MULTIPLIERS OF (CO)SIN HARMONICS   1,00000
```

NACA 64A010 AMES AIRFOIL M=0,780 ALFZNO=1,0 STEADY-STATE CONVERGENCE

ITERATION NO. = 1 ALF (DEG) = 1,0000000 PLUNGE = 0,0000000
TIME = ,0490874 T (DEG) = 8,8125000

| INDEX | X | CPU | CPL | MU | ML | DCP=CPL-CPU |
|---|---|---|---|---|---|---|
| 16 | ,00667 | 1,06394 | 1,36001 | ,10750 | 0,00000 | ,29607 |
| 17 | ,02000 | ,24643 | ,33751 | ,81098 | ,77837 | ,09108 |
| 18 | ,04000 | ,33224 | ,46393 | ,76917 | ,71666 | ,13169 |
| 19 | ,06000 | ,25166 | ,36842 | ,80760 | ,76872 | ,11676 |
| 20 | ,08000 | ,20978 | ,32287 | ,82838 | ,79061 | ,11309 |
| 21 | ,10000 | ,17898 | ,29272 | ,83447 | ,80312 | ,11374 |
| 22 | ,12000 | ,15381 | ,26458 | ,84141 | ,81382 | ,11077 |
| 23 | ,14000 | ,12644 | ,23842 | ,84875 | ,82253 | ,11198 |
| 24 | ,16000 | ,10166 | ,21795 | ,85440 | ,82806 | ,11629 |
| 25 | ,18000 | ,07918 | ,19944 | ,85861 | ,83221 | ,12026 |
| 26 | ,20000 | ,05739 | ,18191 | ,86229 | ,83574 | ,12453 |
| 27 | ,22000 | ,03373 | ,15752 | ,86656 | ,84220 | ,12379 |
| 28 | ,24000 | ,00901 | ,12883 | ,87102 | ,85009 | ,11982 |
| 29 | ,26000 | -,01528 | ,10121 | ,87500 | ,85689 | ,11649 |
| 30 | ,28000 | -,04030 | ,07524 | ,87907 | ,86249 | ,11553 |
| 31 | ,30000 | -,06957 | ,04807 | ,88478 | ,86885 | ,11764 |
| 32 | ,32000 | -,10406 | ,01830 | ,89235 | ,87478 | ,12236 |
| 33 | ,34000 | -,13855 | -,01277 | ,89931 | ,88139 | ,12579 |
| 34 | ,36000 | -,16586 | -,04294 | ,90268 | ,88714 | ,12292 |
| 35 | ,38000 | -,18701 | -,07197 | ,90331 | ,89203 | ,11504 |
| 36 | ,40000 | -,21088 | -,10120 | ,90516 | ,89669 | ,10968 |
| 37 | ,42000 | -,24326 | -,13110 | ,91061 | ,90135 | ,11217 |
| 38 | ,44000 | -,27841 | -,15925 | ,91675 | ,90494 | ,11916 |
| 39 | ,46000 | -,30339 | -,18150 | ,91813 | ,90579 | ,12189 |
| 40 | ,48000 | -,31680 | -,19747 | ,91467 | ,90398 | ,11932 |
| 41 | ,50000 | -,32716 | -,21034 | ,91030 | ,90107 | ,11682 |
| 42 | ,52000 | -,33951 | -,22229 | ,90713 | ,89803 | ,11722 |
| 43 | ,54000 | -,35289 | -,23413 | ,90465 | ,89521 | ,11875 |
| 44 | ,56000 | -,36458 | -,24630 | ,90167 | ,89279 | ,11828 |
| 45 | ,58000 | -,37407 | -,25807 | ,89802 | ,89040 | ,11600 |
| 46 | ,60000 | -,38223 | -,26718 | ,89409 | ,88705 | ,11505 |
| 47 | ,62000 | -,38951 | -,27273 | ,89011 | ,88244 | ,11678 |
| 48 | ,64000 | -,39566 | -,27675 | ,88595 | ,87754 | ,11892 |
| 49 | ,66000 | -,40028 | -,28226 | ,88142 | ,87368 | ,11798 |
| 50 | ,68000 | -,40300 | -,28893 | ,87644 | ,87062 | ,11407 |
| 51 | ,70000 | -,40383 | -,29335 | ,87098 | ,86679 | ,11048 |
| 52 | ,72000 | -,40289 | -,29381 | ,86513 | ,86148 | ,10909 |
| 53 | ,74000 | -,40099 | -,29194 | ,85928 | ,85554 | ,10905 |
| 54 | ,76000 | -,39926 | -,29059 | ,85393 | ,85027 | ,10868 |
| 55 | ,78000 | -,39807 | -,29044 | ,84921 | ,84592 | ,10763 |
| 56 | ,80000 | -,39710 | -,29067 | ,84498 | ,84205 | ,10643 |
| 57 | ,82000 | -,39560 | -,29039 | ,84069 | ,83824 | ,10520 |
| 58 | ,84000 | -,39143 | -,28814 | ,83552 | ,83377 | ,10329 |
| 59 | ,86000 | -,38205 | -,28211 | ,82826 | ,82785 | ,09994 |
| 60 | ,88000 | -,36873 | -,27193 | ,81967 | ,82039 | ,09680 |
| 61 | ,90000 | -,35671 | -,25861 | ,81229 | ,81194 | ,09810 |
| 62 | ,92000 | -,34327 | -,23960 | ,80460 | ,80123 | ,10367 |
| 63 | ,94000 | -,30834 | -,20506 | ,78666 | ,78342 | ,10328 |
| 64 | ,96000 | -,22268 | -,14051 | ,74346 | ,75109 | ,08217 |
| 65 | ,98000 | -,06779 | -,03354 | ,66164 | ,69654 | ,03425 |
| 66 | 1,00000 | ,38144 | ,34040 | ,31166 | ,44627 | -,04104 |

FORCE COEFFICIENTS AT ANGLE OF ATTACK = 1,0000000 PLUNGE DISP. = 0,0000000

AIRFOIL
PITCHING MOMENT (ABOUT X = ,25000 ) = ,2336854E-01 NORMAL FORCE = ,1164373E+00 AXIAL FORCE = ,3681013E-01

NACA 64A010 AMES AIRFOIL M=0.780 ALFZNO=1.0 STEADY-STATE CONVERGENCE

ITERATION NO. = 1024 ALF. (DEG) = 1.0000000 PLUNGE = 0.0000000
TIME = 50.2654825 T (DEG) = 2880.0000000

| INDEX | X | CPU | CPL | MU | ML | DCP=CPL-CPU |
|---|---|---|---|---|---|---|
| 16 | .00667 | .35640 | .97191 | .56809 | 0.00000 | .61550 |
| 17 | .02000 | -.22203 | .36687 | .88678 | .56066 | .58890 |
| 18 | .04000 | -.39426 | .12741 | .96147 | .71153 | .52167 |
| 19 | .06000 | -.41056 | .03057 | .96824 | .76413 | .44113 |
| 20 | .08000 | -.44964 | -.03271 | .98428 | .79663 | .41693 |
| 21 | .10000 | -.47603 | -.07995 | .99497 | .82005 | .39608 |
| 22 | .12000 | -.49381 | -.12362 | 1.00211 | .84113 | .37019 |
| 23 | .14000 | -.52687 | -.16203 | 1.01524 | .85923 | .36484 |
| 24 | .16000 | -.55418 | -.19189 | 1.02596 | .87305 | .36229 |
| 25 | .18000 | -.57305 | -.21605 | 1.03331 | .88407 | .35700 |
| 26 | .20000 | -.58709 | -.23519 | 1.03874 | .89270 | .35190 |
| 27 | .22000 | -.60388 | -.26051 | 1.04520 | .90400 | .34337 |
| 28 | .24000 | -.62367 | -.28984 | 1.05276 | .91691 | .33383 |
| 29 | .26000 | -.64170 | -.31540 | 1.05960 | .92801 | .32630 |
| 30 | .28000 | -.65454 | -.33537 | 1.06445 | .93660 | .31917 |
| 31 | .30000 | -.66657 | -.35399 | 1.06897 | .94453 | .31258 |
| 32 | .32000 | -.68708 | -.37427 | 1.07663 | .95310 | .31282 |
| 33 | .34000 | -.71842 | -.39438 | 1.08823 | .96152 | .32404 |
| 34 | .36000 | -.74912 | -.40942 | 1.09948 | .96777 | .33970 |
| 35 | .38000 | -.76851 | -.41792 | 1.10653 | .97128 | .35059 |
| 36 | .40000 | -.77887 | -.42273 | 1.11027 | .97326 | .35614 |
| 37 | .42000 | -.79313 | -.42644 | 1.11541 | .97479 | .36670 |
| 38 | .44000 | -.81940 | -.42498 | 1.12481 | .97419 | .39442 |
| 39 | .46000 | -.84655 | -.40970 | 1.13444 | .96788 | .43684 |
| 40 | .48000 | -.86263 | -.38281 | 1.14011 | .95668 | .47982 |
| 41 | .50000 | -.86757 | -.35359 | 1.14184 | .94437 | .51397 |
| 42 | .52000 | -.85718 | -.32605 | 1.13819 | .93260 | .53113 |
| 43 | .54000 | -.65066 | -.30059 | 1.06298 | .92159 | .35007 |
| 44 | .56000 | -.32049 | -.27742 | .93021 | .91147 | .04307 |
| 45 | .58000 | -.19646 | -.25557 | .87514 | .90181 | -.05911 |
| 46 | .60000 | -.20798 | -.23197 | .88040 | .89125 | -.02399 |
| 47 | .62000 | -.20587 | -.20547 | .87944 | .87926 | .00040 |
| 48 | .64000 | -.19565 | -.17867 | .87477 | .86696 | .01698 |
| 49 | .66000 | -.18007 | -.15522 | .86760 | .85605 | .02485 |
| 50 | .68000 | -.16097 | -.13474 | .85874 | .84640 | .02623 |
| 51 | .70000 | -.13951 | -.11332 | .84866 | .83620 | .02619 |
| 52 | .72000 | -.11652 | -.08909 | .83774 | .82451 | .02743 |
| 53 | .74000 | -.09319 | -.06383 | .82650 | .81214 | .02936 |
| 54 | .76000 | -.07080 | -.04036 | .81557 | .80047 | .03044 |
| 55 | .78000 | -.04964 | -.01910 | .80510 | .78975 | .03054 |
| 56 | .80000 | -.02946 | .00097 | .79499 | .77950 | .03043 |
| 57 | .82000 | -.00985 | .02061 | .78504 | .76934 | .03045 |
| 58 | .84000 | .01077 | .04089 | .77445 | .75870 | .03012 |
| 59 | .86000 | .03457 | .06315 | .76203 | .74685 | .02858 |
| 60 | .88000 | .06019 | .08723 | .74844 | .73381 | .02704 |
| 61 | .90000 | .08144 | .11111 | .73697 | .72065 | .02967 |
| 62 | .92000 | .09689 | .13478 | .72852 | .70736 | .03790 |
| 63 | .94000 | .11807 | .16343 | .71677 | .69094 | .04536 |
| 64 | .96000 | .16362 | .20616 | .69085 | .66570 | .04254 |
| 65 | .98000 | .24543 | .27420 | .64162 | .62339 | .02877 |
| 66 | 1.00000 | .38469 | .39473 | .54777 | .54037 | .01004 |

FORCE COEFFICIENTS AT ANGLE OF ATTACK = 1.0000000 PLUNGE DISP. = 0.0000000

AIRFOIL
PITCHING MOMENT (ABOUT X = .25000 ) = .9293374E-02 NORMAL FORCE = .2319429E+00 AXIAL FORCE = -.8359784E-02

## Appendix B1 - Results from Unsteady Calculations for Harmonic Motion

### XTRAN2L Input

```
NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   ALFONE=0.5   K=0.075
$AERDEL IRESP=0, UC=100.0, $END
$INPUT XK=0.15, XM=0.780, IREAD=5, MAXIT=1440, NSPC=360, ICPRNT=90, IBUF=1,
 DEL=0.10, XAR=0.25, ALFZRO=1.00, ALFONE=0.50, $END
$MESH $
$AMPLI $
$ORD NINU = 51, NINL = 51,
XINU =
 .006667,  .020000,  .040000,  .060000,  .080000,  .100000,  .120000,  .140000,
 .160000,  .180000,  .200000,  .220000,  .240000,  .260000,  .280000,  .300000,
 .320000,  .340000,  .360000,  .380000,  .400000,  .420000,  .440000,  .460000,
 .480000,  .500000,  .520000,  .540000,  .560000,  .580000,  .600000,  .620000,
 .640000,  .660000,  .680000,  .700000,  .720000,  .740000,  .760000,  .780000,
 .800000,  .820000,  .840000,  .660000,  .880000,  .900000,  .920000,  .940000,
 .960000,  .980000, 1.000000,
ZINU =
 .010144,  .016499,  .022381,  .026732,  .030412,  .033687,  .036532,  .039115,
 .041413,  .043449,  .045258,  .046874,  .048300,  .049535,  .050589,  .051485,
 .052232,  .052792,  .053113,  .053200,  .053113,  .052905,  .052535,  .051921,
 .051053,  .049999,  .048815,  .047508,  .046076,  .044524,  .042865,  .041114,
 .039250,  .037307,  .035385,  .033343,  .031251,  .029124,  .026980,  .024828,
 .022672,  .020513,  .018345,  .016152,  .013956,  .011799,  .009695,  .007538,
 .005196,  .002650, 0.000000,
VINU =
 .666396,  .373066,  .247503,  .201161,  .174588,  .150587,  .135858,  .121238,
 .108089,  .095780,  .085469,  .076060,  .066554,  .057051,  .048547,  .041197,
 .033109,  .022385,  .009743, -.000505, -.007639, -.013740, -.023947, -.037534,
-.048629, -.056247, -.062229, -.068431, -.074733, -.080404, -.085320, -.089694,
-.093739, -.097436, -.100687, -.103473, -.105608, -.106902, -.107439, -.107720,
-.107831, -.108131, -.108983, -.110036, -.109200, -.106129, -.105359, -.111450,
-.122939, -.130770, -.133386,
XINL =
 .006667,  .020000,  .040000,  .060000,  .080000,  .100000,  .120000,  .140000,
 .160000,  .180000,  .200000,  .220000,  .240000,  .260000,  .280000,  .300000,
 .320000,  .340000,  .360000,  .380000,  .400000,  .420000,  .440000,  .460000,
 .480000,  .500000,  .520000,  .540000,  .560000,  .580000,  .600000,  .620000,
 .640000,  .660000,  .680000,  .700000,  .720000,  .740000,  .760000,  .780000,
 .800000,  .820000,  .840000,  .860000,  .880000,  .900000,  .920000,  .940000,
 .960000,  .980000, 1.000000,
ZINL =
-.009941, -.016598, -.022527, -.026839, -.030529, -.033748, -.036542, -.039014,
-.041272, -.043251, -.045019, -.046644, -.048113, -.049395, -.050483, -.051393,
-.052138, -.052706, -.053081, -.053258, -.053246, -.053049, -.052654, -.052038,
-.051206, -.050192, -.049027, -.047730, -.046317, -.044793, -.043155, -.041401,
-.039558, -.037654, -.035699, -.033678, -.031584, -.029437, -.027265, -.025083,
-.022891, -.020688, -.018469, -.016229, -.013974, -.011722, -.009482, -.007215,
-.004875, -.002458, 0.000000,
VINL =
-.755623, -.364001, -.245107, -.199126, -.169990, -.147623, -.134054, -.117215,
-.105643, -.092960, -.084615, -.077618, -.069016, -.059127, -.049812, -.041371,
-.032950, -.023693, -.013753, -.004057,  .005245,  .014597,  .025101,  .036447,
 .046437,  .054702,  .061695,  .067874,  .073371,  .079002,  .084907,  .090180,
 .093908,  .096372,  .099265,  .102933,  .106255,  .108179,  .108874,  .109377,
 .109858,  .110486,  .111425,  .112519,  .112822,  .112177,  .112272,  .114804,
 .119226,  .122218,  .123215,
$END
$COND $
```

## Appendix B1 - Continued

## XTRAN2L Output

```
                            NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   ALFONE=0.5   K=0.075
AERDELASTIC SYSTEM

IRESP          0  HARMONIC OSCILLATION                          NELAST         1  2-DOF , PLUNGE AND PITCH
UC     100.00000  NONDIMENSIONAL VELOCITY                       XMU     60.00000  MASS RATIO
DELT      .00116  TIME STEP, SECONDS                            IEGFLAG        3  EXTRAN EQUATION
AMPLTD    .01745  AMPLITUDE OF PULSE                            WDTHPLS  10000.0  PULSE EXPONENTIAL FACTOR
TZEROST 17.50000  CENTER OF PULSE

INPUT PARAMETERS

XK        .15000  REDUCED FREQUENCY BASED ON CHORD              XM        .78000  MEAN FREE-STREAM MACH NO.
GAM      1.40000  RATIO OF SPECIFIC HEATS
IREAD          5  READ INITIAL CONDITIONS                       ICNVRG         1  GET S-S SOL. ON COARS, THEN FINER GRIDS
MAXIT       1440  MAX. NO. TIME STEPS                           NSPC         360  NO. STEPS PER CYCLE
ITRAN          0  PITCH, PLUNGE, FLAP MOTION                    ISICO          0  SINUSOIDAL VARIATION
ICPRNT        90  ITERATION PRINT INCREMENT FOR CP              ISUF           1  OUTPUT TO LU 6
JFIRST        16  FIRST CHORDWISE GRIDPT FOR CP PRINTING        JLAST         66  LAST CHORDWISE GRIDPT FOR CP PRINTING
LIN            0  LINEARIZED CP                                 IR             1  TIME-DERIV. IN AIRFOIL B.C.
DEL       .10000  AIRFOIL THICKNESS RATIO                       XAR       .25000  POSITION OF PITCH AXIS
ALFZRO   1.00000  MEAN ANGLE OF ATTACK                          ALFONE    .50000  PITCHING AMPLITUDE
Z1       0.00000  PLUNGE AMPLITUDE                              IMODFW         1  TIME-DERIVATIVE IN WAKE CONDITION
RSUB     1.40000  SUBSONIC RELAXATION FACTOR                    RSUP     1.00000  SUPERSONIC RELAXATION FACTOR
MITC         500  MAXIMUM NUMBER OF ITERATIONS                  TOLC     .10E-04  TOLERANCE PARAMETERS IN STEADY
MITM         100  ON COARSE, FINE AND EXT. FINE GRID            TOLM     .10E-05  CALCULATIONS ON COARSE, FINE
MITEF         25  RESPECTIVELY                                  TOLEF    .10E-05  AND EXT. FINE GRID RESPECTIVELY
ICPRUN         0  NO REQUEST FOR OUTPUT OF UNSTEADY PRESSURES   LINDIF         0  NLR-TSP EQUATION (WITH NON-LINEAR TERM)
ICPT           1  TIME-DER. CONTRIBUTES TO CP AND MACH, IF IR=1

N              1  NUMBER OF (CO)SIN HARMONICS
MULTIPLIERS OF (CO)SIN HARMONICS   1.00000
```

NACA 64A010 AMES AIRFOIL M=0.780 ALFZRO=1.0 ALFONE=0.5 K=0.075

ITERATION NO. = 1 ALF (DEG) = 1.0087262 PLUNGE = 0.0000000
TIME = 50.2829357 T (DEG) = 2881.0000000

| INDEX | X | CPU | CPL | MU | ML | DCP=CPL-CPU |
|---|---|---|---|---|---|---|
| 16 | .00667 | .35687 | .97144 | .56781 | 0.00000 | .61457 |
| 17 | .02000 | -.22173 | .36656 | .88669 | .56079 | .58829 |
| 18 | .04000 | -.39406 | .12722 | .96144 | .71156 | .52128 |
| 19 | .06000 | -.41042 | .03043 | .96824 | .76413 | .44084 |
| 20 | .08000 | -.44954 | -.03281 | .98430 | .79661 | .41673 |
| 21 | .10000 | -.47596 | -.08000 | .99499 | .82002 | .39597 |
| 22 | .12000 | -.49381 | -.12363 | 1.00214 | .84108 | .37018 |
| 23 | .14000 | -.52691 | -.16198 | 1.01529 | .85918 | .36493 |
| 24 | .16000 | -.55427 | -.19179 | 1.02602 | .87298 | .36248 |
| 25 | .18000 | -.57320 | -.21590 | 1.03337 | .88400 | .35730 |
| 26 | .20000 | -.58729 | -.23499 | 1.03881 | .89263 | .35230 |
| 27 | .22000 | -.60414 | -.26025 | 1.04527 | .90392 | .34389 |
| 28 | .24000 | -.62398 | -.28953 | 1.05283 | .91682 | .33446 |
| 29 | .26000 | -.64207 | -.31503 | 1.05968 | .92792 | .32708 |
| 30 | .28000 | -.65497 | -.33495 | 1.06453 | .93651 | .32002 |
| 31 | .30000 | -.66705 | -.35350 | 1.06905 | .94443 | .31356 |
| 32 | .32000 | -.68763 | -.37372 | 1.07672 | .95300 | .31391 |
| 33 | .34000 | -.71902 | -.39377 | 1.08833 | .96141 | .32525 |
| 34 | .36000 | -.74979 | -.40875 | 1.09958 | .96766 | .34104 |
| 35 | .38000 | -.76924 | -.41719 | 1.10662 | .97117 | .35205 |
| 36 | .40000 | -.77966 | -.42194 | 1.11037 | .97315 | .35772 |
| 37 | .42000 | -.79399 | -.42558 | 1.11551 | .97467 | .36840 |
| 38 | .44000 | -.82031 | -.42406 | 1.12491 | .97407 | .39625 |
| 39 | .46000 | -.84753 | -.40873 | 1.13455 | .96776 | .43880 |
| 40 | .48000 | -.86367 | -.38177 | 1.14022 | .95655 | .48191 |
| 41 | .50000 | -.86867 | -.35249 | 1.14195 | .94423 | .51618 |
| 42 | .52000 | -.85835 | -.32488 | 1.13831 | .93246 | .53347 |
| 43 | .54000 | -.65189 | -.29935 | 1.06311 | .92145 | .35254 |
| 44 | .56000 | -.32179 | -.27612 | .93036 | .91132 | .04567 |
| 45 | .58000 | -.19782 | -.25420 | .87530 | .90165 | -.05638 |
| 46 | .60000 | -.20941 | -.23054 | .88056 | .89109 | -.02113 |
| 47 | .62000 | -.20736 | -.20398 | .87961 | .87909 | .00339 |
| 48 | .64000 | -.19721 | -.17711 | .87494 | .86678 | .02010 |
| 49 | .66000 | -.18170 | -.15360 | .86778 | .85587 | .02810 |
| 50 | .68000 | -.16267 | -.13305 | .85892 | .84622 | .02962 |
| 51 | .70000 | -.14127 | -.11157 | .84885 | .83602 | .02970 |
| 52 | .72000 | -.11835 | -.08727 | .83793 | .82431 | .03107 |
| 53 | .74000 | -.09508 | -.06195 | .82669 | .81194 | .03314 |
| 54 | .76000 | -.07275 | -.03840 | .81577 | .80026 | .03435 |
| 55 | .78000 | -.05166 | -.01708 | .80531 | .78954 | .03458 |
| 56 | .80000 | -.03155 | .00306 | .79521 | .77928 | .03460 |
| 57 | .82000 | -.01200 | .02276 | .78526 | .76911 | .03476 |
| 58 | .84000 | .00855 | .04311 | .77467 | .75847 | .03456 |
| 59 | .86000 | .03228 | .06544 | .76226 | .74661 | .03315 |
| 60 | .88000 | .05784 | .08958 | .74868 | .73357 | .03174 |
| 61 | .90000 | .07902 | .11353 | .73722 | .72040 | .03451 |
| 62 | .92000 | .09440 | .13727 | .72877 | .70710 | .04287 |
| 63 | .94000 | .11552 | .16598 | .71703 | .69067 | .05047 |
| 64 | .96000 | .16101 | .20878 | .69111 | .66541 | .04777 |
| 65 | .98000 | .24274 | .27689 | .64192 | .62308 | .03414 |
| 66 | 1.00000 | .38359 | .39604 | .54692 | .54108 | .01245 |

FORCE COEFFICIENTS AT ANGLE OF ATTACK = 1.0087262 PLUNGE DISP. = 0.0000000

AIRFOIL
PITCHING MOMENT (ABOUT X = .25000 ) = .1038569E-01 NORMAL FORCE = .2342189E+00 AXIAL FORCE = -.6340326E-02

NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   ALFONE=0.5   K=0.075

ITERATION NO. = 1440   ALF (DEG) = 1.0000000   PLUNGE = 0.0000000
TIME = 75.3982237   T (DEG) = 4320.0000000

| INDEX | X | CPU | CPL | MU | ML | DCP=CPL-CPU |
|---|---|---|---|---|---|---|
| 16 | .00667 | .40822 | .92937 | .53056 | 0.00000 | .52114 |
| 17 | .02000 | -.16362 | .32377 | .86007 | .59123 | .48739 |
| 18 | .04000 | -.34308 | .09094 | .93987 | .73235 | .43402 |
| 19 | .06000 | -.36848 | -.00023 | .95055 | .78074 | .36825 |
| 20 | .08000 | -.40829 | -.06062 | .96712 | .81122 | .34766 |
| 21 | .10000 | -.43818 | -.10580 | .97935 | .83332 | .33238 |
| 22 | .12000 | -.45974 | -.14796 | .98807 | .85341 | .31179 |
| 23 | .14000 | -.49128 | -.18508 | 1.00072 | .87074 | .30620 |
| 24 | .16000 | -.52130 | -.21369 | 1.01262 | .88386 | .30761 |
| 25 | .18000 | -.54240 | -.23666 | 1.02087 | .89427 | .30574 |
| 26 | .20000 | -.55401 | -.25459 | 1.02537 | .90233 | .29942 |
| 27 | .22000 | -.56995 | -.27921 | 1.03152 | .91324 | .29073 |
| 28 | .24000 | -.59210 | -.30824 | 1.04005 | .92595 | .28386 |
| 29 | .26000 | -.61330 | -.33348 | 1.04814 | .93685 | .27983 |
| 30 | .28000 | -.62733 | -.35291 | 1.05344 | .94518 | .27442 |
| 31 | .30000 | -.63918 | -.37103 | 1.05790 | .95287 | .26816 |
| 32 | .32000 | -.65974 | -.39111 | 1.06561 | .96133 | .26863 |
| 33 | .34000 | -.69187 | -.41123 | 1.07758 | .96973 | .28065 |
| 34 | .36000 | -.72333 | -.42596 | 1.08917 | .97584 | .29737 |
| 35 | .35000 | -.74278 | -.43355 | 1.09627 | .97900 | .30924 |
| 36 | .40000 | -.75272 | -.43718 | 1.09986 | .98053 | .31554 |
| 37 | .42000 | -.76667 | -.43982 | 1.10488 | .98166 | .32685 |
| 38 | .44000 | -.79298 | -.43696 | 1.11434 | .98053 | .35602 |
| 39 | .46000 | -.81968 | -.41945 | 1.12386 | .97338 | .40023 |
| 40 | .48000 | -.83308 | -.39030 | 1.12858 | .96134 | .44278 |
| 41 | .50000 | -.82891 | -.35952 | 1.12704 | .94845 | .46940 |
| 42 | .52000 | -.70356 | -.33090 | 1.08144 | .93630 | .37266 |
| 43 | .54000 | -.41870 | -.30463 | .96945 | .92502 | .11406 |
| 44 | .56000 | -.25683 | -.28085 | .89998 | .91468 | -.02403 |
| 45 | .58000 | -.26264 | -.25849 | .90266 | .90485 | .00415 |
| 46 | .60000 | -.25718 | -.23443 | .90029 | .89414 | .02276 |
| 47 | .62000 | -.24329 | -.20750 | .89413 | .88201 | .03579 |
| 48 | .64000 | -.22479 | -.18032 | .88582 | .86959 | .04447 |
| 49 | .66000 | -.20335 | -.15659 | .87609 | .85860 | .04675 |
| 50 | .68000 | -.18001 | -.13589 | .86536 | .84889 | .04412 |
| 51 | .70000 | -.15542 | -.11427 | .85391 | .83864 | .04115 |
| 52 | .72000 | -.13008 | -.08985 | .84193 | .82690 | .04022 |
| 53 | .74000 | -.10493 | -.06442 | .82988 | .81449 | .04050 |
| 54 | .76000 | -.08110 | -.04082 | .81830 | .80280 | .04028 |
| 55 | .78000 | -.05879 | -.01947 | .80730 | .79208 | .03932 |
| 56 | .80000 | -.03766 | .00066 | .79674 | .78184 | .03832 |
| 57 | .82000 | -.01724 | .02034 | .78641 | .77169 | .03758 |
| 58 | .84000 | .00408 | .04064 | .77547 | .76108 | .03657 |
| 59 | .86000 | .02851 | .06291 | .76274 | .74927 | .03441 |
| 60 | .88000 | .05469 | .08698 | .74886 | .73629 | .03229 |
| 61 | .90000 | .07646 | .11083 | .73712 | .72320 | .03437 |
| 62 | .92000 | .09240 | .13443 | .72840 | .71001 | .04203 |
| 63 | .94000 | .11407 | .16299 | .71639 | .69370 | .04892 |
| 64 | .96000 | .16008 | .20561 | .69017 | .66863 | .04553 |
| 65 | .98000 | .24226 | .27351 | .64068 | .62661 | .03125 |
| 66 | 1.00000 | .38270 | .39386 | .54560 | .54422 | .01116 |

FORCE COEFFICIENTS AT ANGLE OF ATTACK = 1.0000000   PLUNGE DISP. = 0.0000000

AIRFOIL
PITCHING MOMENT (ABOUT X = .25000 ) = .1049763E-01   NORMAL FORCE = .2013339E+00   AXIAL FORCE = -.5739490E-02

NACA 64A010 AMES AIRFOIL M=0.780 ALFZRO=1.0 ALFONE=0.5 K=0.075

LAST OSCILLATORY CYCLE OF CM TIME HISTORY

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| .01057 | .01063 | .01070 | .01076 | .01083 | .01089 | .01096 | .01103 | .01109 | .01115 |
| .01122 | .01128 | .01135 | .01141 | .01148 | .01154 | .01160 | .01166 | .01173 | .01179 |
| .01185 | .01191 | .01197 | .01203 | .01209 | .01215 | .01221 | .01227 | .01233 | .01239 |
| .01244 | .01250 | .01256 | .01261 | .01267 | .01273 | .01278 | .01284 | .01289 | .01294 |
| .01299 | .01305 | .01310 | .01315 | .01320 | .01325 | .01329 | .01334 | .01339 | .01343 |
| .01348 | .01352 | .01357 | .01361 | .01365 | .01369 | .01373 | .01377 | .01381 | .01385 |
| .01389 | .01392 | .01396 | .01399 | .01402 | .01405 | .01409 | .01412 | .01414 | .01417 |
| .01420 | .01422 | .01425 | .01427 | .01429 | .01432 | .01434 | .01435 | .01437 | .01439 |
| .01440 | .01442 | .01443 | .01444 | .01445 | .01446 | .01447 | .01448 | .01448 | .01449 |
| .01449 | .01449 | .01449 | .01449 | .01449 | .01448 | .01448 | .01447 | .01446 | .01446 |
| .01444 | .01443 | .01442 | .01440 | .01439 | .01437 | .01435 | .01432 | .01430 | .01428 |
| .01425 | .01422 | .01419 | .01416 | .01413 | .01409 | .01406 | .01402 | .01398 | .01394 |
| .01390 | .01385 | .01381 | .01376 | .01371 | .01366 | .01361 | .01355 | .01350 | .01344 |
| .01338 | .01332 | .01326 | .01319 | .01313 | .01306 | .01299 | .01292 | .01285 | .01278 |
| .01270 | .01262 | .01255 | .01247 | .01239 | .01231 | .01222 | .01214 | .01205 | .01197 |
| .01188 | .01179 | .01170 | .01161 | .01152 | .01143 | .01133 | .01124 | .01114 | .01104 |
| .01095 | .01085 | .01075 | .01065 | .01055 | .01045 | .01035 | .01025 | .01015 | .01004 |
| .00994 | .00984 | .00974 | .00963 | .00953 | .00943 | .00932 | .00922 | .00912 | .00902 |
| .00892 | .00881 | .00871 | .00861 | .00851 | .00841 | .00831 | .00821 | .00811 | .00801 |
| .00792 | .00782 | .00772 | .00763 | .00753 | .00744 | .00735 | .00726 | .00717 | .00708 |
| .00699 | .00690 | .00682 | .00674 | .00665 | .00657 | .00649 | .00642 | .00634 | .00627 |
| .00619 | .00612 | .00605 | .00598 | .00592 | .00585 | .00579 | .00573 | .00567 | .00562 |
| .00556 | .00551 | .00546 | .00541 | .00536 | .00532 | .00528 | .00524 | .00520 | .00516 |
| .00513 | .00510 | .00507 | .00504 | .00501 | .00499 | .00497 | .00495 | .00493 | .00492 |
| .00490 | .00489 | .00488 | .00487 | .00487 | .00486 | .00486 | .00486 | .00486 | .00486 |
| .00487 | .00487 | .00488 | .00489 | .00490 | .00491 | .00492 | .00494 | .00495 | .00497 |
| .00499 | .00501 | .00503 | .00506 | .00508 | .00511 | .00513 | .00516 | .00519 | .00522 |
| .00525 | .00529 | .00532 | .00535 | .00539 | .00543 | .00547 | .00551 | .00555 | .00559 |
| .00563 | .00567 | .00571 | .00576 | .00580 | .00585 | .00590 | .00595 | .00599 | .00604 |
| .00609 | .00614 | .00620 | .00625 | .00630 | .00635 | .00641 | .00646 | .00652 | .00658 |
| .00663 | .00669 | .00675 | .00681 | .00686 | .00692 | .00698 | .00704 | .00711 | .00717 |
| .00723 | .00729 | .00735 | .00742 | .00748 | .00754 | .00761 | .00767 | .00774 | .00780 |
| .00787 | .00793 | .00800 | .00806 | .00813 | .00820 | .00826 | .00833 | .00840 | .00846 |
| .00853 | .00860 | .00867 | .00874 | .00880 | .00887 | .00894 | .00901 | .00908 | .00914 |
| .00921 | .00928 | .00935 | .00942 | .00949 | .00955 | .00962 | .00969 | .00976 | .00983 |
| .00989 | .00996 | .01003 | .01010 | .01016 | .01023 | .01030 | .01036 | .01043 | .01050 |

NACA 64A010 AMES AIRFOIL M=0.780 ALFZRO=1.0 ALFONE=0.5 K=0.075

LAST OSCILLATORY CYCLE OF CN TIME HISTORY

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| .20262 | .20385 | .20510 | .20635 | .20761 | .20888 | .21015 | .21144 | .21273 | .21402 |
| .21532 | .21663 | .21794 | .21925 | .22057 | .22190 | .22323 | .22456 | .22589 | .22723 |
| .22856 | .22990 | .23124 | .23258 | .23392 | .23527 | .23661 | .23795 | .23929 | .24062 |
| .24196 | .24329 | .24462 | .24595 | .24727 | .24859 | .24991 | .25122 | .25253 | .25383 |
| .25513 | .25642 | .25771 | .25898 | .26025 | .26152 | .26277 | .26402 | .26525 | .26648 |
| .26770 | .26891 | .27011 | .27130 | .27248 | .27365 | .27480 | .27595 | .27708 | .27820 |
| .27931 | .28040 | .28148 | .28255 | .28360 | .28464 | .28566 | .28667 | .28767 | .28864 |
| .28961 | .29055 | .29148 | .29239 | .29329 | .29417 | .29503 | .29587 | .29669 | .29750 |
| .29829 | .29906 | .29981 | .30054 | .30125 | .30194 | .30261 | .30326 | .30389 | .30450 |
| .30509 | .30566 | .30620 | .30673 | .30723 | .30772 | .30818 | .30862 | .30903 | .30943 |
| .30980 | .31015 | .31047 | .31078 | .31106 | .31131 | .31155 | .31176 | .31195 | .31211 |
| .31225 | .31237 | .31246 | .31253 | .31258 | .31260 | .31260 | .31257 | .31252 | .31245 |
| .31235 | .31223 | .31208 | .31191 | .31172 | .31150 | .31126 | .31099 | .31071 | .31039 |
| .31006 | .30970 | .30931 | .30891 | .30848 | .30802 | .30755 | .30705 | .30653 | .30598 |
| .30541 | .30482 | .30421 | .30358 | .30292 | .30224 | .30154 | .30082 | .30008 | .29932 |
| .29853 | .29773 | .29690 | .29606 | .29519 | .29431 | .29340 | .29248 | .29154 | .29058 |
| .28960 | .28860 | .28759 | .28656 | .28551 | .28444 | .28336 | .28226 | .28115 | .28002 |
| .27888 | .27772 | .27654 | .27536 | .27416 | .27294 | .27172 | .27048 | .26923 | .26797 |
| .26669 | .26541 | .26412 | .26281 | .26150 | .26018 | .25885 | .25751 | .25616 | .25480 |
| .25344 | .25207 | .25070 | .24932 | .24793 | .24654 | .24515 | .24375 | .24235 | .24094 |
| .23953 | .23812 | .23671 | .23530 | .23389 | .23248 | .23107 | .22966 | .22825 | .22684 |
| .22544 | .22403 | .22263 | .22124 | .21984 | .21846 | .21707 | .21570 | .21433 | .21296 |
| .21161 | .21026 | .20891 | .20758 | .20625 | .20494 | .20363 | .20234 | .20105 | .19978 |
| .19851 | .19726 | .19602 | .19480 | .19358 | .19238 | .19119 | .19002 | .18886 | .18772 |
| .18659 | .18548 | .18438 | .18330 | .18223 | .18119 | .18016 | .17915 | .17815 | .17718 |
| .17622 | .17528 | .17436 | .17346 | .17258 | .17172 | .17088 | .17005 | .16925 | .16847 |
| .16771 | .16697 | .16625 | .16556 | .16488 | .16423 | .16360 | .16299 | .16240 | .16184 |
| .16130 | .16078 | .16028 | .15981 | .15936 | .15893 | .15853 | .15815 | .15779 | .15746 |
| .15715 | .15687 | .15660 | .15636 | .15615 | .15596 | .15579 | .15565 | .15553 | .15543 |
| .15536 | .15531 | .15529 | .15529 | .15531 | .15535 | .15542 | .15552 | .15564 | .15578 |
| .15594 | .15613 | .15634 | .15657 | .15683 | .15711 | .15741 | .15774 | .15809 | .15846 |
| .15885 | .15927 | .15970 | .16016 | .16065 | .16115 | .16167 | .16222 | .16279 | .16337 |
| .16398 | .16461 | .16526 | .16593 | .16662 | .16733 | .16806 | .16881 | .16958 | .17036 |
| .17117 | .17199 | .17283 | .17369 | .17457 | .17546 | .17637 | .17730 | .17824 | .17920 |
| .18018 | .18117 | .18218 | .18320 | .18424 | .18529 | .18635 | .18743 | .18853 | .18963 |
| .19075 | .19188 | .19302 | .19418 | .19535 | .19652 | .19771 | .19891 | .20012 | .20133 |

NACA 64A010 AMES AIRFOIL M=0.780 ALFZRO=1.0 ALFONE=0.5 K=0.075

LAST OSCILLATORY CYCLE OF CHF TIME HISTORY

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

NACA 64A010 AMES AIRFOIL M=0.780 ALFZRO=1.0 ALFONE=0.5 K=0.075

HARMONIC FORCES

| N | CMRE | CMIM | ECM | CNRE | CNIM | ECN | CMFRE | CMFIM | ECMF |
|---|---|---|---|---|---|---|---|---|---|
| 0 | .97992E-02 | 0. | | .23391E+00 | 0. | | 0. | 0. | |
| 1 | .53683E+00 | .95986E-01 | | .82408E+01 | -.36658E+01 | | 0. | 0. | |
| 2 | -.58181E-01 | -.75849E-02 | .1076 | -.77573E-01 | .82979E-01 | .0126 | 0. | 0. | 1.0000 |
| 3 | .69617E-02 | -.13313E-02 | .0130 | .19932E-02 | -.79429E-02 | .0009 | 0. | 0. | 1.0000 |
| 4 | -.55973E-03 | .80837E-03 | .0018 | .15848E-02 | .66550E-03 | .0002 | 0. | 0. | 1.0000 |
| 5 | -.73478E-03 | -.21604E-03 | .0014 | .24466E-04 | .65363E-03 | .0001 | 0. | 0. | 1.0000 |
| 6 | .16882E-03 | .53786E-04 | .0003 | .42862E-03 | -.64612E-04 | .0000 | 0. | 0. | 1.0000 |
| 7 | -.75774E-04 | .93648E-04 | .0002 | .34527E-03 | .14652E-03 | .0000 | 0. | 0. | 1.0000 |
| 8 | .24849E-04 | -.50839E-04 | .0001 | .20800E-03 | -.12070E-04 | .0000 | 0. | 0. | 1.0000 |
| 9 | -.34897E-05 | -.76940E-05 | .0000 | .21157E-03 | .18137E-04 | .0000 | 0. | 0. | 1.0000 |

Appendix B1 - Concluded

## Post-Processed Pressure Harmonics

PRESSURE COEFFICIENT HARMONICS
UPPER PRESSURE COEFFICIENT

| X = | .0067 | | .0200 | | .0400 | | .0600 | | .0800 | | .1000 | | .1200 | | .1400 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .3563 | 0.0000 | -.2238 | 0.0000 | -.3963 | 0.0000 | -.4116 | 0.0000 | -.4519 | 0.0000 | -.4792 | 0.0000 | -.4948 | 0.0000 | -.5242 | 0.0000 |
| 1 | -10.1855 | 5.8240 | -11.3662 | 6.6943 | -9.8447 | 5.9175 | -7.9572 | 4.8422 | -7.8733 | 4.8654 | -7.4138 | 4.5958 | -6.3753 | 3.9399 | -5.9261 | 3.6826 |
| 2 | -.2053 | -.0608 | -.0629 | .0154 | -.0113 | .0216 | -.0666 | -.0268 | .0406 | -.0030 | .1767 | .0536 | -.0700 | -.0230 | -.4170 | -.1557 |
| 3 | .0150 | -.0046 | .0192 | -.0151 | .0187 | -.0280 | .0183 | -.0219 | .0139 | -.0019 | -.0066 | -.0865 | .0329 | -.0266 | .0664 | .0852 |
| 4 | .0018 | .0050 | .0051 | .0037 | -.0004 | .0075 | -.0012 | .0064 | .0119 | -.0005 | .0054 | .0132 | -.0037 | .0138 | -.0203 | .0363 |
| 5 | -.0010 | .0006 | -.0050 | -.0013 | -.0010 | .0003 | -.0023 | .0009 | -.0025 | -.0002 | -.0138 | -.0024 | .0072 | -.0075 | .0207 | -.0016 |

| X = | .1600 | | .1800 | | .2000 | | .2200 | | .2400 | | .2600 | | .2800 | | .3000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.5515 | 0.0000 | -.5730 | 0.0000 | -.5879 | 0.0000 | -.6044 | 0.0000 | -.6241 | 0.0000 | -.6425 | 0.0000 | -.6556 | 0.0000 | -.6678 | 0.0000 |
| 1 | -5.6793 | 3.5452 | -5.7501 | 3.6401 | -5.9621 | 3.8406 | -5.8841 | 3.8138 | -5.5921 | 3.5990 | -5.3387 | 3.3956 | -5.2823 | 3.3844 | -5.3432 | 3.3956 |
| 2 | -.3839 | -.1637 | -.2051 | -.1364 | -.1023 | -.1177 | -.0824 | -.1063 | -.0906 | -.1105 | -.0752 | -.1264 | -.0488 | -.1479 | -.0387 | -.1671 |
| 3 | .0081 | -.0536 | .0097 | -.0769 | .0843 | .0541 | .1119 | .1098 | .0773 | .0611 | .0372 | -.0009 | .0218 | -.0252 | .0215 | -.0279 |
| 4 | -.0143 | .0293 | .0123 | -.0194 | .0039 | -.0062 | -.0104 | .0286 | -.0093 | .0203 | -.0023 | -.0093 | -.0031 | -.0174 | -.0061 | -.0186 |
| 5 | -.0144 | .0030 | -.0091 | .0011 | .0090 | -.0060 | .0028 | -.0059 | -.0044 | -.0023 | .0003 | -.0031 | -.0018 | -.0011 | -.0033 | -.0002 |

| X = | .3200 | | .3400 | | .3600 | | .3800 | | .4000 | | .4200 | | .4400 | | .4600 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.6884 | 0.0000 | -.7197 | 0.0000 | -.7503 | 0.0000 | -.7695 | 0.0000 | -.7795 | 0.0000 | -.7935 | 0.0000 | -.8196 | 0.0000 | -.8463 | 0.0000 |
| 1 | -5.3107 | 3.3844 | -5.1382 | 3.2599 | -4.9962 | 3.1366 | -5.0001 | 3.1081 | -5.1168 | 3.1511 | -5.2361 | 3.1944 | -5.3044 | 3.2039 | -5.4796 | 3.2887 |
| 2 | -.0235 | -.1707 | -.0033 | -.1631 | -.0021 | -.1627 | -.0237 | -.1782 | -.0562 | -.2067 | -.0863 | -.2398 | -.1113 | -.2727 | -.1734 | -.3273 |
| 3 | .0314 | -.0120 | .0429 | .0105 | .0486 | .0241 | .0498 | .0267 | .0485 | .0235 | .0480 | .0195 | .0475 | .0142 | .0465 | -.0127 |
| 4 | -.0095 | -.0130 | -.0123 | -.0022 | -.0139 | .0068 | -.0146 | .0106 | -.0151 | .0105 | -.0156 | .0081 | -.0138 | .0025 | -.0026 | -.0091 |
| 5 | -.0024 | -.0017 | -.0019 | -.0028 | -.0021 | -.0027 | -.0017 | -.0024 | -.0007 | -.0020 | .0006 | -.0015 | .0039 | -.0001 | .0084 | .0029 |

| X = | .4800 | | .5000 | | .5200 | | .5400 | | .5600 | | .5800 | | .6000 | | .6200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.8608 | 0.0000 | -.8510 | 0.0000 | -.7704 | 0.0000 | -.6345 | 0.0000 | -.4825 | 0.0000 | -.3086 | 0.0000 | -.2063 | 0.0000 | -.1927 | 0.0000 |
| 1 | -6.0122 | 3.6099 | -9.2412 | 5.4083 | -22.6313 | 12.8245 | -36.5953 | 21.2036 | -32.3097 | 19.4620 | -10.7151 | 5.1966 | 4.5566 | -5.5836 | 5.0708 | -5.8357 |
| 2 | -.3578 | -.4540 | -2.1998 | -1.7403 | -7.2331 | -5.3557 | -1.9376 | -3.2191 | 13.9317 | 4.3057 | 12.3363 | 4.5420 | 1.0579 | .8857 | -1.2359 | .1398 |
| 3 | .0488 | -.0893 | .2471 | -1.2940 | .7491 | -1.0534 | .9991 | 6.0405 | -.8782 | 3.3509 | -1.9680 | -4.3605 | -.6323 | -1.8576 | .0633 | -.0448 |
| 4 | .0189 | -.0199 | .5286 | -.1327 | -1.0844 | .9216 | -1.2913 | -.0009 | 1.6410 | -1.9555 | .7625 | .0537 | -.5636 | .9718 | .0066 | .0018 |
| 5 | .0088 | .0090 | .0429 | .1291 | -.6037 | -.4791 | .9810 | .0727 | .1362 | .6020 | -.9983 | -.2204 | .4668 | -.0861 | -.0026 | -.0022 |

| X = | .6400 | | .6600 | | .6800 | | .7000 | | .7200 | | .7400 | | .7600 | | .7800 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.1851 | 0.0000 | -.1716 | 0.0000 | -.1542 | 0.0000 | -.1340 | 0.0000 | -.1120 | 0.0000 | -.0894 | 0.0000 | -.0676 | 0.0000 | -.0469 | 0.0000 |
| 1 | 3.6357 | -4.6034 | 2.6330 | -3.7024 | 1.9122 | -3.0319 | 1.4028 | -2.5264 | 1.0272 | -2.1395 | .7516 | -1.8390 | .5488 | -1.6023 | .3987 | -1.4119 |
| 2 | -.9929 | .1291 | -.8028 | .1144 | -.6508 | .1006 | -.5309 | .0884 | -.4369 | .0778 | -.3634 | .0688 | -.3057 | .0611 | -.2598 | .0544 |
| 3 | .0570 | -.0349 | .0508 | -.0242 | .0439 | -.0174 | .0370 | -.0133 | .0309 | -.0108 | .0257 | -.0092 | .0215 | -.0080 | .0181 | -.0071 |
| 4 | .0038 | .0045 | .0017 | .0040 | .0007 | .0031 | .0003 | .0023 | .0001 | .0018 | .0001 | .0014 | .0001 | .0011 | .0001 | .0009 |
| 5 | -.0033 | -.0015 | -.0025 | -.0010 | -.0019 | -.0007 | -.0014 | -.0004 | -.0011 | -.0003 | -.0009 | -.0002 | -.0007 | -.0001 | -.0006 | -.0001 |

| X = | .8000 | | .8200 | | .8400 | | .8600 | | .8800 | | .9000 | | .9200 | | .9400 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.0271 | 0.0000 | -.0078 | 0.0000 | .0126 | 0.0000 | .0361 | 0.0000 | .0616 | 0.0000 | .0826 | 0.0000 | .0980 | 0.0000 | .1190 | 0.0000 |
| 1 | .2873 | -1.2549 | .2051 | -1.1220 | .1450 | -1.0083 | .1016 | -.9073 | .0726 | -.8172 | .0586 | -.7361 | .0586 | -.6607 | .0679 | -.5876 |
| 2 | -.2228 | .0487 | -.1923 | .0438 | -.1667 | .0394 | -.1445 | .0354 | -.1253 | .0319 | -.1093 | .0288 | -.0959 | .0261 | -.0834 | .0235 |
| 3 | .0152 | -.0063 | .0129 | -.0057 | .0110 | -.0051 | .0093 | -.0046 | .0079 | -.0042 | .0067 | -.0038 | .0057 | -.0034 | .0048 | -.0031 |
| 4 | .0002 | .0008 | .0002 | .0007 | .0002 | .0006 | .0002 | .0005 | .0002 | .0004 | .0002 | .0004 | .0002 | .0003 | .0002 | .0003 |
| 5 | -.0005 | -.0001 | -.0004 | -.0000 | -.0003 | -.0000 | -.0003 | -.0000 | -.0002 | -.0000 | -.0002 | -.0000 | -.0002 | .0000 | -.0001 | .0000 |

| X = | .9600 | | .9800 | | 1.0000 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .1644 | 0.0000 | .2461 | 0.0000 | .3852 | 0.0000 | | | | | | | | | | |
| 1 | .0805 | -.5177 | .0957 | -.4553 | .1715 | -.2968 | | | | | | | | | | |
| 2 | -.0702 | .0210 | -.0560 | .0187 | -.0413 | .0149 | | | | | | | | | | |
| 3 | .0039 | -.0027 | .0029 | -.0022 | .0020 | -.0017 | | | | | | | | | | |
| 4 | .0002 | .0002 | .0002 | .0001 | .0001 | .0001 | | | | | | | | | | |
| 5 | -.0001 | .0000 | -.0001 | .0000 | -.0001 | .0000 | | | | | | | | | | |

PRESSURE COEFFICIENT HARMONICS
LOWER PRESSURE COEFFICIENT

| X = | .0067 | | .0200 | | .0400 | | .0600 | | .0800 | | .1000 | | .1200 | | .1400 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .9713 | 0.0000 | .3661 | 0.0000 | .1269 | 0.0000 | .0302 | 0.0000 | -.0330 | 0.0000 | -.0802 | 0.0000 | -.1239 | 0.0000 | -.1623 | 0.0000 |
| 1 | 9.0136 | -4.6901 | 9.0519 | -4.7422 | 7.7599 | -4.0150 | 6.7002 | -3.3890 | 6.1801 | -3.0683 | 5.8231 | -2.8409 | 5.5741 | -2.6741 | 5.3722 | -2.5335 |
| 2 | .2355 | .0423 | .2517 | .0472 | .2015 | .0283 | .1648 | .0171 | .1525 | .0155 | .1416 | .0134 | .1343 | .0126 | .1287 | .0126 |
| 3 | -.0016 | .0113 | -.0002 | .0129 | .0010 | .0100 | .0017 | .0080 | .0023 | .0075 | .0026 | .0068 | .0029 | .0064 | .0031 | .0061 |
| 4 | -.0016 | -.0014 | -.0016 | -.0010 | -.0012 | -.0006 | -.0009 | -.0002 | -.0008 | -.0000 | -.0006 | .0001 | -.0006 | .0002 | -.0005 | .0003 |
| 5 | .0010 | -.0003 | .0010 | -.0003 | .0008 | -.0002 | .0006 | -.0002 | .0005 | -.0002 | .0004 | -.0001 | .0004 | -.0001 | .0004 | -.0001 |

| X = | .1600 | | .1800 | | .2000 | | .2200 | | .2400 | | .2600 | | .2800 | | .3000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.1921 | 0.0000 | -.2162 | 0.0000 | -.2353 | 0.0000 | -.2606 | 0.0000 | -.2900 | 0.0000 | -.3156 | 0.0000 | -.3356 | 0.0000 | -.3542 | 0.0000 |
| 1 | 5.1756 | -2.3968 | 4.9900 | -2.2669 | 4.8004 | -2.1365 | 4.7107 | -2.0603 | 4.7038 | -2.0272 | 4.6960 | -1.9913 | 4.6525 | -1.9349 | 4.6195 | -1.8828 |
| 2 | .1226 | .0126 | .1161 | .0122 | .1079 | .0108 | .1068 | .0129 | .1124 | .0190 | .1175 | .0255 | .1179 | .0301 | .1184 | .0353 |
| 3 | .0032 | .0059 | .0033 | .0055 | .0034 | .0048 | .0035 | .0048 | .0037 | .0057 | .0038 | .0065 | .0038 | .0068 | .0037 | .0070 |
| 4 | -.0005 | .0003 | -.0004 | .0004 | -.0003 | .0004 | -.0003 | .0004 | -.0003 | .0005 | -.0004 | .0006 | -.0004 | .0007 | -.0003 | .0007 |
| 5 | .0003 | -.0001 | .0003 | -.0001 | .0003 | -.0001 | .0003 | -.0001 | .0002 | -.0001 | .0002 | -.0001 | .0002 | -.0000 | .0002 | -.0000 |

| X = | .3200 | | .3400 | | .3600 | | .3800 | | .4000 | | .4200 | | .4400 | | .4600 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.3746 | 0.0000 | -.3949 | 0.0000 | -.4100 | 0.0000 | -.4185 | 0.0000 | -.4232 | 0.0000 | -.4269 | 0.0000 | -.4252 | 0.0000 | -.4096 | 0.0000 |
| 1 | 4.6524 | -1.8625 | 4.7419 | -1.8658 | 4.7856 | -1.8378 | 4.7162 | -1.7477 | 4.5870 | -1.6285 | 4.4755 | -1.5211 | 4.2736 | -1.3759 | 3.8329 | -1.1347 |
| 2 | .1270 | .0463 | .1451 | .0661 | .1570 | .0865 | .1487 | .0970 | .1299 | .1005 | .1167 | .1077 | .0911 | .1033 | .0422 | .0716 |
| 3 | .0036 | .0086 | .0029 | .0130 | .0009 | .0173 | -.0018 | .0172 | -.0042 | .0144 | -.0068 | .0134 | -.0082 | .0093 | -.0062 | .0005 |
| 4 | -.0005 | .0009 | -.0012 | .0013 | -.0021 | .0014 | -.0025 | .0009 | -.0022 | .0001 | -.0024 | -.0005 | -.0017 | -.0011 | -.0002 | -.0013 |
| 5 | .0002 | -.0000 | .0000 | -.0001 | -.0001 | -.0002 | -.0000 | -.0004 | .0001 | -.0004 | .0002 | -.0005 | .0004 | -.0004 | .0005 | -.0001 |

| X = | .4800 | | .5000 | | .5200 | | .5400 | | .5600 | | .5800 | | .6000 | | .6200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.3824 | 0.0000 | -.3530 | 0.0000 | -.3255 | 0.0000 | -.3000 | 0.0000 | -.2769 | 0.0000 | -.2551 | 0.0000 | -.2315 | 0.0000 | -.2050 | 0.0000 |
| 1 | 3.3279 | -.8868 | 2.9476 | -.7110 | 2.6708 | -.5888 | 2.4551 | -.4976 | 2.2794 | -.4268 | 2.1283 | -.3689 | 1.9852 | -.3159 | 1.8473 | -.2662 |
| 2 | .0053 | .0400 | -.0076 | .0258 | -.0119 | .0198 | -.0136 | .0168 | -.0145 | .0151 | -.0151 | .0141 | -.0157 | .0131 | -.0163 | .0123 |
| 3 | -.0034 | -.0039 | -.0020 | -.0037 | -.0014 | -.0031 | -.0011 | -.0026 | -.0008 | -.0022 | -.0006 | -.0020 | -.0005 | -.0018 | -.0003 | -.0016 |
| 4 | .0004 | -.0008 | .0003 | -.0005 | .0002 | -.0003 | .0001 | -.0003 | .0001 | -.0002 | .0000 | -.0002 | .0000 | -.0001 | .0000 | -.0001 |
| 5 | .0004 | .0000 | .0002 | .0000 | .0002 | -.0000 | .0002 | -.0000 | .0001 | -.0000 | .0001 | -.0000 | .0001 | -.0000 | .0001 | -.0000 |

| X = | .6400 | | .6600 | | .6800 | | .7000 | | .7200 | | .7400 | | .7600 | | .7800 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | -.1782 | 0.0000 | -.1548 | 0.0000 | -.1343 | 0.0000 | -.1129 | 0.0000 | -.0887 | 0.0000 | -.0634 | 0.0000 | -.0400 | 0.0000 | -.0187 | 0.0000 |
| 1 | 1.7224 | -.2235 | 1.6167 | -.1910 | 1.5246 | -.1662 | 1.4361 | -.1438 | 1.3483 | -.1221 | 1.2646 | -.1030 | 1.1879 | -.0886 | 1.1171 | -.0788 |
| 2 | -.0167 | .0117 | -.0170 | .0114 | -.0173 | .0112 | -.0176 | .0111 | -.0180 | .0110 | -.0184 | .0109 | -.0188 | .0108 | -.0192 | .0109 |
| 3 | -.0002 | -.0015 | -.0001 | -.0015 | -.0000 | -.0014 | .0000 | -.0014 | .0001 | -.0013 | .0002 | -.0013 | .0003 | -.0013 | .0003 | -.0013 |
| 4 | .0000 | -.0001 | .0000 | -.0001 | .0000 | -.0001 | .0000 | -.0001 | .0000 | -.0001 | .0000 | -.0000 | .0000 | -.0000 | .0000 | -.0000 |
| 5 | .0001 | -.0000 | .0001 | -.0000 | .0001 | .0000 | .0001 | .0000 | .0001 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 |

| X = | .8000 | | .8200 | | .8400 | | .8600 | | .8800 | | .9000 | | .9200 | | .9400 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .0014 | 0.0000 | .0210 | 0.0000 | .0413 | 0.0000 | .0635 | 0.0000 | .0876 | 0.0000 | .1115 | 0.0000 | .1352 | 0.0000 | .1638 | 0.0000 |
| 1 | 1.0497 | -.0723 | .9844 | -.0686 | .9199 | -.0672 | .8551 | -.0672 | .7899 | -.0691 | .7249 | -.0746 | .6589 | -.0843 | .5891 | -.0968 |
| 2 | -.0198 | .0109 | -.0203 | .0110 | -.0210 | .0110 | -.0217 | .0111 | -.0225 | .0112 | -.0234 | .0113 | -.0245 | .0114 | -.0258 | .0116 |
| 3 | .0004 | -.0013 | .0005 | -.0013 | .0005 | -.0013 | .0006 | -.0013 | .0007 | -.0013 | .0008 | -.0013 | .0008 | -.0013 | .0009 | -.0013 |
| 4 | .0001 | -.0000 | .0001 | -.0000 | .0001 | -.0000 | .0001 | .0000 | .0001 | .0000 | .0001 | .0000 | .0001 | .0000 | .0001 | .0000 |
| 5 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | .0000 | -.0000 | .0000 | -.0000 | .0000 |

| X = | .9600 | | .9800 | | 1.0000 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .2066 | 0.0000 | .2746 | 0.0000 | .3951 | 0.0000 | | | | | | | | | | |
| 1 | .5117 | -.1111 | .4200 | -.1293 | .3040 | -.1534 | | | | | | | | | | |
| 2 | -.0273 | .0118 | -.0293 | .0121 | -.0322 | .0123 | | | | | | | | | | |
| 3 | .0011 | -.0014 | .0012 | -.0014 | .0014 | -.0014 | | | | | | | | | | |
| 4 | .0001 | .0000 | .0001 | .0001 | .0001 | .0001 | | | | | | | | | | |
| 5 | -.0000 | .0000 | -.0000 | .0000 | -.0000 | .0000 | | | | | | | | | | |

PRESSURE COEFFICIENT HARMONICS
DELTA PRESSURE COEFFICIENT

| X = | .0067 | | .0200 | | .0400 | | .0600 | | .0800 | | .1000 | | .1200 | | .1400 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .6150 | 0.0000 | .5900 | 0.0000 | .5232 | 0.0000 | .4418 | 0.0000 | .4188 | 0.0000 | .3990 | 0.0000 | .3709 | 0.0000 | .3619 | 0.0000 |
| 1 | 19.1991 | -10.5141 | 20.4181 | -11.4365 | 17.6046 | -9.9324 | 16.6574 | -8.2311 | 16.0534 | -7.9337 | 13.2369 | -7.4366 | 11.9494 | -6.6139 | 11.2984 | -6.2161 |
| 2 | .4408 | .1031 | .3147 | .0318 | .2127 | .0066 | .2314 | .0439 | .1119 | .0165 | -.0350 | -.0402 | .2043 | .0356 | .5456 | .1683 |
| 3 | -.0166 | .0159 | -.0194 | .0280 | -.0177 | .0380 | -.0166 | .0299 | -.0116 | .0094 | .0092 | .0932 | -.0300 | .0330 | -.0633 | -.0791 |
| 4 | -.0033 | -.0064 | -.0067 | -.0048 | -.0008 | -.0080 | .0003 | -.0066 | -.0127 | .0004 | -.0061 | -.0131 | .0031 | -.0136 | .0198 | -.0360 |
| 5 | .0021 | -.0009 | .0060 | .0011 | .0018 | -.0005 | .0029 | -.0011 | .0030 | -.0000 | .0143 | .0023 | -.0068 | .0073 | -.0203 | .0015 |

| X = | .1600 | | .1800 | | .2000 | | .2200 | | .2400 | | .2600 | | .2800 | | .3000 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .3594 | 0.0000 | .3566 | 0.0000 | .3526 | 0.0000 | .3438 | 0.0000 | .3341 | 0.0000 | .3269 | 0.0000 | .3200 | 0.0000 | .3136 | 0.0000 |
| 1 | 10.8550 | -5.9420 | 10.7401 | -5.9070 | 10.7625 | -5.9771 | 10.5948 | -5.8741 | 10.2959 | -5.6261 | 10.0348 | -5.3870 | 9.9348 | -5.2793 | 9.9627 | -5.2784 |
| 2 | .5065 | .1763 | .3212 | .1486 | .2102 | .1285 | .1893 | .1192 | .2031 | .1295 | .1927 | .1520 | .1667 | .1760 | .1571 | .2024 |
| 3 | -.0048 | .0594 | -.0064 | .0823 | -.0810 | -.0493 | -.1083 | -.1050 | -.0736 | -.0554 | -.0334 | .0074 | -.0180 | .0319 | -.0177 | .0349 |
| 4 | .0138 | -.0290 | -.0127 | .0198 | -.0043 | .0066 | .0101 | -.0282 | .0090 | -.0197 | .0019 | .0099 | .0028 | .0181 | .0057 | .0193 |
| 5 | .0147 | -.0031 | .0094 | -.0012 | -.0087 | .0059 | -.0025 | .0058 | .0047 | .0022 | -.0001 | .0031 | .0020 | .0010 | .0035 | .0002 |

| X = | .3200 | | .3400 | | .3600 | | .3800 | | .4000 | | .4200 | | .4400 | | .4600 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .3138 | 0.0000 | .3249 | 0.0000 | .3403 | 0.0000 | .3509 | 0.0000 | .3563 | 0.0000 | .3667 | 0.0000 | .3943 | 0.0000 | .4367 | 0.0000 |
| 1 | 9.9631 | -5.2470 | 9.8801 | -5.1257 | 9.7818 | -4.9764 | 9.7163 | -4.8558 | 9.7038 | -4.7796 | 9.7115 | -4.7155 | 9.5780 | -4.5798 | 9.3125 | -4.4234 |
| 2 | .1505 | .2170 | .1464 | .2292 | .1590 | .2492 | .1724 | .2752 | .1861 | .3072 | .2029 | .3475 | .2024 | .3760 | .2156 | .3988 |
| 3 | -.0279 | .0206 | -.0400 | .0025 | -.0477 | -.0068 | -.0511 | -.0095 | -.0528 | -.0091 | -.0548 | -.0061 | -.0557 | -.0050 | -.0527 | .0131 |
| 4 | .0090 | .0139 | .0111 | .0035 | .0117 | -.0054 | .0121 | -.0097 | .0129 | -.0104 | .0133 | -.0086 | .0120 | -.0036 | .0025 | .0078 |
| 5 | .0026 | .0017 | .0019 | .0028 | .0020 | .0025 | .0016 | .0020 | .0008 | .0016 | -.0004 | .0011 | -.0035 | -.0003 | -.0080 | -.0030 |

| X = | .4800 | | .5000 | | .5200 | | .5400 | | .5600 | | .5800 | | .6000 | | .6200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .4784 | 0.0000 | .4979 | 0.0000 | .4449 | 0.0000 | .3344 | 0.0000 | .2056 | 0.0000 | .0535 | 0.0000 | -.0252 | 0.0000 | -.0123 | 0.0000 |
| 1 | 9.3401 | -4.4967 | 12.1888 | -6.1193 | 25.3022 | -13.4133 | 39.0504 | -21.7812 | 36.5891 | -19.8887 | 12.8434 | -5.5655 | -2.5713 | 5.2677 | -3.2235 | 5.5695 |
| 2 | .3631 | .4940 | 2.1922 | 1.7661 | 7.2212 | 5.3756 | 1.9240 | 3.2359 | -13.9462 | -4.3706 | -12.3514 | -4.5279 | -1.0736 | -.8726 | 1.2196 | -.1276 |
| 3 | -.0522 | .0854 | -.2492 | 1.2903 | -.7505 | 1.0504 | -1.0001 | -6.0430 | .8773 | -3.3531 | 1.9674 | 4.3586 | .6318 | 1.8558 | -.0637 | .0432 |
| 4 | -.0185 | .0190 | -.5283 | .1322 | 1.0846 | -.9219 | 1.2914 | .0006 | -1.6409 | 1.9553 | -.7625 | -.0539 | .5636 | -.9719 | -.0086 | -.0019 |
| 5 | -.0084 | -.0090 | -.0426 | -.1291 | .6039 | .4791 | -.9809 | -.0727 | -.1361 | -.6020 | .9984 | .2204 | -.4667 | .0861 | .0027 | .0022 |

| X = | .6400 | | .6600 | | .6800 | | .7000 | | .7200 | | .7400 | | .7600 | | .7800 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .0070 | 0.0000 | .0169 | 0.0000 | .0199 | 0.0000 | .0211 | 0.0000 | .0233 | 0.0000 | .0260 | 0.0000 | .0276 | 0.0000 | .0282 | 0.0000 |
| 1 | -1.9133 | 4.3799 | -1.0163 | 3.5113 | -.3936 | 2.8658 | .0333 | 2.3827 | .3211 | 2.0174 | .5130 | 1.7360 | .6391 | 1.5137 | .7184 | 1.3331 |
| 2 | .9762 | -.1175 | .7658 | -.1030 | .6335 | -.0893 | .5133 | -.0773 | .4189 | -.0668 | .3450 | -.0579 | .2869 | -.0502 | .2406 | -.0436 |
| 3 | -.0572 | .0333 | -.0510 | .0227 | -.0439 | .0160 | -.0370 | .0120 | -.0308 | .0095 | -.0255 | .0079 | -.0212 | .0067 | -.0177 | .0058 |
| 4 | -.0038 | -.0046 | -.0016 | -.0041 | -.0007 | -.0032 | -.0003 | -.0024 | -.0001 | -.0018 | -.0001 | -.0015 | -.0001 | -.0012 | -.0001 | -.0010 |
| 5 | .0034 | .0015 | .0026 | .0010 | .0020 | .0007 | .0015 | .0004 | .0012 | .0003 | .0009 | .0002 | .0008 | .0001 | .0006 | .0001 |

| X = | .8000 | | .8200 | | .8400 | | .8600 | | .8800 | | .9000 | | .9200 | | .9400 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .0285 | 0.0000 | .0288 | 0.0000 | .0287 | 0.0000 | .0274 | 0.0000 | .0261 | 0.0000 | .0289 | 0.0000 | .0372 | 0.0000 | .0448 | 0.0000 |
| 1 | .7624 | 1.1625 | .7793 | 1.0539 | .7749 | .9411 | .7535 | .8401 | .7173 | .7480 | .6663 | .6616 | .6003 | .5764 | .5212 | .4908 |
| 2 | .2030 | -.0378 | .1720 | -.0328 | .1457 | -.0283 | .1228 | -.0243 | .1028 | -.0207 | .0859 | -.0175 | .0714 | -.0146 | .0576 | -.0118 |
| 3 | -.0148 | .0051 | -.0125 | .0044 | -.0104 | .0039 | -.0087 | .0034 | -.0072 | .0029 | -.0060 | .0025 | -.0049 | .0021 | -.0039 | .0017 |
| 4 | -.0001 | -.0008 | -.0001 | -.0007 | -.0001 | -.0006 | -.0001 | -.0005 | -.0001 | -.0004 | -.0001 | -.0003 | -.0001 | -.0003 | -.0001 | -.0002 |
| 5 | .0005 | .0001 | .0004 | .0001 | .0004 | .0000 | .0003 | .0000 | .0002 | .0000 | .0002 | .0000 | .0002 | .0000 | .0001 | .0000 |

| X = | .9600 | | .9800 | | 1.0000 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG | REAL | IMAG |
| 0 | .0421 | 0.0000 | .0285 | 0.0000 | .0099 | 0.0000 | | | | | | | | | | |
| 1 | .4312 | .4066 | .3243 | .3260 | .1324 | .1435 | | | | | | | | | | |
| 2 | .0430 | -.0092 | .0267 | -.0066 | .0091 | -.0026 | | | | | | | | | | |
| 3 | -.0029 | .0013 | -.0017 | .0008 | -.0006 | .0003 | | | | | | | | | | |
| 4 | -.0001 | -.0002 | -.0001 | -.0001 | -.0000 | -.0000 | | | | | | | | | | |
| 5 | .0001 | .0000 | .0001 | .0000 | .0000 | -.0000 | | | | | | | | | | |

Appendix B2 - Results from Unsteady Calculations for Pulse Motion

## XTRAN2L Input

```
NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   PITCH=PULSE = 0.5
$AEROEL IRESP=3, DELT=0.002454369, UC=100.0, AMPLTD=0.0087266463,
 MDTHPLS=8000.0, TZEROST=30.0, $END
$INPUT XM=0.780, IREAD=5, MAXIT=1024, NSPC=128, ICPRNT=128, IBUF=1,
 DEL=0.10, XAR=0.25, ALFZRO=1.00, ALFONE=0.00, $END
$MESH $
$AMPLI $
$ORD NINU = 51, NINL = 51,
XINU =
 .006667,  .020000,  .040000,  .060000,  .080000,  .100000,  .120000,  .140000,
 .160000,  .180000,  .200000,  .220000,  .240000,  .260000,  .280000,  .300000,
 .320000,  .340000,  .360000,  .380000,  .400000,  .420000,  .440000,  .460000,
 .480000,  .500000,  .520000,  .540000,  .560000,  .580000,  .600000,  .620000,
 .640000,  .660000,  .680000,  .700000,  .720000,  .740000,  .760000,  .780000,
 .800000,  .820000,  .840000,  .860000,  .880000,  .900000,  .920000,  .940000,
 .960000,  .980000, 1.000000,
ZINU =
 .010144,  .016499,  .022381,  .026732,  .030412,  .033687,  .036552,  .039115,
 .041413,  .043449,  .045258,  .046874,  .048300,  .049535,  .050589,  .051465,
 .052232,  .052792,  .053113,  .053200,  .053113,  .052905,  .052535,  .051921,
 .051053,  .049999,  .048815,  .047508,  .046070,  .044524,  .042865,  .041114,
 .039280,  .037367,  .035385,  .033343,  .031251,  .029124,  .026980,  .024828,
 .022672,  .020513,  .018343,  .016152,  .013956,  .011799,  .009695,  .007538,
 .005196,  .002650, 0.000000,
VINU =
 .666396,  .373066,  .247503,  .201161,  .174588,  .150587,  .135858,  .121238,
 .108089,  .095780,  .085469,  .076080,  .066554,  .057051,  .048547,  .041197,
 .033109,  .022365,  .009743, -.000503, -.007639, -.013740, -.023947, -.037534,
-.048629, -.056247, -.062229, -.068431, -.074733, -.080404, -.085320, -.089694,
-.093739, -.097436, -.100687, -.103473, -.105608, -.106902, -.107439, -.107720,
-.107831, -.108131, -.108983, -.110036, -.109200, -.106129, -.105359, -.111450,
-.122939, -.130770, -.133586,
XINL =
 .006667,  .020000,  .040000,  .060000,  .080000,  .100000,  .120000,  .140000,
 .160000,  .180000,  .200000,  .220000,  .240000,  .260000,  .280000,  .300000,
 .320000,  .340000,  .360000,  .380000,  .400000,  .420000,  .440000,  .460000,
 .480000,  .500000,  .520000,  .540000,  .560000,  .580000,  .600000,  .620000,
 .640000,  .660000,  .680000,  .700000,  .720000,  .740000,  .760000,  .780000,
 .800000,  .820000,  .840000,  .860000,  .880000,  .900000,  .920000,  .940000,
 .960000,  .980000, 1.000000,
ZINL =
-.009941, -.016598, -.022527, -.026839, -.030529, -.033748, -.036582, -.039014,
-.041272, -.043251, -.045019, -.046644, -.048113, -.049395, -.050485, -.051393,
-.052138, -.052706, -.053081, -.053258, -.053246, -.053049, -.052654, -.052038,
-.051206, -.050192, -.049027, -.047730, -.046317, -.044793, -.043155, -.041401,
-.039558, -.037654, -.035699, -.033678, -.031584, -.029437, -.027265, -.025085,
-.022891, -.020688, -.018469, -.016229, -.013974, -.011722, -.009482, -.007215,
-.004875, -.002458, 0.000000,
VINL =
-.755623, -.364001, -.245107, -.199126, -.169990, -.147623, -.134054, -.117215,
-.105643, -.092960, -.084615, -.077618, -.069016, -.059127, -.049812, -.041371,
-.032950, -.023693, -.013753, -.004057,  .005245,  .014597,  .025101,  .036447,
 .046437,  .054702,  .061695,  .067874,  .073371,  .079002,  .084907,  .090180,
 .093908,  .096372,  .099265,  .102933,  .106255,  .108179,  .108874,  .109377,
 .109858,  .110486,  .111425,  .112519,  .112822,  .112177,  .112272,  .114804,
 .119226,  .122218,  .123215,
$END
$COND $
```

## Appendix B2 - Continued

## XTRAN2L Output

```
                         NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   PITCH-PULSE = 0.5

AEROELASTIC SYSTEM

IRESP          3  PITCH PULSE TRANSIENT                        NELAST         1  2-DOF , PLUNGE AND PITCH
UC     100.00000  NONDIMENSIONAL VELOCITY                      XMU     60.00000  MASS RATIO
DELT      .00245  TIME STEP, SECONDS                           IEQFLAG        3  EXTRAN EQUATION
AMPLTD    .00873  AMPLITUDE OF PULSE                           WOTMPLS   8000.0  PULSE EXPONENTIAL FACTOR
TZEROST 30.00000  CENTER OF PULSE

INPUT PARAMETERS

XK        .20000  REDUCED FREQUENCY BASED ON CHORD             XM        .78000  MEAN FREE-STREAM MACH NO.
GAM      1.40000  RATIO OF SPECIFIC HEATS
IREAD          5  READ INITIAL CONDITIONS                      ICNVRG         1  GET S-S SOL. ON COARS, THEN FINER GRIDS
MAXIT       1024  MAX. NO. TIME STEPS                          NSPC         128  NO. STEPS PER CYCLE
ITRAN          0  PITCH, PLUNGE, FLAP MOTION                   ISICO          0  SINUSOIDAL VARIATION
ICPRNT       128  ITERATION PRINT INCREMENT FOR CP             IBUF           1  OUTPUT TO LU 8
JFIRST        16  FIRST CHORDWISE GRIDPT FOR CP PRINTING       JLAST         66  LAST CHORDWISE GRIDPT FOR CP PRINTING
LIN            0  LINEARIZED CP                                IR             1  TIME-DERIV. IN AIRFOIL B.C.
DEL       .10000  AIRFOIL THICKNESS RATIO                      XAR       .25000  POSITION OF PITCH AXIS
ALFZRO   1.00000  MEAN ANGLE OF ATTACK                         ALFONE   0.00000  PITCHING AMPLITUDE
Z1       0.00000  PLUNGE AMPLITUDE                             IMOOFR         1  TIME-DERIVATIVE IN WAKE CONDITION
RSUB     1.40000  SUBSONIC RELAXATION FACTOR                   RSUP     1.00000  SUPERSONIC RELAXATION FACTOR
MITC         500  MAXIMUM NUMBER OF ITERATIONS                 TOLC      .10E-04  TOLERANCE PARAMETERS IN STEADY
MITM         100  ON COARSE, FINE AND EXT. FINE GRID           TOLM      .10E-05  CALCULATIONS ON COARSE, FINE
MITEF         25  RESPECTIVELY                                 TOLEF     .10E-05  AND EXT. FINE GRID RESPECTIVELY
ICPRUN         0  NO REQUEST FOR OUTPUT OF UNSTEADY PRESSURES  LINDIF         0  NLR-TSP EQUATION (WITH NON-LINEAR TERM)
ICPT           1  TIME-DER. CONTRIBUTES TO CP AND MACH, IF IR=1

N              1  NUMBER OF (CO)SIN HARMONICS
MULTIPLIERS OF (CO)SIN HARMONICS   1.00000
```

NACA 64A010 AMES AIRFOIL   M=0.780   ALFZNO=1.0   PITCH-PULSE = 0.5

ITERATION NO. = 1   ALF (DEG) = 1.0000000   PLUNGE = 0.0000000
TIME = 50.3145698   T (DEG) = 2882.8125000

| INDEX | X | CPU | CPL | MU | ML | DCP=CPL-CPU |
|---|---|---|---|---|---|---|
| 16 | .00667 | .35640 | .97191 | .56809 | 0.00000 | .61550 |
| 17 | .02000 | -.22203 | .36687 | .88678 | .56066 | .58890 |
| 18 | .04000 | -.39426 | .12741 | .96147 | .71153 | .52167 |
| 19 | .06000 | -.41056 | .03057 | .96824 | .76413 | .44113 |
| 20 | .08000 | -.44964 | -.03271 | .98428 | .79663 | .41693 |
| 21 | .10000 | -.47603 | -.07995 | .99497 | .82005 | .39608 |
| 22 | .12000 | -.49381 | -.12362 | 1.00211 | .84113 | .37019 |
| 23 | .14000 | -.52687 | -.16203 | 1.01524 | .85923 | .36484 |
| 24 | .16000 | -.55418 | -.19189 | 1.02596 | .87305 | .36229 |
| 25 | .18000 | -.57305 | -.21605 | 1.03331 | .88407 | .35700 |
| 26 | .20000 | -.58709 | -.23519 | 1.03874 | .89270 | .35190 |
| 27 | .22000 | -.60388 | -.26051 | 1.04520 | .90400 | .34337 |
| 28 | .24000 | -.62367 | -.28984 | 1.05276 | .91691 | .33383 |
| 29 | .26000 | -.64170 | -.31540 | 1.05960 | .92801 | .32630 |
| 30 | .28000 | -.65454 | -.33537 | 1.06445 | .93660 | .31917 |
| 31 | .30000 | -.66657 | -.35399 | 1.06897 | .94453 | .31258 |
| 32 | .32000 | -.68708 | -.37427 | 1.07663 | .95310 | .31282 |
| 33 | .34000 | -.71842 | -.39438 | 1.08823 | .96152 | .32404 |
| 34 | .36000 | -.74912 | -.40942 | 1.09948 | .96777 | .33970 |
| 35 | .38000 | -.76851 | -.41792 | 1.10653 | .97128 | .35059 |
| 36 | .40000 | -.77887 | -.42273 | 1.11027 | .97326 | .35614 |
| 37 | .42000 | -.79313 | -.42644 | 1.11541 | .97479 | .36670 |
| 38 | .44000 | -.81940 | -.42498 | 1.12481 | .97419 | .39442 |
| 39 | .46000 | -.84655 | -.40970 | 1.13444 | .96788 | .43684 |
| 40 | .48000 | -.86263 | -.38281 | 1.14011 | .95668 | .47982 |
| 41 | .50000 | -.86757 | -.35360 | 1.14184 | .94437 | .51397 |
| 42 | .52000 | -.85718 | -.32605 | 1.13819 | .93260 | .53113 |
| 43 | .54000 | -.65066 | -.30059 | 1.06298 | .92159 | .35007 |
| 44 | .56000 | -.32049 | -.27742 | .93021 | .91147 | .04307 |
| 45 | .58000 | -.19646 | -.25557 | .87514 | .90181 | -.05911 |
| 46 | .60000 | -.20798 | -.23197 | .88040 | .89125 | -.02399 |
| 47 | .62000 | -.20587 | -.20547 | .87944 | .87926 | .00040 |
| 48 | .64000 | -.19565 | -.17867 | .87477 | .86696 | .01698 |
| 49 | .66000 | -.18007 | -.15522 | .86760 | .85605 | .02485 |
| 50 | .68000 | -.16097 | -.13474 | .85874 | .84640 | .02623 |
| 51 | .70000 | -.13951 | -.11332 | .84866 | .83620 | .02619 |
| 52 | .72000 | -.11652 | -.08909 | .83774 | .82451 | .02743 |
| 53 | .74000 | -.09319 | -.06383 | .82650 | .81214 | .02936 |
| 54 | .76000 | -.07080 | -.04036 | .81557 | .80047 | .03044 |
| 55 | .78000 | -.04964 | -.01910 | .80510 | .78975 | .03054 |
| 56 | .80000 | -.02946 | .00097 | .79499 | .77950 | .03043 |
| 57 | .82000 | -.00985 | .02061 | .78504 | .76934 | .03045 |
| 58 | .84000 | .01077 | .04089 | .77445 | .75870 | .03012 |
| 59 | .86000 | .03457 | .06315 | .76203 | .74685 | .02858 |
| 60 | .88000 | .06019 | .08723 | .74844 | .73381 | .02704 |
| 61 | .90000 | .08144 | .11111 | .73697 | .72065 | .02967 |
| 62 | .92000 | .09689 | .13478 | .72852 | .70736 | .03790 |
| 63 | .94000 | .11807 | .16343 | .71677 | .69094 | .04536 |
| 64 | .96000 | .16362 | .20616 | .69083 | .66570 | .04254 |
| 65 | .98000 | .24543 | .27420 | .64162 | .62339 | .02877 |
| 66 | 1.00000 | .38469 | .39473 | .54777 | .54037 | .01004 |

FORCE COEFFICIENTS AT ANGLE OF ATTACK = 1.0000000   PLUNGE DISP. = 0.0000000

AIRFOIL
PITCHING MOMENT (ABOUT X = .25000 ) = .9293374E-02   NORMAL FORCE = .2319428E+00   AXIAL FORCE = -.6339783E-02

NACA 64A010 AMES AIRFOIL M=0.780 ALFZRO=1.0 PITCH-PULSE = 0.5

ITERATION NO. = 1024 ALF (DEG) = 1.0000000 PLUNGE = 0.0000000
TIME = 100.5309649 T (DEG) = 5760.0000000

| INDEX | X | CPU | CPL | MU | ML | DCP=CPL-CPU |
|---|---|---|---|---|---|---|
| 16 | .00667 | .35640 | .97191 | .56809 | 0.00000 | .61550 |
| 17 | .02000 | -.22203 | .36687 | .88678 | .56066 | .58890 |
| 18 | .04000 | -.39426 | .12741 | .96147 | .71153 | .52167 |
| 19 | .06000 | -.41056 | .03057 | .96628 | .76413 | .44113 |
| 20 | .08000 | -.44964 | -.03271 | .98426 | .79663 | .41693 |
| 21 | .10000 | -.47603 | -.07995 | .99497 | .82005 | .39608 |
| 22 | .12000 | -.49381 | -.12362 | 1.00211 | .84113 | .37019 |
| 23 | .14000 | -.52687 | -.16203 | 1.01524 | .85923 | .36484 |
| 24 | .16000 | -.55418 | -.19189 | 1.02596 | .87305 | .36229 |
| 25 | .18000 | -.57305 | -.21605 | 1.03331 | .88407 | .35700 |
| 26 | .20000 | -.58709 | -.23519 | 1.03874 | .89270 | .35190 |
| 27 | .22000 | -.60388 | -.26051 | 1.04520 | .90400 | .34337 |
| 28 | .24000 | -.62367 | -.28984 | 1.05276 | .91691 | .33383 |
| 29 | .26000 | -.64170 | -.31540 | 1.05960 | .92801 | .32630 |
| 30 | .28000 | -.65454 | -.33537 | 1.06445 | .93660 | .31917 |
| 31 | .30000 | -.66657 | -.35399 | 1.06897 | .94453 | .31258 |
| 32 | .32000 | -.68708 | -.37427 | 1.07663 | .95310 | .31282 |
| 33 | .34000 | -.71842 | -.39438 | 1.08823 | .96152 | .32404 |
| 34 | .36000 | -.74912 | -.40942 | 1.09948 | .96777 | .33970 |
| 35 | .38000 | -.76851 | -.41792 | 1.10653 | .97128 | .35059 |
| 36 | .40000 | -.77887 | -.42273 | 1.11027 | .97326 | .35614 |
| 37 | .42000 | -.79313 | -.42644 | 1.11541 | .97479 | .36670 |
| 38 | .44000 | -.81940 | -.42498 | 1.12481 | .97419 | .39442 |
| 39 | .46000 | -.84655 | -.40970 | 1.13444 | .96786 | .43684 |
| 40 | .48000 | -.86263 | -.38281 | 1.14011 | .95668 | .47982 |
| 41 | .50000 | -.86756 | -.35359 | 1.14184 | .94437 | .51397 |
| 42 | .52000 | -.85718 | -.32605 | 1.13819 | .93260 | .53113 |
| 43 | .54000 | -.65065 | -.30059 | 1.06298 | .92159 | .35006 |
| 44 | .56000 | -.32049 | -.27742 | .93021 | .91147 | .04307 |
| 45 | .58000 | -.19646 | -.25557 | .87514 | .90181 | -.05911 |
| 46 | .60000 | -.20798 | -.23197 | .88040 | .89125 | -.02399 |
| 47 | .62000 | -.20587 | -.20547 | .87944 | .87926 | .00040 |
| 48 | .64000 | -.19565 | -.17867 | .87477 | .86696 | .01698 |
| 49 | .66000 | -.18007 | -.15522 | .86760 | .85605 | .02485 |
| 50 | .68000 | -.16097 | -.13474 | .85874 | .84640 | .02624 |
| 51 | .70000 | -.13951 | -.11332 | .84866 | .83620 | .02619 |
| 52 | .72000 | -.11652 | -.08909 | .83774 | .82451 | .02743 |
| 53 | .74000 | -.09319 | -.06383 | .82650 | .81214 | .02936 |
| 54 | .76000 | -.07080 | -.04036 | .81557 | .80047 | .03044 |
| 55 | .78000 | -.04964 | -.01910 | .80510 | .78975 | .03054 |
| 56 | .80000 | -.02946 | .00097 | .79499 | .77950 | .03043 |
| 57 | .82000 | -.00984 | .02061 | .78504 | .76934 | .03045 |
| 58 | .84000 | .01077 | .04089 | .77445 | .75870 | .03012 |
| 59 | .86000 | .03457 | .06315 | .76203 | .74685 | .02858 |
| 60 | .88000 | .06019 | .08723 | .74844 | .73381 | .02704 |
| 61 | .90000 | .08144 | .11111 | .73697 | .72065 | .02967 |
| 62 | .92000 | .09689 | .13478 | .72852 | .70736 | .03790 |
| 63 | .94000 | .11807 | .16343 | .71677 | .69094 | .04536 |
| 64 | .96000 | .16362 | .20616 | .69083 | .66570 | .04254 |
| 65 | .98000 | .24543 | .27420 | .64162 | .62339 | .02877 |
| 66 | 1.00000 | .38469 | .39473 | .54777 | .54037 | .01004 |

FORCE COEFFICIENTS AT ANGLE OF ATTACK = 1.0000000 PLUNGE DISP. = 0.0000000

AIRFOIL
PITCHING MOMENT (ABOUT X = .25000 ) = .9293373E-02 NORMAL FORCE = .2319426E+00 AXIAL FORCE = -.6339768E-02

## Post-Processed Generalized Aerodynamic Forces

| POINT | FREQUENCY | RED FREQ | CM (REAL) | CM (IMAG) | CN (REAL) | CN (IMAG) |
|---|---|---|---|---|---|---|
| 1 | 0. | 0. | .733091364E+00 | 0. | .140928825E+02 | 0. |
| 2 | .250000027E+01 | .125000013E-01 | .712931312E+00 | -.402138855E-01 | .134755840E+02 | -.222893875E+01 |
| 3 | .500000053E+01 | .250000027E-01 | .660184321E+00 | -.548162276E-01 | .119218545E+02 | -.365711055E+01 |
| 4 | .750000080E+01 | .375000040E-01 | .603560708E+00 | -.230992413E-01 | .103811496E+02 | -.386462799E+01 |
| 5 | .100000011E+02 | .500000053E-01 | .585903412E+00 | .260274770E-01 | .962000441E+01 | -.377440571E+01 |
| 6 | .125000013E+02 | .625000066E-01 | .576836005E+00 | .572506903E-01 | .892101721E+01 | -.388498416E+01 |
| 7 | .150000016E+02 | .750000080E-01 | .563647928E+00 | .893436641E-01 | .821981223E+01 | -.382913884E+01 |
| 8 | .175000019E+02 | .875000093E-01 | .551596235E+00 | .125983082E+00 | .763828804E+01 | -.362722352E+01 |
| 9 | .200000021E+02 | .100000011E+00 | .547100301E+00 | .167270306E+00 | .725906867E+01 | -.338760313E+01 |
| 10 | .225000024E+02 | .112500012E+00 | .550682927E+00 | .203212264E+00 | .696131848E+01 | -.324226584E+01 |
| 11 | .250000027E+02 | .125000013E+00 | .553392176E+00 | .232640657E+00 | .664371629E+01 | -.311042068E+01 |
| 12 | .275000029E+02 | .137500015E+00 | .552264755E+00 | .261408435E+00 | .634505698E+01 | -.292650166E+01 |
| 13 | .300000032E+02 | .150000016E+00 | .551177933E+00 | .293787403E+00 | .612452426E+01 | -.271560034E+01 |
| 14 | .325000035E+02 | .162500017E+00 | .554908457E+00 | .326321317E+00 | .596374096E+01 | -.254379437E+01 |
| 15 | .350000037E+02 | .175000019E+00 | .560330260E+00 | .354167955E+00 | .580201451E+01 | -.240480311E+01 |
| 16 | .375000040E+02 | .187500020E+00 | .562678975E+00 | .379231792E+00 | .563509225E+01 | -.225456536E+01 |
| 17 | .400000043E+02 | .200000021E+00 | .562330289E+00 | .405985455E+00 | .549491003E+01 | -.208544742E+01 |
| 18 | .425000045E+02 | .212500023E+00 | .563221941E+00 | .434998156E+00 | .539104056E+01 | -.192539788E+01 |
| 19 | .450000048E+02 | .225000024E+00 | .566213950E+00 | .462895848E+00 | .529929943E+01 | -.178769286E+01 |
| 20 | .475000050E+02 | .237500025E+00 | .568367021E+00 | .488640101E+00 | .520484427E+01 | -.165537296E+01 |
| 21 | .500000053E+02 | .250000027E+00 | .568270405E+00 | .514769962E+00 | .511822367E+01 | -.151557130E+01 |
| 22 | .525000056E+02 | .262500028E+00 | .567932320E+00 | .543048012E+00 | .505047834E+01 | -.137632948E+01 |
| 23 | .550000058E+02 | .275000029E+00 | .569158767E+00 | .572067015E+00 | .499519282E+01 | -.124854960E+01 |
| 24 | .575000061E+02 | .287500031E+00 | .570975498E+00 | .600248617E+00 | .494200423E+01 | -.112879791E+01 |
| 25 | .600000064E+02 | .300000032E+00 | .572008049E+00 | .628377778E+00 | .489199293E+01 | -.100896518E+01 |
| 26 | .625000066E+02 | .312500033E+00 | .572918766E+00 | .657796134E+00 | .485122723E+01 | -.889848858E+00 |
| 27 | .650000069E+02 | .325000035E+00 | .575030656E+00 | .688072747E+00 | .481882175E+01 | -.777008201E+00 |
| 28 | .675000072E+02 | .337500036E+00 | .578165749E+00 | .718071346E+00 | .478954070E+01 | -.670501355E+00 |
| 29 | .700000074E+02 | .350000037E+00 | .581465128E+00 | .747891749E+00 | .476255076E+01 | -.566442288E+00 |
| 30 | .725000077E+02 | .362500039E+00 | .585104019E+00 | .778241607E+00 | .474037842E+01 | -.464354345E+00 |
| 31 | .750000080E+02 | .375000040E+00 | .589785832E+00 | .808930709E+00 | .472297334E+01 | -.366627611E+00 |
| 32 | .775000082E+02 | .387500041E+00 | .595433626E+00 | .839300762E+00 | .470787180E+01 | -.273402972E+00 |
| 33 | .800000085E+02 | .400000043E+00 | .601585960E+00 | .869384514E+00 | .469452869E+01 | -.182903905E+00 |
| 34 | .825000088E+02 | .412500044E+00 | .608337032E+00 | .899455418E+00 | .468395438E+01 | -.949187813E-01 |
| 35 | .850000090E+02 | .425000045E+00 | .615975566E+00 | .929334129E+00 | .467577269E+01 | -.103729997E-01 |
| 36 | .875000093E+02 | .437500047E+00 | .624365252E+00 | .958707805E+00 | .466893353E+01 | .709511825E-01 |
| 37 | .900000096E+02 | .450000048E+00 | .633298376E+00 | .987610078E+00 | .466324891E+01 | .149820030E+00 |
| 38 | .925000098E+02 | .462500049E+00 | .642842830E+00 | .101611186E+01 | .465909344E+01 | .226193383E+00 |
| 39 | .950000101E+02 | .475000050E+00 | .653026943E+00 | .104403241E+01 | .465590820E+01 | .299884962E+00 |
| 40 | .975000104E+02 | .487500052E+00 | .663712404E+00 | .107128166E+01 | .465334063E+01 | .371230607E+00 |
| 41 | .100000011E+03 | .500000053E+00 | .674826248E+00 | .109787180E+01 | .465136260E+01 | .440463874E+00 |
| 42 | .102500011E+03 | .512500054E+00 | .686348558E+00 | .112375287E+01 | .464984425E+01 | .507616951E+00 |
| 43 | .105000011E+03 | .525000056E+00 | .698194947E+00 | .114883804E+01 | .464834402E+01 | .572832204E+00 |
| 44 | .107500011E+03 | .537500057E+00 | .710275402E+00 | .117317025E+01 | .464733814E+01 | .636314682E+00 |
| 45 | .110000012E+03 | .550000058E+00 | .722519780E+00 | .119667141E+01 | .464612352E+01 | .698202881E+00 |
| 46 | .112500012E+03 | .562500060E+00 | .734844210E+00 | .121934326E+01 | .464477777E+01 | .758653147E+00 |
| 47 | .115000012E+03 | .575000061E+00 | .747161707E+00 | .124116393E+01 | .464321066E+01 | .817833746E+00 |
| 48 | .117500012E+03 | .587500062E+00 | .759385934E+00 | .126220078E+01 | .464134835E+01 | .875918592E+00 |
| 49 | .120000013E+03 | .600000064E+00 | .771431753E+00 | .128241358E+01 | .463914029E+01 | .933071581E+00 |
| 50 | .122500013E+03 | .612500065E+00 | .783217831E+00 | .130184935E+01 | .463655027E+01 | .989456241E+00 |
| 51 | .125000013E+03 | .625000066E+00 | .794661263E+00 | .132054686E+01 | .463355741E+01 | .104524369E+01 |
| 52 | .127500014E+03 | .637500068E+00 | .805689256E+00 | .133858009E+01 | .463017681E+01 | .110059691E+01 |
| 53 | .130000014E+03 | .650000069E+00 | .816238748E+00 | .135594424E+01 | .462643026E+01 | .115569442E+01 |
| 54 | .132500014E+03 | .662500070E+00 | .826244428E+00 | .137276390E+01 | .462234701E+01 | .121056882E+01 |
| 55 | .135000014E+03 | .675000072E+00 | .835655978E+00 | .138910242E+01 | .461800202E+01 | .126548294E+01 |
| 56 | .137500015E+03 | .687500073E+00 | .844445212E+00 | .140503900E+01 | .461348172E+01 | .132049238E+01 |
| 57 | .140000015E+03 | .700000074E+00 | .852581451E+00 | .142084628E+01 | .460884968E+01 | .137568868E+01 |
| 58 | .142500015E+03 | .712500076E+00 | .860036555E+00 | .143601694E+01 | .460420057E+01 | .143118400E+01 |
| 59 | .145000015E+03 | .725000077E+00 | .866815938E+00 | .145125280E+01 | .459967895E+01 | .148704869E+01 |
| 60 | .147500016E+03 | .737500078E+00 | .872946334E+00 | .146642967E+01 | .459540393E+01 | .154327095E+01 |
| 61 | .150000016E+03 | .750000080E+00 | .878439251E+00 | .148160909E+01 | .459144543E+01 | .159987449E+01 |
| 62 | .152500016E+03 | .762500081E+00 | .883303381E+00 | .149687599E+01 | .458790288E+01 | .165690454E+01 |
| 63 | .155000016E+03 | .775000082E+00 | .887586759E+00 | .151232869E+01 | .458493749E+01 | .171436487E+01 |
| 64 | .157500017E+03 | .787500084E+00 | .891370613E+00 | .152802054E+01 | .458268751E+01 | .177216593E+01 |
| 65 | .160000017E+03 | .800000085E+00 | .894718330E+00 | .154397488E+01 | .458119934E+01 | .183020038E+01 |
| 66 | .162500017E+03 | .812500086E+00 | .897658314E+00 | .156021360E+01 | .458048343E+01 | .188842942E+01 |
| 67 | .165000018E+03 | .825000088E+00 | .900227147E+00 | .157679523E+01 | .458081099E+01 | .194685044E+01 |
| 68 | .167500018E+03 | .837500089E+00 | .902509504E+00 | .159377733E+01 | .458171001E+01 | .200539544E+01 |
| 69 | .170000018E+03 | .850000090E+00 | .904616519E+00 | .161116546E+01 | .458386285E+01 | .206389776E+01 |
| 70 | .172500018E+03 | .862500092E+00 | .906627414E+00 | .162891090E+01 | .458703613E+01 | .212221796E+01 |
| 71 | .175000019E+03 | .875000093E+00 | .908564250E+00 | .164696546E+01 | .459112689E+01 | .218014995E+01 |
| 72 | .177500019E+03 | .887500094E+00 | .910427123E+00 | .166532528E+01 | .459606973E+01 | .223760997E+01 |
| 73 | .180000019E+03 | .900000096E+00 | .912248359E+00 | .168402025E+01 | .460188870E+01 | .229516389E+01 |
| 74 | .182500019E+03 | .912500097E+00 | .914107736E+00 | .170306194E+01 | .460864549E+01 | .235213417E+01 |
| 75 | .185000020E+03 | .925000098E+00 | .916094842E+00 | .172240475E+01 | .461634265E+01 | .240850369E+01 |
| 76 | .187500020E+03 | .937500100E+00 | .918256022E+00 | .174195713E+01 | .462487403E+01 | .246429798E+01 |
| 77 | .190000020E+03 | .950000101E+00 | .920573489E+00 | .176163121E+01 | .463406352E+01 | .251927161E+01 |
| 78 | .192500020E+03 | .962500102E+00 | .922991909E+00 | .178138814E+01 | .464375488E+01 | .257352880E+01 |
| 79 | .195000021E+03 | .975000104E+00 | .925468333E+00 | .180124503E+01 | .465308115E+01 | .262716903E+01 |
| 80 | .197500021E+03 | .987500105E+00 | .928007160E+00 | .182124242E+01 | .466446809E+01 | .268020357E+01 |
| 81 | .200000021E+03 | .100000011E+01 | .930657946E+00 | .184139949E+01 | .467557720E+01 | .273280164E+01 |
| 82 | .202500022E+03 | .101250011E+01 | .933482121E+00 | .186168789E+01 | .468723302E+01 | .278469563E+01 |
| 83 | .205000022E+03 | .102500011E+01 | .936513457E+00 | .188203861E+01 | .469938000E+01 | .283583528E+01 |
| 84 | .207500022E+03 | .103750011E+01 | .939737052E+00 | .190237388E+01 | .471188992E+01 | .288614980E+01 |
| 85 | .210000022E+03 | .105000011E+01 | .943096688E+00 | .192264283E+01 | .472460895E+01 | .293564731E+01 |
| 86 | .212500023E+03 | .106250011E+01 | .946523449E+00 | .194284137E+01 | .473741534E+01 | .298441231E+01 |
| 87 | .215000023E+03 | .107500011E+01 | .949968765E+00 | .196300811E+01 | .475025840E+01 | .303250512E+01 |
| 88 | .217500023E+03 | .108750012E+01 | .953425827E+00 | .198320077E+01 | .476316341E+01 | .308021036E+01 |
| 89 | .220000023E+03 | .110000012E+01 | .956931158E+00 | .200346570E+01 | .477640351E+01 | .312739443E+01 |
| 90 | .222500024E+03 | .111250012E+01 | .960547788E+00 | .202381454E+01 | .478945305E+01 | .317408987E+01 |
| 91 | .225000024E+03 | .112500012E+01 | .964338644E+00 | .204421511E+01 | .480294224E+01 | .322021048E+01 |
| 92 | .227500024E+03 | .113750012E+01 | .968341320E+00 | .206460089E+01 | .481663049E+01 | .326364934E+01 |
| 93 | .230000024E+03 | .115000012E+01 | .972553342E+00 | .208449145E+01 | .483040581E+01 | .331032442E+01 |
| 94 | .232500025E+03 | .116250012E+01 | .976911794E+00 | .210301693E+01 | .484411052E+01 | .335421420E+01 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 95 | .235000025E+03 | .117500012E+01 | .981406170E+00 | .212493757E+01 | .485758120E+01 | .339737621E+01 |
| 96 | .237500025E+03 | .118750013E+01 | .985898812E+00 | .214465266E+01 | .487069047E+01 | .343993620E+01 |
| 97 | .240000026E+03 | .120000013E+01 | .990346117E+00 | .216419724E+01 | .488337717E+01 | .348200137E+01 |
| 98 | .242500026E+03 | .121250013E+01 | .994714070E+00 | .218362842E+01 | .489565651E+01 | .352392062E+01 |
| 99 | .245000026E+03 | .122500013E+01 | .999003991E+00 | .220300642E+01 | .490760842E+01 | .356564702E+01 |
| 100 | .247500026E+03 | .123750013E+01 | .100324756E+01 | .222237595E+01 | .491934894E+01 | .360731288E+01 |
| 101 | .250000027E+03 | .125000013E+01 | .100749339E+01 | .224175357E+01 | .493099420E+01 | .364892356E+01 |
| 102 | .252500027E+03 | .126250013E+01 | .101178958E+01 | .226112392E+01 | .494262794E+01 | .369043036E+01 |
| 103 | .255000027E+03 | .127500014E+01 | .101616755E+01 | .228044531E+01 | .495428129E+01 | .373175695E+01 |
| 104 | .257500027E+03 | .128750014E+01 | .102063128E+01 | .229466212E+01 | .496592910E+01 | .377283096E+01 |
| 105 | .260000028E+03 | .130000014E+01 | .102515423E+01 | .231872035E+01 | .497750205E+01 | .381361156E+01 |
| 106 | .262500028E+03 | .131250014E+01 | .102968403E+01 | .233750211E+01 | .498890976E+01 | .385410674E+01 |
| 107 | .265000028E+03 | .132500014E+01 | .103415312E+01 | .235623580E+01 | .500006844E+01 | .389437675E+01 |
| 108 | .267500028E+03 | .133750014E+01 | .103849231E+01 | .237470005E+01 | .501094547E+01 | .393452444E+01 |
| 109 | .270000029E+03 | .135000014E+01 | .104264427E+01 | .239302110E+01 | .502147626E+01 | .397467560E+01 |
| 110 | .272500029E+03 | .136250014E+01 | .104657404E+01 | .241126474E+01 | .503176971E+01 | .401495476E+01 |
| 111 | .275000029E+03 | .137500015E+01 | .105027465E+01 | .242950488E+01 | .504190239E+01 | .405540191E+01 |
| 112 | .277500030E+03 | .138750015E+01 | .105376721E+01 | .244781124E+01 | .505200345E+01 | .409623472E+01 |
| 113 | .280000030E+03 | .140000015E+01 | .105709597E+01 | .246623878E+01 | .506221420E+01 | .413733987E+01 |
| 114 | .282500030E+03 | .141250015E+01 | .106031969E+01 | .248482054E+01 | .507266700E+01 | .417867362E+01 |
| 115 | .285000030E+03 | .142500015E+01 | .106350155E+01 | .250356449E+01 | .508346728E+01 | .422017085E+01 |
| 116 | .287500031E+03 | .143750015E+01 | .106669941E+01 | .252245746E+01 | .509468169E+01 | .426171960E+01 |
| 117 | .290000031E+03 | .145000015E+01 | .106995814E+01 | .254146556E+01 | .510653332E+01 | .430319748E+01 |
| 118 | .292500031E+03 | .146250016E+01 | .107330504E+01 | .256054592E+01 | .511840385E+01 | .434449032E+01 |
| 119 | .295000031E+03 | .147500016E+01 | .107674842E+01 | .257965203E+01 | .513084097E+01 | .438550011E+01 |
| 120 | .297500032E+03 | .148750016E+01 | .108027914E+01 | .259874127E+01 | .514350910E+01 | .442613848E+01 |
| 121 | .300000032E+03 | .150000016E+01 | .108387434E+01 | .261770034E+01 | .515650142E+01 | .446642789E+01 |
| 122 | .302500032E+03 | .151250016E+01 | .108750242E+01 | .263674866E+01 | .516955122E+01 | .450630125E+01 |
| 123 | .305000032E+03 | .152500016E+01 | .109112851E+01 | .265563964E+01 | .518264129E+01 | .454579759E+01 |
| 124 | .307500033E+03 | .153750016E+01 | .109471950E+01 | .267443949E+01 | .519571064E+01 | .458495539E+01 |
| 125 | .310000033E+03 | .155000016E+01 | .109824830E+01 | .269322748E+01 | .520871796E+01 | .462386473E+01 |
| 126 | .312500033E+03 | .156250017E+01 | .110169673E+01 | .271196763E+01 | .522164231E+01 | .466245955E+01 |
| 127 | .315000033E+03 | .157500017E+01 | .110505690E+01 | .273070987E+01 | .523448109E+01 | .470091086E+01 |
| 128 | .317500034E+03 | .158750017E+01 | .110833166E+01 | .274940377E+01 | .524724636E+01 | .473922153E+01 |
| 129 | .320000034E+03 | .160000017E+01 | .111153281E+01 | .276831572E+01 | .525996006E+01 | .477742305E+01 |
| 130 | .322500034E+03 | .161250017E+01 | .111467969E+01 | .278722628E+01 | .527264874E+01 | .481555428E+01 |
| 131 | .325000035E+03 | .162500017E+01 | .111779632E+01 | .280622866E+01 | .528533907E+01 | .485350195E+01 |
| 132 | .327500035E+03 | .163750017E+01 | .112090874E+01 | .282532603E+01 | .529805369E+01 | .489150249E+01 |
| 133 | .330000035E+03 | .165000018E+01 | .112404246E+01 | .284452163E+01 | .531080950E+01 | .492934478E+01 |
| 134 | .332500035E+03 | .166250018E+01 | .112722030E+01 | .286380065E+01 | .532501417E+01 | .496707332E+01 |
| 135 | .335000036E+03 | .167500018E+01 | .113046081E+01 | .288314973E+01 | .533646784E+01 | .500467133E+01 |
| 136 | .337500036E+03 | .168750018E+01 | .113377724E+01 | .290255056E+01 | .534936260E+01 | .504212397E+01 |
| 137 | .340000036E+03 | .170000018E+01 | .113717710E+01 | .292198266E+01 | .536228409E+01 | .507941859E+01 |
| 138 | .342500036E+03 | .171250018E+01 | .114066220E+01 | .294142513E+01 | .537521316E+01 | .511655036E+01 |
| 139 | .345000037E+03 | .172500018E+01 | .114422902E+01 | .296083809E+01 | .538012789E+01 | .515351936E+01 |
| 140 | .347500037E+03 | .173750018E+01 | .114786938E+01 | .298026382E+01 | .540100560E+01 | .519035276E+01 |
| 141 | .350000037E+03 | .175000019E+01 | .115157124E+01 | .299462767E+01 | .541362470E+01 | .522700447E+01 |
| 142 | .352500037E+03 | .176250019E+01 | .115531987E+01 | .301843869E+01 | .542656673E+01 | .526355447E+01 |
| 143 | .355000038E+03 | .177500019E+01 | .115909836E+01 | .303819000E+01 | .543921717E+01 | .530000784E+01 |
| 144 | .357500038E+03 | .178750019E+01 | .116288910E+01 | .305737900E+01 | .545176726E+01 | .533634354E+01 |
| 145 | .360000038E+03 | .180000019E+01 | .116667447E+01 | .307690732E+01 | .546421439E+01 | .537274301E+01 |
| 146 | .362500039E+03 | .181250019E+01 | .117043780E+01 | .309558058E+01 | .547636267E+01 | .540908867E+01 |
| 147 | .365000039E+03 | .182500019E+01 | .117416416E+01 | .311460801E+01 | .548882291E+01 | .544540232E+01 |
| 148 | .367500039E+03 | .183750020E+01 | .117784102E+01 | .313360145E+01 | .550101230E+01 | .548184374E+01 |
| 149 | .370000039E+03 | .185000020E+01 | .118145879E+01 | .315257716E+01 | .551315419E+01 | .551840930E+01 |
| 150 | .372500040E+03 | .186250020E+01 | .118501121E+01 | .317155015E+01 | .552527642E+01 | .555503085E+01 |
| 151 | .375000040E+03 | .187500020E+01 | .118849549E+01 | .319053839E+01 | .553741102E+01 | .559177481E+01 |
| 152 | .377500040E+03 | .188750020E+01 | .119191239E+01 | .320955961E+01 | .554959263E+01 | .562865152E+01 |
| 153 | .380000040E+03 | .190000020E+01 | .119526611E+01 | .322863106E+01 | .556165722E+01 | .566566443E+01 |
| 154 | .382500041E+03 | .191250020E+01 | .119856399E+01 | .324776890E+01 | .557424084E+01 | .570281254E+01 |
| 155 | .385000041E+03 | .192500020E+01 | .120181619E+01 | .326698760E+01 | .558677833E+01 | .574008555E+01 |
| 156 | .387500041E+03 | .193750021E+01 | .120503524E+01 | .328629956E+01 | .559950217E+01 | .577746933E+01 |
| 157 | .390000041E+03 | .195000021E+01 | .120823554E+01 | .330571471E+01 | .561244146E+01 | .581494403E+01 |
| 158 | .392500042E+03 | .196250021E+01 | .121143285E+01 | .332524035E+01 | .562562102E+01 | .585240537E+01 |
| 159 | .395000042E+03 | .197500021E+01 | .121464371E+01 | .334488097E+01 | .563906075E+01 | .589006550E+01 |
| 160 | .397500042E+03 | .198750021E+01 | .121788499E+01 | .336463827E+01 | .565277504E+01 | .592765397E+01 |
| 161 | .400000043E+03 | .200000021E+01 | .122117334E+01 | .338451123E+01 | .566677244E+01 | .596521875E+01 |

## Appendix B3 - Results from Unsteady Calculations for Aeroelastic Motion

### XTRAN2L Input

```
NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   U/C=330.0   AEROELASTIC
$AEROEL IRESP=1, DELT=0.00050, UC=330.0, NELAST=1, $END
$INPUT XM=0.780, IHEAD=5, MAXIT=1024, NSPC=128, ICPRNT=128, IBUF=1,
 DEL=0.10, XAR=0.25, ALFZRO=1.00, ALFONE=0.00, $END
$MESH $
$AMPLI $
$ORD NINU = 51, NINL = 51,
XINU =
 .006667,  .020000,  .040000,  .060000,  .080000,  .100000,  .120000,  .140000,
 .160000,  .180000,  .200000,  .220000,  .240000,  .260000,  .280000,  .300000,
 .320000,  .340000,  .360000,  .380000,  .400000,  .420000,  .440000,  .460000,
 .480000,  .500000,  .520000,  .540000,  .560000,  .580000,  .600000,  .620000,
 .640000,  .660000,  .680000,  .700000,  .720000,  .740000,  .760000,  .780000,
 .800000,  .820000,  .840000,  .860000,  .880000,  .900000,  .920000,  .940000,
 .960000,  .980000, 1.000000,
ZINU =
 .010144,  .016499,  .022381,  .026732,  .030412,  .033687,  .036532,  .039115,
 .041413,  .043449,  .045258,  .046874,  .048300,  .049535,  .050589,  .051485,
 .052232,  .052792,  .053113,  .053200,  .053113,  .052905,  .052555,  .051921,
 .051053,  .049999,  .048815,  .047508,  .046076,  .044524,  .042865,  .041114,
 .039280,  .037367,  .035385,  .033343,  .031251,  .029124,  .026980,  .024828,
 .022672,  .020513,  .018343,  .016152,  .013956,  .011794,  .009645,  .007558,
 .005196,  .002650, 0.000000,
VINU =
 .666396,  .373066,  .247503,  .201161,  .174588,  .150587,  .135858,  .121238,
 .108089,  .095780,  .085469,  .076080,  .066554,  .057051,  .048547,  .041197,
 .033109,  .022385,  .009743, -.000503, -.007639, -.013740, -.023947, -.037534,
-.048629, -.056247, -.062229, -.068431, -.074733, -.080404, -.085320, -.089694,
-.093739, -.097456, -.100687, -.103473, -.105608, -.106902, -.107459, -.107720,
-.107831, -.108131, -.108983, -.110036, -.109200, -.106129, -.105359, -.111450,
-.122939, -.130770, -.133366,
XINL =
 .006667,  .020000,  .040000,  .060000,  .080000,  .100000,  .120000,  .140000,
 .160000,  .180000,  .200000,  .220000,  .240000,  .260000,  .280000,  .300000,
 .320000,  .340000,  .360000,  .380000,  .400000,  .420000,  .440000,  .460000,
 .480000,  .500000,  .520000,  .540000,  .560000,  .580000,  .600000,  .620000,
 .640000,  .660000,  .680000,  .700000,  .720000,  .740000,  .760000,  .780000,
 .800000,  .820000,  .840000,  .860000,  .880000,  .900000,  .920000,  .940000,
 .960000,  .980000, 1.000000,
ZINL =
-.009941, -.016596, -.022527, -.026839, -.030529, -.033748, -.036542, -.039014,
-.041272, -.043251, -.045019, -.046644, -.048113, -.049395, -.050483, -.051393,
-.052138, -.052706, -.053081, -.053256, -.053246, -.053049, -.052654, -.052038,
-.051206, -.050192, -.049027, -.047730, -.046317, -.044793, -.043155, -.041401,
-.039558, -.037654, -.035699, -.033678, -.031584, -.029437, -.027265, -.025083,
-.022891, -.020688, -.018469, -.016229, -.013974, -.011722, -.009482, -.007215,
-.004875, -.002456, 0.000000,
VINL =
-.755623, -.364001, -.245107, -.199126, -.169990, -.147623, -.134054, -.117215,
-.105643, -.092960, -.084615, -.077618, -.069016, -.059127, -.049812, -.041371,
-.032950, -.023693, -.013753, -.004057,  .005245,  .014597,  .025101,  .036447,
 .046437,  .054702,  .061645,  .067874,  .073371,  .079002,  .084907,  .090180,
 .093908,  .096372,  .099285,  .102933,  .106255,  .108179,  .108874,  .109377,
 .109858,  .110486,  .111425,  .112519,  .112822,  .112177,  .112272,  .114804,
 .119226,  .122218,  .123215,
$END
$COND $
```

# Appendix B3 - Concluded

## XTRAN2L Output

```
                    NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   U/C=330.0   AEROELASTIC

AEROELASTIC SYSTEM

IRESP            1  AEROELASTIC TRANSIENT                          NELAST           1  2-DOF , PLUNGE AND PITCH
UC       330.00000  NONDIMENSIONAL VELOCITY                        XMU       60.00000  MASS RATIO
DELT        .00050  TIME STEP, SECONDS                             IEQFLAG          3  EXTRAN EQUATION
AMPLTD      .01745  AMPLITUDE OF PULSE                             WUTHPLS    10000.0  PULSE EXPONENTIAL FACTOR
TZEROST   17.50000  CENTER OF PULSE                                XALPHA     1.80000  DIST FROM ELAST AXIS TO AIRF MASS CENTER
RALPHA     1.86500  AIRFOIL RADIUS OF GYRATION                     OMEGAH   100.00000  UNCOUPLED PLUNGE NAT FREQ (RAD/SEC)
OMEGAA   100.00000  UNCOUPLED PITCH NAT FREQ (RAD/SEC)             AH        -2.00000  ELASTIC AXIS LOCATION

INPUT PARAMETERS

XK          .29750  REDUCED FREQUENCY BASED ON CHORD               XM          .78000  MEAN FREE-STREAM MACH NO.
GAM        1.40000  RATIO OF SPECIFIC HEATS
IREAD            5  READ INITIAL CONDITIONS                        ICNVRG           1  GET S-S SOL. ON COARS, THEN FINER GRIDS
MAXIT         1024  MAX. NO. TIME STEPS                            NSPC           128  NO. STEPS PER CYCLE
ITRAN            0  PITCH, PLUNGE, FLAP MOTION                     ISICO            0  SINUSOIDAL VARIATION
ICPRNT         128  ITERATION PRINT INCREMENT FOR CP               IOUF             1  OUTPUT TO LU 6
JFIRST          16  FIRST CHORDWISE GRIDPT FOR CP PRINTING         JLAST           66  LAST CHORDWISE GRIDPT FOR CP PRINTING
LIN              0  LINEARIZED CP                                  IR               1  TIME-DERIV. IN AIRFOIL B.C.
DEL         .10000  AIRFOIL THICKNESS RATIO                        XAR        -.50000  POSITION OF PITCH AXIS
ALFZRO     1.00000  MEAN ANGLE OF ATTACK                           ALFONE     0.00000  PITCHING AMPLITUDE
Z1         0.00000  PLUNGE AMPLITUDE                               IMODFR           1  TIME-DERIVATIVE IN WAKE CONDITION
RSUB       1.40000  SUBSONIC RELAXATION FACTOR                     RSUP       1.00000  SUPERSONIC RELAXATION FACTOR
MITC           500  MAXIMUM NUMBER OF ITERATIONS                   TOLC        .10E-04  TOLERANCE PARAMETERS IN STEADY
MITM           100  ON COARSE, FINE AND EXT. FINE GRID             TOLM        .10E-05  CALCULATIONS ON COARSE, FINE
MITEF           25  RESPECTIVELY                                   TOLEF       .10E-05  AND EXT. FINE GRID RESPECTIVELY
ICPRUN           0  NO REQUEST FOR OUTPUT OF UNSTEADY PRESSURES    LINDIF           0  NLR-TSP EQUATION (WITH NON-LINEAR TERM)
ICPT             1  TIME-DER. CONTRIBUTES TO CP AND MACH, IF IR=1

N                1  NUMBER OF (CO)SIN HARMONICS
MULTIPLIERS OF (CO)SIN HARMONICS   1.00000
```

```
THE A MATRIX IS:

        4         4

0.          0.          .10000E+01 0.
0.          0.         0.          .10000E+01
-.10000E+05 0.         0.         0.
0.          -.86956E+04 0.        0.


THE B MATRIX IS:

        4         2

0.          0.
0.          0.
 .10000E+01 0.
0.           .10000E+01


THE C MATRIX IS:

        4         4

 .10000E+01 0.         0.         0.
0.           .10000E+01 0.        0.
0.          0.          .10000E+01 -.90000E+00
0.          0.         -.90000E+00  .86956E+00



MATRIX ENTERING INVMMX IS:

        4         4

 .10000E+01 0.         0.         0.
0.           .10000E+01 0.        0.
0.          0.          .10000E+01 -.90000E+00
0.          0.         -.90000E+00  .86956E+00


INVERSE OF MATRIX IS:

        4         4

 .10000E+01 0.         0.         0.
0.           .10000E+01 0.        0.
0.          0.          .14601E+02  .15112E+02
0.          0.          .15112E+02  .16791E+02



THE REDUCED SYSTEM IS -

THE A MATRIX IS:

        4         4

0.          0.          .10000E+01 0.
0.          0.         0.          .10000E+01
-.14601E+06 -.13141E+06 0.        0.
-.15112E+06 -.14601E+06 0.        0.


THE B MATRIX IS:

        4         2

0.          0.
0.          0.
 .14601E+02  .15112E+02
 .15112E+02  .16791E+02



THE TRANSITION MATRIX  7 TERMS IS:

        4         4

 .98186E+00 -.16326E-01  .49697E-03 -.27276E-05
-.18775E-01  .98186E+00 -.31368E-05  .49697E-03
-.72148E+02 -.64906E+02  .98186E+00 -.16326E-01
-.74643E+02 -.72148E+02 -.18775E-01  .98186E+00
```

```
THE INTEGRAL OF THE TRANSITION MATRIX IS:

          4          4

 .49697E-03 -.27276E-05  .12462E-06 -.34137E-09
-.31368E-05  .49697E-03 -.39258E-09  .12462E-06
-.18144E-01 -.16326E-01  .49697E-03 -.27276E-05
-.18775E-01 -.18144E-01 -.31368E-05  .49697E-03



THE FINAL MATRICES -

THE PHI MATRIX IS:

          4          4

 .98186E+00 -.16326E-01  .49697E-03 -.27276E-05
-.18775E-01  .98186E+00 -.31368E-05  .49697E-03
-.72148E+02 -.64906E+02  .98186E+00 -.16326E-01
-.74643E+02 -.72148E+02 -.18775E-01  .98186E+00


THE THETA-B-PRIME MATRIX IS:

          4          2

 .18144E-05  .18775E-05
 .18775E-05  .20866E-05
 .72148E-02  .74643E-02
 .74643E-02  .82971E-02

** WARNING **  NEW PITCH AXIS LOCATION (XAR) DOES NOT MATCH OLD PITCH AXIS LOCATION - CMO REDEFINED FOR RESTART


RESTART VALUES

     CNO =       .2319429E+00
     CMO =       .1032505E+00
     CMFO =      0.


THE I. C. VECTOR IS:

    .10000E-01 0.          0.          0.          0.          0.
```

NACA 64A010 AMES AIRFOIL   M=0.780   ALFZNO=1.0   U/C=330.0   AEROELASTIC

ITERATION NO. = 1   ALF (DEG) = .9892427   PLUNGE = .0098186
TIME = 50.3145698   T (DEG) = 2882.8125000

| INDEX | X | CPU | CPL | MU | ML | DCP=CPL-CPU |
|---|---|---|---|---|---|---|
| 16 | .00667 | .35348 | .97482 | .56990 | 0.00000 | .62134 |
| 17 | .02000 | -.22404 | .36888 | .88743 | .55962 | .59292 |
| 18 | .04000 | -.39579 | .12895 | .96181 | .71106 | .52474 |
| 19 | .06000 | -.41196 | .03197 | .96849 | .76382 | .44394 |
| 20 | .08000 | -.45095 | -.03140 | .98446 | .79641 | .41955 |
| 21 | .10000 | -.47725 | -.07872 | .99509 | .81990 | .39853 |
| 22 | .12000 | -.49496 | -.12247 | 1.00219 | .84103 | .37249 |
| 23 | .14000 | -.52794 | -.16095 | 1.01529 | .85917 | .36699 |
| 24 | .16000 | -.55518 | -.19089 | 1.02598 | .87302 | .36429 |
| 25 | .18000 | -.57398 | -.21512 | 1.03331 | .88407 | .35886 |
| 26 | .20000 | -.58794 | -.23434 | 1.03872 | .89273 | .35360 |
| 27 | .22000 | -.60465 | -.25974 | 1.04516 | .90405 | .34491 |
| 28 | .24000 | -.62436 | -.28915 | 1.05270 | .91698 | .33521 |
| 29 | .26000 | -.64231 | -.31480 | 1.05953 | .92810 | .32751 |
| 30 | .28000 | -.65506 | -.33485 | 1.06436 | .93670 | .32021 |
| 31 | .30000 | -.66700 | -.35355 | 1.06887 | .94465 | .31345 |
| 32 | .32000 | -.68743 | -.37392 | 1.07652 | .95322 | .31350 |
| 33 | .34000 | -.71867 | -.39412 | 1.08811 | .96165 | .32455 |
| 34 | .36000 | -.74928 | -.40926 | 1.09935 | .96791 | .34002 |
| 35 | .38000 | -.76857 | -.41785 | 1.10639 | .97144 | .35072 |
| 36 | .40000 | -.77884 | -.42276 | 1.11013 | .97343 | .35607 |
| 37 | .42000 | -.79300 | -.42657 | 1.11526 | .97496 | .36644 |
| 38 | .44000 | -.81917 | -.42520 | 1.12465 | .97437 | .39396 |
| 39 | .46000 | -.84622 | -.41003 | 1.13427 | .96808 | .43618 |
| 40 | .48000 | -.86220 | -.38324 | 1.13993 | .95689 | .47896 |
| 41 | .50000 | -.86703 | -.35413 | 1.14166 | .94458 | .51290 |
| 42 | .52000 | -.85654 | -.32669 | 1.13800 | .93283 | .52986 |
| 43 | .54000 | -.64991 | -.30133 | 1.06278 | .92183 | .34858 |
| 44 | .56000 | -.31965 | -.27827 | .92997 | .91171 | .04138 |
| 45 | .58000 | -.19550 | -.25652 | .87487 | .90206 | -.06102 |
| 46 | .60000 | -.20692 | -.23303 | .88013 | .89152 | -.02611 |
| 47 | .62000 | -.20470 | -.20664 | .87916 | .87954 | -.00194 |
| 48 | .64000 | -.19437 | -.17994 | .87448 | .86725 | .01442 |
| 49 | .66000 | -.17868 | -.15661 | .86731 | .85635 | .02207 |
| 50 | .68000 | -.15948 | -.13624 | .85843 | .84672 | .02324 |
| 51 | .70000 | -.13790 | -.11493 | .84834 | .83653 | .02297 |
| 52 | .72000 | -.11481 | -.09081 | .83740 | .82484 | .02400 |
| 53 | .74000 | -.09136 | -.06566 | .82616 | .81248 | .02570 |
| 54 | .76000 | -.06886 | -.04230 | .81521 | .80083 | .02656 |
| 55 | .78000 | -.04759 | -.02115 | .80474 | .79012 | .02643 |
| 56 | .80000 | -.02729 | -.00120 | .79462 | .77969 | .02610 |
| 57 | .82000 | -.00757 | .01833 | .78465 | .76973 | .02590 |
| 58 | .84000 | .01316 | .03850 | .77405 | .75911 | .02534 |
| 59 | .86000 | .03707 | .06065 | .76162 | .74727 | .02357 |
| 60 | .88000 | .06281 | .08461 | .74801 | .73425 | .02181 |
| 61 | .90000 | .08417 | .10838 | .73653 | .72110 | .02421 |
| 62 | .92000 | .09973 | .13194 | .72806 | .70783 | .03220 |
| 63 | .94000 | .12103 | .16047 | .71630 | .69143 | .03944 |
| 64 | .96000 | .16670 | .20309 | .69034 | .66621 | .03639 |
| 65 | .98000 | .24862 | .27101 | .64108 | .62394 | .02240 |
| 66 | 1.00000 | .38600 | .39324 | .54859 | .53967 | .00725 |

FORCE COEFFICIENTS AT ANGLE OF ATTACK = .9892427   PLUNGE DISP. = .0098186

AIRFOIL
PITCHING MOMENT (ABOUT X = -.50000 ) = .1811804E+00   NORMAL FORCE = .2307509E+00   AXIAL FORCE = -.6338938E-02

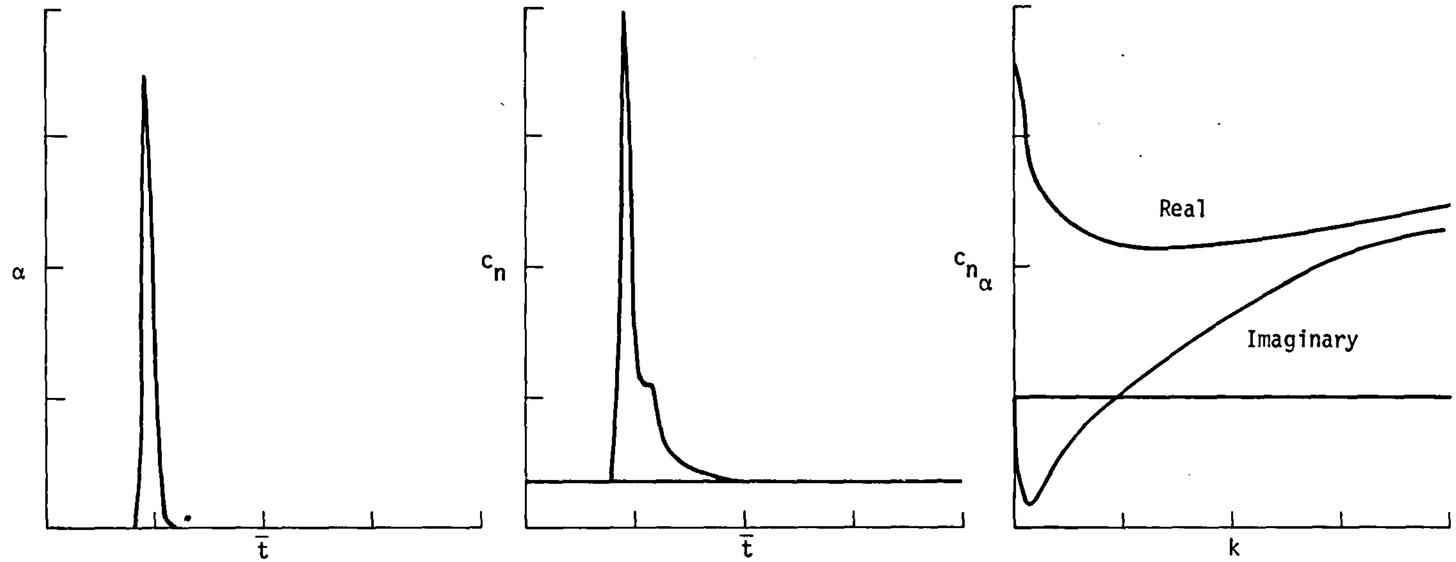
NACA 64A010 AMES AIRFOIL   M=0.780   ALFZRO=1.0   U/C=330.0   AERUELASTIC

ITERATION NO. = 1024   ALF (DEG) = .6718140   PLUNGE = .0044074
TIME = 100.5309649   T (DEG) = 5760.0000000

| INDEX | X | CPU | CPL | MU | ML | DCP=CPL-CPU |
|---|---|---|---|---|---|---|
| 16 | .00667 | .41625 | .91995 | .52420 | 0.00000 | .50369 |
| 17 | .02000 | -.15552 | .31405 | .85618 | .59739 | .46957 |
| 18 | .04000 | -.33661 | .08223 | .93708 | .73673 | .41884 |
| 19 | .06000 | -.36342 | -.00814 | .94845 | .78439 | .35528 |
| 20 | .08000 | -.40359 | -.06824 | .96526 | .81456 | .33535 |
| 21 | .10000 | -.43386 | -.11324 | .97773 | .83644 | .32061 |
| 22 | .12000 | -.45584 | -.15533 | .98668 | .85640 | .30050 |
| 23 | .14000 | -.48749 | -.19243 | .99944 | .87362 | .29507 |
| 24 | .16000 | -.51758 | -.22099 | 1.01142 | .88666 | .29659 |
| 25 | .18000 | -.53850 | -.24391 | 1.01966 | .89699 | .29459 |
| 26 | .20000 | -.54985 | -.26176 | 1.02411 | .90496 | .28808 |
| 27 | .22000 | -.56572 | -.28643 | 1.03029 | .91584 | .27929 |
| 28 | .24000 | -.58775 | -.31561 | 1.03882 | .92855 | .27215 |
| 29 | .26000 | -.60864 | -.34099 | 1.04684 | .93947 | .26765 |
| 30 | .28000 | -.62226 | -.36052 | 1.05203 | .94779 | .26175 |
| 31 | .30000 | -.63375 | -.37872 | 1.05639 | .95549 | .25503 |
| 32 | .32000 | -.65409 | -.39899 | 1.06407 | .96398 | .25509 |
| 33 | .34000 | -.68609 | -.41940 | 1.07605 | .97246 | .26669 |
| 34 | .36000 | -.71730 | -.43433 | 1.08761 | .97863 | .28296 |
| 35 | .38000 | -.73623 | -.44188 | 1.09455 | .98175 | .29435 |
| 36 | .40000 | -.74538 | -.44531 | 1.09789 | .98318 | .30007 |
| 37 | .42000 | -.75842 | -.44771 | 1.10264 | .98419 | .31071 |
| 38 | .44000 | -.78386 | -.44441 | 1.11183 | .98288 | .33945 |
| 39 | .46000 | -.80931 | -.42605 | 1.12096 | .97540 | .38325 |
| 40 | .48000 | -.82011 | -.39601 | 1.12480 | .96301 | .42410 |
| 41 | .50000 | -.79762 | -.36459 | 1.11675 | .94986 | .43304 |
| 42 | .52000 | -.59080 | -.33549 | 1.03973 | .93753 | .25531 |
| 43 | .54000 | -.33179 | -.30885 | .93424 | .92609 | .02294 |
| 44 | .56000 | -.26350 | -.28475 | .90446 | .91562 | -.02126 |
| 45 | .58000 | -.26919 | -.26211 | .90696 | .90567 | .00708 |
| 46 | .60000 | -.26045 | -.23778 | .90308 | .89485 | .02267 |
| 47 | .62000 | -.24466 | -.21061 | .89603 | .88261 | .03405 |
| 48 | .64000 | -.22501 | -.18321 | .88718 | .87009 | .04181 |
| 49 | .66000 | -.20285 | -.15928 | .87710 | .85901 | .04357 |
| 50 | .68000 | -.17908 | -.13839 | .86615 | .84922 | .04068 |
| 51 | .70000 | -.15421 | -.11660 | .85456 | .83888 | .03761 |
| 52 | .72000 | -.12870 | -.09202 | .84251 | .82706 | .03669 |
| 53 | .74000 | -.10346 | -.06643 | .83041 | .81457 | .03703 |
| 54 | .76000 | -.07960 | -.04267 | .81880 | .80280 | .03693 |
| 55 | .78000 | -.05729 | -.02118 | .80781 | .79201 | .03611 |
| 56 | .80000 | -.03619 | -.00091 | .79726 | .78168 | .03529 |
| 57 | .82000 | -.01582 | .01891 | .78696 | .77146 | .03473 |
| 58 | .84000 | .00543 | .03935 | .77606 | .76076 | .03392 |
| 59 | .86000 | .02978 | .06175 | .76338 | .74887 | .03197 |
| 60 | .88000 | .05588 | .08596 | .74955 | .73579 | .03008 |
| 61 | .90000 | .07755 | .10994 | .73789 | .72261 | .03240 |
| 62 | .92000 | .09337 | .13369 | .72925 | .70931 | .04032 |
| 63 | .94000 | .11490 | .16240 | .71733 | .69289 | .04750 |
| 64 | .96000 | .16078 | .20519 | .69123 | .66767 | .04440 |
| 65 | .98000 | .24288 | .27330 | .64188 | .62543 | .03043 |
| 66 | 1.00000 | .38294 | .39377 | .54750 | .54275 | .01083 |

FORCE COEFFICIENTS AT ANGLE OF ATTACK = .6718140   PLUNGE DISP. = .0044074

AIRFOIL
PITCHING MOMENT (ABOUT X = -.50000 ) = .1502362E+00   NORMAL FORCE = .1887418E+00   AXIAL FORCE = -.6082320E-02




(a) Pulse input. (b) Force output. (c) Unsteady force response.

Fig. 1 Pulse transfer-function analysis for unsteady aerodynamic forces;

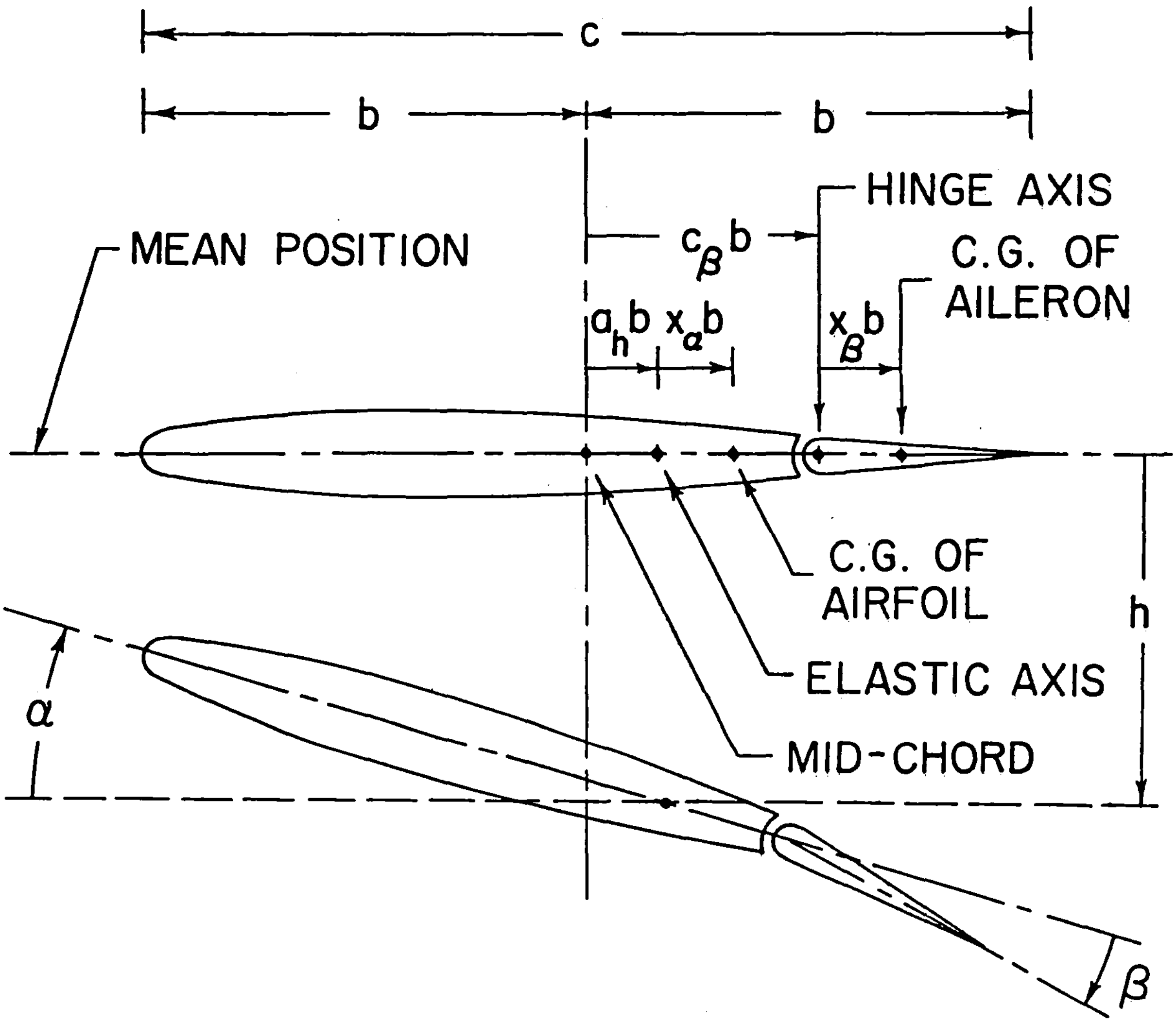



Fig. 2 Definition of structural parameters for three degree-of-freedom aeroelastic analysis.

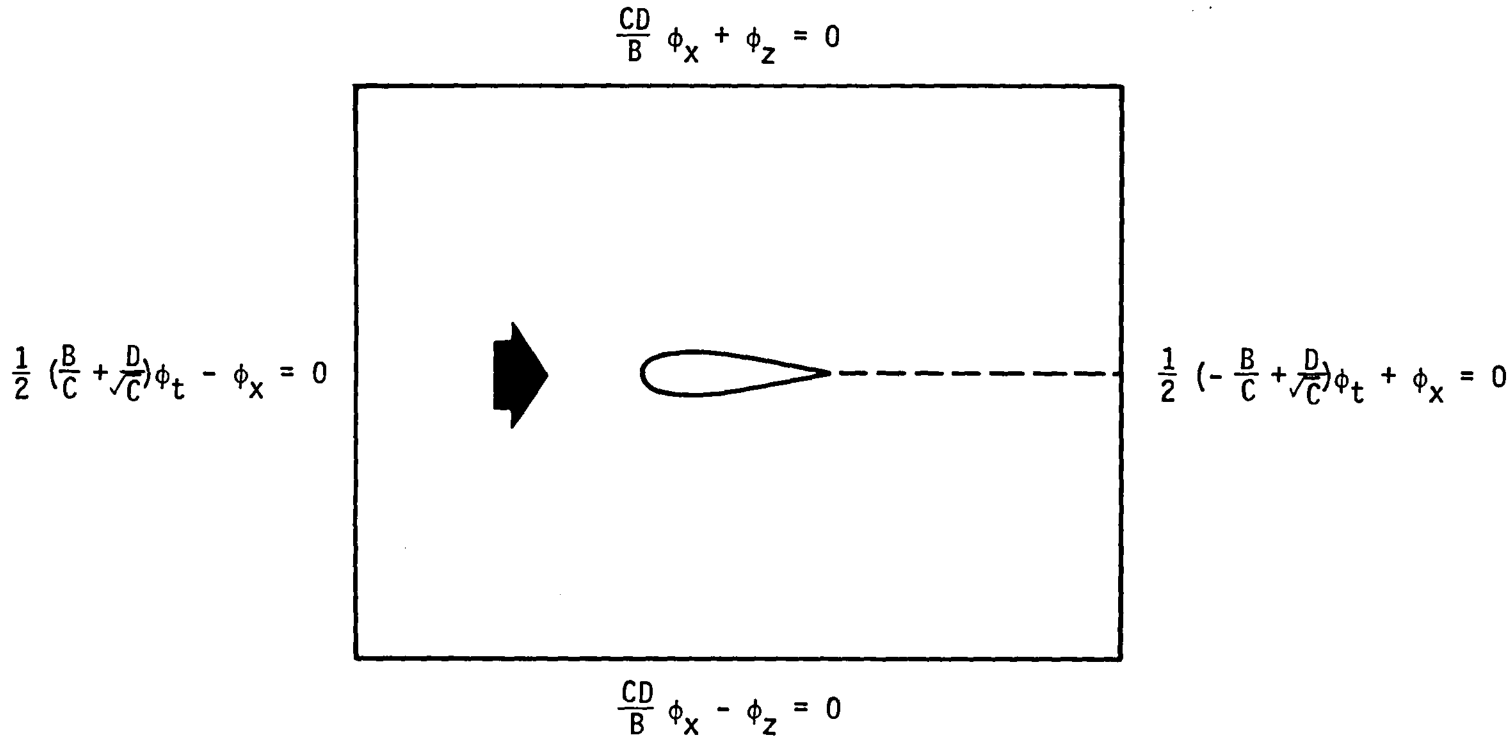



Fig. 3 Nonreflecting farfield boundary conditions.

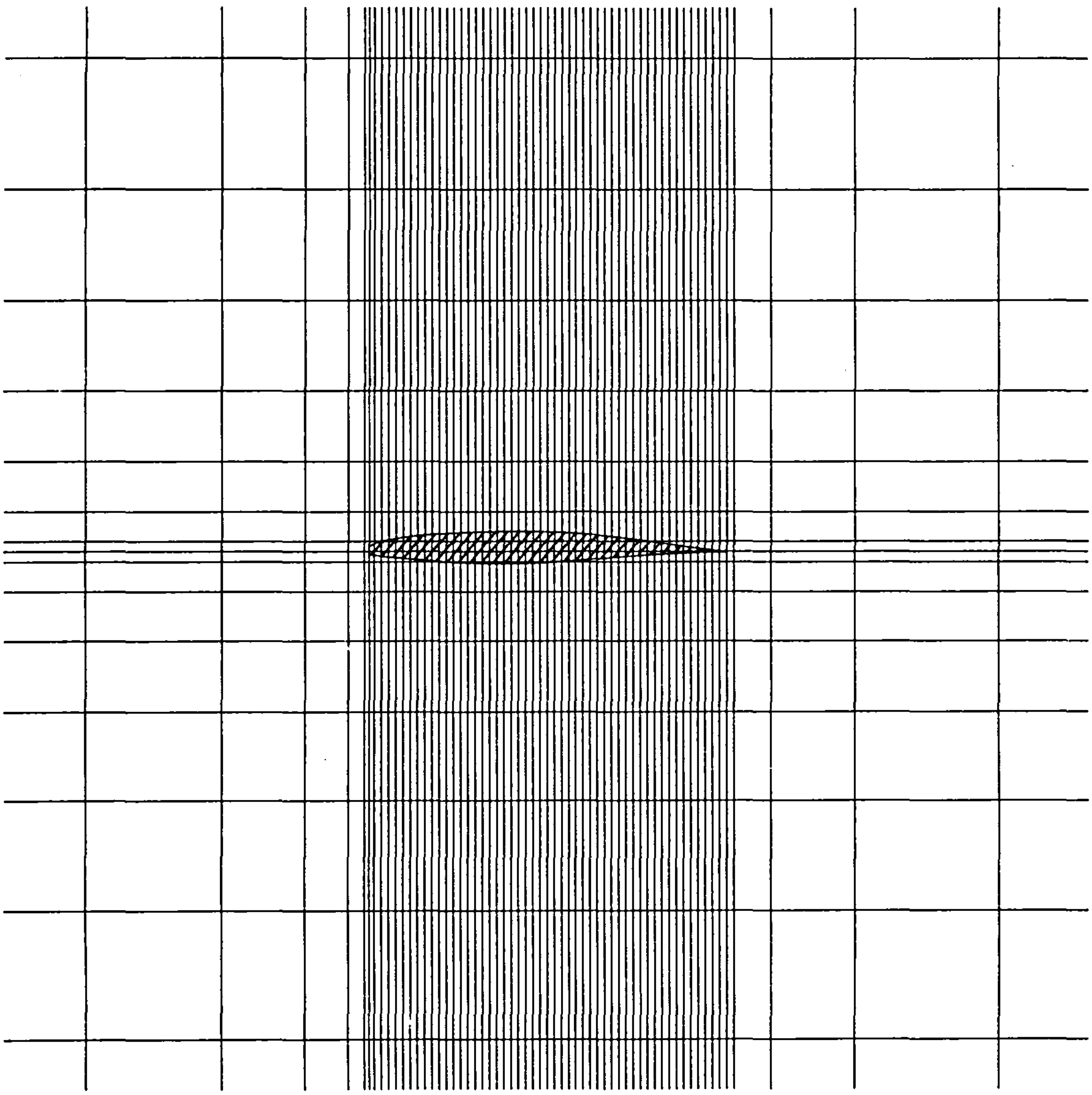
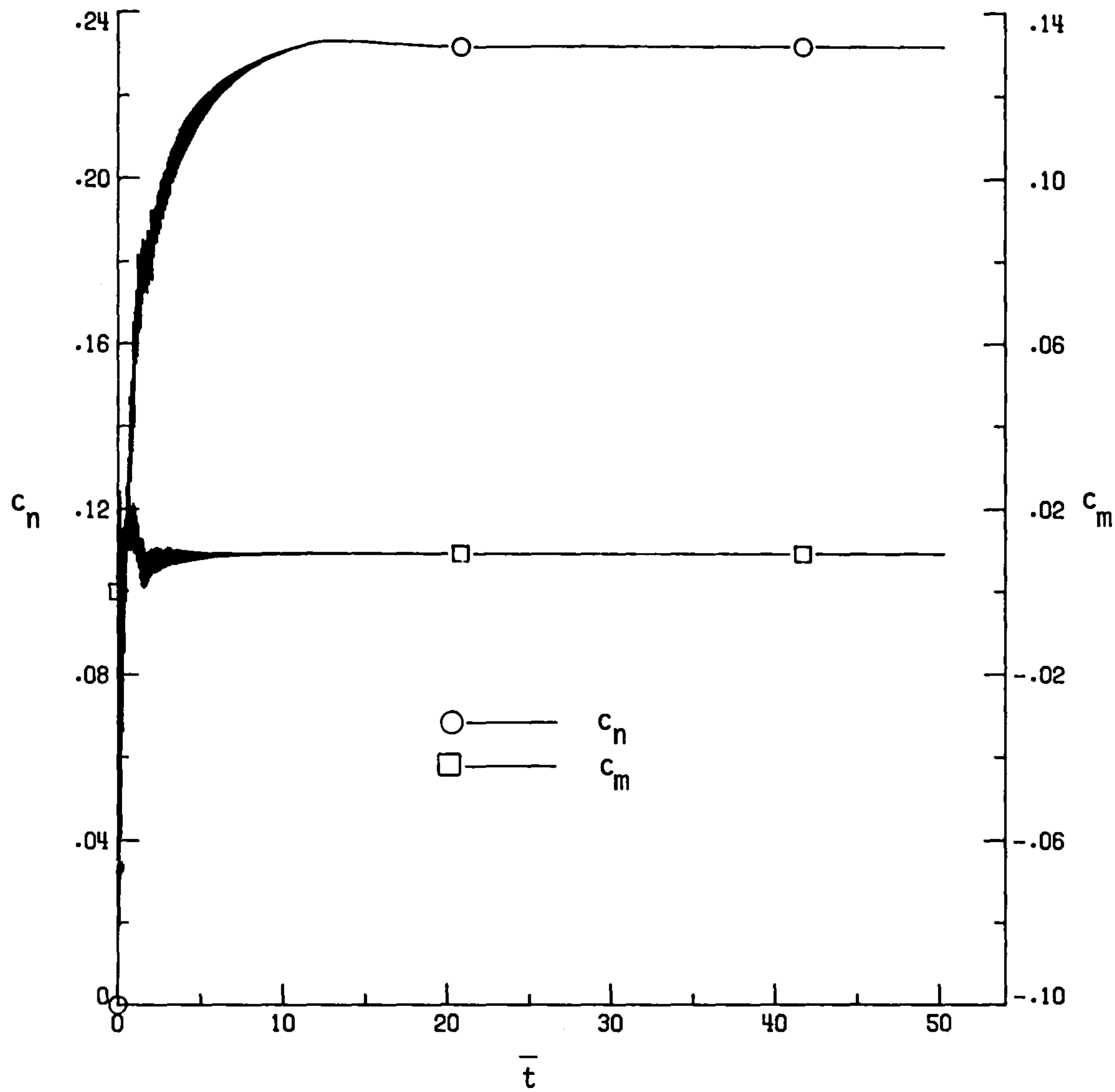
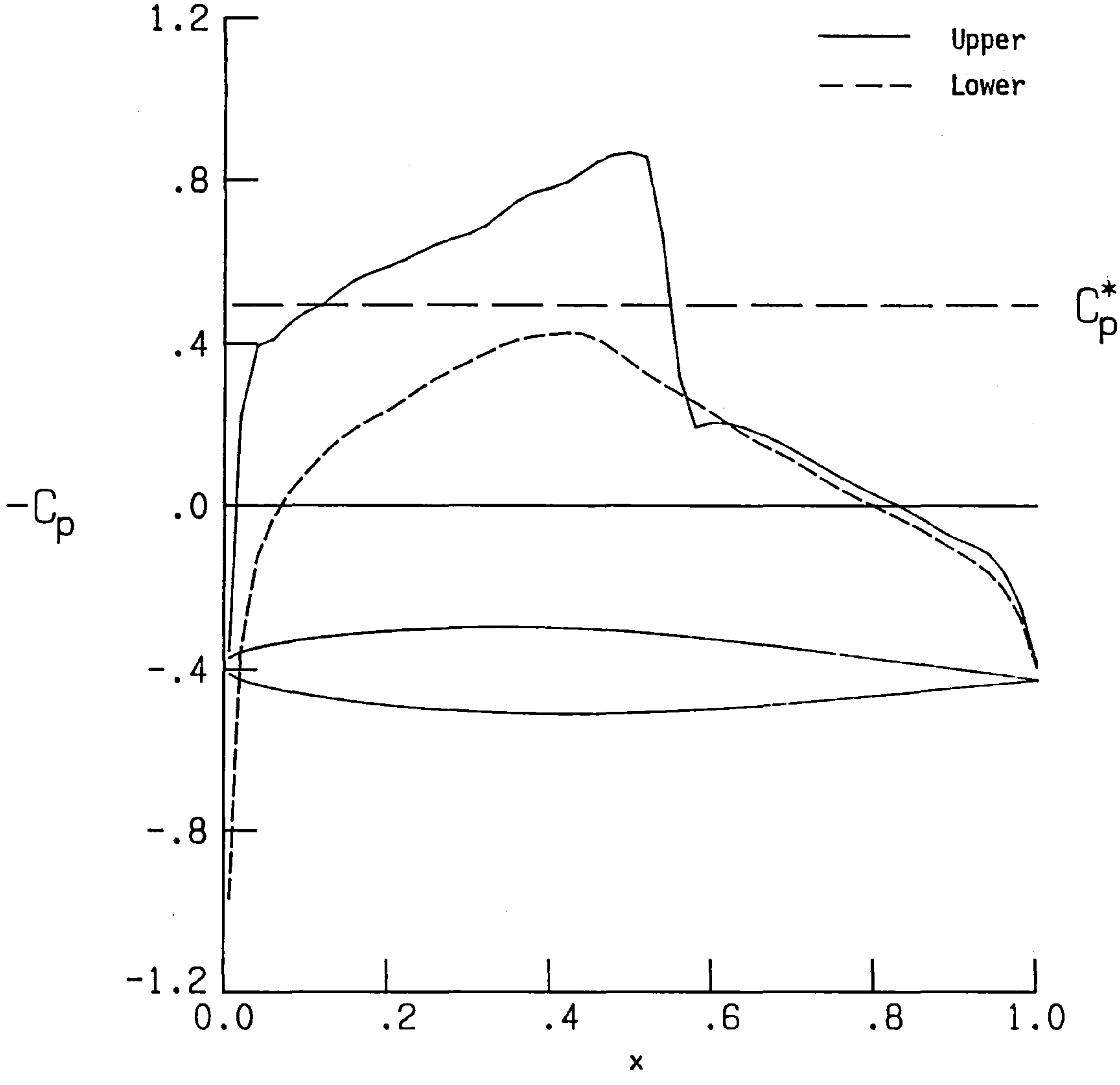


Fig. 4 XTRAN2L default grid near airfoil.



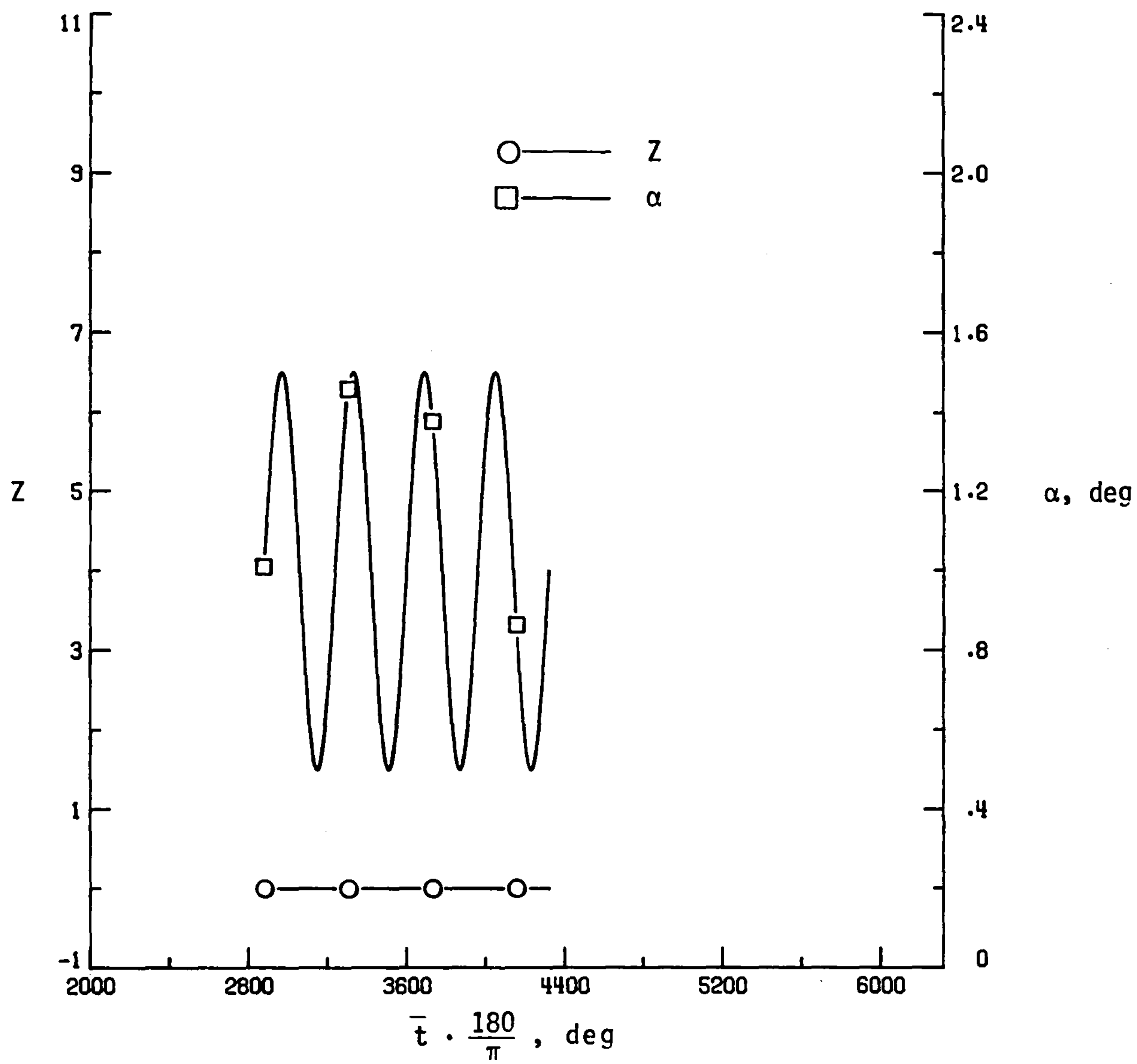

(a) Normal force coefficient and pitching moment coefficient time histories.

Fig. 5 Results from steady calculations (no airfoil motion, IRESP = 5) for the NACA 64A010A airfoil at $M_\infty = 0.78$ and $\alpha_0 = 1.0°$;



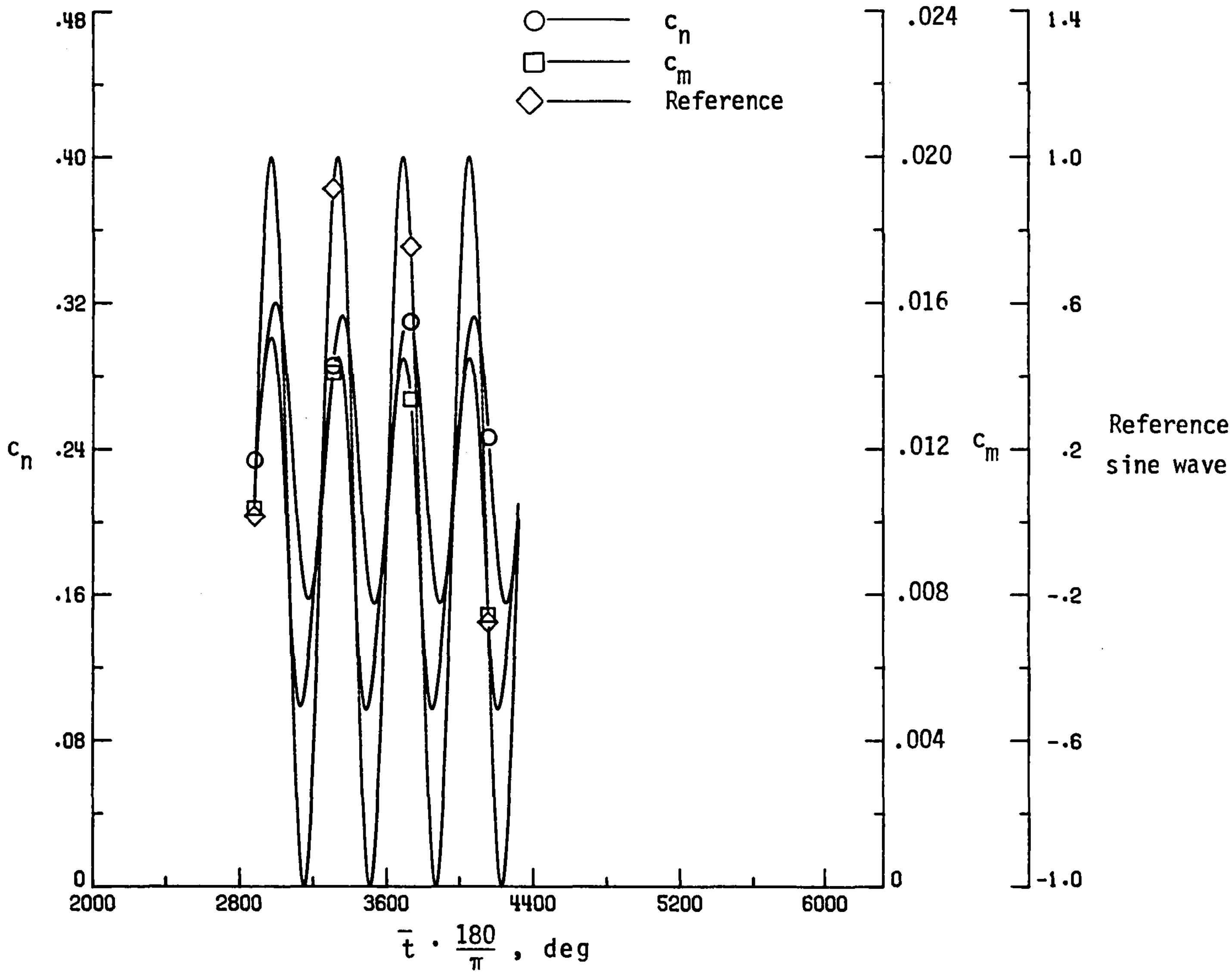

(b) Steady pressure distribution.

Fig. 5 Concluded.



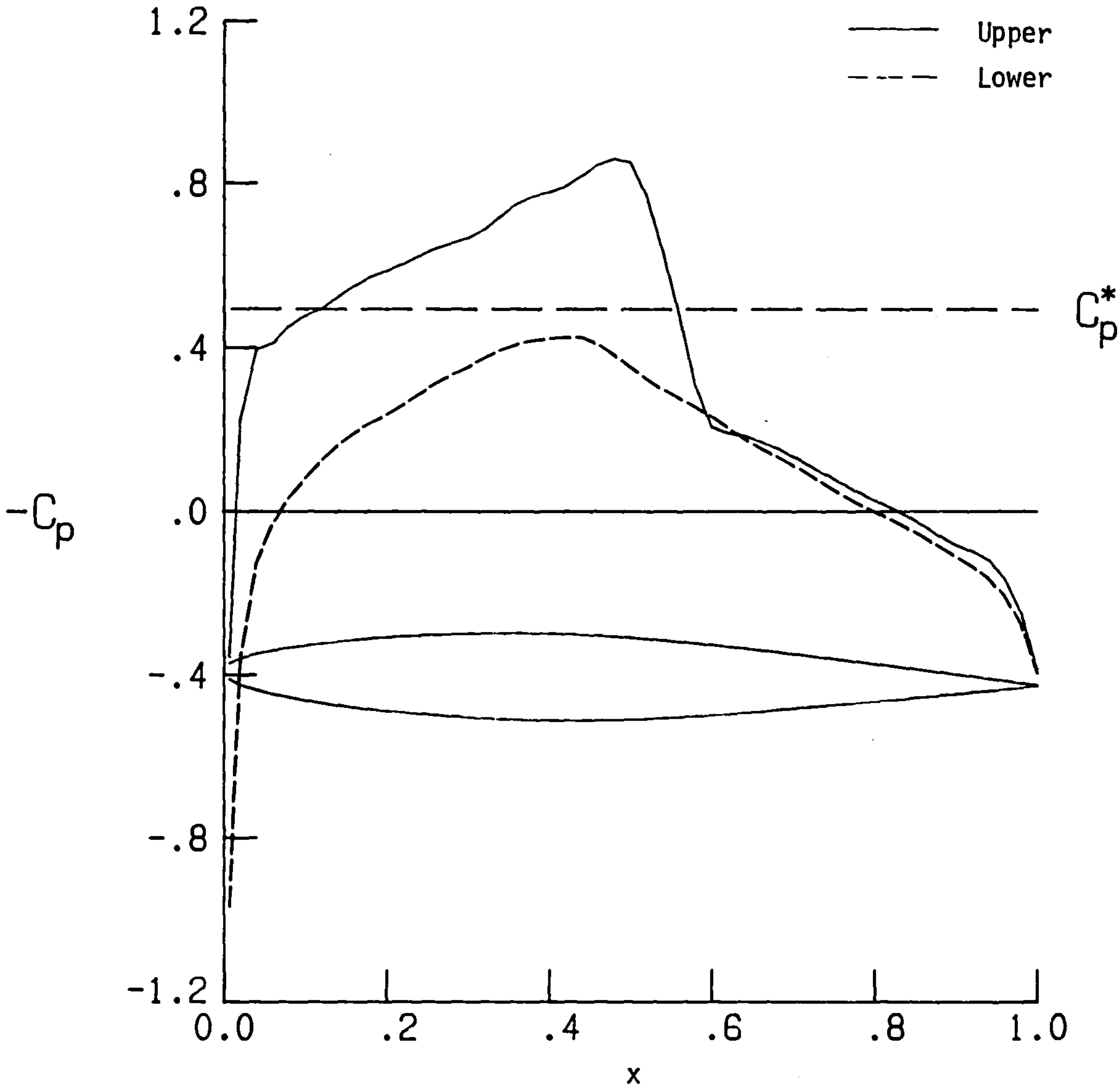

(a) Four cycles of simple harmonic pitching motion about the quarter-chord.

Fig. 6 Results from unsteady calculations due to harmonic pitching motion (IRESP = 0) for the NACA 64A010A airfoil at $M_\infty = 0.78$, $\alpha_0 = 1.0°$, $k = 0.075$, and $\alpha_1 = 0.5°$;



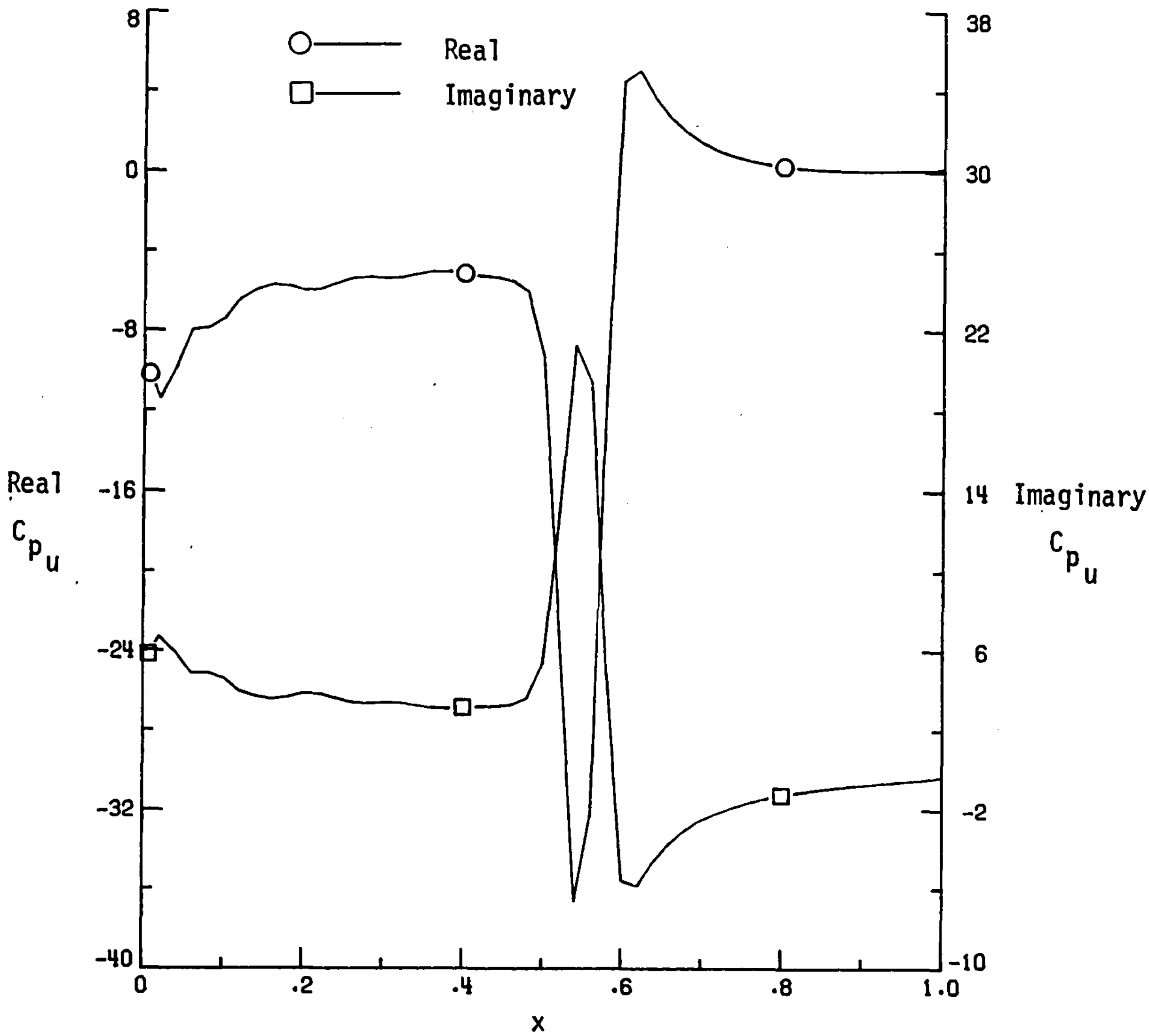

(b) Resulting normal force coefficient, pitching moment coefficient, and reference sine wave.

Fig. 6 Continued.



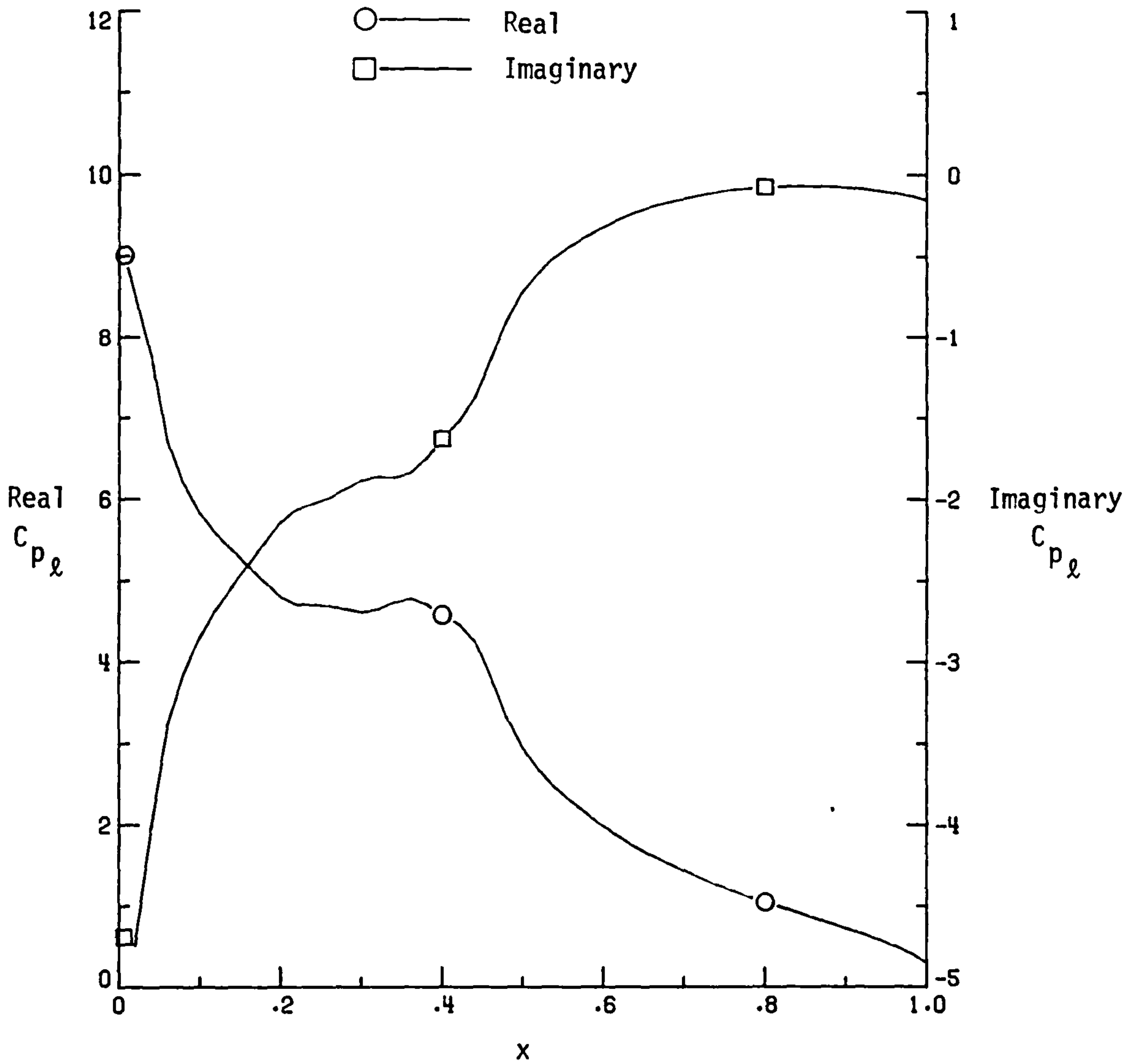

(c) Mean pressure distributions.

Fig. 6 Continued.



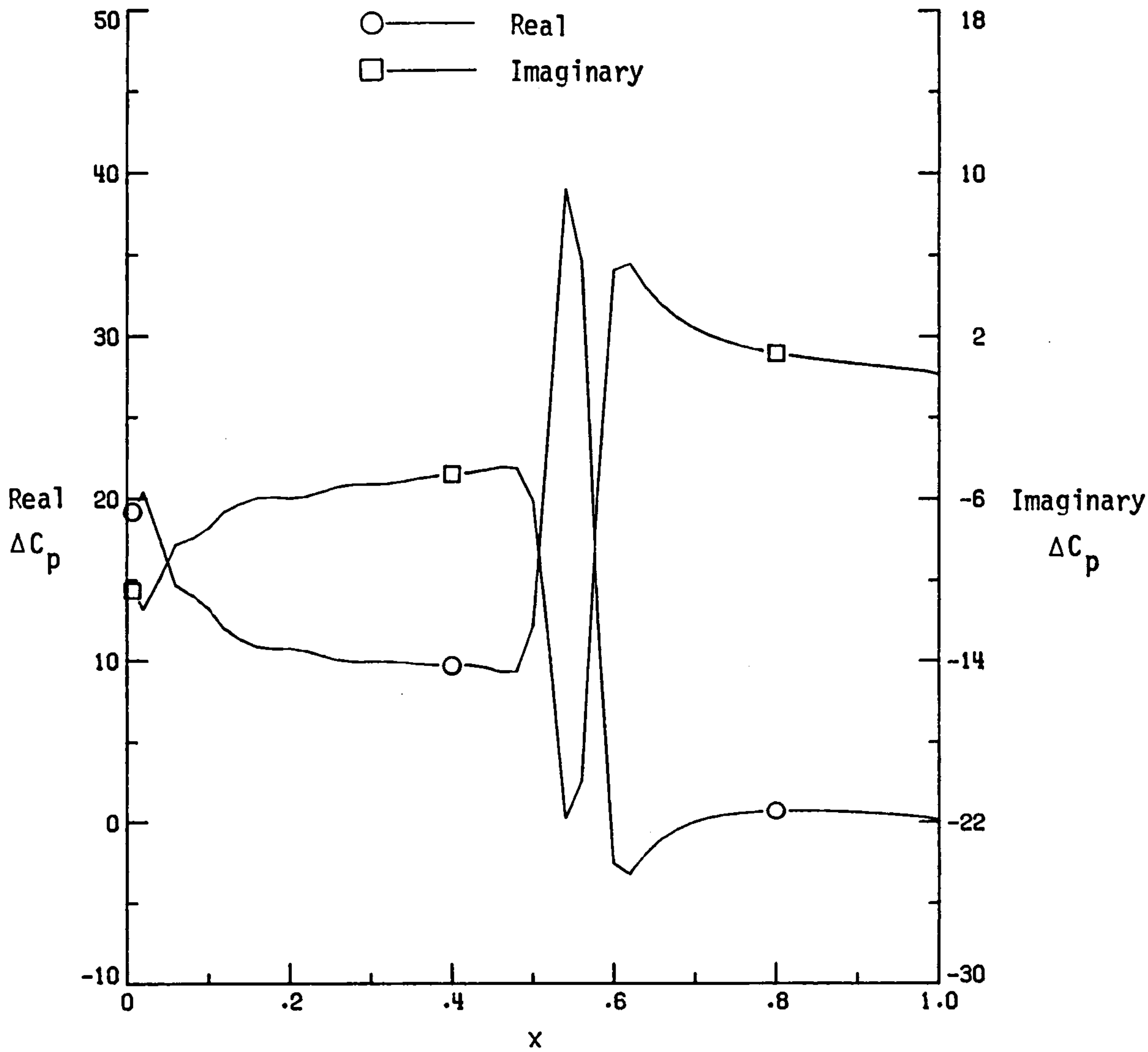

(d) Real and imaginary components of the upper surface pressure coefficient.

Fig. 6 Continued.



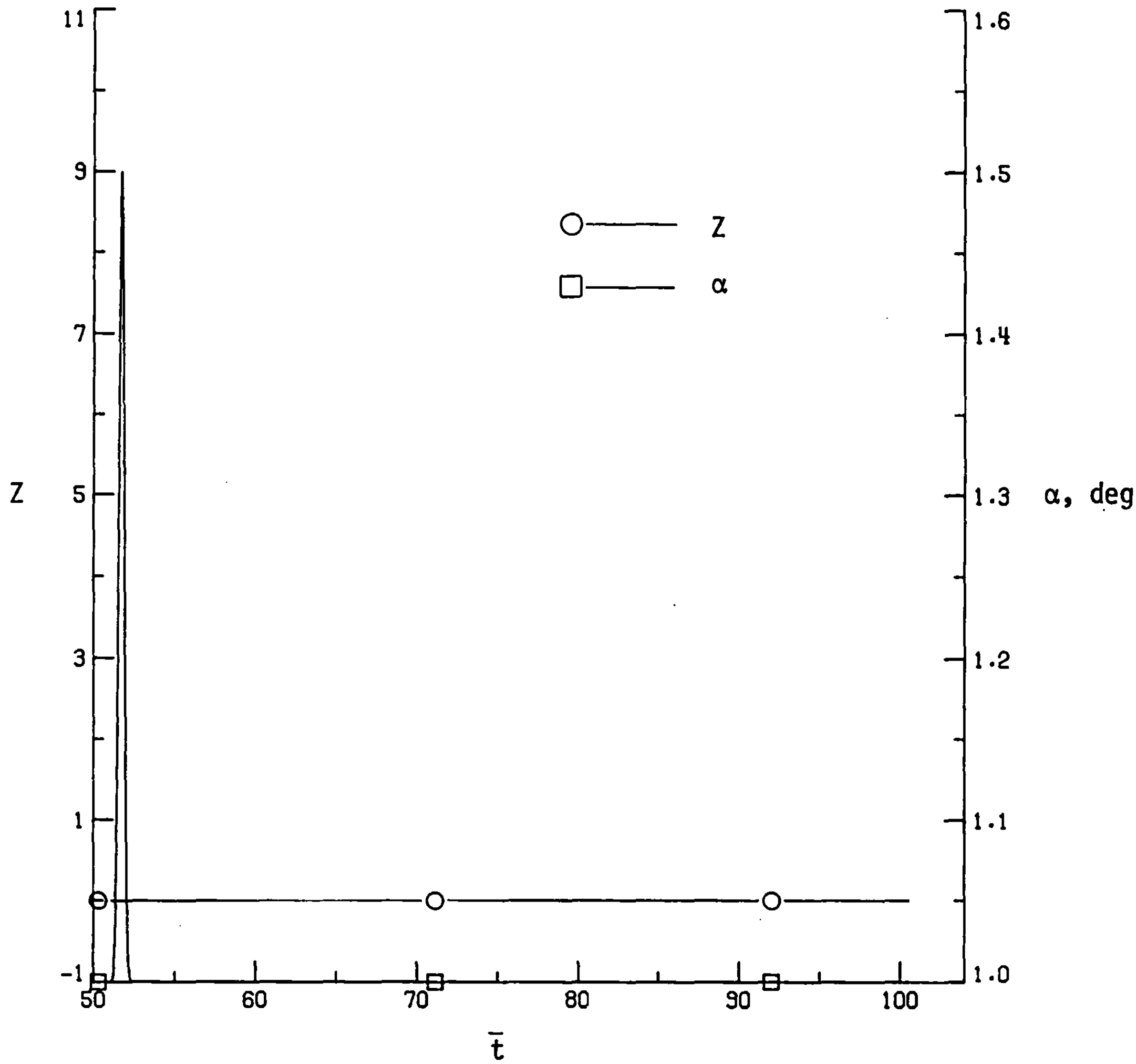

(e) Real and imaginary components of the lower surface pressure coefficent.

Fig. 6 Continued.



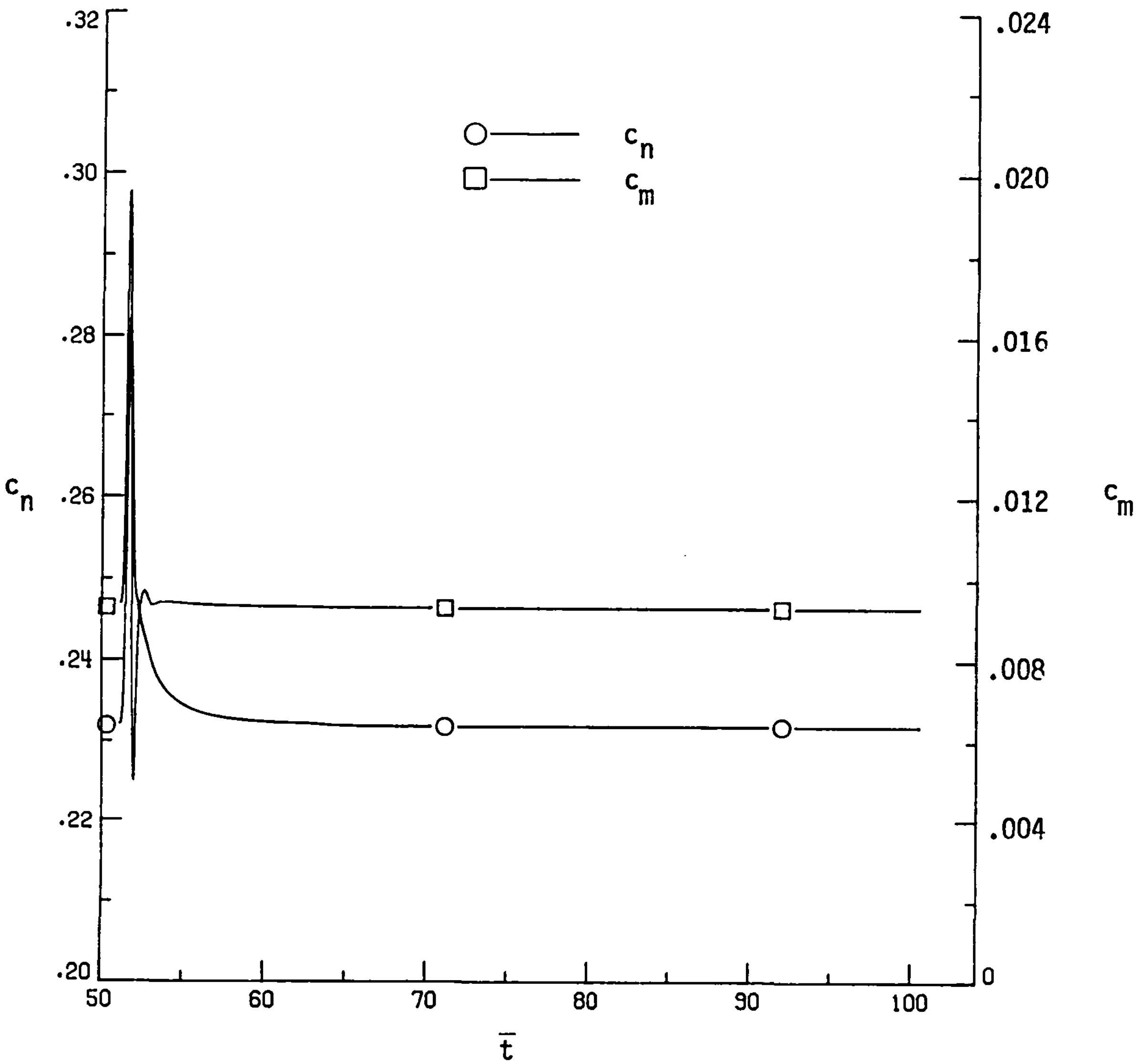

(f) Real and imaginary components of the lifting pressure coefficient.

Fig. 6 Concluded.



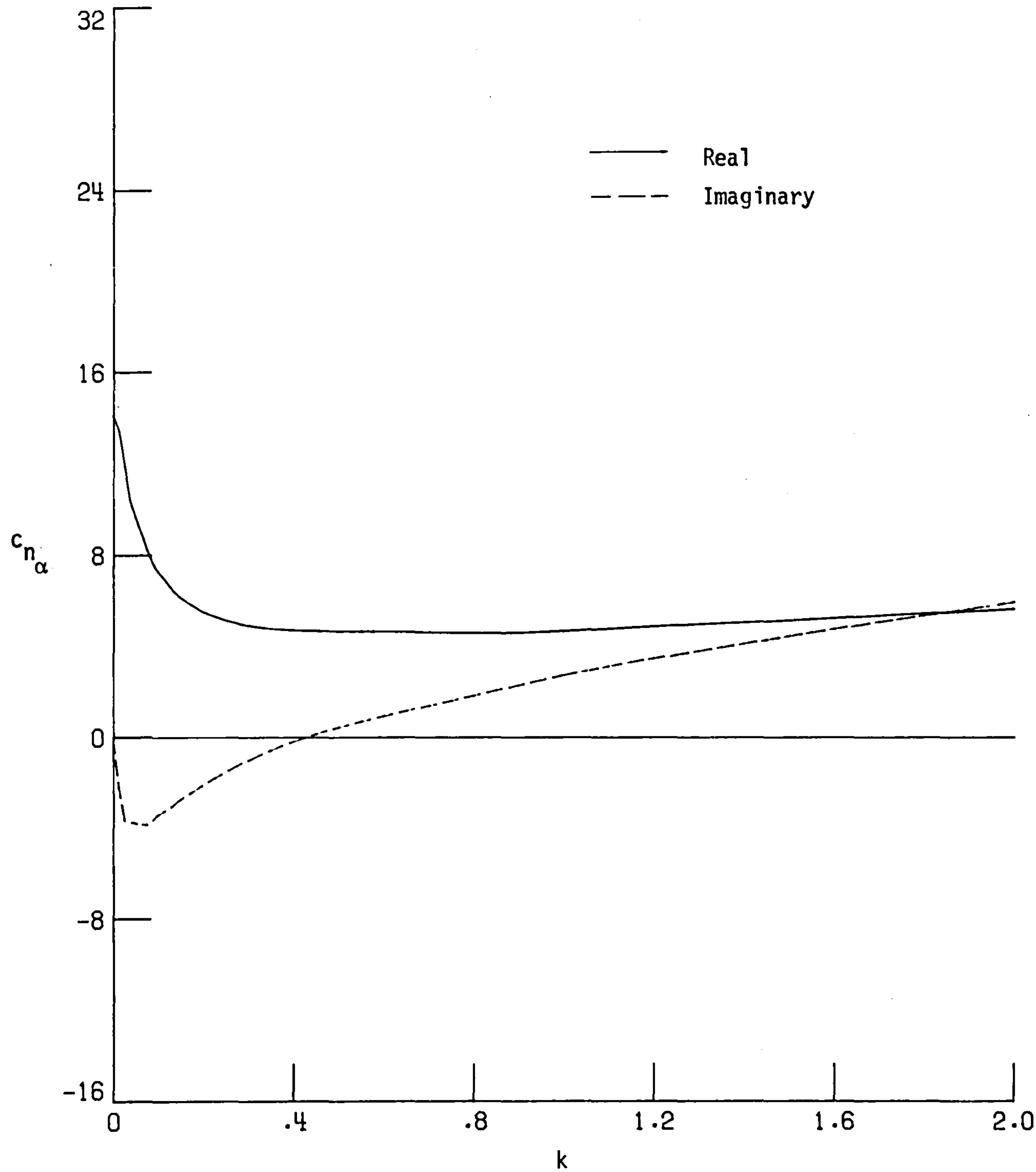

(a) Pitch pulse input.

Fig. 7 Results from unsteady calculations due to pitch pulse (IRESP = 3) for the NACA 64A010A airfoil at $M_\infty = 0.78$ and $\alpha_0 = 1.0°$;



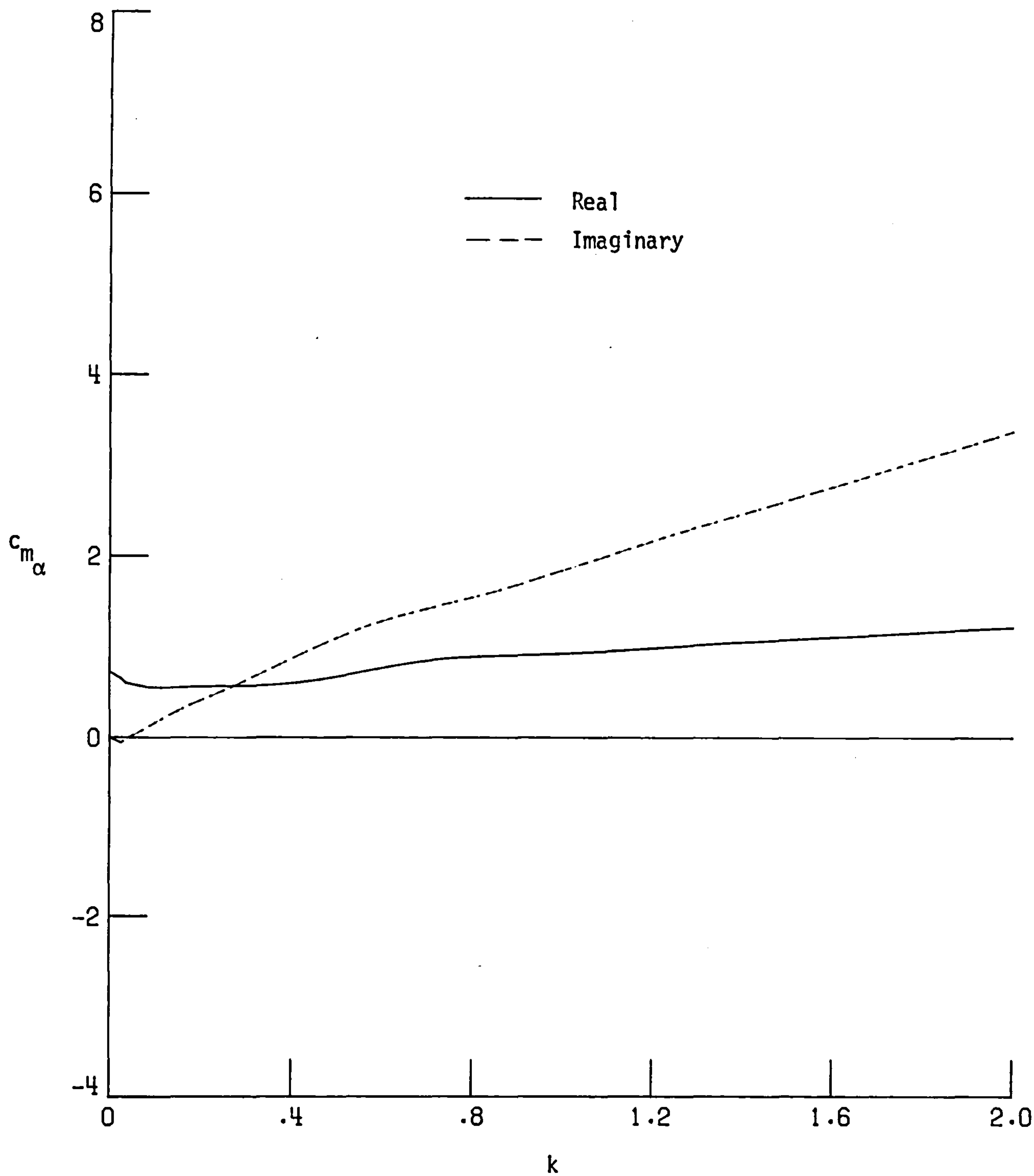

(b) Resulting normal force coefficient and pitching moment coefficient responses.

Fig. 7 Continued.



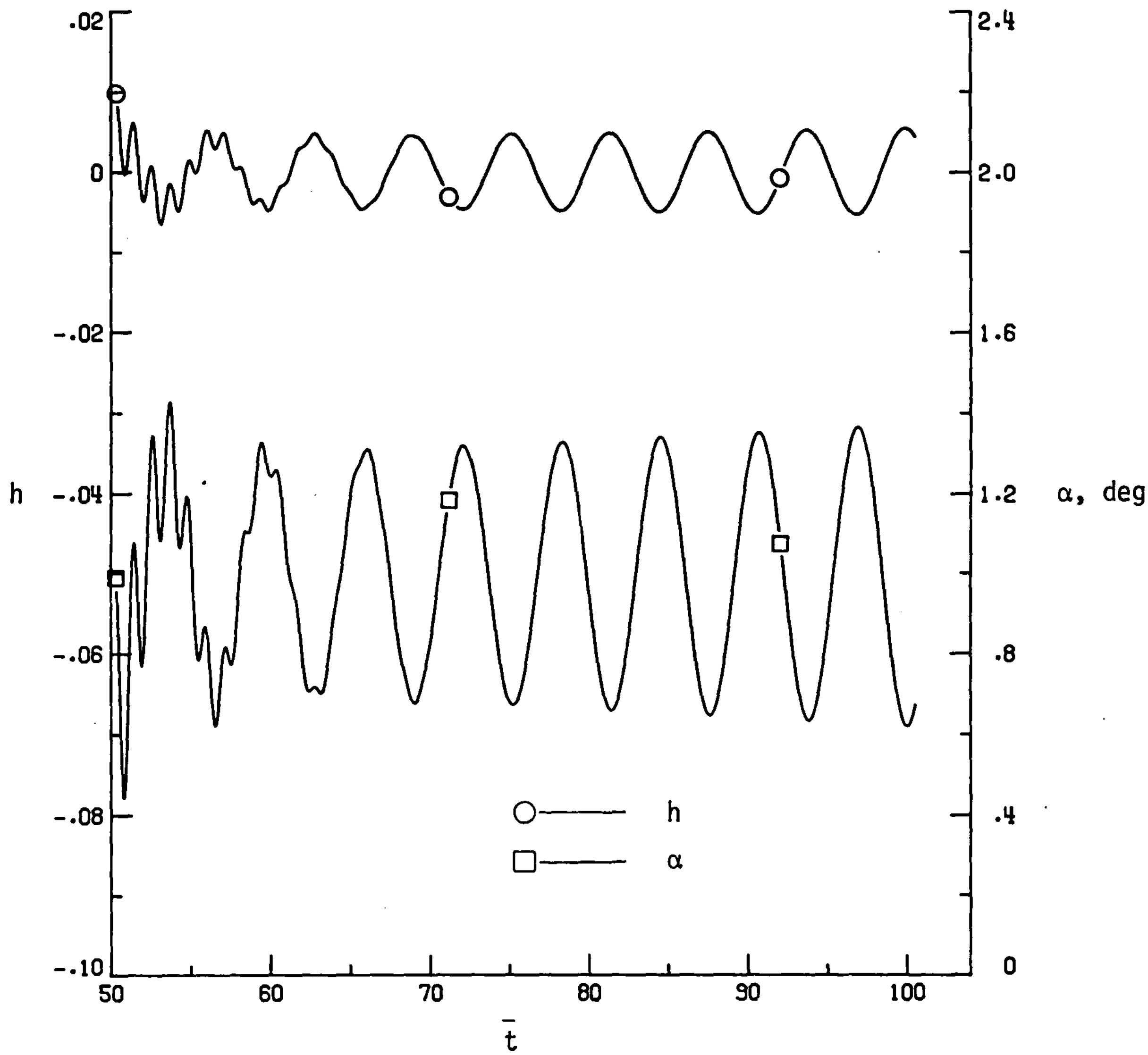

(c) Normal force coefficient due to pitching as a function of reduced frequency k.

Fig. 7 Continued.



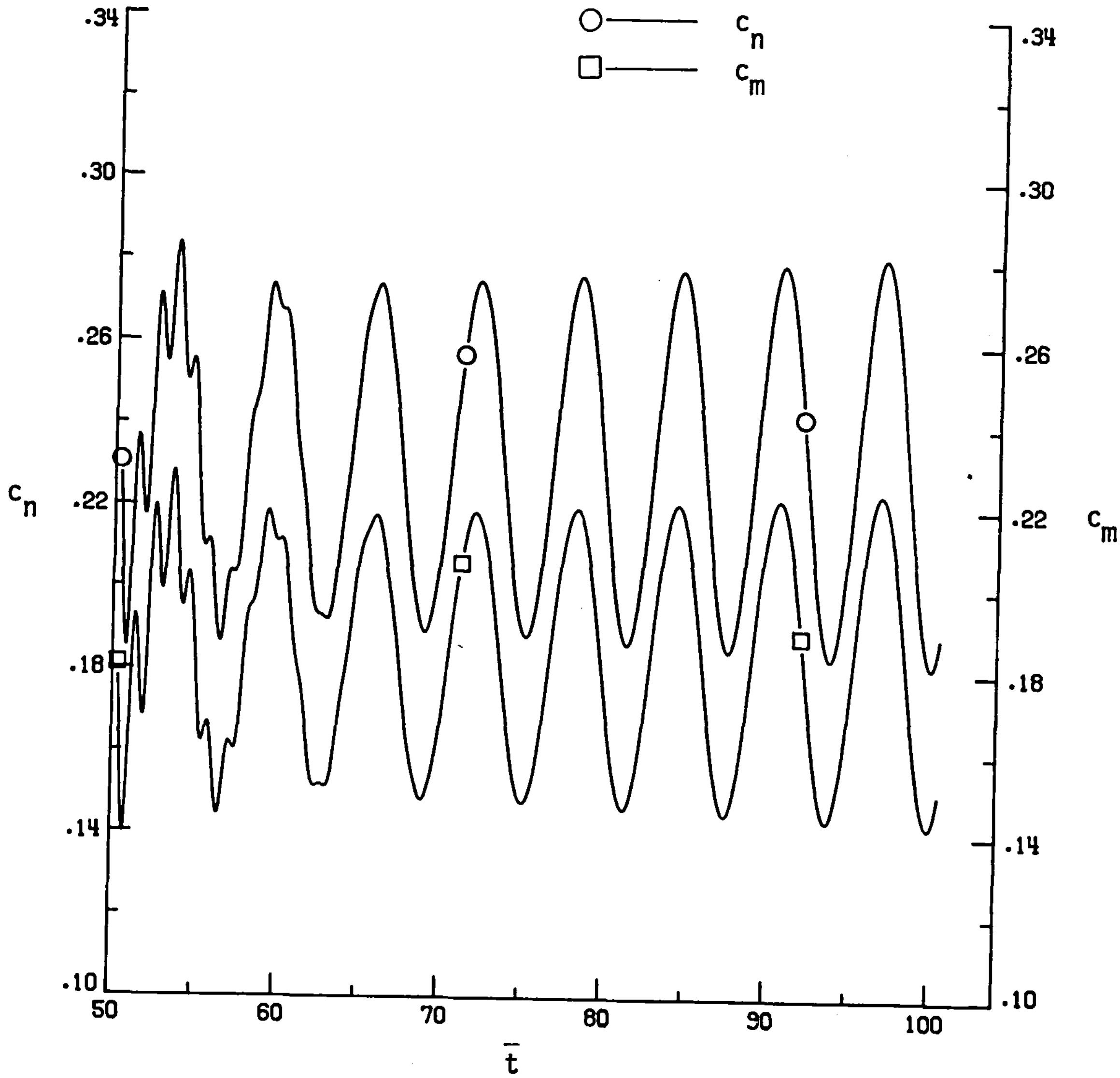

(d) Pitching moment coefficient due to pitching as a function of reduced frequency k.

Fig. 7 Concluded.




(a) Pitch and plunge aeroelastic transients.

Fig. 8 Results from unsteady calculations for aeroelastic motion (IRESP = 1) for the NACA 64A010A airfoil at $M_\infty = 0.78$, $\alpha_0 = 1.0°$, and $U/c = 330.0$;




(b) Normal force coefficient and pitching moment coefficient aeroelastic transients.

Fig. 8 Concluded.

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4. Title and Subtitle
USER'S MANUAL FOR XTRAN2L (VERSION 1.2): A PROGRAM FOR SOLVING THE GENERAL-FREQUENCY UNSTEADY TRANSONIC SMALL-DISTURBANCE EQUATION

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16. Abstract


The development, use, and operation of the XTRAN2L program that solves the two-dimensional unsteady transonic small-disturbance potential equation are described. The XTRAN2L program is used to calculate steady and unsteady transonic flow fields about airfoils and is capable of performing self-contained transonic flutter calculations. Operation of the XTRAN2L code is described, and tables defining all input variables, including default values, are presented. Sample cases that use various program options are shown to illustrate operation of XTRAN2L. Computer listings containing input and selected output are included as an aid to the user.


| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
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