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A DIGITAL COMPUTER PROGRAM FOR EXTRACTING AERODYNAMIC COEFFICIENTS FROM SIX-DEGREE-OF-FREEDOM DYNAMIC DATA

UNIVERSITY OF FLORIDA

TECHNICAL REPORT AFATL-TR-73-221

NOVEMBER 1973

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AIR FORCE ARMAMENT LABORATORY

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EGLIN AIR FORCE BASE, FLORIDA
A Digital Computer Program For Extracting Aerodynamic Coefficients From Six-Degree-Of-Freedom Dynamic Data

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M. H. Clarkson
T. E. Bullock
FOREWORD

This analysis was conducted by the University of Florida, Gainesville, Florida, under Contract F08635-73-C-0009, with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. The effort was conducted during the period March 1972 to March 1973. Dr. George B. Findley (DLMA) was program manager for the Armament Laboratory. This work was partially supported by the Air Force Office of Scientific Research (AFOSR) under its project 9871.

The principal investigators for the University of Florida were Drs. T. E. Bullock and M. H. Clarkson.

This technical report has been reviewed and is approved.

RICHARD M. KELLER, Colonel, USAF
Chief, Air-to-Surface Modular Guided Weapons Division
ABSTRACT

The development of a digital computer program to extract aero-
dynamic coefficients from dynamic data for six-degree-of-freedom
systems is presented. The derivation of a system mathematical model
is discussed in detail. Results and associated problems of extracting
coefficients from one-, two-, three-,and six-degree-of-freedom systems
data are also presented.

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SECTION 1
INTRODUCTION

Early methods of extracting aerodynamic coefficients from dynamic data required assumptions and limitations so that the equations of motion could be solved in closed form. Therefore, usually only linear aerodynamics were considered. As a result, the range of motions and the number of coefficients extracted were severely limited.

The method of extracting coefficients by means of parametric differentiation developed by Chapman and Kirk(1) is not restricted by the requirement of linear aerodynamics. In this report the method of parametric differentiation is used to develop a six-degree-of-freedom digital computer program to extract aerodynamic coefficients from free flight data. The program is an extension of the one- and three-degree-of-freedom programs of Daniel and Bullock(2), respectively, and draws on their experience in developing those programs.

The equations of motion for the six-degree-of-freedom mathematical model were developed so that the aerodynamic coefficients presented by Holmes(3) may be used. The model, which is intended for use in an aero-ballistic wind tunnel range, uses a fixed plane axis system to represent the angular orientation of the body with respect to a tunnel fixed axis system. By definition, the fixed plane axes are free to pitch and yaw with the body but do not roll with the body. The relationship between the axis systems is depicted in the diagram below.

![Diagram of axis systems]

- \( (\ )_T \) Tunnel Fixed axes
- \( (\ )_B \) Fixed plane axes
- \( (\ )_B \) Body fixed axes
SECTION II
EQUATIONS OF MOTION

The derivation of the equations of motion for the six-degree-of-freedom model used in the program assumes that the missile is regarded as a rigid axisymmetric body moving with velocity \( V_T \) relative to a wind tunnel axis system. In addition, the body fixed axes are chosen to coincide with the principal axes of the missile.

The equations for translational and angular motion, based on Newton's second law, may be written as

\[
m \frac{d}{dt} \vec{V}_T = \vec{F}_T \tag{1}
\]

and

\[
\frac{d\vec{h}}{dt} + \omega_{FP} \times \vec{h} = \vec{M}_{FP} \tag{2}
\]

where:  
\( \vec{F}_T \) is the resultant external force.  
\( \omega_{FP} \) is the angular velocity of the fixed plane axes with respect to the tunnel fixed axes.  
\( \vec{h} \) is the moment of momentum.  
\( \vec{M}_{FP} \) is the resultant external moment.

The equations of motion above provide a form suitable for fitting to the data. First, however, it is necessary to define the orientation of the fixed plane axes with respect to the aerodynamic data axes, which contain the cameras that recorded the motion and position of the body during flight, and then to define the tunnel axes (assumed inertial) with respect to the fixed plane axes.

Choosing the body fixed axes to lie along the principal axes of the missile results in the products of inertia being zero. Thus, the angular momentum vector may be expressed in terms of the angular velocity and the moments of inertia.

\[
h = h_x \hat{i} + h_y \hat{j} + h_z \hat{k} = I_x \omega_x \hat{i} + I_y \omega_y \hat{j} + I_z \omega_z \hat{k} \tag{3}
\]
Recalling the relationship between the fixed plane axes and the body fixed axes, equation (2) may be written in component form

\[ \begin{align*}
I_{xx} \dot{\omega}_x + \omega_y \omega_z &= M_x \\
I_{yy} \dot{\omega}_y + \omega_x \omega_z &= M_y \\
I_{zz} \dot{\omega}_z + \omega_x \omega_y &= M_z
\end{align*} \]  

(4)

Recalling that the body fixed axes were principal axes implies that

\[ I_x = I_y = I_z \]  

(5)

Now expressing the angular velocity components of the fixed plane axes in terms of the Euler angles yields

\[ \begin{align*}
\omega_x^{FP} &= -\dot{\psi} \sin \theta - \dot{\phi} \\
\omega_y^{FP} &= \dot{\theta} \\
\omega_z^{FP} &= \dot{\psi} \cos \theta
\end{align*} \]  

(6)

and the angular velocity components of the body fixed axes are

\[ \begin{align*}
\omega_x &= \dot{\phi} - \dot{\psi} \sin \theta \\
\omega_y &= \dot{\theta} \\
\omega_z &= \dot{\psi} \cos \theta
\end{align*} \]  

(7)

which have time derivatives

\[ \begin{align*}
\ddot{\omega}_x &= \ddot{\phi} - \dot{\psi} \sin \theta - \dot{\theta} \dot{\psi} \cos \theta \\
\ddot{\omega}_y &= \ddot{\theta} \\
\ddot{\omega}_z &= \ddot{\psi} \cos \theta - \dot{\theta} \dot{\psi} \sin \theta
\end{align*} \]  

(8)
Now applying equations (5), (6), (7) and (8) to the first of equation (4) results in

\[ \text{I_x} \left[ \ddot{\phi} - \ddot{\psi} \sin \theta - \dot{\psi} \dot{\phi} \cos \theta \right] = M_{x_{FP}} \quad (9) \]

Similarly the second of equations (4) becomes

\[ \ddot{\theta} + \ddot{\psi} \cos \theta \text{I_x} \left[ \dot{\phi} - \dot{\psi} \sin \theta \right] + \dot{\psi} \sin \theta \text{I_x} \dot{\phi} \cos \theta = M_{y_{FP}} \quad (10) \]

Rearranging terms yields

\[ \ddot{\theta} + \ddot{\psi} \cos \theta \left[ \text{I_x} \dot{p} + \text{I} \dot{\psi} \sin \theta \right] = M_{y_{FP}} \quad (11) \]

or

\[ \ddot{\theta} + \left[ \frac{\text{I_x} \dot{p}}{\text{I}} + \dot{\psi} \sin \theta \right] \ddot{\psi} \cos \theta = \frac{M_{y_{FP}}}{\text{I}} \quad (12) \]

Now operating in the same manner on the third of equations (4) yields

\[ \text{I} \left[ \ddot{\psi} \cos \theta - \ddot{\phi} \sin \theta \right] - \ddot{\psi} \sin \theta \text{I}_x \left[ \dot{\phi} - \dot{\psi} \sin \theta \right] = M_{z_{FP}} \quad (13) \]

Rearranging terms yields

\[ \text{I} \left[ \ddot{\psi} \cos \theta - \ddot{\phi} \sin \theta \right] - \dot{\psi} \left[ \text{p I}_x + \text{I} \dot{\psi} \sin \theta \right] = M_{z_{FP}} \quad (14) \]

or

\[ \ddot{\psi} \cos \theta - \left[ \text{p I}_x + 2 \dot{\psi} \sin \theta \right] \dot{\theta} = \frac{M_{z_{FP}}}{\text{I}} \quad (15) \]

Consider, now, equation (1) for translational motion. It may be written, directly, in component form as

\[ \begin{align*}
\ddot{x} &= \frac{F_{x_T}}{m} \\
\ddot{y} &= \frac{F_{y_T}}{m} \\
\ddot{z} &= \frac{F_{z_T}}{m}
\end{align*} \quad (16) \]
The definitions of the resultant aerodynamic forces above and the resultant aerodynamic moments were represented in terms of resultant aerodynamic force and moment coefficients, $C_x$, $C_y$, $C_z$ and $C_L$, $C_M$, $C_N$ which lie along the aerodynamic data axes. For the translational equations of motion it was first necessary to prescribe how the components of each aerodynamic coefficient along the tunnel fixed axes would be determined in terms of the fixed plane axes. Then for all of the equations of motion it was necessary to transform the components along the fixed plane axes in terms of the aerodynamic axes. The transformations for the translational equations of motion were:

\[
L(\psi) = \begin{bmatrix}
\cos \psi & -\sin \psi & 0 \\
\sin \psi & \cos \psi & 0 \\
0 & 0 & 1
\end{bmatrix}
\]  \hspace{1cm} (17)

\[
L(\theta) = \begin{bmatrix}
\cos \theta & 0 & \sin \theta \\
0 & 1 & 0 \\
-\sin \theta & 0 & \cos \theta
\end{bmatrix}
\]  \hspace{1cm} (18)

\[
L(\phi) = \begin{bmatrix}
1 & 0 & 0 \\
0 & \cos \phi & \sin \phi \\
0 & -\sin \phi & \cos \phi
\end{bmatrix}
\]  \hspace{1cm} (19)

The first and second transformations are straightforward transformations through the Euler angles $\psi$ and $\theta$ from the tunnel fixed axes to the fixed plane axes. The third transformation is the transformation of the coefficients in terms of the fixed plane axes to the coefficients in terms of the aerodynamic data axes. The application of the transformation matrices yields the equations:

\[
\begin{bmatrix}
\ddot{x}_T \\
\ddot{y}_T \\
\ddot{z}_T + g
\end{bmatrix} = \frac{QA}{m} \begin{bmatrix} L(\psi) & L(\theta) & L(\phi) \end{bmatrix} \begin{bmatrix}
C_x \\
C_y \\
C_z
\end{bmatrix}
\]  \hspace{1cm} (20)
or, in expanded form,

\[
\begin{align*}
\ddot{X}_T &= \frac{QA}{m} \left\{ C_X (\cos \theta \cos \psi) - C_Y (\sin \psi \cos \phi + \\
&\quad \sin \theta \cos \psi \sin \hat{\psi}) - C (\sin \psi \sin \hat{\phi} - \\
&\quad \sin \theta \cos \psi \cos \hat{\phi}) \right\} \\
\ddot{Y}_T &= \frac{QA}{m} \left\{ C_X (\cos \theta \sin \psi) + C_Y (\cos \psi \cos \phi - \\
&\quad \sin \theta \sin \psi \sin \hat{\psi}) + C_Z (\cos \psi \sin \hat{\phi} + \\
&\quad \sin \theta \sin \psi \cos \hat{\phi}) \right\} \\
\ddot{Z}_T &= \frac{QA}{m} \left\{ C_X (-\sin \theta) - C_Y (\cos \theta \sin \hat{\psi}) + \\
&\quad C_Z (\cos \theta \cos \hat{\phi}) \right\} - g
\end{align*}
\]

Before arriving at the final form of the angular equations of motion a transformation to obtain the components of the coefficients along the aerodynamic axes employing the third transformation, equation (19), must be carried out. The resulting equations are

\[
\begin{bmatrix}
M_X \\
M_Y \\
M_Z
\end{bmatrix} = \text{QAd} \begin{bmatrix}
C_L \\
C_M \\
C_N
\end{bmatrix}
\]

or, in expanded form,

\[
\psi = \left\{ \left( p \frac{I_x}{I} + 2 \psi \sin \theta \right) \hat{\theta} + \frac{\text{QAd}}{I} (C_N \cos \hat{\phi} - C_M \sin \hat{\psi} + \\
C_M \left( \frac{\psi_d}{2\sqrt{V_A}} \right) \cos \theta \right\} \frac{1}{\cos \theta}
\]
\[
\dot{\theta} = - \left( I_x \frac{d}{dt} + \dot{\psi} \sin \theta \right) \dot{\psi} \cos \theta + \frac{Q \dot{A}}{I} \left( C_M \cos \phi + C_N \sin \phi + C_{MD} \left( \frac{\delta d}{2V_A} \right) \right)
\]

\[
\ddot{\phi} = \sin \theta \dot{\psi} + \dot{\psi} \cos \theta + \frac{Q \dot{A}}{I} \left( C_L \right)
\]

The resultant coefficients in the equations of motion are defined in the following fashion:

\[
C_x = C_{x_0} + C_{x_2} \dot{a}^2
\]

\[
C_y = (C_{y_2} \dot{a} + C_{y_3} \dot{a}^3) \sin (N \cdot \phi) + (C_{y_{ap}} \dot{a} + C_{y_{ap}^3} \dot{a}^3) \left( \frac{\delta d}{2V_A} \right)
\]

\[
C_z = C_{z_3} \dot{a} + C_{z_3} \dot{a}^3
\]

\[
C_L = (C_{k_{a}} \dot{a} + C_{k_{ap}} \dot{a}^3) \sin (N \cdot \phi) + C_{k_{ap}} \left( \frac{\delta d}{2V_A} \right)
\]

\[
C_M = C_{M_{a}} \dot{a} + C_{M_{ap}} \dot{a}^3
\]

\[
C_{MD} = C_{M_{2}q_{a}} + C_{M_{a}q_{a}} \dot{a}^2
\]

\[
C_N = (C_{n_{a}} \dot{a} + C_{n_{ap}} \dot{a}^3) \sin (N \cdot \phi) + (C_{n_{ap}} \dot{a} + C_{n_{ap}} \dot{a}^3) \left( \frac{\delta d}{2V_A} \right)
\]

Individual coefficients are defined in the list of symbols.

In order to avoid ambiguities which might occur, the Euler angles \( \psi, \theta \) and \( \phi \) are limited to the following ranges:

\[-\pi < \psi < \pi\]

\[-\frac{\pi}{2} < \theta < \frac{\pi}{2}\]

\[0 < \phi < 2\pi\]
For non-planar motion, that is, pitching and yawing motions occurring simultaneously, the limits on the ranges of the Euler angles $\psi$ and $\theta$ should be

$$-\frac{\pi}{6} < \psi < \frac{\pi}{6}$$

$$-\frac{\pi}{6} < \theta < \frac{\pi}{6}$$

to obtain reasonable accuracy of the coefficients extracted without an excessive number of iterations.
SECTION III

METHOD OF EXTRACTING COEFFICIENTS
AND DESCRIPTION OF THE COMPUTER PROGRAM

1. Chapman and Kirk Coefficient Extraction Method

The value of using parametric influence coefficients in the analysis of dynamic systems has been recognized for some time. The following briefly describes the general scheme developed by Chapman and Kirk to use the method of parametric influence coefficients for determining aerodynamic coefficients. A more detailed presentation of the theory is given in references 1 and 2.

The basis of the method is the minimization of the deviations of a set of experimental data from a calculated motion. The system model that yields the calculated motion is given by the set of differential equations

\[ x(t) = f(x,C,t) , \quad x(0) = a \]  

(29)

where \( x(t) \) is an \((n \times 1)\) state vector, \( f \) is the \((n \times 1)\) vector-valued function, and \( a \) is the \((n \times 1)\) vector of initial conditions. The set of experimental data, \( z(t) \), are the components of the state vector. Assuming that \( x(t) \) is measured for \( 0 \leq t \leq \tau \), then it is desired to find the parameters \( C \) which minimize the expression

\[ \text{MSQE} = \frac{1}{\tau} \int_{0}^{\tau} \left\{ \sum_{i=1}^{n} (x(t) - z(t))^{2} \right\} Q_{w}(t) \, dt \]  

(30)

where \( z(t) \) are the experimental data corresponding to the calculated motion of the state vector \( x(t) \) and \( Q_{w}(t) \) is an \((n \times n)\) weighting matrix whose purpose is to give weight, or value, to only those components of the state vector \( x(t) \) for which measured experimental data are available.

The method used to determine the parameters \( C \) that satisfy equation (30) was an iterative one. For each iteration a calculated motion and a corresponding mean square error (MSQE) was determined. If the change in the root of the mean square error was not less than a predetermined value, the parameters \( C \) were updated, or corrected, toward that end. This was accomplished by integrating the set of equations obtained by taking the partial derivatives of each of the equations of motion with respect to the parameters of interest. These will be referred to as parametric differential equations in this paper. The solutions of the parametric differential equations, parameter influence coefficients, were then used to construct the \((p \times p)\) matrix of what will be referred to as parametric influence coefficients.
For example, if there were 4 initial conditions and 6 coefficients, or 10 parameters of interest, sixty second order parametric differential equations were integrated to obtain the 10 x 10 matrix of parametric influence coefficients. Simultaneously, the gradient

\[
A_{jk} = \sum_{i=1}^{NPTS} \left( \frac{\partial f}{\partial C_j} \right)_i \left( \frac{\partial f}{\partial C_k} \right)_i Q_w(t)
\]  

was obtained. Then the p x 1 matrix of parameter corrections, \( \Delta C \), was found by

\[
[\Delta C] = [A]^{-1} [B]
\]

The parameters for the next, or \( \ell + 1 \), iteration were

\[
[C]_{\ell+1} = [C]_\ell + [\Delta C]_\ell
\]

Once the parameters were corrected, a new calculated motion was determined by integrating the equations of motion. The entire process was repeated until the predetermined value for the change of the root of the mean square error was satisfied, and the process was said to have converged, or the maximum number of iterations allowed was exceeded and the program was terminated.

2. Development of the Program

The program is written in Fortran IV for use primarily on an IBM 360/65 or 370/165 computer. The program provides the user with three general options:

1. Flight simulation
2. Coefficient extraction
3. Flight simulation with punched output of state vector component time histories.

The paragraphs that follow describe the functions of the main program, its subroutines, and the program options. A flow chart and a complete listing of the program and the required data input form are given in the appendices.
The function of the main program is to control the flow of the program in accordance with the options chosen. To do this, the main program reads and writes all input and output information, organizes the information, and calls the subroutines to use it. The main program does all of the calculations necessary to determine if convergence has been achieved and all of the calculations preparing for each iteration.

Subroutine ADDUM integrates the equations of motion and the parametric differential equations. The numerical method used is a fourth order Runge-Kutta starter solution and a fourth order Adams-Bashforth predictor-corrector method for integrating. This subroutine is described in detail in reference 5.

Subroutine XDOT1 computes current values of the derivatives of the set of first order equations to which the equations of motion have been reduced as required by ADDUM. The subroutine also computes the value of the derivative of the mean square error, which is integrated simultaneously with the equations of motion by ADDUM when the coefficient extraction option is specified.

Subroutine OUT1 stores the results of the numerically integrated equations of motion during each iteration until convergence is tested.

Subroutine XDOT2 computes current values of the derivatives of the set of first order equations to which the parametric differential equations have been reduced as required by ADDUM.

Subroutine OUT2 calculates the elements of the parametric influence coefficient matrix, [A], and the state vector difference matrix, [B], for use in the main program.

Subroutine MINV inverts the p x p matrix of parametric influence coefficients using a standard Gauss-Jordan method and is described in detail in reference 6.

Subroutine PLOT9 is a printer-plotter routine intended to give the program user a visual understanding of the angular orientation of the missile as calculated by the equations of motion.

The amount of input data required by the program is determined by the program option chosen. The specific data in each option are delineated in the following paragraphs. The formats and units of entries on specific data cards may be found in Appendix III.

(1) Flight simulation
    (a) Program control codes

These integer constants tell the program which program options are in effect and which equations of motion are to have values computed for
their derivatives in XD0T1. The integrated values of all other equations of motion are set to zero. The purpose of allowing the program user to specify the equations of motion that will have nonzero-integrated values is to avoid unnecessary computation, thus reducing execution time.

(b) Integration constants

The integration constants include the numerical integration step size, frequency of storage of integrated values, time at which integration is to stop, initial time, YES or NO codes to specify printer plots of each of the three angular motions, and the number of fins on the missile. The number of fins choice allows the user to specify a four-finned missile or an unfinned projectile.

(c) Aerodynamic and physical constants

The aerodynamic constants are air density and the free stream velocity that are specified during the flight simulation. The physical constants are the body cross-sectional area (neglecting fins), body diameter or equivalent, spin rate of the body at time zero, gravitational acceleration due to the earth, moment of inertia about the longitudinal axis, moment of inertia about the axes normal to the pitch and yaw planes, and mass of the body.

(d) Aerodynamic coefficients

For flight simulation the aerodynamic coefficients values are constant and are not altered by the program.

(e) Initial conditions

These values are the initial conditions for the equations of motion. Like the aerodynamic coefficients, they are constant and are not altered by the program.

(f) Printer plotter constants

These constants are required only if the plot option was specified in the integration constants. The constants are the width of the plot, value of the initial point, type of plot, field type for the data point values printed, and a scale factor.

(2) Coefficient extraction

(a) Output labels

These labels allow the program to identify the extracted values and the estimated standard deviations with appropriate labels.

(b) Program control codes
In addition to those listed for flight simulation, there are constants to specify initial conditions and aerodynamic coefficients to be adjusted, values for the weight factors in equation (30), maximum number of iterations allowed, and convergence tolerance before the iteration process is automatically terminated.

(c) Data

The initial condition and coefficient values input are now guesses and not constant values. In addition, values for the experimental data points of the state vector components must also be read.

(3) Flight simulation with punched output

The input for this option differs from the flight simulation only in the addition of a program control code to specify which state vector components are to be punched on cards.
Eleven test cases of the program were run to check its operation. The test cases began with a one-degree-of-freedom case and were increased to a six-degree-of-freedom case. In all but two cases, the initial conditions and aerodynamic coefficients used to generate the data for the extraction program were known. This provided the easiest method for checking the validity of extracted initial conditions and coefficients. In the two cases where initial conditions and coefficients were not known, the extracted values were compared with those obtained from the same data by Daniel using UFPLANAR. The reason for investigating these two cases was to check the capability of the program to handle noisy data. The noise was simulated by random measurement errors in UFNOISE(2). A table of the results of the eleven cases may be found in Appendix IV.

The two cases with noisy data considered one-degree-of-freedom cases with linear and non-linear static restoring moment and pitch damping coefficients. As intuition would lead one to expect, the estimated standard deviations of the values extracted from noisy data were much larger than the standard deviations of the values extracted from data without noise. The standard deviations of the values extracted from data without noise were essentially zero, as they should have been, since the data were generated from the same equations of motion. However, the important result was that the number of iterations required for convergence was the same for both types of cases. This is very desirable from a computing standpoint because free flight test data will most certainly be noisy.

As stated previously in Chapter II, the mathematical model of the missile was restricted to low angles of attack for multiangular degree of freedom cases. In order to quantitatively demonstrate the necessity for this restriction, two cases were run with initial pitch and yaw angles both equal to 20 degrees in the first case and 30 degrees in the second. The 20-degree case required a reasonable six iterations to extract initial conditions and coefficients. On the other hand, the 30-degree case required eleven iterations to extract the correct values.

Several multi-degree-of-freedom combinations of angular and translational motions were among the cases run. It was found for these cases that the extraction process had to be a two- or three-step process, depending on the complexity of the case. The necessity for this procedure is a matter of the relative sensitivity of the parameters. This sensitivity may be observed by comparing the magnitudes of the elements along the main diagonal of the influence coefficient matrix. If a parameter is either insensitive or too sensitive to the motion of the missile, it will cause the adjustment of the parameters from iteration
to iteration to be incorrect, that is, too small or too large. By carrying out the extraction process in a certain order of steps, this problem can be avoided. The steps should be as follows:

1. Extract initial conditions and coefficients related solely to translational motion.

2. Extract initial conditions and coefficients related solely to angular motion.

3. Extract coefficients related to interacting motions, such as the magnus forces and moments.

The order of the steps is as important as the steps themselves. The translational motion must be dealt with first since the formulation of the total angle of attack requires the inclusion of the velocity components.

For cases considering only pitching and/or yawing motions with a rolling motion, the extraction process requires only two steps:

1. Extract initial conditions and coefficients related solely to rolling motion.

2. Extract initial conditions and coefficients related to pitching and/or yawing motion.

It should be noted that the two aforementioned processes are recommendations.
SECTION V
CONCLUDING REMARKS

In summary, the purpose of this report was to construct a six-degree-of-freedom digital computer program which extracts aerodynamic coefficients from free flight test data using the Chapman and Kirk scheme. The mathematical model chosen for the program is somewhat arbitrary; the model has limitations such as the number and type of aerodynamic coefficients and magnitude of the angles of attack for multiangular degree of freedom cases as has already been shown. These limitations are not a function of the extraction scheme. With this in mind, the program was designed to be readily adaptable to a wide range of mathematical models. Major portions of the model are incorporated in subroutines to facilitate any changes. For instance, the input and output of information and the associated operations are contained in the main program, the model equations of motion are in XD0T1, and the parametric differential equations are in XD0T2. In addition to making program changes an easier process, this feature allows major portions of the program to be bypassed, depending on the program option chosen.

Segmenting the program into subroutines and using only those necessary in a given run is a method of keeping execution time to a minimum. However, since the program was designed to be capable of handling a maximum of six degrees of freedom, its operation on only one or two degrees of freedom is relatively costly. Thus, for maximum efficiency its use should be limited to multi-degree of freedom cases.

There are several areas of the program to be considered for further study or refinement. The first is the system model. One can see that this is an area of problem trade-offs. A very general model capable of handling a greater and more varied number of aerodynamic coefficients is more desirable from a purist's standpoint. However, the increased complexity and execution time of such a model is undesirable. Of course, the model may be designed to satisfy only certain requirements and yield good execution times but at the expense of generality. In addition, important aspects of any change are the time and effort necessary to make that change.

A second area that should be considered is the programming techniques used in constructing the program. The program was written in a straightforward manner rather like translating English to a foreign language word by word to make the program logic more understandable to the user. Although efficient programming techniques would reduce execution times, this is accompanied by a program that would be less understandable to the user.

Other areas that might be considered are much more complex. From informal discussions with Chapman and other sources, such as Meissinger (4),
the author feels that the parameter influence coefficients and parametric influence coefficients in the [A] matrix are another important area for further study. It has already been found that the elements of the [A] matrix can be an important guide to the sensitivity of a parameter to the motion of the system model. With further study it might be possible to determine not only the numerical value of a parameter, but also its importance to the system relative to the other parameters in a quantitative sense rather than just a qualitative one.
APPENDIX I

SIX-DEGREE-OF-FREEDOM NOMENCLATURE LIST
AND PROGRAM LISTING

Nomenclature list (partial)

<table>
<thead>
<tr>
<th>PROGRAM VARIABLE</th>
<th>MATH SYMBOL</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>$\Delta t$</td>
<td>Numerical integration step size (sec)</td>
</tr>
<tr>
<td>ITO</td>
<td></td>
<td>Frequency of numerical integration output</td>
</tr>
<tr>
<td>TMAX</td>
<td>$t_{\text{max}}$</td>
<td>Cutoff time for numerical integration (sec)</td>
</tr>
<tr>
<td>TZERO</td>
<td>$t_0$</td>
<td>Initial time for numerical integration (sec)</td>
</tr>
<tr>
<td>XZO(I)</td>
<td></td>
<td>Initial condition labels</td>
</tr>
<tr>
<td>STDIC(I)</td>
<td></td>
<td>Initial condition standard deviation labels</td>
</tr>
<tr>
<td>COEF(I)</td>
<td></td>
<td>Coefficient labels</td>
</tr>
<tr>
<td>STDC(I)</td>
<td></td>
<td>Coefficient standard deviation labels</td>
</tr>
<tr>
<td>ICADJ(I)</td>
<td></td>
<td>Initial conditions extracted code</td>
</tr>
<tr>
<td>CADJ(I)</td>
<td></td>
<td>Coefficients extracted code</td>
</tr>
<tr>
<td>QW(I)</td>
<td>$Q_w(t)$</td>
<td>Weight factor</td>
</tr>
<tr>
<td>MAXIT</td>
<td></td>
<td>Maximum number of iterations before program terminates</td>
</tr>
<tr>
<td>TOL</td>
<td></td>
<td>Convergence criteria for change in root mean square error</td>
</tr>
<tr>
<td>NPTS</td>
<td></td>
<td>Number of experimental data points</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>Number of first order differential equations</td>
</tr>
<tr>
<td>RO</td>
<td>$\rho$</td>
<td>Air density</td>
</tr>
<tr>
<td>PROGRAM VARIABLE</td>
<td>MATH SYMBOL</td>
<td>DEFINITION</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>V</td>
<td>v</td>
<td>Wind tunnel velocity (ft/sec)</td>
</tr>
<tr>
<td>AR</td>
<td>A</td>
<td>Body reference area (ft)</td>
</tr>
<tr>
<td>D</td>
<td>d</td>
<td>Body reference diameter (ft)</td>
</tr>
<tr>
<td>P</td>
<td>p</td>
<td>Body spin rate (rad/sec)</td>
</tr>
<tr>
<td>G</td>
<td>g</td>
<td>Gravitational constant (ft/sec)</td>
</tr>
<tr>
<td>AIX</td>
<td>I_x</td>
<td>Moment of inertia about an axis longitudinally through the CG of the body (slug ft)</td>
</tr>
<tr>
<td>AM</td>
<td>m</td>
<td>Mass of the body (slugs)</td>
</tr>
<tr>
<td>CLA</td>
<td>C_{\alpha}</td>
<td>Rolling moment coefficient (rad)</td>
</tr>
<tr>
<td>CLP</td>
<td>C_{\rho}</td>
<td>Roll damping coefficient (rad)</td>
</tr>
<tr>
<td>CMA</td>
<td>C_{\sigma}</td>
<td>Static pitching moment coefficient (rad)</td>
</tr>
<tr>
<td>CNA</td>
<td>C_{\alpha}</td>
<td>Pitching moment (due to fins) coefficient (rad)</td>
</tr>
<tr>
<td>CNPA</td>
<td>C_{npa}</td>
<td>Magnus moment coefficient (rad)</td>
</tr>
<tr>
<td>CMQO</td>
<td>C_{mqo}</td>
<td>Pitch and/or yaw damping coefficient (rad)</td>
</tr>
<tr>
<td>CXO</td>
<td>C_{xo}</td>
<td>Drag coefficient (rad)</td>
</tr>
<tr>
<td>CYA</td>
<td>C_{\alpha}</td>
<td>Side force coefficient (rad)</td>
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<tr>
<td>CYAP</td>
<td>C_{\rho}</td>
<td>Magnus force coefficient (rad)</td>
</tr>
<tr>
<td>CZA</td>
<td>C_{\sigma}</td>
<td>Normal force coefficient (rad)</td>
</tr>
<tr>
<td>( )^2</td>
<td></td>
<td>Second order term</td>
</tr>
<tr>
<td>( )^3</td>
<td></td>
<td>Third order term</td>
</tr>
<tr>
<td>Angle of pitch in X-Z plane (rad)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROGRAM VARIABLE</td>
<td>MATH SYMBOL</td>
<td>DEFINITION</td>
</tr>
<tr>
<td>------------------</td>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>X</td>
<td>x</td>
<td>Angle of yaw in X-Y plane (rad)</td>
</tr>
<tr>
<td>Y</td>
<td>y</td>
<td>Angle of body roll relative to fixed plane axis system (rad)</td>
</tr>
<tr>
<td>Z</td>
<td>z</td>
<td>X position of body relative to tunnel reference point (ft)</td>
</tr>
<tr>
<td>( )</td>
<td>( \frac{d}{dt} )</td>
<td>Y position of body relative to tunnel reference point (ft)</td>
</tr>
<tr>
<td>( )</td>
<td>( \frac{d^2}{dt^2} )</td>
<td>Z position of body relative to tunnel reference point (ft)</td>
</tr>
<tr>
<td>( )</td>
<td></td>
<td>First derivative with respect to time</td>
</tr>
<tr>
<td>DATUM(I)</td>
<td>z(t)</td>
<td>Second derivative with respect to time</td>
</tr>
<tr>
<td>DCALC(I)</td>
<td>x(t)</td>
<td>Experimental data point values</td>
</tr>
<tr>
<td>IEQ(I)</td>
<td></td>
<td>Calculated point values</td>
</tr>
<tr>
<td>IEQ(I)</td>
<td></td>
<td>Equations of motion to be integrated code</td>
</tr>
<tr>
<td>IP</td>
<td></td>
<td>Psi plot code</td>
</tr>
<tr>
<td>IT</td>
<td></td>
<td>Theta plot code</td>
</tr>
<tr>
<td>IFE</td>
<td></td>
<td>Phi plot code</td>
</tr>
<tr>
<td>NF</td>
<td></td>
<td>Number of fins code</td>
</tr>
</tbody>
</table>

21
DIMENSION XL(372), FI(500), ZERD(372),
1 XDIC(19), SDIV(19), ISV(12)
DIMENSION DEC(31), SDGEV(31), CEXT(19), XZU(12),
1 XDUG(12), COEF(17)
DIMENSION AK(961), L1(31), L2(31)
INTEGER TEST1, TEST2, CADJ(19)
DIMENSION Y(200, 1), X(2232)
REAL *4 FMT(6)
REAL *4 AL
COMMON N, T, X
COMMON V, R0, AR, D, AX, A1, AM, C, P
COMMON DATUM(12, 500), DDCALC(12, 500)
COMMON / DATA1/NEO, NIC, NC, NP, CADJ, QW(12), AK1, NPTS, KKK,
1 K(19), H, B(31), IEO(6), MOD, JJ, NF, ICADJ(12), JT
COMMON / DATA2/ AKJ(31, 31)
EXTERNAL XDOTJ, OUT1, XDOT2, OUT2
N=12
NPL=1
JJJ=0
READ(5, 103) MODE
103 FORMAT (11)
KWR=MODE+1
GO TO (1031, 1032, 1033), KWR
1031 WRITE(6, 2031)
GO TO 1035
2031 FORMAT ('C15X,' 'THE PURPOSE OF THIS RUN IS FLIGHT SIMULATION')
1032 WRITE(6, 2032)
2032 FORMAT ('C15X,' 'THE PURPOSE OF THIS RUN IS COEFFICIENT',
1 'EXTRACTION.')
GO TO 1034
1033 WRITE(6, 2033)
2033 FORMAT ('C15X,' 'THE PURPOSE OF THIS RUN IS FLIGHT',
1 'SIMULATION WITH PUNCHED OUTPUT.')
GO TO 1035
1034 READ(5,1002)(XZO(I),I=1,12)
READ(5,1002)(STDC(I),I=1,12)
1002 FORMAT(12A4)
READ(5,1003)(COEF(I),I=1,19)
READ(5,1003)(STOC(I),I=1,19)
1003 FORMAT(19A4)
READ(5,101)(ICADJ(KIC),KIC=1,12)
101 FORMAT(1211)
READ(5,102)(CADJ(KC),KC=1,19)
102 FORMAT(1911)
READ(5,104)(QH(KWF),KWF=1,12)
104 FORMAT(12F5.2)
READ(5,3)MAXIT,TOL
3 FORMAT(5E10.4)
WRITE(6,33)MAXIT,TOL
33 FORMAT(*C",S5,"IF THE SOLUTION DOES NOT CONVERGE IN",
112,"ITERATIONS OR SATISFY THE CONVERGENCE TOLERANCE",
2512.5,"THE PROGRAM TERMINATES.")
C DETERMINE NUMBER AND WHICH INITIAL CONDITIONS ARE TO BE
C ADJUSTED
NIC=0
DO 110 KIC=1,12
TEST1=ICADJ(KIC)+1
GO TO (110,111),TEST1
111 NIC=NIC+1
ICADJ(NIC)=KIC
110 CONTINUE
C NIC IS THE NUMBER OF INITIAL CONDITIONS TO BE ADJUSTED
C ICADJ CONTAINS POINTERS TO IC'S TO BE ADJUSTED
C NOW DETERMINE NUMBER AND WHICH COEFFICIENTS ARE TO BE ADJUSTED
NC=3
DO 120 KC=1,19
TEST2=CADJ(KC)+1
CG YO (120,121),TEST2
121  NC=NC+1
123  CONTINUE
C  NC IS NUMBER OF COEFFICIENTS TO BE ADJUSTED
C  CAOJ CONTAINS POINTERS TO THOSE COEFFICIENTS
1035 READ(5,LOG1)(IEQ(KEQ),KEQ=1,6)
1001 FORMAT(6I1)
C  DETERMINE NUMBER AND WHICH EQUATIONS OF MOTION ARE TO BE
C  INTEGRATED
   KEQ=0
   GO TO 112 KEQ=1,6
   JTEST=IEQ(KEQ)+1
   GO TO (112,113),JTEST
113  NEQ=KEQ+1
114  IEQ(NEQ)=KEQ
112  CONTINUE
C  NEQ IS THE NUMBER OF EQUATIONS TO BE INTEGRATED
C  IEQ CONTAINS POINTERS TO EQUATIONS TO BE INTEGRATED
WRITE(6,2001) NEQ
2001 FORMAT('2*5X,'THERE ARE '*,11,' DEGREES OF FREEDOM."
   IF(MODE.EQ.0) GO TO 1036
   READ(5,101)(ISV(KSV),KSV=1,12)
1036 READ(5,1)H,IT0,TMAX,TZERO,IP,IT,IFE,NF
1 FORMAT(F5.2,I3,2F5.3,4I1)
   WRITE(6,2)H,IT0,TMAX,TZERO,N,IP,IT,IFE,NF
2 FORMAT('0*5X,'INTEGRATION CONSTANTS*/+*5X,21('*)/
   '0*10X,'H=','F5.3,2X,'IT0=','I3,2X,'TMAX=','F5.3,2X,'TZERO=','
   2F5.3,2X,'N=','I2,2X,'IP=','I1,2X,'IT=','I1,2X,'IFE=','I1,
   22X,3HNF=','12)
   AT0=IT0
   NPTS=((TMAX-TZERO)/(H=AT0))+1.2
   IF(MODE.EQ.0) GO TO 1161
C  DETERMINE NUMBER AND WHICH STATE VECTORS ARE TO BE READ
C  AND INFLUENCING THE RMS ERROR
NSV=0
DO 116 KSV=1,12
LTEST=ISV(KSV)+1
GO TO (116,117),LTEST
117 NSV=NSV+1
ISV(NSV)=KSV
116 CONTINUE
C NSV IS THE NUMBER OF STATE VECTORS AND THE ISV'S
C CONTAINS POINTERS
1161 IF(MODE.NE.1) GO TO 130
   WRITE(6,201)(XZ0(ICADJ(I)),I=1,NIC)
201 FORMAT(1HO,5X,3SH'THE FOLLOWING INITIAL CONDITIONS ARE,
12H ADJUSTED IN THIS RUN /1H0,10X,12(A4,2X))
   WRITE(6,202)(COEF(ICADJ(I)),I=1,NC)
202 FORMAT('O',5X,'THE FOLLOWING COEFFICIENTS ARE ADJUSTED',
1' IN THIS RUNO'/'O',10X,15('4,2X))
   WRITE(6,2051)
2051 FORMAT('O',5X,'TIME HISTORIES OF THE FOLLOWING STATE',
1' VECTOR COMPONENTS AND THEIR TIME DERIVATIVES ARE INPUT',
2' AS DATA'/5X,'WITH THE WEIGHTING FACTORS SHOWN FOR',
3' THE MEAN SQUARED ERROR CALCULATION.')
   WRITE(6,2052)(XZ0(ISV(I)),QW(ISV(I)),I=1,NSV)
2052 FORMAT('O',10X,A4,'0',F5.2)
NP=NC+NIC
  NALL=NP+12
  GO 122 NA=1,NALL
122 XZERO(NA)=0.0
  IF(NIC)1241,1241,123
123 DO 124 NK=1,NIC
     J=ICADJ(NK)+(NK-1)*12
     XZERO(J)=1.0
124 CONTINUE
1241 CONTINUE
C START FLYSIM
READ(5,105)RO,V,AR,D,P,G,AIX,AL,AM
106 FORMAT(F11,8,4F11,4)
WRITE(6,12)
12 FORMAT('O',10X,'AERODYNAMIC AND PHYSICAL INPUT DATA'*'*',10X,135(''''''))
WRITE(6,2CS)RO,V,AR,D,P,G,AIX,AL,AM
206 FORMAT(1H0,9X,2HRD,11X,1HV,10X,4HAREA,6X,8HDIAMETER,4X,10HSPIN-RATE/1H,5X,11H!SLG/FT**3,3X,8H(FT/SFC),5X,7H(FT**2),2X,4H(FT),6X,9H(RAD/SEC),/1H0,5X,F10.7,3X,F9.3,2(3X,F9.5),3X,3F10.3//7X,7HGRAVITY,8X,2HI,11X,1HI,9X,4HMAS5/5X,41H(FT/SEC**2),2X,11H(SLG-FT**2),1X,11H(SLG-FT**2),3X,56H(SLGS),//6X,F10.9,6,3(3X,F9.5))
READ(5,107)CLA,CLA3,CLP,CMA,CMA3,CNA,CNA3,CNPA,CNPA3,CMIO,
1CMQ2,CLKO,CKA42,CYA,CYA3,CYAP,CYAP3,CAZ,CZAT
107 FORMAT(8F10,4)
WRITE(6,14)
14 FORMAT('O',10X,'AERODYNAMIC COEFFICIENT ESTIMATES'*'*',10X,133(''''''))
WRITE(6,207)CLA,CLA3,CLP,CMA,CMA3,CNA,CNA3,CNPA,CNPA3,
1CMQ2,CMG2,CLKO,CKA42,CYA,CYAP,CYAP3,CAZ,CZAT,NPTS
207 FORMAT('O',5X,'CLA=','F7.3,4X,'CLA3=','F7.3,3X,'CLP=','F7.3,4X,
1'CMA=','F7.3,4X,'CMA3=','F7.3,3X,'CNA=','F7.3,4X,'CNA3=','F7.3,5X,
2'CNPA=','F7.3,3X,'CNPA3=','F7.3,2X,'CMIO=','F8.3,3X,'CMQ=','F8.3,3X,
3'CMQ2=','F7.3,4X,'CKA42=','F7.3,3X,'CYA=','F7.3,5X,'CYA3=','F7.3,3X,
4'CYAP=','F7.3,3X,'CYAP3=','F7.3,2X,'CAZ=','F7.3,4X,'CZAT=','F7.3,
5'NPTS=','F7.3,13)
1P1=P*AIX/AL
C MODE 0= FLIGHT SIMULATION
C 1= READ DATA AND EXTRACT COEFFICIENTS
C 2= FLIGHT SIMULATION WITH PUNCHED OUTPUT
KTEST=MODE+1
GO TO (139,32,139)*KTEST
131 DO 1311 L=1,NSV
131 READ(5,105)(DATUM(ISV(L),KPT),KPT=1,NPTS)
105   FORMAT(5E16.6)
108   DO 1312 I=1,NSV
1312 WRITE(6,205)(DATUM(ISV(I),KPT),KPT=1,NPTS)
   205   FORMAT(1X,5E16.6)
       N=N+1
139   CONTINUE
   READ(5,108)(XZ(I),I=1,N)
108   FORMAT(8F10.4)
   VA=SQR((V*XZ(8))/2*XZ(10)/2*XZ(12)/2)
   C=0.5*RO*VA**2
   CON1=(Q*AR*D)/AIX
   CON3=(Q*AR*D)/AI
   CCN5=Q*AR*AM
   IF(VA.EQ.0) GO TO 999
   CON2=(Q*AR*D**2)/(2*VA*AIX)
   CCN4=(Q*AR*D**2)/(2*VA*AI)
   C(1)=C041*CLA
   C(2)=C041*CLA3
   C(3)=C042*CLP
   C(4)=C043*CAM
   C(5)=C043*CAM3
   C(6)=C043*CN
   C(7)=C043*CN3
   C(8)=C044*CNPA
   C(9)=C044*CNPA3
   C(10)=C044*CMG0
   C(11)=C044*CMQ2
   C(12)=C045*CX0
   C(13)=C045*CA2
   C(14)=C045*CYA
   C(15)=C045*CYA3
   C(16)=C045*CYAP
   C(17)=C045*CYAP3
   C(18)=C045*CZA

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C(19)=CGNS*CZA3

1391 CONTINUE
KXX=0
140 CALL AUCUM(H,IT0,TZERO,TMAX,XZ,XDOT1,OUT1,+999)
IF(IN_LT.13) GO TO 1429
MSQE=X(13)
1429 KTEST=MODE+1
GO TO (141,142,143),KTEST
143 DO 1431 I=1,NSV
1431 WRITE(7,105)(DCALC(ISV(I),KPT),KPT=1,NPTS)
GO TO 141
142 DO 144 J=1,MP
D(I,J)=0.0
144 DO 144 K=1,MP
AJK(J,K)=0.0
N=(NIC+NC)+12
CALL AUCUM(H,IT0,TZERO,TMAX,XZERO,XDOT2,OUT2,+999)
IF(JJJ GT.0) GO TO 171
WRITE(6,270)
270 FORMAT('1',5X,'CURRENT PARAMETER VALUES ARE 0')
GO TO 172
171 WRITE(6,271)
271 FORMAT('0',5X,'CURRENT PARAMETER VALUES ARE 0')
172 WRITE(6,272)JXX,(XZ(I),I=1,12)
273 FORMAT('0',5X,'ITERATION NUMBER',12/1H0,5X,'PSI=',F10.4,
12X,'PSIDOT=',F10.4,2X,'THA=',F10.4,2X,'THADOT=',F10.4,2X,
2,'FEE=',F10.4,2X,'FBDOT=',F10.4,2X,'0=',F10.4,2X,'EX=',F10.4,2X,
3,'EYD=',F10.4,2X,'Z=',F10.4,2X,'ZEDOT=',F10.4)
WRITE(6,273) C(I),I=1,19
273 FORMAT('0',5X,'C13=',E12.5,'C14=',E12.5,'C15=',E12.5,
15X,'C16=',E12.5,'C17=',E12.5,'C18=',E12.5,'C19=',E12.5,
2,'C20=',E12.5,'C21=',E12.5,'C22=',E12.5,'C23=',E12.5,
3E12.5,'0=',5X,'C25=',E12.5)
45X,'C26=','E12.5,5X,'C27=','E12.5/"0",5X,'C28=','E12.5,5X,'C29=','E12.5,5X,'C30=','E12.5,5X,'C31=','E12.5
DO 173 J=1,NP
DELC(J)=0.0
173 STDEV(J)=0.0
DO 590 M=1,NP
DO 590 N=1,NP
590 AJK1((M-1)*NP+N)=AJK(M,N)
CALL MINV(AJK1,NP,R,L1,L2)
DO 591 M=1,NP
DO 591 N=1,NP
591 AJK(M,N)=AJK1((M-1)*NP+N)
IF(JJJ.GT.0) GO TO 175
RMSE=0.0
DIFF=1.0E20
175 RMSEP=RMSE
DIFFP=DIFF
RMSE=SQRT(MSCE/(TMAX-TZERO))
DIFF=ABS(RMSE-RMSEP)
1751 DO 176 J=1,NP
176 STDEV(J)=RMSE*SQRT(AJK(J,J))
WRITE(6,274)RMSE
274 FORMAT('0',5X,'RMS ERROR=','E16.8)
WRITE(6,2741)
2741 FORMAT('0',10X,'CURRENT PARAMETER STANDARD DEVIATIONS',
1 ' ARE0'/"0",10X,42('/'0'))
WRITE(6,275)ICADJ(I),STDEV(I),I=1,NIC
275 FORMAT('0',5X,'SDIC( '+'I2, '+'*'=','E12.5,5X,'SDIC( '+'I2, '+'*'=','E12.5,5X,'SDIC( '+'I2, '+'*'=','E12.5,5X,'SDIC( '+'I2, '+'*'=','E12.5)
WRITE(6,276)ICADJ(I),STDEV(I+NIC),I=1,NC
276 FORMAT('0',5X,'SDC( '+'I2, '+'*'=','E12.5,5X,'SDC( '+'I2, '+'*'=','E12.5,5X,'SDC( '+'I2, '+'*'=','E12.5)
IF(DIFF.GT.TOL) GO TO 1991
IF(MSCE.LT.SQRT(TOL)) GO TO 199
IF(VA.EQ.0) GO TO 999
CON2=(Q*AR*U*E2)/(2*VA*AI)
CON4=(Q*AR*J*E2)/(12*VA*AI)
GO 190 I=1,NC
MC=CAJD(I)
GO TO (191,191,192,193,193,193,194,194,194,194,195,195,
1195,195,195,195,195),MC
191 CEXT(MC)=C(MC)/CON1
GO TO 190
192 CEXT(MC)=C(MC)/CON2
GO TO 190
193 CEXT(MC)=C(MC)/CON3
GO TO 190
194 CEXT(MC)=C(MC)/CON4
GO TO 190
195 CEXT(MC)=C(MC)/CON5
190 CONTINUE
GO 185 I=1,NC
M=CAJD(I)
GO TO (181,181,182,183,183,183,183,184,184,184,185,185,
1185,185,185,185,185),M
181 SDCO(M)=STDEV(NIC+I)/CON1
GO TO 180
182 SDCO(M)=STDEV(NIC+I)/CON2
GO TO 180
183 SDCO(M)=STDEV(NIC+I)/CON3
GO TO 180
184 SDCO(M)=STDEV(NIC+I)/CON4
GO TO 180
185 SDCO(M)=STDEV(NIC+I)/CON5
180 CONTINUE
WRITE(6,284)
284 FORMAT('O',5X,'EXTRACTED INITIAL CONDITIONS AND',
1 ' THEIR STANDARD DEVIATIONS ARE')
WRITE(6,235)(XLC[I],ICADJ(I),XZ(ICADJ(I)),I=1,NIC)
235 FORMAT('O',4(5X,A4,'=','F9.4))
WRITE(6,222)(ICADJ(I),STOE(I),I=1,NIC)
282 FORMAT('O',4(5X,A4,'=','E12.5))
WRITE(6,286)
286 FORMAT('O',5X,'EXTRACTED COEFFICIENTS AND THEIR',
1' STANDAVD DEVIATIONS ARE ')
WRITE(6,277)(CEXTCADJ(I),CSTDICADJ(I),I=1,NC)
287 FORMAT('O',3(5X,A4,'=','F9.3))
WRITE(6,288)(STDCADJ(I),STOCADJ(I),I=1,NC)
288 FORMAT('O',5(5X,A4,'=','E12.5))
141 CONTINUE
5Q 132 I=1,NPTS
TI(I)=H*ITO*(I-1)
132 CONTINUE
NOUT=1
152 IF(NPTS.LE.(NOUT+49)) GO TO 155
WRITE(6,215)
215 FORMAT('O',7X,'TIME',7X,'ANGLE-OF-YAW',4X,'ANGLE-OF-PITCH',
15X,'ANGLE-OF-ROLL',5X,'X-POSITION',5X,'Y-POSITION',5X,
21X,'Z-POSITION',5X, '(SECONDS)', 7X, '(RADIANS)', 8X, '(RADIANS)',
39X,(RADIANS)', 9X, '(FEET)', 9X, '(FEET)', 9X, '(FEET)'/)
NUP=NOUT+49
DO 211 I=NOUT,NUP
WRITE(6,216)TI(I),(DCALC(KX,I),KX=1,11,2)
211 FORMAT(5X,F8.5,7X,F8.5,5X,F8.5,10X,F8.5,9X,F8.5,3,2(7X,F8.3))
NOUT=NOUT+50
GO TO 155
155 WRITE(6,215)
DO 220 I=NOUT,NPTS
WRITE(6,216)TI(I),(DCALC(KX,I),KX=1,11,2)
TIME=H*ITO
IF(IT.EQ.1) GO TO 301
220 IF(IT.EQ.1) GO TO 303
304 IF(IFE.EQ.1) GO TO 307
GO TO 9999
301 DO 305 K=1,200
305 Y(K,1)=DCALC(1,K)+0.6
WRITE(6,310)
310 FORMAT(1H1/'55X,8HPS1 PLOT)
WRITE(6,320)TIME
320 FORMAT(1H0,46X,2BHTIME BETWEEN DATA POINTS IS ,F5.3,3HSEC,//)
WRITE(6,322)
322 FORMAT(1X,'-0.6',6X,'-0.5',6X,'-0.4',6X,'-0.3',6X,'-0.2',
16X,'-0.1',7X,'0.0',7X,'0.1',7X,'0.2',7X,'0.3',7X,'0.4',7X,
2'0.5',7X,'0.6',//)
CALL PLOT91Y,K,NPL)
GO TO 302
303 DO 306 K=1,200
306 Y(K,1)=DCALC(3,K)+0.6
WRITE(6,311)
311 FORMAT(1H1/'55X,1GTHETA PLOT)
WRITE(6,320)TIME
WRITE(6,322)
CALL PLOT91Y,K,NPL)
GO TO 304
307 DO 308 K=1,200
308 Y(K,1)=DCALC(5,K)+6.0
WRITE(6,312)
312 FORMAT(1H1/'55X,8PHI PLOT)
WRITE(6,320)TIME
WRITE(6,323)
323 FORMAT(1X,'-6.0',6X,'-5.0',6X,'-4.0',6X,'-3.0',6X,'-2.0',
16X,'-1.0',7X,'0.0',7X,'1.0',7X,'2.0',7X,'3.0',7X,'4.0',7X,
2'5.0',7X,'6.0',//)
CALL PLOT91Y,K,NPL)
9998 GO TO 9999
997 WRITE(6,998)
998 FORMAT('C',5X,'THE RMS ERROR IS GETTING WORSE. TRY ',
1'BETTER GUESSES OR MORE DATA POINTS')
GO TO 9999
999 WRITE(6,115)
115 FORMAT(1HO,5X,'THERE WAS A DIVISION BY ZERO THAT RESULTED IN ',
1'INFINITY')
9999 CONTINUE
STOP
END
SUBROUTINE ADDU(AITH, ITO, TZERO, TMAX, X, F, OUT, * )
DIMENSION X(372), CX(372, 6), X(372, 6)
COMMON N, T, X
H = ADS(AITH)
IT = ITO - 1
C = TZERO - TMAX
IF (IT).NE.1,1,1
1 T = -H
2 HH = 0.5*H
C = H/24.0
T = TZERO
ISET = 0
DO 3 I = 1, N
3 X(I, 1) = XZ(I)
3 X(I, 6) = XZ(I)
CALL F(X(1, 5), 1, +99)
CALL F(X(1, 2), 0, +99)
IF (IT).EQ.5, 5, 4
4 CALL OUT(1)
5 DO 6 K = 1, N
6 CX(K, 1) = X(K, 5) * HH
6 X(K, 1) = X(K, 1) * CX(K, 1)
T = T + HH
CALL F(CX(1, 2), 3, +99)
7 DO 8 K = 1, N
8 CX(K, 2) = H * CX(K, 2)
7 X(K, 1) = X(K, 6) + CX(K, 2)
CALL F(CX(1, 3), 3, +99)
8 DO 8 K = 1, N
8 CX(K, 3) = H * CX(K, 3)
8 X(K, 1) = X(K, 6) + CX(K, 3)
T = T + HH
CALL F(CX(1, 4), 1, +99)
DO 9 K = 1, N
9
ADDU 120
ADDU 130
ADDU 140
ADDU 150
ADDU 160
ADDU 170
ADDU 180
ADDU 190
ADDU 200
ADDU 210
ADDU 220
ADDU 230
ADDU 260
ADDU 280
ADDU 310
ADDU 330
ADDU 370
ADDU 400
ADDU 420
\[ CX(K, 4) = CX(K, 4) + n \]
\[ X(K, 1) = X(K, 1) + \frac{1}{2}CX(K, 1) + CX(K, 2) + CX(K, 3) + \]
\[ \begin{align*}
1 & \quad C.5\cdot CX(K, 4) + C.3333333333333 \quad \text{ADDU 450} \\
9 & \quad X(K, 6) = X(K, 1) \quad \text{ADDU 460} \\
& \quad \text{ISET = ISET + 1} \quad \text{ADDU 465} \\
& \quad \text{GO TO (10, 12, 17), ISET} \quad \text{ADDU 470} \\
10 & \quad \text{CALL F(X(1, 5), 0, +99)} \quad \text{ADDU 490} \\
& \quad \text{DO} \quad \text{ADDU 500} \\
11 & \quad X(K, 3) = X(K, 5) \quad \text{ADDU 510} \\
& \quad \text{GO TO 18} \quad \text{ADDU 520} \\
12 & \quad \text{CALL F(X(1, 5), 0, +99)} \quad \text{ADDU 530} \\
& \quad \text{DO} \quad \text{ADDU 540} \\
13 & \quad X(K, 4) = X(K, 5) \quad \text{ADDU 550} \\
& \quad \text{GO TO 18} \quad \text{ADDU 560} \\
14 & \quad \text{T = T + H} \quad \text{ADDU 570} \\
& \quad \text{DO} \quad \text{ADDU 580} \\
15 & \quad \text{K = 1, N} \quad \text{ADDU 590} \\
16 & \quad X(K, 1) = X(K, 6) + 0.5\cdot (55.0\cdot X(K, 5) - 59.0\cdot X(K, 4) + 37.0\cdot X(K, 3) - 9.0\cdot X(K, 2)) \quad \text{ADDU 600} \\
& \quad X(K, 2) = X(K, 3) \quad \text{ADDU 610} \\
& \quad X(K, 3) = X(K, 4) \quad \text{ADDU 620} \\
& \quad \text{CALL F(X(1, 5), 1, +99)} \quad \text{ADDU 630} \\
& \quad \text{DO} \quad \text{ADDU 640} \\
17 & \quad \text{K = 1, N} \quad ++4 \\
18 & \quad X(K, 6) = X(K, 6) + 0.5\cdot (9.0\cdot X(K, 5) + 19.0\cdot X(K, 4) - 5.0\cdot X(K, 3) + X(K, 2)) \quad \text{ADDU 690} \\
19 & \quad X(K, 1) = X(K, 6) \quad \text{ADDU 710} \\
& \quad \text{ISET = 3} \quad \text{ADDU 720} \\
20 & \quad \text{IF (IT) \{G = ? + 20 \}} \quad \text{ADDU 730} \\
& \quad \text{ISET = ITU} \quad \text{ADDU 740} \\
21 & \quad \text{CALL OUT(G)} \quad \text{ADDU 750} \\
22 & \quad \text{GO TO (5, 5, 14), ISET} \quad \text{ADDU 760} \\
99 & \quad \text{RETURN} \quad \text{ADDU 770} \\
& \quad \text{END} \quad \text{ADDU 780}
SUBROUTINE XDOTI(A,K,*)
INTEGER CADJ(19)
DIMENSION A(13),XZ(380)
COMMON N,T,X(2232)
COMMON V,RO,AR,E,AIX,AI,AM,G,P
COMMON DATUM(12,500),DCALC(12,500)
COMMON /CATAL/NEQ,NIC,NC,NP,CADJ,QW(12),AK1,NPTS,KKK,
1C(19),H,B(31),IEQ(6),MODE,JJJ,NF,ICADJ(12),JT
EQUVALEANCE (X(1),PSI),(X(2),PSIDOT),(X(3),THA),(X(4),THADOT),
1(X(5),FE),(X(6),FEEDOT),(X(7),EX),(X(8),EXDOT),(X(9),WY),
2(X(10),KYDOT),(X(11),ZE),(X(12),ZEDOT)
DO 2 I=1,12
2 A(I)=0.0
747 ST=SIN(THA)
CT=COS(THA)
SP=SIN(PSI)
CP=COS(PSI)
92 R1=(V+EXDOT)*ST*CP+KYDOT*ST*SP+ZEDOT*CT
R2=-(V+EXDOT)*SP+KYDOT*CP
R3=(V+EXDOT)*CT*CP+KYDOT*CT*SP-ZEDOT*ST
IF(R3.EQ.0) GO TO 6
ARGA=R1/R3
ARGB=R2/R3
IERROR=1
GO TO 13
6 IF(R1.EQ.0) GO TO 7
IERROR=2
GO TO 100
7 ARG=0
IERROR=1
11 IF(R2.EQ.0) GO TO 12
IERROR=2
GO TO 100
12 ARG=0
IEEGR=1
13
AHAT=ATAN(ARGA)
BHAT=ATAN(ARGB)
ALBAR=SQR(T(AHAT**2+BHAT**2)
SA=SIN(AHAT)
SB=SIN(BHAT)
SAL=SIN(ALBAR)
IF(ALBAR.EQ.0) GO TO 601
CSFEHT=SA/SAL
SNFEHT=SB/SAL
GO TO 602
601
CSFEHT=1.0
SNFEHT=0.0
602
FEEP=FEE+ARSIN(SNFEHT)
S4F=SIN(NF*FEEP)
CC1=C(1)*ALBAR+C(2)*ALBAR**3
CC2=C(4)*ALBAR+C(5)*ALBAR**3
CC3=C(6)*ALBAR+C(7)*ALBAR**3
CC4=C(8)*ALBAR+C(9)*ALBAR**3
CC5=C(10)+C(11)*ALBAR**2
CC6=C(12)+C(13)*ALBAR**2
CC7=C(14)+ALBAR+C(15)*ALBAR**3
CC8=C(16)*ALBAR+C(17)*ALBAR**3
CC9=C(18)*ALBAR+C(19)*ALBAR**3
DO 1600 I=1,NEQ
KT=1EQ(I)
GO TO (21,22,23,24,25,26),KT
21
A(1)=PSIDOT
A1=(4*K1+2*A(1))/T-T+ADQT/CT
A2=CC3*S4F*CSFEHT
A3=CC4*FEEDQT*CSFEHT
A4=-CC2*SNFEHT
A5=CC5*A(1)
A(2)=A1+(A2+A3+A4)/CT+A5
GO TO 1000

22  A(3)=THADOT
    A6=-A1*A(1)*CT-A(1)*2*ST*CT
    A7=CC2*CSFEHT
    A8=(CC3*S4F+CC4*FEEDOT)*SNFEHT
    A9=CC5*THADOT
    A(4)=A6+A7+A8+A9
    GO TO 1000

23  A(5)=FEEDOT+P
    A(6)=CC1+S4F+C(3)*A(5)+A(1)*A(3)*CT+ST*X(1)
    GO TO 1000

24  A(7)=EXDOT
    A13=CC6*CT*CP
    A14=CC7*S4F
    A15=CC8*A(5)
    A16=SNFEHT*ST*CP+CSFEHT*SP
    A17=CC9
    A18=-CSFEHT*ST*CP+SNFEHT*SP
    A(8)=A13-(A13+A14+A15)*A16+A17*A18
    GO TO 1000

25  A(9)=WYDOT
    A19=CC6*CT*SP
    A20=CSFEHT*CP-SNFEHT*ST*SP
    A21=CSFEHT*ST*SP+SNFEHT*CP
    A10=A19+(A14+A15)*A20+A17*A21
    GO TO 1000

26  A(11)=ZEDOT
    A22=-CC6*ST
    A23=SNFEHT*CT
    A24=CSFEHT*CT
    A(12)=A22-(A14+A15)*A23+A17*A24-G
1000  CONTINUE
     J=T/H+1.2
     IF(MODE.NE.1) GO TO 70
40 DMSE=0.2
40 GO TO 60
10 I=1+12
11 IF(QX(I))=01,60,61
61 IF(K-3)62,63,62
62 DMSE=QW(I)*(X(I))-.5*DATUM(I,J)-.5*DATUM(I,J+1)**2+DMSE
62 GO TO 60
62 DMSE=QW(I)*(X(I))-DATUM(I,J)**2+DMSE
63 CONTINUE
65 A(13)=DMSE
100 GO TO(70,80),IERROR
70 RETURN
80 RETURN 1
END
SUBROUTINE OUT1(K)
INTEGER CADJ(19)
COMMON N,T,X(2232)
COMMON V,RO,AR,D,AIX,AS,AM,G,P
COMMON DATUM(12,500),DCALC(12,500)
COMMON /DATA1/NEQ,NIC,NC,LP,CADJ,GW(12),AK1,NPTS,KKK,
LC(19),H,B(31),IEQ(6),MODE,JJJ,NI,ICADJ(12),JT

KKK=KKK+1
700 DO I=1,12
CCALC(I,KKK)=X(I)
RETURN
END
SUBROUTINE XDOT2(DOT, KDUM, *)
INTEGER CADJ(19)
DIMENSION DOT(1), FSX(12, 12)
COMMON N, T, X(2232)
COMMON V, RO, AR, C, AIX, AI, AM, G, P
COMMON DATUM(12, 500), DCALC(12, 500)
COMMON /DATA1/NEQ, NIC, NC, NP, CADJ, G(N), AKI, NPTS, KKK,
IC(19), H, B(31), IEQ(6), MODE, JJJ, NF, ICADJ(12), JT
DATA FSX/144*0.0/
IF(KDUM.NE.1) GO TO 10
1 JT=T/H+1.5
PSI=CCALC(1, JT)
PSIDOT=DCALC(2, JT)
THA=CCALC(3, JT)
THADOT=DCALC(4, JT)
FEE=CCALC(5, JT)
FEEDOT=DCALC(6, JT)
EX=CCALC(7, JT)
EXUC=DCALC(8, JT)
WY=CCALC(9, JT)
WYDOT=DCALC(10, JT)
ZE=CCALC(11, JT)
ZEDOT=DCALC(12, JT)
747 SP=SIN(PSI)
CP=CCS(PSI)
ST=SIN(THA)
CT=CCS(THA)
92 TT=TAN(THA)
R1=(V*EXDOT)*ST*CP+WYDOT*ST*SP+ZEDOT*CT
R2=-((V*EXDOT)*SP+WYDOT*CP
R3=(V*EXDOT)*CT*CP+WYDOT*CT*SP-ZEDOT*ST
IF(R3.EQ.0) GO TO 6
ARCA=R1/R3
ARB=R2/R3
GO TO 11
6  IF(R1.EQ.0) GO TO 7
GO TO 151
7  ARG0=0
IF(R2.EQ.0) GO TO 12
GO TO 151
12  ARG0=0
11  AHAT=ATAN(ARGA)
     BHAT=ATAN(ARGB)
     ALBAR=SQR(AHAT**2+BHAT**2)
     SA=SIN(AHAT)
     CA=COS(AHAT)
     SB=SIN(BHAT)
     CB=COS(BHAT)
     SAL=SIN(ALBAR)
     CAL=COS(ALBAR)
     IF(ALBAR.EQ.0) GO TO 601
     CSFEHT=SA/SAL
     SNFEHT=SB/SAL
     GO TO 602
601  CSFEHT=1.0
     SNFEHT=G.0
     FEEP=FEE+AR SIN(SNFEHT)
91  SF=E SIN(NF+FEEP)
     CF=COS(NF+FEEP)
     SN=E SIN(NF+FEEP)
     CN=E COS(NF+FEEP)
     SNFAS=SIN(NF*AR SIN(SNFEHT))
     CNFAS=COS(NF*AR SIN(SNFEHT))
     CC1=C(1)*ALBAR+C(2)*ALBAR**3
     CC2=C(4)*ALBAR+C(5)*ALBAR**3
     CC3=C(6)*ALBAR+C(7)*ALBAR**3
     CC4=C(8)*ALBAR+C(9)*ALBAR**3
     CC5=C(10)+C(11)*ALBAR**2
E2=0.0
E3=0.0
E4=0.0
E5=0.0
E6=0.0

702  E011=E1*DA4+E2*DB4
     E012=E3*DA4+E4*DB4
     E013=E5*DA4+E6*DB4
     E021=E1*DA5+E2*DB5
     E022=E3*DA5+E4*DB5
     E023=E5*DA5+E6*DB5
     E031=E1*DA1+E2*DB1
     E032=E3*DA1+E4*DB1
     E033=E5*DA1+E6*DB1
     E041=E1*DA2+E2*DB2
     E042=E3*DA2+E4*DB2
     E043=E5*DA2+E6*DB2
     E051=E1*DA3+E2*DB3
     E052=E3*DA3+E4*DB3
     E053=E5*DA3+E6*DB3

CO 1000 I=1,NEQ
KT=1EQ(I)
GO TO (21,22,23,24,25,26),KTI

C  PSI EQUATION HOMOGENEOUS TERMS
21  F11=-CC5*PSDOT-DC4*FEEDOT*CSFEHT/CT+DC2*SNFEHT/CT-DC3
     1*SF4*CSFEHT/CT-CC3*CSFEHT/CT*NF*SB*CAL*
     2*(SNFE*SNFAS+CNFE*CNFAS)/(SAL*SQRT(SAL**2-SB**2))
     F112=CC3*CSFEHT/CT*NF*CB*(SNFE*SNFAS+CNFE*CNFAS)/
     1SQRT(SAL**2-SB**2)
     F12=CC2/CT
     F13=-CC4*FEEDOT/CT-CC3*SF4/CT
2*SX(2,1)=F11*ED11+F12*ED12+F13*ED13+F112*E2*DB4
2*SX(2,2)=-(2*THADOT*TT+CC5)
2*SX(2,3)=-ST/CT**2*(2*PSDOT*THADOT*ST+AK1*THADOT+
CC4*FEEDOT*CSFEHT-CC2*SNFEHT+CC3*S4F*CSFEHT)+F11*ED21+F12*ED22
2+F13*ED23+F112*E2*DB5
FSX(2,4)=-2*PSIDOT*TT-AK1/CT
FSX(2,5)=-NF*CC3*CSFEHT/CT*(CNFAS*CNFE-SNFA-SNFE)
FSX(2,6)=-CC4*CSFEHT/CT
FSX(2,8)=F11*ED31+F12*ED32+F13*ED33+F112*E2*DB1
FSX(2,10)=F11*ED41+F12*ED42+F13*ED43+F112*E2*DB2
FSX(2,12)=F11*ED51+F12*ED52+F13*ED53+F112*E2*DB3
GO TO 1000

C THETA EQUATION HOMOGENEOUS TERMS
22 F21=-DC5*THACOT-CSFEHT*DC2-FEEDOT*SNFEHT*DC4-S4F*
1SNFEHT*DC3-CC3*SNFEHT*NF*SB*CAL*
2(SNFE*SNFAS+CNFE*CNFAS)/(SAL*SQRT(SAL*2-SB*2))
F22=-CC4*FEEDOT*CC3*S4F
F212=CC3*SNFEHT*NF*CB*(SNFAS*SNFE+CNFAS*CNFE)/
1SQRT(SAL*2-SB*2)
F23=-CC3
FSX(4,1)=F21*ED11+F23*ED13+F22*ED12+F212*E2*DB4
FSX(4,2)=AK1/CT*PSIDOT*2*ST/CT
FSX(4,3)=PSIDOT**2*(CT**2-ST**2)-PSIDOT*AK1*ST+F23*ED23
1+F21*ED21+F22*ED22+F212*E2*DB5
FSX(4,4)=-CC3
FSX(4,5)=-NF*CC3*SNFEHT*(CNFAS*CNFE-SNFA-SNFE)
FSX(4,6)=-CC4*SNFEHT
FSX(4,8)=F21*ED31+F22*ED32+F23*ED33+F212*E2*DB1
FSX(4,10)=F21*ED41+F22*ED42+F23*ED43+F212*E2*DB2
FSX(4,12)=F21*ED51+F22*ED52+F23*ED53+F212*E2*DB3
GO TO 1005

C FEE EQUATION HOMOGENEOUS TERMS
23 IF(IEQ(1).EQ.1) AND IEQ(2).EQ.0) GO TO 231
IF(ALBAR.EQ.0) GO TO 231
F31=-S4F*DC1-NF*CB*CAL*(SNFE*SNFAS*CNFE*CNFAS)/(SAL*)
1SQRT(SAL*2-SB*2)) *CC1
F312=-NF*CB/SQRT(SAL*2-SB*2)*(SNFE*SNFAS*CNFAS*CNFE)*CC1
GO TO 232

231  F31=-S4F*DC1
    F312=0.0

232  FSX(6,1)=F31*ED11+F312*E2*DB4
    FSX(6,2)=THADOT*C'T
    FSX(6,3)=F31*ED21-X(1)*THADOT*C'T+PSIDOT*THADOT**2*ST
    FSX(6,4)=-PSIDOT*C'T
    FSX(6,5)=-NF*(CNFAS*CNFE-SNFAS*SNFE)*CC1
    FSX(6,6)=-C(3)
    FSX(6,8)=F31*ED31+F312*E2*DB1
    FSX(6,10)=F31*ED41+F312*E2*DB2
    FSX(6,12)=F31*ED51+F312*E2*DB3
    GO TO 1000

C
EX EQUATION HOMOGENEOUS TERMS

24  AT1=SP*CSFEHT-ST*CP*SNFEHT
    AT2=SP*SNFEHT-ST*CP*CSFEHT
    F41=FEEDOT*AT1+DC8-DC6*CT*CP+S4F*AT1+DC7+AT2+DC9
    1+AT1=CC7*NF*SB*CAL*(SNFE*SNFAS+CNFE*CNFAS)/
    2(SAL>SQRT(SAL**2-SB**2))
    F412=-AT1+CC7*NF*CB*(SNFE*SNFAS+CNFE*CNFAS)/
    1SQRT(SAL**2-SB**2)
    F42=CC8*FEEDOT*ST*CP+CC7*S4F*ST*CP+CC9*SP
    F43=CC8*FEEDOT*SP+CC7*S4F*SP-CC9*ST*CP
    FSX(8,1)=CP*(CC8*FEEDOT*CSFEHT+CC7*S4F*CSFEHT+CC9*SNFEHT)-
    1SP*(CC8*FEEDOT*ST*SNFEHT+CC7*S4F*ST*SNFEHT-CC6*CT-CC9*ST*-
    2CSFEHT)+F41*ED11+F42*ED12+F43*ED13+F412*E2*DB4
    FSX(8,3)=CT*(CC8*FEEDOT*CP*SNFEHT+CC7*S4F*CP*SNFEHT-CC9*-
    1CP*CSFEHT)+CC6*ST*CSFEHT+F41*ED21+F42*ED22+F43*ED23
    2+F412*E2*DB5
    FSX(8,5)=AT1*CC7*NF*(CNFAS*CNFE-SNFAS*SNFE)
    FSX(8,6)=CCd*AT1
    FSX(8,8)=F41*ED31+F42*ED32+F43*ED33+F412*E2*DB1
    FSX(8,10)=F41*ED41+F42*ED42+F43*ED43+F412*E2*DB2
    FSX(8,12)=F41*ED51+F42*ED52+F43*ED53+F412*E2*DB3
GO TO 1000
C  XY EQUATION HOMOGENEOUS TERMS
25  AT3=-CP*CSFEHT+ST*SP*SNFEHT
   AT4=CP*SNFEHT-ST*SP*CSFEHT
   F51=AT3*(FEEDOT*DC8+S4F*DC7)-AT4*DC9-DC6*CT*SP
   1+AT3*CC7*NF*SB*CAL*(SNFE*SNFAS+CNFE*CNFAS)/
   2(SAL*SQRT(SAL**2-SB**2))
   F512=-AT3*CC7*NF*CB*(SNFE*SNFAS+CNFE*CNFAS)/
   SQRT(SAL**2-SB**2)
   F52=CC8*FEEDOT*ST*SP+CC7*S4F*ST*SP-CC9*CP
   F53=-{CC8*FEEDOT*CP+CC7*S4F*CP+CC9*ST*SP}
   FSX(10,1)=CP*{CC8*FEEDOT*ST*SNFEHT-CC6*CT+CC7*S4F*ST*SNFEHT}
   1-CC9*ST*CSFEHT)*SP*{CC8*FEEDOT*CSFEHT+CC7*S4F*CSFEHT+}
   2CC9*SNFEHT)}*F51*ED11+F52*ED12+F53*ED13+F512*E2*DB4
   FSX(10,3)=CT*(CC8*FEEDOT*SP+SNFEHT+CC7*S4F*SP*SNFEHT-CD9*
1SP*CSFEHT)*ST*(CC6*SP)+F51*ED21+F52*ED22+F53*ED23
   2+F512*E2*DB5
   FSX(10,5)=AT3*CC7*NF*(CNFAS*CNFE-SNFAS*SNFE)
   FSX(10,6)=CC8*AT3
   FSX(10,8)=F51*ED31+F52*ED32+F53*ED33+F512*E2*DB1
   FSX(10,10)=F51*ED41+F52*ED42+F53*ED43+F512*E2*DB2
   FSX(10,12)=F51*ED51+F52*ED52+F53*ED53+F512*E2*DB3
GO TO 1000
C  ZE EQUATION HOMOGENEOUS TERMS
26  AT6=CT*SNFEHT
   AT6=CT*CSFEHT
   F61=AT5*(FEEDOT*DC8+S4F*DC7)-AT6*DC9+DC6*ST
   1+AT5*CC7*NF*SB*CAL*(SNFE*SNFAS+CNFE*CNFAS)/
   2(SAL*SQRT(SAL**2-SB**2))
   F612=-AT5*CC7*NF*CB*(SNFE*SNFAS+CNFE*CNFAS)/
   SQRT(SAL**2-SB**2)
   F62=CC8*FEEDOT*CT+CC7*S4F*CT
   F63=-CC7*CT
   FSX(12,1)=F61*ED11+F62*ED12+F63*ED13+F612*E2*DB4
FSX(12,3)=CC6*CT-ST*(CC8*FEED*SF=S*SF=S)
LCC9*SF=S)+F61*ED21+F62*ED22+F63*ED23+F612*ED2*DB5
FSX(12,5)=AT5*CC7*VF*(CMF=CMF=S*SF=S*SF=S)
FSX(12,6)=CC9*CT*SF=S
FSX(12,8)=F61*ED21+F62*ED22+F63*ED23+F612*ED2*DB5
FSX(12,10)=F61*ED41+F62*ED42+F63*ED43+F612*ED2*DB2
FSX(12,12)=F61*ED51+F62*ED52+F63*ED53+F612*ED2*DB3

1000 CONTINUE
10 DU 100 M=1,NP
CO 9991 JJ=1,12
J=J+(M-1)*12
DOT(J)=0.0
98 K=JJ+1
L=J+1
DOT(J)=X(L)
GO TO 9991
99 DO 201 K=1,12
L=K+(M-1)*12
991 DOT(J)=DOT(J)-FSX(JJ,K)*X(L)
9991 CONTINUE
100 CONTINUE
IF(VC=12-12
IF(NC)=19,27,19
19 DU 20 M=1,NC
JC=ADD(J)
JX=I1+M*12
GO TO (101,162,163,164,165,166,167,168,169,JC
101 DOT(JX+6)=DOT(JX+6)+ALBAR*S4F
GO TO 20
102 DOT(JX+6)=DOT(JX+6)+ALBAR*S3*S4F
GO TO 20
103 DOT(JX+6)=DOT(JX+6)+FEEEDOT
104   DOT(JX+2)=DOT(JX+2)-ALBAR*SNFEHT/CT
      DOT(JX+4)=DOT(JX+4)+ALBAR*CSFEHT
      GO TO 20
105   DOT(JX+2)=DOT(JX+2)-ALBAR**3*SNFEHT/CT
      DOT(JX+4)=DOT(JX+4)+ALBAR**3*CSFEHT
      GO TO 20
106   DOT(JX+2)=DOT(JX+2)+ALBAR*S4F*CSFEHT/CT
      DOT(JX+4)=DOT(JX+4)+ALBAR*S4F*SNFEHT
      GO TO 20
107   DOT(JX+2)=DOT(JX+2)+ALBAR**3*S4F*CSFEHT/CT
      DOT(JX+4)=DOT(JX+4)+ALBAR**3*S4F*SNFEHT
      GO TO 20
108   DOT(JX+2)=DOT(JX+2)+ALBAR*FEEDOT*CSFEHT/CT
      DOT(JX+4)=DOT(JX+4)+ALBAR*FEEDOT*SNFEHT
      GO TO 20
109   DOT(JX+2)=DOT(JX+2)+ALBAR**3*FEEDOT*CSFEHT/CT
      DOT(JX+4)=DOT(JX+4)+ALBAR**3*FEEDOT*SNFEHT
      GO TO 20
110   DOT(JX+2)=DOT(JX+2)+PS1DOT
      DOT(JX+4)=DOT(JX+4)+THADOT
      GO TO 20
111   DOT(JX+2)=DOT(JX+2)+ALBAR**2*PS1DOT
      DOT(JX+4)=DOT(JX+4)+ALBAR**2*THADOT
      GO TO 20
112   DOT(JX+8)=DOT(JX+8)+CT*CP
      DOT(JX+10)=DOT(JX+10)+CT*SP
      DOT(JX+12)=DOT(JX+12)-ST
      GO TO 20
113   DOT(JX+8)=DOT(JX+8)+ALBAR**2*CT*CP
      DOT(JX+10)=DOT(JX+10)+ALBAR**2*CT*SP
      DOT(JX+12)=DOT(JX+12)+ALBAR**2*ST
      GO TO 20
114   DOT(JX+3)=DOT(JX+3)-ALBAR*S4F*AT2
DCT(JX+10) = DOT(JX+10) - ALBAR*S4F*AT3
DCT(JX+12) = DOT(JX+12) - ALBAR*S4F*AT5
GO TO 20

115 DCT(JX+8) = DOT(JX+8) - ALBAR**3*S4F*AT1
DCT(JX+10) = DOT(JX+10) - ALBAR**3*S4F*AT3
DCT(JX+12) = DOT(JX+12) - ALBAR**3*S4F*AT5
GO TO 20

116 DCT(JX+8) = DOT(JX+8) - ALBAR*FEED*AT1
DCT(JX+10) = DOT(JX+10) - ALBAR*FEED*AT3
DCT(JX+12) = DOT(JX+12) - ALBAR*FEED*AT5
GO TO 20

117 DCT(JX+8) = DOT(JX+8) - ALBAR**3*FEED*AT1
DCT(JX+10) = DOT(JX+10) - ALBAR**3*FEED*AT3
DCT(JX+12) = DOT(JX+12) - ALBAR**3*FEED*AT5
GO TO 20

118 DCT(JX+6) = DOT(JX+8) - ALBAR*AT2
DCT(JX+10) = DOT(JX+10) + ALBAR*AT4
DCT(JX+12) = DOT(JX+12) + ALBAR*AT6
GO TO 20

119 DCT(JX+8) = DOT(JX+8) - ALBAR**3*AT2
DCT(JX+10) = DOT(JX+10) + ALBAR**3*AT4
DCT(JX+12) = DOT(JX+12) + ALBAR**3*AT6
GO TO 20

CONTINUE

RETURN

RETURN 1

END
SUBROUTINE OUT2(KDUM)
INTEGER CADJ(19)
COMMON N, T, X(2232)
COMMON V, R, AR, C, AIX, AI, AM, G, P
COMMON DATUM(12, 500), GCALC(12, 500)
COMMON /DATA1/NEQ, NIC, NG, NP, CADJ, QW(12), AK1, NPTS, KKK,
I(19), H, B(31), IFQ(6), MODE, JJJ, NF, ICADJ(12), JT
COMMON /DATA2/AJK(31, 31)
27 DO 150 M = 1, NP
  I = (M-1)*12
  DO 149 K = 1, 12
  IF (QW(K).EQ.0) GO TO 149
  E(M) = B(M) + X(I+K)*QW(K)*{(DATUM(K, JT) - GCALC(K, JT))}
148 DO 148 J = 1, M
  JJ = (J-1)*12
  AJK(M, J) = AJK(M, J) + X(I+K)*X(JJ+K)*QW(K)
147 IF (M.EQ. J) GO TO 148
  AJK(J, M) = AJK(M, J)
143 CONTINUE
149 CONTINUE
150 CONTINUE
RETURN
END
SUBROUTINE MINV(A,N,D,L,M)
DIMENSION A(1),L(1),M(1)
D=1.0
NK=-N
DO 80 K=1,N
NK=NK+N
L(K)=K
M(K)=K
KK=NK+K
BIGA=A(KK)
DO 20 J=K,N
IZ=N*(J-1)
DO 20 I=K,N
IJ=IZ+I
10 IF(ABS(BIGA)-ABS(A(IJ)))<15,20,20
15 BIGA=A(IJ)
L(K)=I
M(K)=J
20 CONTINUE
J=L(K)
IF(J-K)35,35,25
25 KI=K-N
DO 30 I=1,N
KI=KI+N
HOLD=-A(KI)
JI=KI-K+J
A(KI)=A(JI)
30 A(JI)=HOLD
I=M(K)
IF(I-K)45,45,38
35 JP=N*(I-1)
DO 40 J=1,N
JK=NK+J
JI=JP+J
HOLD=-A(JK)
A(JK)=A(JI)
40 A(JI)=HOLD
45 IF(BIGA) = 48, 46, 48
50 K=K+N
55 CONTINUE
60 IF(I-K) = 60, 65, 60
65 CONTINUE
70 A(KJ)=A(KJ)/BIGA
75 CONTINUE
80 CONTINUE
100 K=(K-1)
     IF(K)= 150, 150, 10
105  I=L(K)
   IF(I-K) 120,120,108
108  JQ=N*(K-1)
   JR=N*(I-1)
   DO 110 J=1,N
   JK=JQ+J
   HOLD=A(JK)
   JI=JR+J
   A(JK)=-A(JI)
110  A(JI)=HOLD
120  J=M(K)
   IF(J-K) 100,100,125
125  KI=K-N
   DO 130 I=1,N
   KI=KI+N
   HOLD=A(KI)
   JI=KI-K+J
   A(KI)=-A(JI)
130  A(JI)=HOLD
   GO TO 100
150  RETURN
END
SUBROUTINE PLOTOY(NK,NPL)
REAL*4 LINE1(121),LINE2(121),Y(NK,NPL),FMT(6),SYM(9),FORMS(3)
INTEGER*4 J1(9)
REAL*8 SYM8(9)
DATA FMT/"(2X,*,"121 ',"A1,3',"X,1',"9A10',*) */,
1FIV10/4H9A10/,SIX/4H/) /
DATA SYMB/"Y(X,1)'','Y(X,2)'','Y(X,3)'','Y(X,4)'','Y(X,5)'','Y(X,6)'','Y(X,7)'','Y(X,8)'','Y(X,9)'*/
DATA STAR=X,BLANK,PLUS,ZERO/4H=***,4HXXXX,4H++++,4HI///
DATA FORMS/*E','F','X*/
DATA SYM/4HXXXX,4H0000,4H0000,4H4444,4H5555,4H6666,4H7777,4H8888,14H9999/,FIVE/4HP9E1/,SIXE/4H0.2/,FIVEF/4H9F7/,SIXF/4H2) */,
2FIV1/4H9A7/,INT/0/
FMT(5)=FIVA10
FMT(6)=SIX
READ (5,2) FMT(2),LMAX,LO,LUG,FORM,SR
2 FORMAT (A3,T1,I3,T5,I3,T9,I1,T11,A1,T13,F10.3)
IF(LO.LT.1)  LO=1
IF(LG.GT.LMAX)  L0=LMAX
DO 10 I=1,LMAX
LINE1(I)=PLUS
10 LINE2(I)=BLANK
DO 20 I=1,LMAX,10
IF((LO+I-1).GT.0)  L1=LO+1-I
IF((LO-I+1).LT.(LMAX+1))  L2=LO-1+I
20 CONTINUE
DO 30 I=L1,L2,10
LINE2(I)=PLUS
LINE1(LO)=ZERO
LINE2(LO)=ZERO
IF (LUG .GT. 0) GC TO 51
GC TO 42
51 IS=LUG*10
WRITE (6,301) IS,SR
300 FORMAT (14X,I2,="LOG10(1.1PE10.3, Y)"")
42    IP=NPL
    IF (FORM .EQ. FORMS(3)) GO TO 52
    IF (FORM .EQ. FORMS(2)) GO TO 43
    IF ((LMAX + 10*NPL) .GT. 135) IP=(135-LMAX)/10
    GO TO 53
43    IF ((LMAX + 7*NPL) .GT. 135) IP=(135-LMAX)/7
    FMT(5)=FIVA7
53    IF (IP .LT. 1) GO TO 52
    GO TO 44
52    WRITE(6,FMT) (LINE1(M),M=1,LMAX)
    GO TO 45
44    WRITE (6,FMT) (LINE1(M),M=1,LMAX),(SYMB(M),M=1,IP)
45    FMT(5)=FIVE
    FMT(6)=SIXE
    IF (FORM .EQ. FORMS(3)) IP = 0
    IF (FORM .EQ. FORMS(2)) GO TO 16
    GO TO 46
16    FMT(5)=FIVEF
    FMT(6)=SIXF
46    K=10
    DO 60 I=1,NK
70    CO 11 I2=1,NPL
    IF (LOG .GT. 0) GO TO 47
    J1(I2)=Y(I,I2) * SF + LO + 0.5
    GO TO 48
47    J1(I2)=IS * ALOG10(ABS(Y(I,I2) * SF)) + LO + 0.5
48    IF(J1(I2) .GT. LMAX) J1(I2)=LMAX
    IF(J1(I2) .LT. 1)     J1(I2)=1
11    CONTINUE
    IF (I-K) 40,70,40
70    CO 12 I2=1,NPL
    J=J1(I2)
12    LINE1(J)=SYM(I2)
IF (IP .LT. 1) GO TO 61
Y(I, M) = Y(I, M) - 0.6
WRITE (6, FMT) (LINE1(M), M=1, LMAX), (Y(I, M), M=1, IP)
GO TO 62
61 WRITE (6, FMT) (LINE1(M), M=1, LMAX)
62 CONTINUE
DO 13 I2=1, NPL
J=J1(I2)
13 LINE1(J) = PLUS
LINE1(L0)=ZERO
K=K + 10
GO TO 63
40 DO 14 I2=1, NPL
J=J1(I2)
14 LINE2(J) = SYM(I2)
IF (IP .LT. 1) GO TO 63
Y(I, M) = Y(I, M) - 0.6
WRITE (6, FMT) (LINE2(M), M=1, LMAX), (Y(I, M), M=1, IP)
GO TO 64
50 WRITE (6, FMT) (LINE2(M), M=1, LMAX)
64 CONTINUE
DO 15 I2=1, NPL
J=J1(I2)
15 LINE2(J) = BLANK
DO 500 I2=L1, L2, 10
500 LINE2(I2) = PLUS
LINE2(L0) = ZERO
60 CONTINUE
WRITE (6, I11)
111 FORMAT(/)
I11=1
RETURN
END
/
APPENDIX II
FLOW CHART OF COMPUTER PROGRAM

Read input codes

Flight simulation

Read and write initial conditions and coefficients and other data

Integrate equations of motion

Write or punch flight simulation time history

End

Convergence achieved.
Write extracted parameters

End

Calculate mean square error and test root mean square error for convergence

Convergence failed. Maximum number of iterations exceeded

End

Calculate parameter corrections

Update parameters

Go to integration of equations of motion
APPENDIX III
DATA INPUT FORMAT

CASE I Flight simulation

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20 I1
21 I1
22 .I1

4 1-11 F11.8
12-22 F11.4
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Case II  Coefficient extraction

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NCARDS

| 1-10  | F10.4   | $Y_0$ |             |
| 11-20 | F10.4   | $\dot{Y}_0$ |         |
| 21-30 | F10.4   | $Z_0$ |             |
| 31-40 | F10.4   | $\dot{Z}_0$ |         |
| 41-50 | F10.4   | MSQE (always 0.0) |         |

20, 21, 22

Same as PLOT9 data in Case I

NCARDS

Case III Flight simulation with punched output

Same as Case I except a card like card #11 of Case II is inserted between cards #2 and #3 of Case I.
Output Labels (Cards 2-5) For Case II Coefficient Extraction

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## APPENDIX IV

### RESULTS OF PROGRAM TEST RUNS

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<th>DEGREES OF FREEDOM</th>
<th>PARAMETER</th>
<th>INITIAL EXTRACTED</th>
<th>EXTRACTED VALUE</th>
<th>ESTIMATED STANDARD DEVIATION</th>
<th>CORRECT VALUE</th>
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<td>0.00129</td>
<td>0.1754*</td>
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*Values obtained from UFPLANAR
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## APPENDIX IV (Continued)

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A Digital Computer Program For Extracting Aerodynamic Coefficients From Six-Degree-Of-Freedom Dynamic Data

Final Report - March 1972 to March 1973

November 1973

Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied November 1973. Other requests for this document must be referred to the Air Force Armament Laboratory (DLMA), Eglin Air Force Base, Florida 32542.

Available in DDC

The development of a digital computer program to extract aerodynamic coefficients from dynamic data from six-degree-of-freedom systems is presented. The derivation of a system mathematical model is discussed in detail. Results, and associated problems, of extracting coefficients from one, two, three and six-degree-of-freedom systems data are also presented.
Aerodynamic Coefficients
Dynamic Data
Six-Degree-of-Freedom Systems