NASA/CR—2000-210560

TAILSIM Users Guide

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December 2000

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Prepared under Grant NAG3–2007

National Aeronautics and
Space Administration

Glenn Research Center

December 2000

Available from

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1.0 Program Overview

The TAILSIM program uses a 4th order Runge-Kutta method to integrate the standard aircraft equations-of-motion (EOM). The EOM determine three translational and three rotational accelerations about the aircraft's body axis reference system. The forces and moments that drive the EOM are determined from aerodynamic coefficients, dynamic derivatives, and control inputs. Values for these terms are determined from linear interpolation of tables that are a function of para-meters such as angle-of-attack and surface deflections. Buildup equations combine these terms and dimensionalize them to generate the driving total forces and moments.

Features that make TAILSIM applicable to studies of tailplane stall include modeling of the reversible control system, modeling of the pilot performing a load factor and/or airspeed command task, and modeling of vertical gusts. The reversible control system dynamics can be described as two hinged masses connected by a spring, resulting in a fifth order system. The pilot model is a standard form of lead-lag with a time delay applied to an integrated pitch rate and/or airspeed error feed-back. The time delay is implemented by a Pade approximation, while the commanded pitch rate is determined by a com-manded load factor. Vertical gust inputs include a single 1-cosine gust and a continuous NASA Dryden gust model. These dynamic models, coupled with the use of a nonlinear database, allow the tailplane stall characteristics, elevator response, and resulting aircraft response, to be modeled. A useful output capability of the TAILSIM program is the ability to display multiple post-run plot pages to allow a quick assessment of the time history response. There are 16 plot pages currently available to the user. Each plot page displays 9 parameters. Each parameter can also be displayed individually, on a one plot-per-page format. For a more refined display of the results the program can also create files of tabulated data, which can then be used by other plotting programs.

The TAILSIM program was written straightforwardly assuming the user would want to change the database tables, the buildup equations, the output parameters, and the pilot model parameters. A separate database file and input file are automatically read in by the program. The use of an include file to set up all common blocks facilitates easy changing of parameter names and array sizes.

1.1 Program Structure

The functional program structure is shown in the program flow block diagram of figure 1.1.1. Here INIT represents the initialization actions of the program. The main action of the initialization subroutine is to setup the input/output file structure, set constants and calculate gains, read in the input data, and trim the aircraft to the input flight condition.

Reading in the aircraft geometry and flight condition data, and input and output file names is performed in the main program. The subroutine SMINIT is then called. This program sets constants for the standard atmosphere, gust calcul-ations, reversible control system, and pilot model, and initializes the random function and calculates pilot model gains. The database is then read in using subroutine TBLIN. Output variable names are placed into arrays in VNOUT. Any adjust-ments to gross weight or inertias, as required by the input run file configuration, are calculated in CGTRAN. The trim process is then started by determining the initial surface deflections defined by the flight controls subroutine, FCSYS.

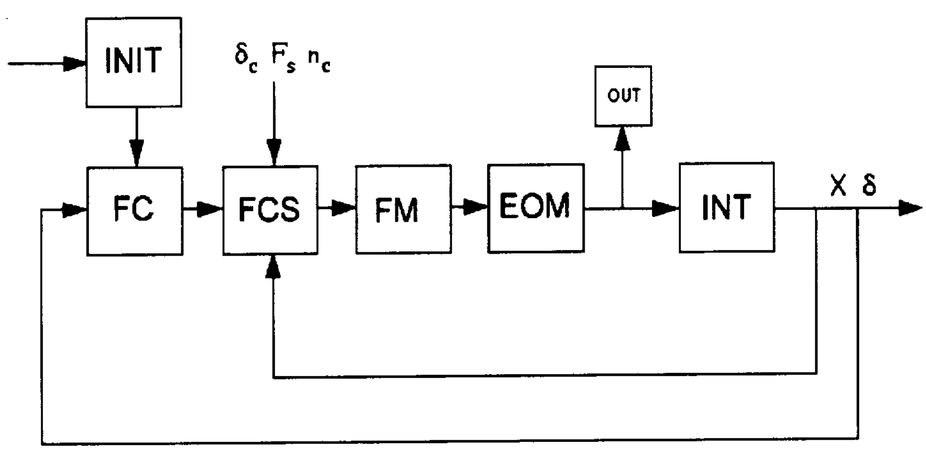

Figure 1.1.1—TAILSIM Program Flow Block Diagram.

The trimming subroutine, SMTRIM, is then called. This program trims using the control surface inputs and thrust to bring the accelerations of the six degree-of-freedom body axis equations of motion to within specified tolerances. To facilitate convergence, the longitudinal and lateral/directional EOM are trimmed separately within an iterative loop. For the longitudinal EOM, the best convergence properties were found by using a Newton-Raphson recursion on angle of attack and elevator deflection to trim w dot and q dot within an iterative loop on thrust coefficient to trim u dot. The lateral/directional EOM are trimmed by a Newton-Raphson recursion on sideslip and rudder deflection to trim v dot and r dot with an iterative loop on aileron deflection to trim p dot.

Subroutine FMTRM is used to adjust the buildup equation coefficients calculated in AEROFMC to steady state values for trimming. Specifically, the dynamically lagged downwash term is set to a steady state value and pitching moment is calculated from table data developed from trim flight test data, as apposed to a local pitching moment slope used for a dynamic response. With the aerodynamic coefficients known, FMTRM calls AEROFM to calculate the total aerodynamic forces and moments, performing any database-to-aircraft C.G. transfer calculations. Body axis accelerations are then calculated in EOMACB.

Multiple options exist for trimming the aircraft. In all options, Mach number and altitude are inputs. These are used with the standard atmosphere calculations to determine the true and calibrated airspeeds. Angle-of-attack is always a variable, and is set to match the required load factor. If thrust coefficient is an input, the trim function will vary the flight path angle to provide unaccelerated flight. If thrust coefficient is not an input, the trim will be to the input flight path angle, and thrust will be varied. If maximum or minimum thrust levels would be exceeded, the flight path angle is again allowed to vary to trim. A bank angle can also be input to trim to the aircraft in a coordinated turn.

The main line on the block diagram defines the Runge-Kutta integration loop. This loop defines the structure in the main program and starts with the determination of the current flight condition, as noted by the FC block. This action is performed by a call to subroutine FLTCOND. The FCS block represents the calculation of the control inputs, performed in subroutine FCSYS. Control inputs are read in directly from input tables, and can vary depending on the input option chosen. The inputs can be direct elevator deflection, stick force to drive the reversible control stick dynamics, or load factor and/or trim airspeed, which drive the pilot model and commands a stick force. Gust inputs are also calculated in this block.

These input tables are a function of the integration time, which depends on the step size and the current "pass" of the Runke-Kutta integration. Integration time is calculated in program RKTIME, which is the first subroutine accessed in the Runke-Kutta integration loop. Note that since a 4th order Runke-Kutta integration is used, four "passes" are required in each time step.

With the time history flight condition and surface inputs known, the forces and moments acting on the aircraft may be determined. The FM block represents this program action, which is performed in series of subroutines, some of which have been noted in the trim discussion. In AEROFMC the table lookup program, TBLOOK, is used to access the required tables and determine the stability and control derivatives. These are then used in the buildup equations to determine total coefficients. The total coefficients are then used at the known flight condition to calculate the total forces and moments, accomplished in AEROFM. Any adjustment for differences in the assumed C.G. for the database and the input aircraft C.G. are accomplished in AEROFM.

Most terms of the buildup equations are determined on each of the four passes of the Runge-Kutta integration, as their derivatives are secant derivatives. The angle-of-attack derivatives, however, are tangential derivatives. To provide a more correct usage of these derivatives and enhance the accuracy of the longitudinal motion, these terms were summed in the main program prior to their usage in the Runge-Kutta loop. Inside the Runge-Kutta loop, a $\Delta\alpha$ is then applied to the derivative and added to the summed terms.

The total forces and moments are input to EOMACC, which calculates Earth oriented translational and Euler axis accelerations. Required body axis accelerations are generated by a call to subroutine EOMACB. These accelerations and rates are then integrated, along with the integrations for the pilot model and stick dynamics, in subroutine COMPINT (INT block). This maintains the proper vector nature of the EOM. A useful feature of the TAILSIM program is that the Runge-Kutta integrations are performed in a separate subroutine, RKINT. For parameters that have physical limits, such as surface deflections, RKINTL is used. These subroutines are called by COMPINT, and keep track of past values and properly scale them to calculate the values for the next pass of the Runge-Kutta loop.

Finally, the OUT block indicates the saving of output parameters into individual arrays. The location of this saving action in the Runge-Kutta loop was chosen to provide a direct comparison of state and control parameters to EOM accelerations. The subroutine PSAVE saves all desired parameters into arrays at this point in the Runge-Kutta loop. Arrays are used to provide the option of creating an output data file for a time history and to provide post run plotting capability. The formats for the output data files are contained in subroutine POUT, which is called by the main program, if desired, after a run is completed. Five output files, to minimize the size of each file, contain all variable names set in VNOUT and all parameters saved in PSAVE.

Not shown in the block diagram is the plotting subroutine, PPLOT. This subroutine is accessed after the completion of a time history run, and displays multiple plot pages of the desired parameters stored in the arrays contained in PSAVE. These plots may be screen dumped to provide a hard copy of the time history.

2. Program Operation

2.1 Program Setup

TAILSIM was written in Fortran using the Microsoft Fortran Powerstation v1.0. The screen plotting features in the program used compiler specific functions. It is not known if these features will be compatible with other Fortran compilers. All other program operations should work on any Fortran compiler.

In its current version TAILSIM assumes that all program files are contained in the directory C:\DH6DYN. The required program files are; C:\DH6DYN\TAILSM16.FOR, C:\DH6DYN\TAILSM16.RUN, and C:\DH6DYN\TAILSM16.COM. The current database is contained in C:\DH6DYN\DH6NTF12.DAT. A font file is contained in C:\DH6DYN\COURB.FON.

2.2 Input File Parameters

This section assumes that a TAILSIM program and all required files are ready to use and that an executable file can be created successfully. The TAILSM16.RUN input file is then used to set up the simulation run conditions. An example of this input file is shown in Figure 2.2.1. Note that all data in the input file is labeled.

The first two lines of the input file are comment lines that are used to provide a description of the input file configur-ation. The third line contains the run number which is used in the output file filenames. An error will occur if this run number matches that of the output files in the current directory. The remaining parameters will be described below with reference to their labels. Each set of inputs is also given a description indicated on the left of each comment line.

The input parameters are:

LENGTH	Program run time in seconds
STEP	Runge-Kutta integration step size. Typically, 0.01 or 0.02 (100 or 50 Hz integration frequency) are used
EXTRAP	Extrapolation flag variable. Optional input to the table look-up subroutine to turn extrapolation on, 1.0 or off, 0.0
TMINS	Starting time to begin checking for the minimum load factor
GW	Aircraft nominal gross weight, lbs
WING S	Wing reference area, ft^2
MAC	Reference chord length, ft (Mean Aerodynamic Chord (MAC))
SPAN	Wingspan, ft
DGW	Delta gross weight from nominal, lbs
AREA	Tailplane planform reference area, ft^2
CHORD	Tailplane MAC, ft
ARM	Reference distance from the wing quarter chord point to the tailplane quarter chord point, ft
HT	Tailplane height above the reference center-of-gravity (C.G.)
XCG0	X axis C.G. location, %MAC, positive aft
YCG0	Y axis C.G. location, %MAC, positive right
ZCG0	Z axis C.G. location, %MAC, positive up
DXCG	Delta X axis C.G. location due to DGW, %MAC, positive aft
DYCG	Delta Y axis C.G. location due to DGW, %MAC, positive right
DZCG	Delta Z axis C.G. location due to DGW, %MAC, positive up
XCGDB	X axis C.G. location of database, %MAC, positive aft
YCGDB	X axis C.G. location of database, %MAC, positive aft
ZCGDB	X axis C.G. location of database, %MAC, positive aft
IXX0	I_x inertia, slug-ft^2, for nominal gross weight
IXY0	I_{xy} inertia, slug-ft^2, for nominal gross weight
IXZ0	I_{xz} inertia, slug-ft^2, for nominal gross weight
IYY0	I_y inertia, slug-ft^2, for nominal gross weight
IYZ0	I_{yz} inertia, slug-ft^2, for nominal gross weight

IZZ0	I_{zz} inertia, slug-ft^2, for nominal gross weight
ALT	Initial altitude, ft
MACH	Initial Mach Number
TCTF	Initial thrust coefficient setting. If set to 0.0 the trim routine will vary the thrust coefficient as required
TAOA	Initial angle-of-attack used in the trim routine, deg
TGAMMA	Initial flight path angle used in the trim routine, deg
TPHI	Bank angle for a trim in a coordinated turn, deg
GVEL	Gust peak amplitude, ft/sec
T START	Starting time for single pulse or NASA Dryden gust input
T END	Ending time for NASA Dryden gust input
ICOPT	Control input type flag: 1-elevator input; 2-stick force input; 3-load factor command input; 4-load factor
and	
	airspeed command input
QPFR	Ratio of pitch rate to integrated pitch rate error
APFR	Ratio of airspeed to integrated airspeed error
PMTLAG	Pilot model lag time constant, sec
PMTLEAD	Pilot model lead time constant, sec
PMTDELAY	Pilot model time delay, sec

The next lines define the filename of the command input file and the database. For completeness, the full path name is required in the filename.

```
TAILSM16 RUNS
DH6 TWIN OTTER with TAIL 'LOW' DATA FROM NLRC
RUN                 01
TIMES          LENGTH       STEP   EXTRAP     TMINS
                 9.98      0.020      1.0      8.50
A/C GEOM           GW     WING S      MAC      SPAN       DGW
              10000.0     420.00     6.50     65.00       0.0
TAIL GEOM        AREA      CHORD      ARM        HT
                 98.0       4.75    25.66      2.63
C.G.             XCG0       YCG0     ZCG0      DXCG      DYCG       DZCG
                 0.25       0.00     0.00      0.00      0.00       0.00
CG DATABASE     XCGDB      YCGDB    ZCGDB
                 0.25       0.00     0.00
INERTIAS         IXX0       IXY0     IXZ0      IYY0      IYZ0       IZZ0
              19324.0       0.00   1099.0   24688.0      0.00    35357.0
FLT COND          ALT       MACH     TCTF      TAOA    TGAMMA       TPHI
              7200.00      0.133    0.000      8.00      0.00       0.00
GUST             GVEL    T START    T END
                50.00       0.50    10.00
CMD OPTION      ICOPT       QPFR     APFR    PMTLAG   PMTLEAD   PMTDELAY
                    3        0.0        5       0.5       0.4       0.12
COMMANDS  C:\DH6DYN\CMDPGST.DAT
DATA BASE C:\DH6DYN\DH6NTF12.DAT
```

Figure 2.2.1—Example Run Input File.

2.3 Input Tables

The input tables are used to define the surface deflections, stick force, load factor, and thrust delta commands, and to turn icing on or off. These tables are contained in the command file indicated in the input file in section 2.2. In the example, the command input file is C:\DH6DYN\CMDPGST.DAT and is shown in figure 2.3.1.

The tables are used by defining sets of time and input values. The simulation program then linearly interpolates between the time values as required. No extrapolation is allowed. Changes are made directly by typing in the desired values. In practice, there has been no practical limit to the number of break points allowed.

All tables have a single dependent parameter, indicated by the 1 in the first line of each table. The next line shows the single independent parameter name and output parameter name, followed by the number of data points. Note that all parameter name labels are included in the table for convenience, but are not read by the table input program. The next lines indicate the values of the independent parameters, followed by the values of the dependent parameters. All inputs, numeric or character, are right justified, with the spacing indicated by the header line. The TRA in the last line defines the end of the table. Comments are allowed, using the COM label as indicated.

Descriptions of the table input parameters follow:

DLFAP	Flap deflection, deg
DELEVC	Elevator deflection command, deg
FSTCKC	Stick force command, lbs
ANLFC	Load factor command, g
DAILC	Aileron deflection command, deg
DRUDC	Rudder deflection command, deg
CTHRSTC	Delta thrust coefficient increment command from trim
FICE	Tailplane icing flag: 0-uniced tailplane; 1-iced tailplane

```
      COM
      COM FILE CMDPGST.DAT
      COM
      COM  FOR SPACING
      COM          1.0000    2.0000    3.0000    4.0000    5.0000    6.0000  COM
CTAB01 TBL 1
       TIME      DFLAP
        4.00
        0.00       1.00      6.00     100.0
       20.00      20.00     20.00     20.00
       COM
CTAB08 TBL 1
       TIME      NLFC
       12.00
        0.00       1.00      1.50      5.00      5.50      9.50
       12.50      14.50     15.50     17.50     18.50     80.00
        1.00       1.00      0.65      0.65      1.50      1.50
       -0.20      -0.20      1.80      1.80      1.00      1.00
CTAB07 TBL 1
       TIME     FSTCKC
        6.00
        0.00       1.00      1.01      3.50      4.00      6.00
        0.00       0.00      0.00      0.00      0.00      0.00
CTAB02 TBL 1
       TIME     DELEVC
        6.00
        0.00       1.00      3.00      7.00     10.00     13.00
        0.00       0.00      0.00      0.00      0.00      0.00
CTAB03 TBL 1
       TIME      DAILC
        6.00
        0.00       1.00      2.00      2.50      4.00      5.00
        0.00       0.00      0.00      0.00      0.00      0.00
CTAB04 TBL 1
       TIME      DRUDC
        6.00
        0.00       1.00      2.00      2.50      4.00      5.00
        0.00  0              0.00      0.00      0.00      0.00      0.00
CTAB05 TBL 1
       TIME   CTHRSTC
        3.00
        0.00       1.00      6.00     40.00
       0.000      0.000     0.000     0.000
CTAB06 TBL 1
       TIME       FICE
        2.00
      0.0000    100.000
       0.000      0.000
        TRA
```

Figure 2.3.1—Example Command Input File

2.4. Input Parameter Guidelines

It is expected that a nominal configuration input will be for a given aircraft geometry and a nominal gross weight, C.G., and set of inertias. For simple changes in gross weight, as may occur for some fuel loadings, TAILSIM includes the capability to adjust the C.G. and inertias. The calculations assume that any change in gross weight defined by input DGW and input changes in C.G., DXCG, DYCG, and DZCG, are caused by a single point mass. Therefore, adjustments to these inertias should only be considered an approximation.

A database is usually built up around an assumed quarter chord C.G., so TAILSIM includes the ability to transfer the database moments to the given configuration C.G. This adjustment occurs in subroutine AEROFM and is applicable to the calculated total moments. The internal calculations used in generating the total forces and moments remain in the database C.G. configuration. Total nonadjusted forces and moments from the buildup equation coefficients of AEROFMC are also calculated and output for diagnostic purposes.

The maximum number of data samples is set by the PARAMETER statement in the common file, TAILSM16.COM. This is used with the STEP size to determine a maximum run length. (The program is currently set to allow the recording of 4110 data samples, or over 80 sec at 50 samples/sec.) A step size of 0.02 gives good accuracy and allows reasonable run times. For maximum accuracy, a minimum step size of 0.01 is suggested. Note that output file parameters are saved for each time step, so the output file size will be twice as large for the 0.01 step size, compared to the 0.02 step size.

The TAOA and TGAMMA inputs initialize their representative parameters in the trim subroutine. Angle-of-attack is varied as required to meet the desired load factor. If a TCTF value is nonzero, flight path angle, gamma, is varied so that thrust equals drag if required. If TCTF is set to 0.0, thrust coefficient is varied so that thrust equals drag at the TGAMMA flight path angle. If the thrust coefficient limits of 0.0 or 0.16 are reached, gamma is varied as required. These trim opera-tions are also valid if TPHI is nonzero, which will cause a trim in a coordinated turn at the specified TPHI bank angle.

The magnitude of the peak vertical gust is set by the GVEL value, with the starting time for the gust calculation set by T START. (If no gust is desired, VGEL is set to 0.00.) If a 1-cosine gust is desired, T END is set to 0.0. The 1-cosine gust calculation determines the duration of the gust based on airspeed. If a continuous NASA Dryden gust input is desired, T END is set to the desired end time for the gust inputs.

Full capability to vary the pilot model gains is provided by the CMD OPTION inputs. This includes the lead, lag, and delay terms, as well as the ratio of proportional to integral error feedback. As discussed below, nominal values are shown in the example input run file. Care should be taken when changing these values, as significant changes in response can occur for small changes.

2.5 Running the Program

With the input run file defined and saved, the program may now be executed. Upon execution, the program will initialize and start the trim process. When the trim is completed, a list of trim parameters will be displayed, and the user will be prompted to start the program to calculate the time history response, or abandon the run. If the program is abandoned, the input file parameter list and the trim data will be saved in an TS16XX.TRM file, (where XX is the input run number), and all other output files will be deleted. This feature allows the user to target a specific flight condition for the time history, and use trial and error to ensure it is reached. If the time history is started, a message "TAILSIM program started" is displayed until the program is finished computing the time history response.

3. Program Outputs

When the time history response calculations are completed, the first of 16 pages of 9 plots per page is displayed. A message line at the top of the plot indicates further display options. A one plot per page format may be accessed simply by entering the number of the plot. The plot number is defined from left to right with 1 at the upper left and 9 at the lower right. The 9 plot per page format may then be displayed by entering 10. To view another plot page or exit the plot displays, 88 is entered. The plot page menu is then displayed in addition to the program exit options. A new plot page is then accessed by entering the number for that page.

The minimum tailplane angle-of-attack and load factor are found for each run. The search for the minimum load factor starts after the TMINS input time. These values and the values of other parameters at these minimums are output to the TS16XX.TRM file.

Two program exit options allow for the time history data to be abandoned or saved. If abandoned, all output files except the TS16XX.TRM file are deleted. If the time history data is saved, the program then writes designated parameters to five output files in column format. This data may then be accessed by other plotting packages.

The output files a currently designated as:

C:\DH6DYN\TS16XX.TRM	Trim parameter listing
C:\DH6DYN\TS16XXP1.OUT	First output file listing
C:\DH6DYN\TS16XXP2.OUT	Second output file listing
C:\DH6DYN\TS16XXP3.OUT	Third output file listing
C:\DH6DYN\TS16XXP4.OUT	Fourth output file listing
C:\DH6DYN\TS16XXP3.OUT	Fifth output file listing
C:\DH6DYN\TS16XX.TST	Diagnostic output file (As required)

The output files list all the parameters of the plot pages in the same order with the same names. A typical file contains 27 parameters and TIME. A header line defines the parameter names as defined in VNOUT, with TIME always in the first column. The use of five output files allows reasonable file sizes and functionality with most potting programs.

4. Changing the Aircraft Configuration Model

The TAILSIM program was written in a straight forward manner to facilitate modifications by the user. The expected user modifications are; build up equations, output parameters, plot page parameters, reversible control system, and pilot model. The build up equations will change for different aircraft and different available coefficients. It is assumed that these equations will be available to the user. The desired output parameters may be different or may be desired in different formats. Other pilot model architectures may be desired to investigate the effects of pilot technique on the response of the aircraft.

4.1 Modifying the Buildup Equations

The buildup equations are contained in subroutine AEROFMC. In this subroutine all of the tables of the database are accessed and the coefficients are scaled and combined to produce a total coefficient for all six axes. Additional parameters specific to the buildup equations are calculated as required. Any other calculations using the coefficients are performed in this subroutine if possible. These summation equations are readily programmed using the available variables. Any modi-fications to the input or output of AEORMFC that may be required for steady state conditions, as required for trimming, are programmed in subroutine FMTRM. This structure minimizes programming errors by providing one source for the complete buildup equations.

To simplify the use of variables in the program, all variables that are passed between any subroutine are contained in an include file. This file is currently named C:\DH6DYN\TAILSM16.COM, and is inserted into all the subroutines with a Fortran include statement. Appendix A contains the current include file and Appendix B a partial list of the internal variables of the program.

To obtain coefficients from the database the TBLOOK subroutine is used. Before calling this subroutine, the variables X1IN through X5IN must be assigned. The TBLOOK subroutine assumes that the current values of X1IN through X5IN correctly define the independent parameter values for the table that is being accessed. All variable names in the tables are used for reference only. Table names from ATAB01 to ATAB99, and BTAB01 to DTAB99 are allowed, and can be inserted in the database in any order. The format of the tables is fixed. The table name, table output name, and extrapolation flag are included in the call to the TBLOOK program. The extrapolation flag can be input as 0, 1, or EXTRAP, the global extrapolation parameter. An example file listing showing the use of the TBLOOK subroutine is shown in figure 4.1.1.

```
X1IN = VALPHA*RTD
X2IN = CTHRST
X3IN = DFLAP
X4IN = FICE
X5IN = 0.0
CALL TBLOOK('BTAB81', 0, CL00T)
CALL TBLOOK('BTAB82', 0, CD00T)
CALL TBLOOK('BTAB83', 0, CM00T)
```

Figure 4.1.1—Example Use of TBLOOK Subroutine Call

4.2 Modifying Output Parameters

The time history output formats are contained in the VNOUT, PSAVE and POUT subroutine. These are straight forward and changes are readily implemented if desired. The trim output formats are contained in the SMTRIM subroutine.

The output filenames are contained in the MAIN program. A naming hierarchy was established for the current program as noted in section 3. Straight forward WRITE and FORMAT statements are use to set the output file names to a unit number. This unit number is then used as required in WRITE and READ statements. Any valid Fortran file naming convention may be used for the file names.

The subroutine PPLOT contains the main display functions. A single set of arrays are accessed to generate a plot page. These arrays are filled with different parameters obtained from different arrays in the PSAVE subroutine. These arrays are indicated by their respective page numbers in this subroutine. They are dimensioned in the include file, allowing name changes or additions to be readily implemented.

In PPLOT, the programming to set the parameters displayed on each page are indicated by their respective page numbers. The output parameters are determined by setting the values of the DATPLOT array to those of the desired array from the PSAVE subroutine. The labeling for the plots is accomplished directly by using the two dimensional array of names set in VNOUT.

Additional pages can be added by duplicating the programming for each page in PPLOT, and adding a new array to VNOUT, PSAVE and the include file. Loop and GO TO counters must be changed as required. To change or add a title for the plot, programming in the MAIN program must be modified. This programming is clearly indicated near the end of the MAIN program, and consists of straight forward Fortran print statements. Note that the range of the ISTORE parameter is checked in an IF statement below this programming, which must be modified as well.

5. Modifications to the Reversible Control, Pilot, and Gust Models

The reversible elevator control model, pilot model, and gust models were implemented in the FCSYS subroutine. The pertinent equations and parameters used in this subroutine are shown below. The current values of constants that will need to be modified to obtain different dynamics are also given. Only a basic background description of each model is given

The constant parameters of the reversible control system model were chosen based on analysis of available information on the Twin Otter geometry, and to match characteristics in the flight test data. These parameters would change for a different aircraft configuration, or to "tweek" the existing dynamics. The constant parameters of the pilot model were determined from a range of typical values, and to obtain acceptable simulation responses over a wide range of flight con-ditions. The gust model dynamic and constants were implemented directly from their indicated sources. These sources are listed here as the gust models were not implemented for the dissertation.

5.1 Reversible Elevator Control Model

As noted in the introduction, the aircraft of interest in this study have reversible control systems. These systems typically use cables to directly connect the stick to the elevator. Due to the length of the cables, cable stretch can be noticeable to the pilot. To model this type of control system, a simple description was chosen. The cable was modeled as a spring, driven by pilot stick force and elevator hinge moment. Both the stick and the elevator were assumed to have mass and inertia. To simulate damping of the cable due to pilot action and frictional effects, values of damping were chosen to be –20.0 for the stick and –4.0 for the elevator. All of these constants are set in the SIMINT initialization subroutine.

The final dynamic equations as implemented in the program are:

WSDOT = -STKDMP*WSTCK + ASTCK/AIS*FCABLE + FSTCKC*BSTCK/AIS
WEDOT = -ELVDMP*WELEV + AELEV/AIE*FCABLE + DMHT/AIE
FCDOT = -AKC*ASTCK*WSTCK - AKC*AELEV*WELEV
FSTCK = FCABLE*ASTCK/BSTCK + FSTCKC
DMHT = CMHT*QDP*SECE*QTR + DMHTRIM
DELEV = DELEVT + DELEVC*RTD
DSTCK = DSTCKT + DSTCKC*RTD

The parameter description and their values are shown below:

AELEV = 0.25	Length of elevator control arm, ft
AIE = 1.08	Elevator inertia, slug-ft^2
AIS = 0.44	Control stick inertia, slug-ft^2
AKC = 5890.0	Cable spring constant, lb/in
ASTCK = 0.50	Length of control stick pivot to cable, ft
BSTCK = 2.383	Length of control stick, ft
DELEV	Total calculated elevator deflection, deg
DELEVC	Calculated elevator deflection, rad
DELEVT	Trim elevator deflection, deg
DMHT	Elevator hinge moment, ft-lb
DMHTRIM	Trim elevator hinge moment, ft-lb
DSTCK	Total calculated stick deflection, deg
DSTCKC	Calculated stick deflection, rad
DSTCKT	Trim stick deflection, deg
ELVDMP = 4.0	Damping coefficient for elevator
FCABLE	Cable force, lb
FSTCKC, FSTCK	Commanded stick force and calculated stick force, lb
QDP	Dynamic pressure, lb/ft^2
QTR	Tailplane dynamic pressure ratio
SECE = 57.3	Elevator planform area, ft^2
STKDMP = 20.0	Damping coefficient for stick
WELEV, WEDOT	Stick angular rate and acceleration, rad/sec, rad/sec^2
WSTCK, WSDOT	Elevator angular rate and acceleration, rad/sec, rad/sec^2

5.2 Pilot Model

In classical form a pilot model is a transfer function that consists of some combination of a pure gain, delay term, lead term, and one or more lag terms. The delay term represents a reaction time delay while one lag term corresponds to a neuromuscular lag, neither of which are adjustable by the pilot. However, human pilots are very adaptable, and may vary their performance to match the desired response. This is represented by a lead and lag term with adjustable time constants in the pilot model. The form of the pilot model as implemented in the ALFCS subroutine is:

XP1DOT = XP2
XP2DOT = PMG21*XP1 + PMG22*XP2 + QGAIN*PMG2E*QDTOT + PMG2E*ASFBT
DEPILOT =PMGC1*XP1 + PMGC2*XP2 + QGAIN*PMGCE*QDTOT + PMGCE*ASFBT
DELEVP = DELEVT + DEPILOT*RTD

Inputs and gains are defined below:

ASFBED = ((VINFTRM –VINF)*0.1) – ASFBE)*0.2
ASFBEK = (VINFTRM – VINF)*0.1
ASFBT = (ASFBED*APFR + (1.0 – APFR)*ASFBEKI))/RTD
DMHTP = CMHTP*QDP*SECE*QTR + DMHTRIMU
FSTCKC = SEGEAR*DMHTP
QDES = G*(NLFC – 1.0)/VINF
QDESE = QDES – QR
QDTOT = QDESE*QPFR + (1.0 – QPFR)*QDESEI
QGAIN = (ZAOA*MQT – MAOAT*VINF)/(ZDE*MAOAT – ZAOA*MDET)

The description and values for the unique pilot model parameters are shown below:

ASFBED	Filtered airspeed rate, scaled, kts/s
ASFBEK	Airspeed error, scaled, kts
ASFBEKI	Integrated scaled airspeed error, kts
CMHTP	Uniced elevator hinge moment coefficient
DEPILOT	Elevator command, rad
DELEVP	Total commanded elevator, deg
DELEVT	Trim elevator, deg
DMHTP	Uniced commanded elevator hinge moment, ft-lb
DMHTRIMU	Trim elevator uniced hinge moment, ft-lb
MAOAT	Dimensional pitching moment slope
MDET	Dimensional elevator effectiveness
MQT	Dimensional pitching moment due to pitch rate
NLFC	Commanded load factor, g
QGAIN	Gain, pitch rate to elevator deflection
QDES	Commanded pitch rate, rad/sec
QDESE	Commanded pitch rate error, rad/sec
QDESI	Integrated pitch rate error, rad
SEGEAR = 0.8392	Stick force to elevator gearing
XP1,XP1DOT,XP2,XP2DOT	Canonical form variables and their derivatives
ZAOA	Dimensional Z-force slope
ZDE	Dimensional Z-force due to elevator deflection

Note that the airspeed feedback is only used when ICOPT = 4, but is included here for completeness.

The gains shown in the above equations are obtained from the following definitions and parameters, with nominal values indicated:

PMTLG	$T_I = 0.5$ – Lag time constant, sec
PMTLD	$T_L = 0.4$ – Lead time constant, sec
PMTD	$\tau = 0.12$ – Time constant for pilot reaction delay, sec
PMG21	$-1.0/(T_I*\tau/2) = -33.3$
PMG22	$-(T_I + \tau/2)/(T_I*\tau/2) = -18.67$
PMG2E	$1.0/(T_I*\tau/2) = 33.3$
PMGC1	$1.0 + T_I/T_L = 1.8$
PMGC2	$T_L - \tau/2 + T_L/T_I*(T_I+\tau/2) = 0.788$
PMGCE	$T_I/T_L = 0.8$

As noted above, the constants indicated in this section resulted in acceptable simulation responses. If changes are desired, they should be done judiciously, and some trial-and-error should be expected. Since changes are probable, the lead, lag, delay, and proportional to integral ratios are included as parameters in the input run file.

5.3 Gust Models

Two gust models were implemented in TAILSIM. The simplest is a single pulse 1-cosine gust that represents a sharp edged gust. It is referenced in Federal Aviation Regulations, Subpart C—Structure, in determining the structural requirements for aircraft.

The second gust model is a continuous implementation of the Dryden PSD function to represent continuous atmospheric turbulence. Both gust models are taken from Reference 1. When implementing the Dryden gust, a white noise generator is needed. This has been approximated using a random function, RAN1, from reference 2, which is stated to have uniform properties.

When implementing gusts using data obtained from steady state conditions, the inability of the aerodynamic forces to respond instantaneously to rapid changes in angle of attack must be considered. To account for this delay in aerodynamic reaction, the Kussner function has been developed for aeroelastic analysis. The Kussner function as defined in reference 3 has been implemented and applied to the gust velocity generated by the above models to create an effective gust velocity. Finally, to account for the difference in time that the gust reaches the wing and tailplane as the aircraft flies through the gust, a pade delay is applied to the effective gust velocity to determine the effective gust velocity acting at the tailplane.

The sharp edged gust implementation is:

```
SARG = PI*VINF*(TIME–TGUSTS)*2.09/GUSTL
IF(SARG .LE. 2.0*PI ) WGUST = GUSTV/2.0*(1 - COS(SARG))
```

Parameters are defined below:

GUSTL	Gust length = 25*CREF, ft
GUSTV	Input gust amplitude, ft/sec
SARG	Gust angle, rad
WGUST	Instantaneous gust velocity, ft/sec

The Dryden gust implementation is:

```
SQWKW = SQRT(3.0*WSIG*WSIG*VINF/(WLW*PI))
BETAW = VINF/(1.73*WLW)
WLTHW = VINF/WLW
VRAND = RAN1(IDUM)
WGRAND = GUSTV*(VRAND – 0.5)*2.0
WGDRY1D = WGDRY2
WGDRY2D = –2.0*WLTHW*WGDRY2 – WLTHW*WLTHW*WGDRY1 + WGRAND
WGUST = SQWKW*WGDRY2 + SQWKW*BETAW*WGDRY1
```

Specific parameters are defined below;

BETAW	Scaled turbulence frequency, 1/sec
VRAND	Random function output between 0 and 1
WGDRY1,WGDRY1D	Generalized variable and derivative in realization
WGDRY2,WGDRY2D	Generalized variable and derivative in realization
WGRAND	Random gust velocity, ft/sec
WLTHW	Turbulence frequency, 1/sec
WLW	Turbulence scale length = 1750 ft. for thunderstorms
WSIG	Turbulence intensity = 21 ft/sec. for thunderstorms

The Kussner function and Pade delay implementation are:

```
TKDEN = 2.0*VINF
TK5 = 4.35*CREF/TKDEN
TK6 = 7.69*CREF/TKDEN
TK7 = CREF/TKDEN
WGEF1D = WGEF2
WGEF2D = (– (TK6+TK7)*WGEF2 – WGEF1 + WGUST)/(TK6*TK7)
WGEF = WGEF1 + TK5*WGEF2
WGEFD = WGEF1D + TK5*WGEF2D
ARGEF = ATAN2(WGEF,VU)
ARGEFD = ATAN2(WGEFD,VU)
TCAT = LTAIL/(VINF*2.0)
WGEFLD = (WGEF – TCAT*WGEFD – WGEFL)/TCAT
ATGEFL = ATAN2(WGEFL,VU)
```

The parameters are:

ARGEF,ARGEFD	Effective gust angle of attack and rate rad, rad/s^2
ATGEFL	Effective gust tailplane angle of attack, rad/sec
TCAT	Pade delay time constant, sec
TKDEN	Time constant scale factor
TK5,TK6,TK7	Time constants, 2 poles, 1 zeros, sec
WGEF,WGEFD	Effective gust velocity and rate, ft/sec, ft/s^2
WGEFL,WGEFLD	Tailplane effective gust velocity and rate, ft/sec, ft/s^2
WGEF1,WGEF1D	Generalized variable and derivative in realization.
WGEF2,WGEF2D	Generalized variable and derivative in realization.

References

1. McLean, D., *Automatic Flight Control Systems*, Prentice Hall, 1990.
2. Press, W.H., Teukolsky, S.A., Vetterling, W.T., Flannery, B.P., *Numerical Recipes in Fortran 77, The Art of Scientific Computing, Second Edition*, Cambridge University Press, 1992.
3. Van der Vart, J.C., "Effects of Aerodynamic Lags on Aircraft Responses," AGARD CP–386, 1985, pp. 33-1–33-11.

Appendix A

TAILSM16.COM Include File Listing

```
C FILENAME: TAILSM16.COM 04-17-99
C
C COMMON BLOCKS FOR ALL SUBROUTINES FOR TAILSM16 PROGRAM
C
      PARAMETER (NP=4110)
      REAL IXX,IXY,IXZ,IYY,IYZ,IZZ,MACH
      REAL IXX0,IXY0,IXZ0,IYY0,IYZ0,IZZ0
      REAL LFTOT,NFTOT,LMTOT,MMTOT,NMTOT,LTAIL
      REAL NX,NY,NZ,NZFC,NLF,NLFC,NF
      REAL MAOA,MQ,MDE,MAOAT,MQT,MDET
C
      CHARACTER*12 VLBL
C
      COMMON/PROGA1/AINTA(50,4),DATLDP(9,NP),
     1               DATA1(NP),DATPLOT(9,NP),
     2               DATPLT1(9,NP),DATPLT2(9,NP),DATPLT3(9,NP),
     3               DATPLT4(9,NP),DATPLT5(9,NP),DATPLT6(9,NP),
     4               DATPLT7(9,NP),DATPLT8(9,NP),DATPLT9(9,NP),
     5               DATPLT10(9,NP),DATPLT11(9,NP),DATPLT12(9,NP),
     6               DATPLT13(9,NP),DATPLT14(9,NP),DATPLT15(9,NP),
     7               DATPLT16(9,NP),
     8               COEFFO(8,NP),ALPHA(NP),TIMEA(NP),
     9               VLBL(16,9)
C
      COMMON/PROGC1/IRUN,ISCRN,IKEYB,TIME,TMAX,DT,IMAX,NPTS,ITHIST,
     1               IRPT,PI,RTD,DTR,T0
C
      COMMON/PROGV2/GW,GW0,DGW,SREF,CREF,SPAN,FNPODM,CFG2,
     1               IXX,IXY,IXZ,IYY,IYZ,IZZ,
     2               IXX0,IXY0,IXZ0,IYY0,IYZ0,IZZ0,
     3               ALT,MACH,TCTF,FCND1,FCND2,FCND3,SCDUM,SCTST,
     4               G,UGC,PSL,TSL,RSL,
     5               XCG0,YCG0,ZCG0,DXCG,DYCG,DZCG,XCG,YCG,ZCG,
     6               XCGDB,YCGDB,ZCGDB,
     7               XAARM,YAARM,ZAARM,DBXARM,DBYARM,DBZARM
C
      COMMON/DBCOEF/CZ00, CZAOA, CZQ, CZDE,
     1               CX00, CXAOA, CXAOA2, CXQ, CXDE,
     2               CMAOA, CMQ, CMDE, CMAOAT, CMQT, CMDET,
     3               CLB, CLP, CLR, CLDA, CLDR,
     4               CNB, CNP, CNR, CNDA, CNDR,
     5               CYB, CYP, CYR, CYDA, CYDR,
     6               CMMQD, CFZQD, CFXQD, CMHTRIM,
     7               CL00,CD00,CL00T,CD00T,CZ00T,CX00T,CM00T
C
      COMMON/COM/COMM(2)
```

```
C
      COMMON/EOM1/DX,DY,DZ,VU,VV,VW,PR,QR,RR,PHIR,THETAR,PSIR,
     1            GAMMAR,GAMMAD,ALPHAR,ALPHAD,BETAR,BETAD,
     2            NF,NZ,NLF,NX,NY,PHID,PSID,VUID,
     3            VDOT,ALPHARD,BETARD,ALPHARM,
     4            DXD,DYD,DZD,VUD,VVD,VWD,PRD,QRD,RRD,
     5            PHIRD,THETARD,PSIRD,PSIRDT,PHIDT,PHIRT
C
      COMMON/FMS1/LFTOT,NFTOT,ZFTOT,DFTOT,XFTOT,YFTOT,
     1            LMTOT,MMTOT,NMTOT,FNPM,THRUST,
     2            VINF,VINFK,VINFEK,TEMP,PRESS,RHO,SOS,QDP,
     3            VINFCK,CFL,CFD,CFZ,CFX,CMM,CML,CMN,CFY,
     4            CLMIN,CDMIN,CDK1,CDK2,
     5            DFLS,DFDS,DFZB,DFXB,DFYS,DMMS,DMLB,DMNB
C
      COMMON/TRIM1/CFZTRM,CFXTRM,CZ00TRM,CX00TRM,CM00,
     1            TOLU,TOLV,TOLW,TOLP,TOLQ,TOLR,CMMTRM,
     2            AOATRM,DMHT,DMHTRIM,VTHETAT,XFTOTT,VTHETAE,
     3            VTRIM,TRMMACH,TRMDFLAP,MCOUNT,TRMCT,ATSTALL,
     4            ATHMBRK,GAMMADT,VINFTRM
C
      COMMON/TBL1/X1IN,X2IN,X3IN,X4IN,X5IN,EXTRAP
C
      COMMON/PROGV3/DELEV,DFLAP,VAR4,VAR5,DAIL,DRUD,DHZT,
     1            TVECT,TFACT,DLEF,DTEF,ANGTHR,PLA,
     2            DAILT,DAILC,DRUDT,DRUDC,DELEVT,DELEVC,
     3            CTHRSTC,CTHRSTT,GAMMART,CTHRST,FICE
C
      COMMON/TAIL1/EDW,QTR,STAIL,CTAIL,LTAIL,HTAIL,
     1            CFZT,CFXT,CFLT,CFDT,CMMT,CMHT,CMHTU,
     2            ALPHARL,CMMAT,CMMADL,
     3            AOATA,AOATQ,AOAT,CFXA2L,EDWL,CMDAOA,
     4            CFZHT,CFXHT,CMMHT,EDPWR,SEDPWR
C
C     COMMON/GUST1/TGUSTS,TGUSTE,GUSTV,VAGD,VWG,VWGD,
C    1            ARGEFDD,ARGEFD,ARGEF,ALPHARG,ARGD
C
      COMMON/GUST1/TGUSTS,TGUSTE,GUSTV,WGUST,VRAND,WGRAND,
     1            ARGEFDD,ARGEFD,ARGEF,ALPHARG,ARGD,
     2            WGEF1D,WGEF1,WGEF2D,WGEF2,WGEFD,WGEF,
     3            WGEFLD,WGEFL,TKDEN,TK5,TK6,TK7,
     4            WLW,WSIG,SQWKW,BETAW,WLTHW,
     5            WGDRY1D,WGDRY1,WGDRY2D,WGDRY2,WGDRY
C
      COMMON/ALAGS1/DEDA,EDWT,EDWTL,EDWTLD,ATGEFL,ATGEFLD
C
      COMMON/STCK1/FSTCK,FSTCKC,DSTCKDD,DSTCKD,DSTCKT,DSTCK,
     1            DSTCKC,DELEVDD,DELEVD,DMHD,FSTCKA,
     2            FSTCKP,FCABLE,WELEV,WSTCK,STKDMP,ELVDMP,
     3            WSDOT,WEDOT,FCDOT,ASTCK,BSTCK,NZFC,
     4            AKC,AIE,AIS,AELEV,
     5            NLFC,XP1,XP1DOT,XP2,XP2DOT,QDESE,QDESEI,QDES,
     6            ICOPT,X1QDOT,X1Q,DELEVP,CMHTP,DMHTP,QGAIN,
```

```
     7                MAOA,MQ,MDE,ZAOA,ZDE,DMHTU,DMHTRIMU,
     8                ASFBED,ASFBEKI,ASFBE,ASFBEK,QPFR,APFR,QAPFB,
     9                MAOAT,MQT,MDET,PMG21,PMG22,PMG2E,
     1                PMGC1,PMGC2,PMGCE,PMTLG,PMTLD,PMTD
C
      COMMON/INTLIM/ELVMAX,ELVMIN,STKMAX,STKMIN
C
      COMMON/QDOTLIM/CFZTMN,CFZTMP,CFXTMN,CFXTMP,CMMTMN,CMMTMP,
     1                  CMHTMN,CMHTMP,CFZDMN,CFZDMP,CFXDMN,CFXDMP,
     2                  CMMDMN,CMMDMP,QRDTMN,QRDTMP
C
      COMMON/TBLACCS/DTA(20000),LOCALE(400)
```

Appendix B

Partial Internal Parameter Listing

ALPHAD	Angle-of-attack, deg
ALPHAR	Angle-of-attack, rad
ALPHARD	Angle-of-attack rate, rad/sec
ALT	Altitude, ft
AOAT	Tailplane angle of attack, rad
AOATA	Aerodynamic contribution to tailplane angle of attack, rad
AOATQ	Pitch rate contribution to tailplane angle of attack, rad
BETAD	Angle-of-sideslip, deg
BETAR	Angle-of-sideslip, rad
BETARD	Angle-of-sideslip rate, rad/sec
CD00	Total aircraft trimmed drag coefficient
CD00T	Tailplane contribution to trimmed drag coefficient
CFD	Total drag coefficient
CFDT	Tailplane drag coefficient
CFL	Total lift coefficient
CFLT	Tailplane lift coefficient
CFX	Total axial force coefficient
CFXT	Tailplane axial force coefficient
CFY	Total sideforce coefficient
CFZ	Total force coefficient in Z-axis direction
CFZQ	Total aircraft Z-force due to pitching moment
CFZQD	Tailplane contribution to Z-force due to pitching moment
CFZT	Tailplane force coefficient in Z-axis direction
CL00	Total aircraft trimmed lift coefficient
CL00T	Tailplane contribution to trimmed lift coefficient
CMAOA	Built-up total aircraft pitching moment slope
CMDE	Tailplane moment coefficient
CMHT	Tailplane hinge moment coefficient
CMHTU	Uniced tailplane hinge moment coefficient
CML	Total rolling moment coefficient
CMM	Total pitching moment coefficient
CMMADL	Pitching moment coefficient - summed incremental angle of attack times local pitching moment slope
CMMAT	Tailplane contribution to built-up pitching moment slope
CMMT	Tailplane pitching moment coefficient
CMN	Total yawing moment coefficient
CMQ	Total aircraft pitching moment due to pitch rate
CMQD	Tailplane contribution to pitching moment due to pitch rate
CM00T	Tailplane contribution to trimmed moment coefficient
CREF	Reference chord length, MAC, ft
CTAIL	Tailplane chord, ft
CTHRST	Thrust coefficient
CTHRSTC	Delta commanded thrust coefficient from trim
CZAOA	Total aircraft Z-force slope
DAIL	Aileron deflection, deg
DEDA	Derivative of downwash angle with respect to angle of attack
DELEV	Elevator deflection, deg
DMHT	Tailplane hinge moment, ft-lbs
DMHTU	Uniced tailplane hinge moment, ft-lbs
DRUD	Rudder deflection, deg

DSTCK	Stick angular deflection, deg
DSTCKC	Calculated commanded stick deflection, deg
DFLAP	Flap deflection, deg
DFTOT	Total drag force, lbs
DMHT	Elevator hinge moment, ft-lbs
DX,DXD	Velocity, acceleration in Earth fixed X axis direction, ft/sec, ft/sec^2
DY,DYD	Velocity, acceleration in Earth fixed Y axis direction, ft/sec, ft/sec^2
DZ,DZD	Velocity, acceleration in Earth fixed Z axis direction, ft/sec, ft/sec^2
EDW	Aerodynamic contribution to downwash angle, deg
EDWPWR	Power contribution to downwash angle, deg
EDWT	Total aerodynamic and power downwash angle, deg
EDWTL	Total lagged downwash angle, deg
FNPM	Net thrust, lbs
GAMMAD	Flight path angle, deg
GAMMAR	Flight path angle, rad
GW	Aircraft gross weight, lbs
HTAIL	Tailplane height above reference, CG, ft
IXX	Moment of inertia about X axis, slug-ft^2
IYY	Moment of inertia about Y axis, slug-ft^2
IZZ	Moment of inertia about Z axis, slug-ft^2
IXY	Product of inertia in XY axis, slug-ft^2
IXZ	Product of inertia in XZ axis, slug-ft^2
IYZ	Product of inertia in YZ axis, slug-ft^2
LFTOT	Total lift force, lbs
LMTOT	Total rolling moment, ft-lbs
LTAIL	Reference distance from wing to tail 1/4 chord, ft
MACH	Mach number
MMTOT	Total pitching moment, ft-lbs
NFTOT	Total normal force, lbs
NF	Normal acceleration, g
NLF	Load factor, g
NLFC	Commanded load factor, g
NMTOT	Total yawing moment, ft-lbs
NX	Acceleration in body axis x-direction, g
NY	Acceleration in body axis y-direction, g
NZ	Acceleration in body axis z-direction, g
PHID	Bank angle, deg
PHIR	Bank angle, rad
PHIRD	Rate of change of bank angle rad/sec
PSID	Heading angle, deg
PSIR	Heading angle, rad
PSIRD	Rate of change of heading angle, rad/sec
PR	Roll rate, rad/sec
PRD	Roll angular acceleration, rad/sec^2
QDESI	Integrated pitch rate error, rad
QGAIN	Gain, pitch rate to elevator deflection
QDP	Dynamic pressure, lb/ft^2
QR	Pitch rate, rad/sec
QRD	Pitch angular acceleration, rad/sec^2
QRDTMN	Pitch acceleration with minimum elevator deflection, rad/sec^2
QRDTMP	Pitch acceleration with maximum elevator deflection, rad/sec^2
QTR	Tailplane dynamic pressure ratio
RR	Yaw rate, rad/sec
RRD	Yaw angular acceleration, rad/sec^2

SEDPWR	Power factor in downwash due to power effects
SPAN	Wingspan, ft
SREF	Wing Reference area, ft^2
STAIL	Tailplane reference area, ft^2
THETAR	Pitch angle, rad
THETARD	Rate of change of pitch angle, rad/sec
THRUST	Thrust, lbs
VDOT	Rate of change of airspeed, ft/sec^2
VINF	Airspeed, ft/sec, and
VINFK	Airspeed, knots
VINFEK	Equivalent airspeed, knots
VINFCK	Calibrated airspeed, knots
VU,VUD	Velocity, acceleration in body X axis direction, ft/sec, ft/sec^2
VV,VVD	Velocity, acceleration in body Y axis direction, ft/sec, ft/sec^2
VUID	Velocity in earth oriented axis system, ft/s
VW,VWD	Velocity, acceleration in body Z axis direction, ft/sec, ft/sec^2
WELEV,WEDOT	Elevator deflection, rate, rad, rad/sec
WSTCK,WSDOT	Stick angular deflection, rate, rad, rad/sec
XFTOT	Total axial force, lbs
YFTOT	Total sideforce, lbs
ZFTOT	Total body axis lift force, lbs

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 2000

3. REPORT TYPE AND DATES COVERED
Final Contractor Report

4. TITLE AND SUBTITLE
TAILSIM Users Guide

5. FUNDING NUMBERS
WU-711-21-23-00
NAG3-2007

6. AUTHOR(S)
Dale W. Hiltner

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Ohio State University Research Foundation
1960 Kenny Road
Columbus, Ohio 43210-1063

8. PERFORMING ORGANIZATION REPORT NUMBER
E-12512

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA CR—2000-210560

11. SUPPLEMENTARY NOTES

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12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Categories: 08 and 61 Distribution: Nonstandard
Available electronically at http://gltrs.grc.nasa.gov/GLTRS
This publication is available from the NASA Center for AeroSpace Information, 301-621-0390.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

The TAILSIM program uses a 4th order Runge-Kutta method to integrate the standard aircraft equations-of-motion (EOM). The EOM determine three translational and three rotational accelerations about the aircraft's body axis reference system. The forces and moments that drive the EOM are determined from aerodynamic coefficients, dynamic derivatives, and control inputs. Values for these terms are determined from linear interpolation of tables that are a function of parameters such as angle-of-attack and surface deflections. Buildup equations combine these terms and dimensionalize them to generate the driving total forces and moments. Features that make TAILSIM applicable to studies of tailplane stall include modeling of the reversible control system, modeling of the pilot performing a load factor and/or airspeed command task, and modeling of vertical gusts. The reversible control system dynamics can be described as two hinged masses connected by a spring, resulting in a fifth order system. The pilot model is a standard form of lead-lag with a time delay applied to an integrated pitch rate and/or airspeed error feedback. The time delay is implemented by a Pade approximation, while the commanded pitch rate is determined by a commanded load factor. Vertical gust inputs include a single 1-cosine gust and a continuous NASA Dryden gust model. These dynamic models, coupled with the use of a nonlinear database, allow the tailplane stall characteristics, elevator response, and resulting aircraft response, to be modeled. A useful output capability of the TAILSIM program is the ability to display multiple post-run plot pages to allow a quick assessment of the time history response. There are 16 plot pages currently available to the user. Each plot page displays 9 parameters. Each parameter can also be displayed individually, on a one plot-per-page format. For a more refined display of the results the program can also create files of tabulated data, which can then be used by other plotting programs. The TAILSIM program was written straightforwardly assuming the user would want to change the database tables, the buildup equations, the output parameters, and the pilot model parameters. A separate database file and input file are automatically read in by the program. The use of an include file to set up all common blocks facilitates easy changing of parameter names and array sizes.

14. SUBJECT TERMS
Aircraft icing; Tailplane icing; Stability and control; Flight dynamics; Flight simulation

15. NUMBER OF PAGES
27

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102