Public Domain Computer Programs for the Aeronautical Engineer

(Last updated September 2, 2025 by Ralph Carmichael, PDAS)

For many years the Air Force, Navy, NASA and educational institutions have sponsored the development of computer software for the use of aeronautical engineers and aviation technicians. Public Domain Aeronautical Software's purpose is to make this treasure house available to the aeronautical community on modern personal computers. The programs come with descriptions and complete source code. Many programs include sample cases (both input and output). You may use the source code in whole or in part in any of your aeronautical studies.
Some of the programs are noted as *work-in-progress*, indicating that they are lacking in instructions or documentation or do not run properly.

CONTENTS OF CURRENT VERSION (16.4)

The bold name following the slash at the end of each description is the name of the folder holding the files for this program.

1. **Wave Drag by Area Rule (D2500)** This is the famous Harris Wave Drag Program from NASA Langley named D2500. It calculates the supersonic zero-lift wave drag of complex aircraft configurations by use of the supersonic area rule. This an extension of the transonic area rule that states that the zero-lift drag of an airplane configuration is the same as that of a body of revolution having the same cross-sectional area distribution. Instead of using a single equivalent body, D2500 calculates a series of bodies, one for each roll angle. The total aircraft configuration wave drag is the integrated average of the equivalent body wave drags through the full roll range of 360 degrees. There are program options that permit the calculation of best fuselage shaping for drag reduction. **/wavedrag**

2. **Subsonic/Supersonic Panel Code (WingBody)** This is the Woodward panel code popularly known as the NASA-Ames WingBody Program. This program estimates the aerodynamics of a simple wing-body-tail combination in subsonic or supersonic flow, as well as calculating wing shape for minimum drag in supersonic cruise. The body is represented by line sources and doublets and the lifting surfaces are represented by source panels and constant pressure panels. Constant pressure panels are placed around the body and the condition of zero flow thru these panels give the wing-body interference effect. This is a PDAS program in the public domain. **/wingbody**

3. **Panel Aerodynamics (PanAir)** This program computes subsonic and supersonic flow about general aircraft configurations using a higher order panel method. In contrast to the low order codes such as WingBody, the source and doublet strengths are variable over the individual panels. This leads to a solution with continuous doublet strength over the surface of the vehicle, thereby eliminating the flow singularities associated with jumps in doublet strength. This is necessitated by the more stringent requirements of supersonic problems. The potential for numerical error is greatly reduced in the PanAir program by requiring the singularity strength to be continuous. It is also this higher order attribute which allows PanAir to be used to analyze flow about arbitrary configurations. To perform an analysis, the aircraft surface is partitioned into several networks of surface grid points. The user also supplies information concerning the freestream onset flow, the angle of attack, and the angle of sideslip. Numerous flow quantities are computed at points on the vehicle surface and at points in space. These include pressure coefficients, total and perturbation values of velocity and mass flux components, total and perturbation potential, local Mach number, and vacuum pressure coefficient. The pressure coefficients on individual panels are fitted with two-dimensional quadratic splines and integrated to obtain the force and the moment coefficients (six components). These coefficients may be output for each panel, for columns of panels, for each network, or for any combination of networks. The user has extensive control over the type and quantity of data that is output during a PanAir Analysis. This program was written by Boeing, under contract to NASA Ames and Langley, USAF and USN). **/panair**

4. **Coordinates of NACA Airfoils** This program computes the coordinates of 4-digit, 4-digit-modified, 5-digit, 6-series, and 16-series airfoils. This is a complete revision of the original NASA Langley programs. The coordinates are shown in various densities, from coarse to very fine. Numerous sample cases are included to help a user to become familiar with the input data. In fact, input files are provided for all of the airfoils shown in the appendices to Abbott and von Doenhoff, *Theory of Airfoil Sections*. Coding is provided to show how all of the tables in Abbott and von Doenhoff have been recomputed to correct numerous typographic errors in the published book. These corrected appendices are posted on the PDAS web site at www.pdas.com. A copy of the NASA program released in 1996 is also included for reference. This is a PDAS program in the public domain. **/naca456**

5. **Digital Datcom** The USAF Data Compendium is a large document describing methods for computing aircraft stability and control characteristics. Many methods are included so as to compute the characteristics of a wide variety of airplane and missile configurations. The Digital Datcom program was developed to automate the process of extracting variables from the hundreds of empirical charts in the printed document. This program was written by a team from Douglas Aircraft under contract to USAF. **/datcom**

6. **Characteristics of the Standard Atmosphere** A procedure is supplied that

computes pressure, density, and temperature from sea level to 1000 km, using the equations of the 1976 Standard Atmosphere. Separate versions are available in Basic, C, Fortran77, Pascal (Delphi), Java, Python, C++, and modern Fortran. Sample programs in each language allow printing an atmosphere table. The tables also show the calculation of speed of sound as well as dynamic and kinematic viscosity. A web-based calculator is included that gives results at an arbitrary altitude without the need for interpolation. The routines from 86 to 1000 km are a contribution of Steve Pietrobon. In addition to the standard atmosphere, routines are provided for both hot and cold days as well as the MIL-standard arctic and tropical days. All of the software in this item is from PDAS in the public domain. A web-based calculator is included that gives results at any altitude without the need for interpolation. **/atmos**

7. **Mean Aerodynamic Chord of an Arbitrary Planform** This program solves for the mean aerodynamic chord of a wing made up of several segments. This is a straightforward coding of the standard equations. The output defines the length of the mean aerodynamic chord as well as its x- and y-positions and the location of the quarter-chord point. This is a PDAS program in the public domain. **/meanaerochord**

8. **Compressible Flow Solvers (FlowCalc and VuCalc)** FlowCalc and VuCalc permit one to compute compressible flow quantities. They calculate isentropic flow, normal shock, oblique shock, flight in the standard atmosphere, Rayleigh and Fanno flows. In addition to direct solutions, they also performs inverse calculations. VuCalc was originally written by Tom Benson of the NASA Glenn Research Center in C++ for a Silicon Graphics workstation. It was converted by PDAS to the Delphi programming environment for use with Microsoft Windows. In 2020-2021, it was converted by PDAS into FlowCalc, a web-based application using HTML, CSS, and Javascript. This web program, called FlowCalc, should run on any device (computer, tablet, smartphone, etc.) that has a JavaScript-enabled web browser. This is a PDAS program in the public domain. **/vucalc**

9. **PanAir Input Preprocessor.** This program allows the user to write a script file in free format that reads a geometry file in LaWGS format and produces a properly formatted input file for PanAir. The column formatted file that is the native input for PanAir is quite efficient, but error prone. The PanAir Input Preprocessor will help you get a correct input file for PanAir. This is a PDAS program in the public domain. **/panin**

10. **Wing and Fuselage Geometry Generator** This program creates wireframe models of wings or bodies that are then used with the PanAir preprocessor to create input files for PanAir, or for visualization with HiddenLine or ThreeView. The wings can have NACA 4-digit airfoils as well as several supersonic airfoils. Bodies that have

been programmed include parabolic, Sears-Haack, von Karman Ogive, ellipsoid, etc. This is a PDAS program in the public domain. **/makewgs**

11. **Potential Flow About Airfoils with Boundary-Layer Coupled One-Way (PABLO)** The PABLO program solves for potential flow about airfoils and computes the boundary layer, thereby giving the solution for flow over the combined airfoil and boundary layer. PABLO has a very nice graphical interface displaying geometry, pressures, and boundary-layer characteristics. This program is from KTH in Sweden, compliments of Christian Wauquiez and Art Rizzi. Pablo is written in Matlab and requires that a version of Matlab (student edition is OK) be installed on the user's machine. **/pablo**

12. **Quiz Program** This program drills the student for simple facts. There are currently quizzes for the aviation phonetic alphabet, Morse code, dimensionless numbers of fluid mechanics and 3-letter airport codes. This is a PDAS program in the public domain. **/quiz**

13. **Flow Field in Supersonic Inlet** This program computes the flow in axisymmetric or two-dimensional inlets designed with smooth compression surfaces and for which the attached bow shock falls outside the cowl lip. The method of characteristics has been used to calculate a uniform field of points and at each of these points the total pressure, Mach number, local flow angle, and static pressure ratio are printed. The numerical procedures used are fully described and a test case is presented. This is a NASA Ames program written by Virginia Sorensen in 1964. In 2024, this program was completely updated and modernized by Zoe Ashford of Cranfield University. The program is compliant with modern Fortran standards and compiles without warning messages on the gfortran compiler. **/inlet**

14. **Arrow Wing Wave Drag and Lift** This module encodes the closed form solution for the wave drag of an arrow or delta wing with sharp edges. It is based on a paper by Arthur Rogers that generalized the classic result of Puckett and Stewart. The tedious equations are coded in a module that should prove easy to use in various aerodynamic programs. Some sample programs illustrate the use of the module. This code is from PDAS in the public domain. **/rogers**

15. **Thermodynamic and transport properties of gases.** The Gas Properties module has been written to calculate the thermodynamic and transport properties of argon, carbon dioxide, carbon monoxide, fluorine, methane, neon, nitrogen, and oxygen. Gas Properties accepts any two of pressure, temperature, or density as input. In addition, entropy and enthalpy are possible inputs. Outputs are temperature, density, pressure, entropy, enthalpy, specific heats, expansion coefficient, sonic velocity, viscosity, thermal conductivity, and surface tension. A special technique is provided to estimate the thermal conductivity near the thermodynamic critical point. GasProperties is coded as a module of Fortran subroutines. The user typically would

write a main program that invoked the module to provide only the described outputs. The GasProperties package was developed to be used with heat transfer and fluid flow applications. It is particularly useful in applications of cryogenic fluids. Some problems associated with the liquefication, storage, and gasification of liquefied natural gas and liquefied petroleum gas can also be studied using GasProperties. This is a NASA Lewis (now Glenn) program by Robert Hendricks, Anne Baron, and Ildiko Peller. **/gasp**

16. **Thermodynamic and transport properties of fluids.** The FLUID program was developed to calculate the thermodynamic and transport properties of pure fluids in both the liquid and gas phases. Fluid properties are calculated using a simple gas model, empirical corrections, and an efficient numerical interpolation scheme. FLUID produces results that are in very good agreement with measured values, while being much faster than older more complex programs (such as GasProperties) developed for the same purpose. A Van der Waals equation of state model is used to obtain approximate state values. These values are corrected for real gas effects by model correction factors obtained from tables based on experimental data. These tables also accurately compensate for the special circumstances which arise whenever phase conditions occur. Viscosity and thermal conductivity values are computed directly from tables. Interpolation within tables is based on Lagrange's three point formula. A set of tables must be generated for each fluid implemented. FLUID currently contains tables for nine fluids including dry air and steam. The user can add tables for any fluid for which adequate thermal property data is available. This is a NASA Lewis (now Glenn) program by Theodore Fessler. **/fluid**

17. **Three-Dimensional Surface Viewer** Viewer is a module of Fortran procedures that will assist in drawing three-dimensional surfaces of the form $z = f(x, y)$ over a rectangular domain. It uses a given algorithm to generate views of the surface after arbitrary rotations about the three spatial axes.The function f and the bounding values for x and y are the inputs. The surface thus defined may be drawn after arbitrary rotations. The output has been converted to gnuplot format. The viewing algorithm is completely described and sample programs are included. Viewer was written by Bruce Canwright and Paul Swigert of NASA Lewis (now Glenn). **/viewer**

18. **Induced Drag from Span Load Distribution.** Advanced aerodynamics textbooks show you how to compute induced drag by Fourier analysis of the span load function. They don't tell you what to do if you only know a few discrete points on the loading function. This procedure is based on a note by Jerry Lundry that allows you to compute the induced drag from the spanwise load distribution when only a few load values are known. This is a PDAS program in the public domain. **/induced**

19. **Wing Shape for Minimum Induced Drag by Vortex Lattice** A new subsonic method has been developed by which the mean camber surface can be determined for trimmed noncoplanar planforms with minimum vortex drag. This method uses a

vortex lattice and overcomes previous difficulties with chord loading specification. This method uses a Trefftz plane analysis to determine the optimum span loading for minimum drag, then solves for the mean camber surface of the wing, which will provide the required loading. Pitching-moment or root-bending-moment constraints can be employed as well at the design lift coefficient. This is a NASA Langley program by John Lamar. **/vlmd**

20. **A Smoothing Algorithm using Cubic Spline Functions** A technique for smoothing arbitrary sets of two-dimensional data is described. Both explicit and parametric cubic spline functions are used in a least-squares algorithm to obtain a least-squares cubic polynomial spline fit for smoothing data. The primary advantage of the least-squares spline technique is that a set of data can be represented by a continuous function with continuous first and second derivatives. This is a NASA Langley program by Robert Smith and Lona Howser. **/fairdata**

21. **Hidden-Line Program** The hidden line program draws perspective views with hidden line removal of an arbitrary configuration defined by wireframe meshes of gridpoints. The configuration description is in the format known as the Langley Wire Frame Geometry Standard (LaWGS). The output is for gnuplot or PostScript. This is the Silhouette program by David Hedgley of NASA Dryden (now Armstrong). **/hlp**

22. **ThreeView** This program produces plan, side, and rear views from the same input file as HiddenLine. This program does not remove hidden lines, but they do not prove to be as confusing as in views from arbitrary angles. The output is for gnuplot or PostScript. This is a PDAS program in the public domain. **/3view**

23. **Programs for Conversion to LaWgs** This is a set of three programs for converting input files for WingBody, WaveDrag, or PanAir into LaWGS format. The resulting file can be used as input for Panin, HiddenLine, or ThreeView. A fourth program that converts input files from the S/HABP program into LaWGS is also included, but must be regarded as a work in progress. These are PDAS program in the public domain. **/2wgs**

24. **Turbulent Skin Friction** This is a simple subroutine and test program for encoding the reference temperature method of computing turbulent skin friction. **/turbsf**

25. **Design and Analysis of Low Speed Airfoils** This is a classic program for the design of 2-D airfoils including the effects of the boundary layer. This is the original version of the airfoil program by Richard Eppler of the University of Stuttgart and Dan Somer of NASA Langley. **/eppler**

26. **Solution of Quartic and Cubic Polynomials with Real Coefficients** Algorithms have been developed and coded to avoid overflow and roundoff errors in computing roots of polynomials with real coefficients, up to quartic order. These subroutines were carefully written by Alfred Morris and William Davis of the Naval

Surface Weapons Center and converted to Fortran 90 by Alan Miller of CSIRO (Australia). **/quartic**

27. **Contour Plotter** The graphical presentation of experimentally or theoretically generated data sets frequently involves the construction of contour plots. The input data for this algorithm is a set of points irregularly distributed over a plane. The algorithm is based on an interpolation scheme in which the points in the plane are connected by straight line segments to form a set of triangles. In general, the data is smoothed using a least-squares-error fit of the data to a bivariate polynomial. To construct the contours, interpolation along the edges of the triangles is performed, using the bivariable polynomial if data smoothing was performed. Once the contour points have been located, the contour may be drawn. This program is from NASA Ames Research Center, but authors are uncredited. **/conplot**

28. **Optimal Aircraft Trajectories for Specified Range (OPTTRAJ)** *work-in-progress* For an aircraft operating over a fixed range, the operating costs are basically a sum of fuel cost and time cost. While minimum fuel and minimum time trajectories are relatively easy to calculate, the determination of a minimum cost trajectory can be a complex undertaking. This computer program was developed to optimize trajectories with respect to a cost function based on a weighted sum of fuel cost and time cost. As a research tool, the program could be used to study various characteristics of optimum trajectories and their comparison to standard trajectories. It might also be used to generate a model for the development of an airborne trajectory optimization system. The program could be incorporated into an airline flight planning system, with optimum flight plans determined at takeoff time for the prevailing flight conditions. The use of trajectory optimization could significantly reduce the cost for a given aircraft mission. The algorithm incorporated in the program assumes that a trajectory consists of climb, cruise, and descent segments. The optimization of each segment is not done independently, as in classical procedures, but is performed in a manner which accounts for interaction between the segments. This is accomplished by the application of optimal control theory. The climb and descent profiles are generated by integrating a set of kinematic and dynamic equations, where the total energy of the aircraft is the independent variable. At each energy level of the climb and descent profiles, the airspeed and power setting necessary for an optimal trajectory are determined. The variational Hamiltonian of the problem consists of the rate of change of cost with respect to total energy and a term dependent on the adjoint variable, which is identical to the optimum cruise cost at a specified altitude. This variable uniquely specifies the optimal cruise energy, cruise altitude, cruise Mach number, and, indirectly, the climb and descent profiles. If the optimum cruise cost is specified, an optimum trajectory can easily be generated; however, the range obtained for a particular optimum cruise cost is not known a priori. For short range flights, the program iteratively varies the optimum cruise cost until the computed range converges to the specified range. For long-range flights,

iteration is unnecessary since the specified range can be divided into a cruise segment distance and full climb and descent distances. This program is from NASA Ames, but author is uncredited. **/opttraj**

29. **Orbiting solar array simulation model** Solar arrays are becoming an increasingly important means of generating power for earth orbiting spacecraft. Applications for solar arrays include providing power for space shuttle payloads and manned space stations. This computer program was developed to simulate the capabilities of earth orbiting arrays. The model used is based on an improved version of a finite-element radiation shape factor subprogram. The inherent simplicity and speed of the original subprogram has been augmented with an improved shadow evaluation technique to provide the user with an efficient array model. The program allows the characteristics of orbiting arrays to be evaluated with a minimum of user effort and computer cost. Input to the program consists of a brief description of the array and the orbital parameters. The orbital parameters are used to determine the direct solar radiation incident on the cells, incident solar radiation reflected to cells from the earth, and the shadowing of any cells. Once the amount of thermal radiation gained and lost by the array is known, the amount of power which can be generated and the temperature of the array is determined. **/solararr**

30. **Renumbering and Indenting Fortran Source Code (Tidy)** After a computer program has been under development for some time, the statement numbers and indentation patterns tend to get out of order and lack consistency. The Tidy program renumbers Fortran programs and indent loops consistently. Tidy can convert variables to upper or lower case. It can also convert Hollerith strings to quote-delimited. (Originally from USAF Weapons Center (Kirtland)) **/tidy**

31. **LineInt and LinIntrp** Solve for intersections of straight lines and compute interpolated points on a straight line. These programs are useful in making configuration layouts. These are PDAS programs in the public domain. **/lineint** and **/linintrp**

32. **Computer Methods for Mathematical Computation** A translation into Modern Fortran of the procedures from the classic textbook *Computer Methods for Mathematical Computation* by Forsythe, Malcolm and Moler. **/fmm**

33. **Analysis of aircraft motions** *work-in-progress* This program was developed by Ames Research Center, in cooperation with the National Transportation Safety Board, as a technique for deriving time histories of the motion of an airplane from Air Traffic Control (ATC) radar records. This technique uses the radar range and azimuth data, along with the downlinked altitude data, to derive an expanded set of data which includes airspeed, lift, attitude angles (pitch, roll, and heading), etc. This technique should prove useful as a source of data in the investigation of commercial airline accidents and in the analysis of accidents involving aircraft which do not have

onboard data recorders (e.g., military, short-haul, and general aviation). The technique used to determine the aircraft motions involves smoothing of raw radar data. These smoothed results, in combination with other available information (wind profiles and aircraft performance data), are used to derive the expanded set of data. This program uses a cubic least-square fit to smooth the raw data. This moving-arc procedure provides a smoothed time history of the aircraft position, the inertial velocities, and accelerations. Using known winds, these inertial data are transformed to aircraft stability axes to provide true airspeed, thrust minus drag, lift, and roll angle. Further derivation, based on aircraft dependent performance data, can determine the aircraft angle of attack, pitch, and heading angle. Results of experimental tests indicate that values derived from ATC radar records using this technique agree favorably with airborne measurements. NASA Ames program by Ralph Bach and Rodney Wingrove. **/atc**

34. **Supersonic Airplane Design** *work-in-progress* This is the famous Carlson-Middleton program for analysis and design of supersonic wings. Over a period of years, NASA-Langley has developed a basic computerized series of supersonic design and analysis methods for aerodynamic configuration studies. The methods are characterized by their reliability in use and input simplicity. The Boeing Company has extended this basic series of methods and combined them into an integrated system of computer programs. The extensions to the methods provide several new features:

    (a) Addition of a near-field (thickness pressure) wave drag program, to complement the existing supersonic area rule program.
    (b) Improved modeling of fuselage in lifting surface design and analysis programs.
    (c) Addition of configuration-dependent loadings in the wing design program, so that the wing design is performed in the presence of fuselage and nacelle effects.
    (d) Addition of pressure limiting terms in the lifting pressure programs, to constrain the linear theory solution.
    (e) A plot module is included in the system to produce configuration drawings, and a common geometry module is used to permit a single geometry input for all programs. A wing pressure module permits summaries of wing pressures at desired conditions.

    The basis of the system is supersonic linearized theory, modified in two respects:

    (a) The Whitham correction to disturbance positioning is used in the propagation of body pressure fields.
    (b) The wing lifting pressure modules contain an optional limiting pressure feature to control the permissible level of upper surface pressure coefficient. In addition, the wing design module contains a further constraint feature to limit the upper surface streamwise pressure gradient.

Superposition is used to build up the theoretical force coefficients of a selected configuration. The goals of the integrated system have been to develop an easily used supersonic design and analysis capability, with recognition of the need for constraints on linear theory methods to provide physical realism, and with inclusion of interactive display for increased design control over optimization cycles. **/tea201**

35. **Modified strip analysis method for predicting wing flutter at subsonic to hypersonic speeds** *work-in-progress* A modified strip analysis has been developed for rapidly predicting flutter of finite-span, swept or unswept wings at subsonic to hypersonic speeds. The method employs distributions of aerodynamic parameters which may be evaluated from any suitable linear or nonlinear steady-flow theory or from measured steady-flow load distributions for the undeformed wing. The method has been shown to give good flutter results for a broad range of wings at Mach number from 0 to as high as 15.3. The principles of the modified strip analysis may be summarized as follows: Variable section lift-curve slope and aerodynamic center are substituted respectively, for the two-dimensional incompressible-flow values of 2 pi and quarter chord which were employed by Barmby, Cunningham, and Garrick. Spanwise distributions of these steady-flow section aerodynamic parameters, which are pertinent to the desired planform and Mach number, are used. Appropriate values of Mach number-dependent circulation functions are obtained from two-dimensional unsteady compressible-flow theory. Use of the modified strip analysis avoids the necessity of reevaluating a number of loading parameters for each value of reduced frequency, since only the modified circulation functions, and of course the reduced frequency itself, vary with frequency. It is therefore practical to include in the digital computing program a very brief logical subroutine, which automatically selects reduced-frequency values that converge on a flutter solution. The problem of guessing suitable reduced-frequency values is thus eliminated, so that a large number of flutter points can be completely determined in a single run. This program by E. Carson Yates is from NASA Langley Research Center. **/flutter**

36. **Grids About Practically Anything (GRAPE)** The GRAPE program computes two-dimensional grids about airfoils and other shapes by the use of Poisson's equation. The ability to treat arbitrary boundary shapes is one of the most desirable characteristics of a method for generating grids, including those about airfoils. In a grid used for computing aerodynamic flow over an airfoil, or any other body shape, the surface of the body is usually treated as an inner boundary and often cannot be easily represented as an analytic function. The GRAPE computer program was developed to incorporate a method for generating two-dimensional finite-difference grids about airfoils and other shapes by the use of the Poisson differential equation. GRAPE can be used with any boundary shape, even one specified by tabulated points and including a limited number of sharp corners. The GRAPE program has been developed to be numerically stable and computationally fast. The GRAPE procedure generates a grid between an inner and an outer boundary by utilizing an

iterative procedure to solve the Poisson differential equation subject to geometrical restraints. In this method, the inhomogeneous terms of the equation are automatically chosen such that two important effects are imposed on the grid. The first effect is control of the spacing between mesh points along mesh lines intersecting the boundaries. The second effect is control of the angles with which mesh lines intersect the boundaries. Along with the iterative solution to Poisson's equation, a technique of coarse-fine sequencing is employed to accelerate numerical convergence. This program is by Reese Sorensen of the NASA Ames Research Center. **/grape**

37. **Mass properties of a rigid structure (MASSPROP)** This computer program was developed to calculate the mass properties of complex rigid structural systems. The program's basic premise is that complex systems can be adequately described by a combination of basic elementary structural shapes. Thirteen widely used basic structural shapes are available in this program. They are as follows: Discrete Mass, Cylinder, Truncated Cone, Torus, Beam (arbitrary cross section), Circular Rod (arbitrary cross section), Spherical Segment, Sphere, Hemisphere, Parallelepiped, Swept Trapezoidal Panel, Symmetric Trapezoidal Panels, and a Curved Rectangular Panel. These elements provide a designer with a simple technique that requires minimal input to calculate the mass properties of a complex rigid structure and should be useful in any situation where one needs to calculate the center of gravity and moments of inertia of a complex structure. Rigid body analysis is used to calculate mass properties. Mass properties are calculated about component axes that have been rotated to be parallel to the system coordinate axes. Then the system center of gravity is calculated and the mass properties are transferred to axes through the system center of gravity using the parallel axis theorem. System weight, moments of inertia about the system origin, and the products of inertia about the system center of mass are calculated and printed. From the information about the system center of mass the principal axes of the system and the moments of inertia about them are calculated and printed. The only input required is simple geometric data describing the size, location, and orientation of each element and the respective material density or weight of each element. This program was written by Reid Hull, John Gilbert, and Phillip Klitch of NASA Langley. **/massprop**

38. **Steady and oscillatory kernel function method for interfering surfaces in subsonic, transonic and supersonic flow** *work-in-progress* The characteristic of transonic flow which causes the greatest difficulty when attempting to apply uniform flow theory to such problems is the presence of shocks imbedded in the flow. Linear theory cannot account for this phenomenon and finite difference approaches often require extremely costly amounts of computer time. This computer program was developed to provide an analysis method based on a kernel function technique which uses assumed pressure functions with unknown coefficients. With this technique, generalized forces can be calculated in unsteady flow and pressure distributions can be obtained in both steady and unsteady flow. Once the aerodynamic matrices are

computed and inverted, they may be saved and used on subsequent problems at very little cost as long as Mach number, reduced frequencies, and aerodynamic geometry remain unchanged. This method should be very useful for design applications where the structural mode shapes change continually due to structural changes and payload variations but the aerodynamic parameters remain constant. In this program, a wing over which the flow has mixed subsonic and supersonic components with imbedded shocks is treated as an array of general aerodynamic lifting surface elements. Each element is allowed to have mutual interference with the other elements. Each element is assigned the appropriate Mach number and its downwash modified accordingly. The Mach number distribution and shock geometry may be obtained either experimentally or by a finite difference technique. The solution proceeds in a manner identical to ordinary aerodynamic interference methods based on a collocation technique. The unknown pressure function is assumed to be composed of a series of polynomials weighted by a user selected weighting function that is characteristic of each lifting surface. The non-planar kernel function is computed using a Mach number and a reduced frequency determined from values at a downwash control point. To link subsonic and supersonic linear theory solutions, it is assumed that the appropriate Mach number for computing downwash at a point is the Mach number at that point and that the reduced frequency is modified according to the local velocity such that the physical frequency is held constant. Thus, the computation procedure becomes a problem of testing the Mach number of the downwash point. If the downwash point is supersonic, the self-induced downwash and all interference effects at that point are computed with the supersonic kernel function. Likewise, if the downwash point is subsonic, the subsonic kernel function is used. The presence of a normal shock is simulated by a line doublet which represents the load induced by shock movement. The appropriate steady or unsteady normal shock boundary conditions are satisfied across the shock along the surface of the wing. This program is by Atlee Cunningham of General Dynamics under contract to NASA Langley. **/kernel**

39. **Aerodynamic lift on wing-body combinations at small angles of attack in supersonic flow (MISLIFT)** *work-in-progress* Two separate and distinct theories are incorporated in this computer program to estimate the lift-induced pressures existent on a wing-body combination. These are (1) the second-order shock-expansion theory, which is used to obtain the lifting pressures on the body alone at small angles of attack, and (2) the linear-theory integral equations, which is used to evaluate the lifting pressures induced by the wing. These equations relate the local surface slope at a point on the lifting surface to the pressure differential at the point and the influence of the pressures upstream of the point. The numerical solution of these equations is effected by treating the wing planform as a composite of elemental rectangles and applying summation techniques to satisfy the necessary integral relations. This program is from the NASA Langley Research Center. **/mislift**

40. **Optimal regulator algorithms for the control of linear systems (ORACLS)** This control theory design package was developed to aid in the design of controllers and optimal filters for systems which can be modeled by linear, time-invariant differential and difference equations. Optimal linear quadratic regulator theory, currently referred to as the Linear-Quadratic-Gaussian (LQG) problem, has become the most widely accepted method of determining optimal control policy. Within this theory, the infinite duration time-invariant problems, which lead to constant gain feedback control laws and constant Kalman-Bucy filter gains for reconstruction of the system state, exhibit high tractability and potential ease of implementation. A variety of new and efficient methods in the field of numerical linear algebra have been combined into the ORACLS program, which provides for the solution to time-invariant continuous or discrete LQG problems. The ORACLS package is particularly attractive to the control system designer because it provides a rigorous tool for dealing with multi-input and multi-output dynamic systems in both continuous and discrete form. The ORACLS programming system is a collection of subroutines which can be used to formulate, manipulate, and solve various LQG design problems. The ORACLS package is constructed in a manner which permits the user to maintain considerable flexibility at each operational state. This flexibility is accomplished by providing primary operations, analysis of linear time-invariant systems, and control synthesis based on LQG methodology. The input-output routines handle the reading and writing of numerical matrices, printing heading information, and accumulating output information. The basic vector-matrix operations include addition, subtraction, multiplication, equation, norm construction, tracing, transposition, scaling, juxtaposition, and construction of null and identity matrices. The analysis routines provide for the following computations: the eigenvalues and eigenvectors of real matrices; the relative stability of a given matrix; matrix factorization; the solution of linear constant coefficient vector-matrix algebraic equations; the controllability properties of a linear time-invariant system; the steady-state covariance matrix of an open-loop stable system forced by white noise; and the transient response of continuous linear time-invariant systems. The control law design routines of ORACLS implement some of the more common techniques of time-invariant LQG methodology. For the finite-duration optimal linear regulator problem with noise-free measurements, continuous dynamics, and integral performance index, a routine is provided which implements the negative exponential method for finding both the transient and steady-state solutions to the matrix Riccati equation. For the discrete version of this problem, the method of backwards differencing is applied to find the solutions to the discrete Riccati equation. A routine is also included to solve the steady-state Riccati equation by the Newton algorithms described by Klein, for continuous problems, and by Hewer, for discrete problems. Another routine calculates the prefilter gain to eliminate control state cross product terms in the quadratic performance index and the weighting matrices for the sampled data optimal linear regulator problem. For cases with measurement noise, duality

theory and optimal regulator algorithms are used to calculate solutions to the continuous and discrete Kalman-Bucy filter problems. Finally, routines are included to implement the continuous and discrete forms of the explicit (model-in-the-system) and implicit (model-in-the-performance-index) model following theory. These routines generate linear control laws which cause the output of a dynamic time-invariant system to track the output of a prescribed model. In order to apply ORACLS, the user must write an executive (driver) program which inputs the problem coefficients, formulates and selects the routines to be used to solve the problem, and specifies the desired output. Several example programs are provided to illustrate the useage. This software was written by Ernest Armstrong of NASA Langley. **/oracls**

41. **Variable dimension automatic synthesis program (VASP)** *work-in-progress* VASP is a variable dimension Fortran version of the Automatic Synthesis Program, ASP. The program is used to implement Kalman filtering and control theory. Basically, it consists of 31 subprograms for solving most modern control problems in linear, time-variant (or time-invariant) control systems. These subprograms include operations of matrix algebra, computation of the exponential of a matrix and its convolution integral, and the solution of the matrix Riccati equation. The user calls these subprograms by means of a Fortran main program, and so can easily obtain solutions to most general problems of extremization of a quadratic functional of the state of the linear dynamical system. Particularly, these problems include the synthesis of the Kalman filter gains and the optimal feedback gains for minimization of a quadratic performance index. VASP, as an outgrowth of the Automatic Synthesis Program, has the following improvements: more versatile programming language; more convenient input/output format; some new subprograms which consolidate certain groups of statements that are often repeated; and variable dimensioning. The pertinent difference between the two programs is that VASP has variable dimensioning and more efficient storage. The documentation for the program contains a VASP dictionary and example problems. The dictionary contains a description of each subroutine and instructions on its use. The example problems include dynamic response, optimal control gain, solution of the sampled data matrix Riccati equation, matrix decomposition, and a pseudo-inverse of a matrix. This subroutine library was written by John White and Homer Lee of the NASA Ames Research Center. **/vasp**

42. **Variable metric algorithm for constrained optimization (VMACO)** This is a program developed to calculate the least value of a non-linear function of N variables subject to general constraints (both equality and inequality). Generally, the first set of constraints is an equality (the target) and the remaining constraints are inequalities (boundaries). The program utilizes an iterative method in seeking the optimal solution. It can be linked with a driver program (examples are provided) which can calculate the values for the real function, constraints, and their first order partials with respect to the controls. The algorithm is based upon a variable metric method presented by M.J.D. Powell and a quadratic programming method by R.

Fletcher. VMACO was written by J. D. Frick of McDonnell Douglas Corp./Houston for the NASA Marshall Spaceflight Center. **/vmaco**

43. **Supersonic wing design and analysis (W12SC3)** *work-in-progress* The W12SC3 program combines source and vortex panel singularity distributions based on the USSAERO program for calculating the linear theory estimate of the configuration aerodynamics. The user can specify Woodward II calculations for arbitrary body models or Woodward I calculations for an interference shell that approximates actual body shape. The Carlson correction for supersonic linear theory wing calculations is applied at wing control points. W12SC3 can perform the following aerodynamic functions:

    (a) full analysis,

    (b) full design,

    (c) full optimization,

    (d) mixed design-analysis, and

    (e) mixed design-optimization.

    Results from W12SC3 include wing camber distribution, surface velocities, pressure coefficients and drag. **/w12sc3**

44. **Rational spline subroutines** Scientific data often contains random errors that make plotting and curve-fitting difficult. The Rational-Spline Approximation with Automatic Tension Adjustment algorithm leads to a flexible, smooth representation of experimental data. The user sets the conditions for each consecutive pair of knots: (knots are user-defined divisions in the data set) to apply no tension; to apply fixed tension; or to determine tension with a tension adjustment algorithm. The user also selects the number of knots, the knot abscissas, and the allowed maximum deviations from line segments. The selection of these quantities depends on the actual data and on the requirements of a particular application. This program differs from the usual spline under tension in that it allows the user to specify different tension values between each adjacent pair of knots rather than a constant tension over the entire data range. The subroutines use an automatic adjustment scheme that varies the tension parameter for each interval until the maximum deviation of the spline from the line joining the knots is less than or equal to a user-specified amount. This procedure frees the user from the drudgery of adjusting individual tension parameters while still giving control over the local behavior of the spline. This software was developed and coded by James R. Schiess and Patricia A. Kerr of NASA Langley. **/rspline**

45. **Transient response of ablating axisymmetric bodies including the effects of shape change (ABAXI)** *work-in-progress* Some of the features of the analysis and the associated program are (1) the ablation material is considered to be orthotropic

with temperature-dependent thermal properties; (2) the thermal response of the entire body is considered simultaneously; (3) the heat transfer and pressure distribution over the body are adjusted to the new geometry as ablation occurs; (4) the governing equations and several boundary-condition options are formulated in terms of generalized orthogonal coordinates for fixed points in a moving coordinate system; (5) the finite-difference equations are solved implicitly; and (6) other instantaneous body shapes can be displayed with a user-supplied plotting routine. NASA Langley program by Lona Howser. **/abaxi**

46. **Sonic Boom Computer Program** This program computes the shock overpressure on the ground caused by a supersonic airplane with arbitrary lift and volume distribution flying through the atmosphere. In addition, effects due to aircraft acceleration, flight path angle and curvature and acoustical cutoff are computed and presented by the program. The analysis is based on ray tube concepts, that is, a small segment of shock is considered to be propagating down a ray tube and its strength and location are determined along the ray path until it strikes the ground. The computer output gives:

    (a) A listing of pertinent input data.

    (b) The location and strength of the shock corresponding to a selected input angle at intermediate computed points between the aircraft and the ground.

    (c) The location and strength of the shock at the shock-ground intersection.

    NASA Langley computer program by Manfred Friedman. **/boom**

47. **Takeoff and Landing Performance Capabilities of Transport Category Aircraft (TOL)** One of the most important considerations in the design of a commercial transport aircraft is the aircraft's performance during takeoff and landing operations. The aircraft must be designed to meet field length constraints in accordance with airworthiness standards specified in the Federal Aviation Regulations. In addition, the noise levels generated during these operations must be within acceptable limits. This computer program provides for the detailed analysis of the takeoff and landing performance capabilities of transport category aircraft. The program calculates aircraft performance in accordance with the airworthiness standards of the Federal Aviation Regulations. The aircraft and flight constraints are represented in sufficient detail to permit realistic sensitivity studies in terms of either configuration modifications or changes in operational procedures.This program provides for the detailed performance analysis of the takeoff and landing capabilities of specific aircraft designs and allows for sensitivity studies. The program is not designed to synthesize configurations or to generate aerodynamic, propulsion, or structural characteristics. This type of information must be generated externally to the program and then input as data. The program's representation of the aircraft data is extensive and includes realistic limits on engine and aircraft operational

boundaries and maximum attainable lift coefficients. The takeoff and climbout flight-path is generated by a stepwise integration of the equation of motion. Special features include options for nonstandard-day operation, for balanced field length, for derated throttle to meet a given field length for off-loaded aircraft, and for throttle cutback during climbout for community noise alleviation. Advanced takeoff procedures for noise alleviation such as programmed throttle and control flaps may beinvestigated with the program. Approach profiles may incorporate advanced procedures such as two segment approaches and decelerating approaches. The landing performance considers the application of wheel brakes, spoilers, and thrust reversers. This program is from NASA Langley Research Center and is known as WEF1041. **/tol**

48. **Transformation of coordinates in Celestial Coordinates** The CELEST procedures relate three basic frames of reference for finding position.

    (a) Equatorial (geocentric) system. The equatorial plane, determined by the plane through the earth's equator, describes a great circle on the celestial sphere.

    (b) Ecliptic (heliocentric) system. The ecliptic plane, determined by the path of the earth's orbit around the sun, also describes a great circle on the celestial sphere. The great circles of the equatorial and ecliptic systems intersect at the First Point of Aries. This is considered to be the (0,0) point for these two systems.

    (c) Galactic system. The galactic plane is formed by the Milky Way. The Milky Way is a relatively flat galaxy and can be adequately represented by a plane.

    Three Fortran subroutines, required to give the coordinate transformations among the equatorial, ecliptic, and galactic systems, have been defined and coded. A brief review of spherical trigonometry is included in the reference NASA document (TM 53943). These coordinate transformations were developed and programmed for use in the determination of the ecliptic (Zodiacal Light) with respect to the other systems for analysis of the S-073/T-027 AAP experiment data.

    NASA Marshall computer program by Nadine Bicket and Gilmer Gary. **/celest**

49. **An Earth-Mars Mission Analysis Program (TOMARS)** *work-in-progress* A rapid, flexible, preliminary Earth-Mars mission-analysis computer program has been developed. The program computes a conic interplanetary trajectory approximation, a noncoplanar impulsive deboost maneuver into a closed orbit about the target planet, and many mission-dependent and mission-independent parameters to allow examination of the entire flight profile. The input data to the program allows the mission planner to select launch and arrival dates as well as a specific landing point located in a scientifically interesting area with proper lighting for any onboard optical equipment. The orbit about the planet must satisfy constraints such as communication requirements with the Earth and the necessity for solar cells to be exposed to sunlight for the greater part of each orbit. The many different problems

involved in preliminary mission analyses present a real task for the flight planner. The program is written for Mars missions where the spacecraft is placed in an orbit about Mars followed by the separation of a landing module, but could be adapted for other interplanetary journeys. Examples of program input and output and sample data analyses are presented for an Earth-Mars mission during the 1973 launch opportunity. The accuracy of the program is limited by the use of Keplerian mechanics and impulsive-burn maneuvers rather than finite burn integrating schemes. However, it is felt that for preliminary mission design, the order-of-magnitude accuracy involved in the approximations, as compared with an integrating program, is far outweighed by the several orders of magnitude gained in computational speed and program flexibility. This program is from the NASA Langley Research Center. **/tomars**

50. **V/STOL aircraft sizing and performance (VASCOMP II)** *work-in-progress* The VASCOMP2 computer program was developed to aid in the comparative design study of V/STOL aircraft systems by rapidly providing aircraft size and mission performance data. VASCOMP2 can be used to define design requirements such as weight breakdown, required propulsive power, and physical dimensions of aircraft which are to meet specified mission requirements. The program is also useful in sensitivity studies involving both design trade-offs and performance trade-offs. Generality and flexibilitywere maintained during formulation of the program in order to permit an accurate simulation of virtually any V/STOL configuration. VASCOMP2 is capable of approximating the design process involved in the layout and sizing of a wide variety of V/STOL aircraft and synthesizing the performance of these aircraft. The program is intended for use in the study of V/STOL aircraft which use fixed wing lift for primary cruise flight. The program is not suited for the study of aircraft which employ rotary wing lift for forward flight. This program was developed by Boeing Vertol Co. for the NASA Ames Research Center. This is a preliminary release. **/vascomp**

51. **Analytical comparisons of ablative nozzle materials** *work-in-progress* This program is designed to predict the ablation performance of rocket nozzle heat protection materials. The program is based on the use of nonsymmetrical difference equations that are employed to solve systems of complex partial differential equations. The program can be used to predict the thermal degradation of a wide variety of materials exposed to an external source of heat. It can be generally adapted to the simulation of processes involving heat and mass transfer by substituting specific parameters into the basic equations. The program also includes the effects of mass addition on heat transfer, the calculation of internal gas pressure and internal material stresses, and a number of other options for surface or char removal. The program has previously been used to compare performance of phenolic nylon, phenolic graphite, and phenolic refrasil as rocket nozzle heat protection materials. This program was developed by General Electric under contract to the NASA Glenn (formerly Lewis) Research Center. **/ablate**

52. **Velocity gradient method for calculating velocities in an asymmetric annular duct. (ANDUCT)** *work-in-progress* Turbomachinery components are often connected by ducts, which are usually annular. The configurations and aerodynamic characteristics of these ducts are crucial to the optimum performance of the turbomachinery blade rows. The ANDUCT computer program was developed to calculate the velocity distribution along an arbitrary line between the inner and outer walls of an annular duct with axisymmetric swirling flow. Although other programs are available for duct analysis, the use of the velocity gradient method (also known as the stream filament or streamline curvature method) makes the ANDUCT program fast and convenient while requiring only modest computer resources. This method has been used extensively for blade passages but has not been widely used for ducts, except for the radial equilibrium equation. A velocity gradient equation derived from the momentum equation is used to determine the velocity variation along an arbitrary straight line between the inner and outer wall of an annular duct. The velocity gradient equation is used with an assumed variation of meridional streamline curvature. Upstream flow conditions may vary between the inner and outer walls, and an assumed total pressure distribution may be specified.

    NASA Lewis (now Glenn) computer program by Theodore Katsanis. **/anduct**

53. **Three-dimensional supersonic flow (AOFA)** This program determines the complete viscous and inviscid flow around a body of revolution at a given angle of attack and traveling at supersonic speeds. The viscous calculations from this program agree with experimental values for surface and pitot pressures and with surface heating rates. At high speeds, lee-side flows are important because the local heating is difficult to correlate and because the shed vortices can interact with vehicle components such as a canopy or a vertical tail. This program should find application in the design analysis of any high speed vehicle. Lee-side flows are difficult to calculate because thin-boundary-layer theory is not applicable and the concept of matching inviscid and viscous flow is questionable. This program uses the parabolic approximation to the compressible Navier-Stokes equations and solves for the complete inviscid and viscous regions of flow, including the pressure. The parabolic approximation results from the assumption that the stress derivatives in the streamwise direction are small in comparison with derivatives in the normal and circumferential directions. This assumption permits the equation to be solved by an implicit finite difference marching technique which proceeds downstream from the initial data point, provided the inviscid portion of flow is supersonic. The viscous cross-flow separation is also determined as part of the solution. To use this method it is necessary to first determine an initial data point in a region where the inviscid portion of the flow is supersonic. NASA Ames program by John Rakich. **/aofa**

54. **Aircraft roll-out iterative energy simulation program (ARIES)** This program analyzes aircraft brake performance during rollout. The program simulates a three degree of freedom rollout after nose gear touchdown. The amount of brake

energy dissipated during landing determines the life expectancy of brake pads. ARIES incorporates brake pressure, actual flight data, crosswinds, and runway characteristics to calculate the following:

(a) brake energy used during rollout for up to four independent brake systems,

(b) time profiles of rollout distance, velocity, deceleration, and lateral runway position, and

(c) all aerodynamic moments on the vehicle.

ARIES can be adapted for modeling most landing aircraft during unpowered rollout. Optimum braking procedures can be developed with ARIES to minimize brake deterioration while staying within specified lengths of runway. ARIES has been used to evaluate several Shuttle Orbiter brake pad failures. After the input of initial runway and landing conditions, ARIES utilizes three simulation models to evaluate the rollout at given time intervals. The brake force simulation requires tire and brake information along with actual flight data. The equations of motion allow force and moment balances to be calculated. The aerodynamic effects are computed, including lift, drag, axial and normal forces, and roll, pitch, and yaw moments. The various aerosurface effects are obtained from interpolation of the Rockwell Aero Sciences Group Design Data Book tables. The output is in both printed and plotted form. ARIES iterates the calculations until the computed forward velocity is below three knots. Rockwell International. **/aries**

55. **Non-rotating blade-to blade, steady, potential transonic cascade flow analysis code (CAS2D)** *work-in-progress* An exact, full-potential-equation model for the steady, irrotational, homoentropic, and homoenergetic flow of a compressible, inviscid fluid through a two-dimensional planar cascade together with its appropriate boundary conditions has been derived. The CAS2D computer program numerically solves an artificially time-dependent form of the actual full-potential-equation, providing a nonrotating blade-to-blade, steady, potential transonic cascade flow analysis code. In CAS2D, the governing equation is discretized by using type-dependent, rotated finite differencing and the finite area technique. The flow field is discretized by providing a boundary-fitted, nonuniform computational mesh. This mesh is generated by using a sequence of conformal mapping, nonorthogonal coordinate stretching, and local, isoparametric, bilinear mapping functions. The discretized form of the full-potential equation is solved iteratively by using successive line over relaxation. Possible isentropic shocks are captured by the explicit addition of an artificial viscosity in a conservative form. In addition, a four-level, consecutive, mesh refinement feature makes CAS2D a reliable and fast algorithm for the analysis of transonic, two-dimensional cascade flows. The results from CAS2D are not directly applicable to three-dimensional, potential, rotating flows through a cascade of blades because CAS2D does not consider the effects of the Coriolis force that would be

present in the three-dimensional case. This program was written by George Dulikravich of the NASA Glenn Research Center. **/cas2d**

56. **Dissociated air flow effects during plasma arc testing (COLDARC)** *work-in-progress* The COLDARC program was developed as part of an effort to predict the heating rate and surface friction effects on the Thermal Protection System of the Space Shuttle Orbiter during re-entry environments. COLDARC enables the user to predict the heating rate and surface friction on a test article during plasma arc testing. This program takes into account the effects of dissociated air flow over the specimen and the associated heat flux and surface temperatures. Normally, plasma arc testing involves air flow over a test specimen having a relatively smooth surface. Since the orbiter Thermal Protection System does not constitute a smooth mold line surface, the COLDARC program was necessary to assess the impact of this surface roughness and the dissociated air flow. COLDARC uses a simplified frozen flow model to represent the dissociated air flow and to predict the heat flux and surface friction, including the effects or retarded atomic recombination, from test facility data. This program was developed by Rockwell International for the NASA Marshall Space Flight Center. **/coldarc**

57. **Conical Relaxation for supersonic wing design and analysis (COREL)** *work-in-progress* COREL is useful in the aerodynamic design and analysis of wings for supersonic maneuvering. It uses the Super Critical Conical Camber (SC3) concept, in which high supersonic lift coefficients are obtained by controlling cross flow development. COREL solves the nonlinear full potential equation for a spanwise section of a wing in the crossflow plane and corrects the result for any nonconical geometry. COREL computes the mixed subsonic/supersonic crossflow that develops on supersonic wings with high lift coefficients at Mach numbers normal to shock waves of 1.3 or less. The bow and crossflow shocks are captured as part of the solution. The initial aerodynamic solution is produced on a crude grid and is then reiterated. A finer mesh is then mapped, keeping the bow shock within the boundary of the new computed crossflow. The input geometry can be specifically defined or calculated internally using bicubic spline patches. This program was written by William Mason and Bruce Rosen of Grumman Aerospace for the NASA Langley Research Center. **/corel**

58. **Aeroelastic divergence characteristics of unguided, slender body, multi-stage launch vehicles (DIVERGE)** *work-in-progress* The primary function of this computer program is the calculation of the divergence dynamic pressure and associated divergence modal characteristics of unguided, slender-body, multistage launch vehicles. The divergence dynamic pressure is obtained as the non-trivial solution to a homogenous stability equation using matrix recurrence techniques. Provision is made for modulating the distributed lift curve coefficient slope function and the stiffness function. The program also includes an option for calculating a generalized static margin which approximates the degeneration in rigid-body static

margin due to aeroelasticity effects. Evaluated equations are also programmed to allow for the exclusion of the effect of aerodynamic crossflow resulting from vehicle angular velocities if desired. Other physical and aerodynamic properties calculated include total mass, center of mass, moments of inertia in pitch about the reference station, total aerodynamic lift curve slope, static aerodynamic center of pressure, rigid body static margin, and short period frequency. NASA Langley Research Center **/diverge**

59. **University of Kansas static aeroelasticity program (ELASTIC)** *work-in-progress* This software package contains three programs which compute geometric, mass, aerodynamic, and structural characteristics of fighter type aircraft. The programs were developed for computational support of a parametric study of planform and aeroelastic effects on aerodynamic center and stability derivatives. They calculate alpha- and q- stability derivatives and induced drag for thin elastic aeroplanes at subsonic and supersonic speeds. The programs are applicable to studies of steady state aeroelastic effects on stability characteristics of airplanes, but results are limited in validity to wings of typical fighter airplanes with a weight of 40,000 pounds (178,000 Newtons) and wing structures designed to withstand a limit load of 7.33 g's. The programs represent the airplane at subsonic and supersonic speeds as thin surface(s) (without dihedral) composed of discrete panels of constant pressure for the aerodynamic effects, and as slender beam(s) for the structural effects. They compute the static aeroelastic angle-of-attack and pitch rate stability derivatives for a twisted and cambered thin airplane configuration at various flight conditions. This program was written by J. Roshkam, C. Lan, and S.Mehrata of U. Kansas for NASA Langley. **/elastic**

60. **Analysis of three-dimensional supersonic nozzle exhaust flow fields (EXHAUST)** *work-in-progress* A second order numerical method employing reference plane characteristics has been developed for the calculation of geometrically complex three dimensional nozzle-exhaust flow fields, heretofore uncalculable by existing methods. The nozzles may have irregular cross sections with swept throats and may be stacked in modules using the vehicle undersurface for additional expansion. The nozzles may have highly nonuniform entrance conditions, the medium considered being an equilibrium hydrogen-air mixture. The program calculates and carries along the underexpansion shock and contact as discrete discontinuity surfaces, for a nonuniform vehicle external flow. Additionally, shock formation due to coalescence is detected. A wide variety of geometric problems may be considered since the reference plane method has been developed for three separate coordinate systems, all incorporated into a single program. This program was developed by Advanced Technology Labs. for the NASA Glenn Research Center. **/exhaust**

61. **Flexible spacecraft dynamics (FSD)** *work-in-progress* The Flexible Spacecraft Dynamics and Control program (FSD) was developed to aid in the simulation of a large class of flexible and rigid spacecraft. FSD is extremely versatile and can be used

in attitude dynamics and control analysis as well as in-orbit support of deployment and control of spacecraft. FSD is applicable to inertially-oriented spinning, earth oriented, or gravity gradient stabilized spacecraft. The spacecraft flexibility is treated in a continuous manner (instead of finite element) by employing a series of shape functions for the flexible elements. Torsion, bending, and three flexible modes can be simulated for every flexible element. FSD can handle up to ten tubular elements in an arbitrary orientation. FSD is appropriate for studies involving the active control of pointed instruments, with options for digital PID (proportional, integral, derivative) error feedback controllers and control actuators such as thrusters and momentum wheels. The input to FSD is in four parts: 1) Orbit Construction - FSD calculates a Keplerian orbit with environmental effects such as drag, magnetic torque, solar pressure, thermal effects, and thruster adjustments; or the user can supply a GTDS format orbit tape for a particular satellite/timespan; 2) Control words - for options such as gravity gradient effects, control torques, and integration ranges; 3) Mathematical descriptions of spacecraft, appendages, and control systems, including element geometry, properties, attitudes, libration damping, tip mass inertia, thermal expansion, magnetic tracking, and gimbal simulation options; and 4) Desired state variables to output, i.e., geometries, bending moments, fast Fourier transform plots, gimbal rotation, filter vectors, etc. All FSD input is of free format, namelist construction. (NASA Goddard Space Flight Center) **/fsd**

62. **A general optical systems evaluation program (GENOPTICS)**
work-in-progress The General Optical Systems Evaluation Program, GENOPTICS, was developed as an aid for the analysis and evaluation of optical systems that employ lenses, mirrors, diffraction gratings, and other geometrical surfaces. The GENOPTICS evaluation is performed by means of geometrical ray tracing based upon Snell's law. The GENOPTICS program can provide for the exact ray tracing of as many as 800 rays through as many as 40 surfaces. These surfaces may be planar, conic, toric, or polynomial shaped lenses, mirrors, and diffraction gratings. Each surface may be tilted about as many as three axes and may be decentered. Surfaces having bilateral symmetry may also be analyzed. GENOPTICS provides for user-oriented input and for a wide range of output for the evaluation of the optical system being analyzed. GENOPTICS provides a wide range of features for the optical system analyst. GENOPTICS performs paraxial ray tracing and computation of the third order aberrations including aspheric contribution. Graphical output can be generated for spot diagrams, radial energy distributions, and modulation transfer functions, for each object point and each color. Sag tables may be generated for any rotationally symmetric surface, with options to obtain the sag differences from a reference sphere in units of lengths or wavelengths. Statistics and plots of ray intercepts with any surface in the system may be obtained for use in vignetting analysis and beam distribution analysis. Afocal systems can be examined with image statistics generated in terms of tangents of angles with respect to the optical axis. For exact ray tracing, a ray pattern at the entrance pupil can be specified as a rectangular

or polar grid, where each ray samples an equal amount of area, or as a pattern where each ray samples an equal amount of solid angle for a finite object. This latter pattern is useful in radiometric work. Input to GENOPTICS includes program control statements, system definition data, surface data, and task data. Multiple cases may be examined in a single run. Output includes printed and graphical results. The user can specify which portions of an analysis are to be printed. Optional printout includes system data, surface-to-surface printout of each ray, modulation transfer function values, radial energy distribution values, and paraxial ray data including aberrations. (NASA Goddard Space Flight Center) **/goptics**

63. **Improved price estimation guidelines (IPEG)** *work-in-progress* The Improved Price Estimation Guidelines, IPEG, program provides a simple yet accurate estimate of the price of a manufactured product. IPEG facilitates sensitivity studies of price estimates at considerably less expense than would be incurred by using the Standard Assembly-line Manufacturing Industry Simulation, SAMIS, program (COSMIC program NPO-16032). A difference of less than one percent between the IPEG and SAMIS price estimates has been observed with realistic test cases. However, the IPEG simplification of SAMIS allows the analyst with limited time and computing resources to perform a greater number of sensitivity studies than with SAMIS. Although IPEG was developed for the photovoltaic industry, it is readily adaptable to any standard assembly line type of manufacturing industry. IPEG estimates the annual production price per unit. The input data includes cost of equipment, space, labor, materials, supplies, and utilities. Production on an industry wide basis or a process wide basis can be simulated. Once the IPEG input file is prepared, the original price is estimated and sensitivity studies may be performed. The IPEG user selects a sensitivity variable and a set of values. IPEG will compute a price estimate and a variety of other cost parameters for every specified value of the sensitivity variable. IPEG is designed as an interactive system and prompts the user for all required information and offers a variety of output options. (Cal Tech/Jet Propulsion Lab.)

    /ipeg

64. **A Graphics Library (LONGLIB)** *work-in-progress* This library is a set of subroutines designed for vector plotting to CRT's, plotters, dot matrix, and laser printers. LONGLIB subroutines are invoked by program calls similar to standard CALCOMP routines. In addition to the basic plotting routines, LONGLIB contains an extensive set of routines to allow viewport clipping, extended character sets, graphic input, shading, polar plots, and 3-D plotting with or without hidden line removal. LONGLIB capabilities include surface plots, contours, histograms, logarithm axes, world maps, and seismic plots. LONGLIB includes master subroutines, which are self-contained series of commonly used individual subroutines. When invoked, the master routine will initialize the plotting package, and will plot multiple curves, scatter plots, log plots, 3-D plots, etc. and then close the plot package, all with a

single call. The latest version, 5.0, is significantly enhanced and has been made more portable. This program is from the Jet Propulsion Laboratory of Caltech. **/longlib**

65. **Mistuning effects on turbofan cascades (MISER2)** *work-in-progress* In the development of modern aircraft turbofan engines, the aeroelastic stability and response of bladed-disk assemblies have been among the most difficult problems encountered. The study of stability and response in these assemblies is complicated by the presence of small differences between the individual blades, known as mistuning. The Mistuning Effects on Turbofan Cascades program, MISER2, was developed to improve the basic understanding of the effects of mistuning on aeroelastic stability and response. The MISER2 program calculates the flutter boundaries and aeroelastic response of a cascade of arbitrarily mistuned airfoils. It is based on a formulation incorporating incompressible subsonic and supersonic, unsteady, two-dimensional aerodynamic theories. Each blade is modeled as a two degree-of-freedom oscillator having inertial coupling between the bending and torsional motions. It is possible to consider any type of uncoupled bending and torsional frequencies, damping ratios, mass ratios, and elastic axis and center of gravity positions. Special cases which can be treated by MISER2 include: tuned and mistuned cases; uncoupled bending and uncoupled torsion cases; and the tuned coupled bending-torsion case. This program is from the NASA Glenn Research Center) **/miser2**

66. **Monte Carlo investigation of trajectory operations and requirements (MONITOR)** *work-in-progress* This program was developed to perform spacecraft mission maneuver simulations for geosynchronous, single maneuver, and comet encounter trajectories. MONITOR is a multifaceted program which enables the modeling of various orbital sequences and missions, the generation of Monte Carlo simulation statistics, and the parametric scanning of user requested variables over specified intervals. It has been used primarily to study geosynchronous missions and has the capability to model Space Shuttle deployed satellite trajectories. The ability to perform a Monte Carlo error analysis of user specified orbital parameters using predicted maneuver execution errors can make MONITOR a significant part of any mission planning and analysis system. The MONITOR program can be executed in four operational modes. In the first mode, analytic state covariance matrix propagation is performed using state transition matrices for the coasting and powered burn phases of the trajectory. A two-body central force field is assumed throughout the analysis. Histograms of the final orbital elements and other state dependent variables may be evaluated by a Monte Carlo analysis. In the second mode, geosynchronous missions can be simulated from parking orbit injection through station acquisition. A two-body central force field is assumed throughout the simulation. Nominal mission studies can be conducted; however, the main use of this mode lies in evaluating the behavior of pertinent orbital trajectory parameters by making use of a Monte Carlo analysis. In the third mode, MONITOR performs

parametric scans of user-requested variables for a nominal mission. Various orbital sequences may be specified; however, primary use is devoted to geosynchronous missions. A maximum of five variables may be scanned at a time. The fourth mode simulates a mission from orbit injection through comet encounter with optional Monte Carlo analysis. Midcourse maneuvers may be made to correct for burn errors and comet movements. This program is from the NASA Goddard Space Flight Center. **/monitor**

67. **Nastran Plotting Post Processor (NASTPLT)** *work-in-progress* The NASTRAN Plotting Post Processor was developed to read NASTRAN generated NASTPLT plot files, to check the file contents for validity, and to translate the NASTPLT plot commands into appropriate calls to plotting routines for either CalComp, Tektronix PLOT10, or Versatec plotting systems. This program was originally written to generate a summary of the contents of a NASTPLT plot file for the purposes of debugging and checking the validity and characteristics of the file contents. The summary information generated includes the following information for each plot on the NASTPLT file: plot number, draw-lines summary, draw-axis summary, draw-character summary, maximum and minimum values in the x-range and y-range, and pen change information. The summary information also includes the following information for the NASTPLT file as a whole: the number of records read, the number of commands, and the number of plots. The summary generation program was extended to include the plot routine calls for the CalComp, Tektronix PLOT10, and Versatec plotting systems. The Post Processor is run interactively and prompts the user for all of the required input. The user may request the summary information and then use that information to determine which plots on the file are to be output. The Post Processor is compatible with either VAX or IBM NASTRAN generated NASTPLT files. (Computer Sciences Corp. for NASA Langley). [This program may be totally obsolete today, but the source code may be of some value.] **/nastplt**

68. **A Segmented Mission Analysis Program for Low and High Speed Aircraft (NSEG)** *work-in-progress* NSEG was developed to perform rapid aircraft mission analyses. It is based upon the use of approximate equations of motion whose form varies with the type of flight segment. Flight segments considered are takeoff, accelerations, climbs, cruises, descents, decelerations, and landings. Layered atmosphere options are available. The program can also be used for flight envelope mapping. NSEG provides the capability to analyze aircraft missions from low to hypersonic speeds. Realistic and detailed vehicle characteristics are input to NSEG to permit accurate mission analysis. NSEG allows engine scaling so as to fit the design under analysis. NSEG contains several approximate flight path optimization capabilities based on Rutowski energy-like criteria for considering minimum time or fuel flight segments and maximum range segments during climb or descent. Takeoff and landing analysis is based on the Air Force Flight Dynamics Laboratory

DATCOM method of high lift aerodynamic modelling. There are three main atmosphere options available; the 1962 U.S. Standard atmosphere, a stratified atmosphere model, and an external atmosphere model supplied by the user. The stratified atmosphere model requires the input of the number of layers (maximum 25), altitudes, temperatures, and pressures. The mission specification is open-ended in that the upper limit on the number of flight segments to be included in a mission profile can be increased with a simple program change. Input consists of vehicle characteristic data, data to specify details of the mission, and selection of program options. This program was written by D.S. Hague and H.L. Rozendaal of Aerophysics Research Corp. for the NASA Langley Research Center. **/nseg**

69. **A vertical profile which minimizes aircraft fuel burn or direct operating cost (OPTIM)** The OPTIM computer program was developed to generate optimum vertical profiles for turbojet powered aircraft. Specifically, OPTIM generates a profile of altitude, airspeed, and flight path angle as a function of range between a given set of origin and destination points for particular models of transport aircraft. The profile may be optimized in the sense of minimizing fuel or time or in minimizing the direct operating cost expressed as a combination of fuel and time. Inputs to the program include the vertical wind profile, the aircraft takeoff weight, and the aircraft engine and aerodynamic characteristics. The optimum vertical flight profile is generated by calculating the airspeed and thrust required to minimize the Hamiltonian at specific energy increments. (Analytical Mechanics Associates for NASA Langley) **/optim**

70. **Parameterized Investigation of Launch Opportunities and Trajectories (PILOT)** *work-in-progress* The launch window for an earth satellite mission defines the dates and the times of day that a satellite can be launched and satisfy the mission constraints. This program was developed to perform mission simulation computations that yield data for use in delimiting optimum launch windows. PILOT performs parametric scans of a user specified trajectory over launch date and initial right ascension of the ascending node. During each scan various mission parameters are generated and output to a data file. The CoPILOT utility program is used to read and format the PILOT generated data file. The user specifies acceptable limits on the various PILOT generated parameters, CoPILOT checks the data, and generates an output table with notations of any constraint violations. Any time that no contraints are violated, an acceptable launch time exists. For each date, the acceptable launch times are printed. A printer plot may also be generated to visually display the launch window. (Computer Sciences Corp. for NASA Goddard) **/pilot**

71. **Design of two-dimensional supersonic turbine rotor blades with boundary layer correction (RBLADE)** *work-in-progress* A computer program has been developed for the design of supersonic rotor blades where losses are accounted for by correcting the ideal blade geometry for boundary layer displacement thickness. The ideal blade passage is designed by the method of characteristics and is based on establishing vortex flow within the passage. Boundary-layer parameters

(displacement and momentum thicknesses) are calculated for the ideal passage, and the final blade geometry is obtained by adding the displacement thicknesses to the ideal nozzle coordinates. The boundary-layer parameters are also used to calculate the aftermixing conditions downstream of the rotor blades assuming the flow mixes to a uniform state. The computer program input consists essentially of the rotor inlet and outlet Mach numbers, upper- and lower-surface Mach numbers, inlet flow angle, specific heat ratio, and total flow conditions. The program gas properties are set up for air. Additional gases require changes to be made to the program. The computer output consists of the corrected rotor blade coordinates, the principal boundary-layer parameters, and the aftermixing conditions. This program is from the NASA Glenn Research Center. **/rblade**

72. **Fast Mars relay communication link (RELAY)** *work-in-progress* This program evaluates the communications link between the Viking Orbiter and Lander vehicles. The program calculates the trajectory of the Orbiter and Lander simultaneously. Using data from both vehicles, this program calculates communication geometry. This program was developed by Martin Marietta for the NASA Langley Research Center. **/relay**

73. **Aeroelastic analysis for rotorcraft in flight or in a wind tunnel (ROTOR)** *work-in-progress* The testing of rotorcraft, either in flight or in a wind tunnel, requires a consideration of the coupled aeroelastic stability of the rotor and airframe, or the rotor and support system. Even if the primary purpose of a test is to measure rotor performance, ignoring the question of dynamic stability introduces the risk of catastrophic failure of the aircraft. This computer program was developed to incorporate an analytical model of the aeroelastic behavior of a wide range of rotorcraft. Such an analytical model is desirable for both pre-test predictions and post-test correlations. The program is also applicable in investigations of isolated rotor aeroelasticity and helicopter flight dynamics and could be employed as a basis for more extensive investigations of aeroelastic behavior, such as automatic control system design. The program incorporates an analytical model which is applicable to a wide range of rotors, helicopters, and operating conditions. The equations of motion used in the model were derived using an integral Newtonian method, which provides considerable insight into the blade inertial and aerodynamic forces. The rotor model includes coupled flap-lag bending and blade torsion degrees of freedom, and is applicable to articulated, hingeless, gimbaled, and teetering rotors with an arbitrary number of blades. The aerodynamic model is valid for both high and low inflow, and for both axial and nonaxial flight. Rotor rotational speed dynamics, including engine inertia and damping, and perturbation inflow dynamics are included in the aerodynamic model. For a rotor on a wind-tunnel support, a normal mode representation of the test module, strut, and balance is used. The aeroelastic analysis for rotorcraft in flight is applicable to a general two-rotor aircraft, including single main-rotor and tandem helicopter configurations, and side-by-side or tilting

prop-rotor aircraft configurations. The rotor model includes rotor-rotor aerodynamic interference and ground effect. The aircraft model includes rotor-fuselage-tail aerodynamic interference, engine dynamics, and control dynamics. A constant-coefficient approximation is used for nonaxial flow and a quasistatic approximation is used for the low frequency dynamics. The coupled system dynamics results is a set of linear differential equations which are used to determine the stability and aeroelastic response of the system. This program is from Wayne Johnson of the NASA Ames Research Center. **/rotor**

74. **Super/Hypersonic inviscid flow around real configurations (SHIFARC)** *work-in-progress* This package was developed to compute the inviscid super/hypersonic flow field about complex vehicle geometries accurately and efficiently. A second-order accurate finite difference scheme is used to integrate the three-dimensional Euler equations in regions of continuous flow, while all shock waves are computed as discontinuities via the Rankine-Hugoniot jump conditions. This package has the ability to compute blunt nose entropy layers in detail. Real gas effects for equilibrium air are included using curve fits of Mollier charts. This package can be a very useful tool in the design and analysis of high speed vehicles such as supersonic aircraft, hypersonic transports, and re-entry spacecraft (shuttle orbiter). This package consists of three separate computer programs. STEIN is the program that solves the Euler equations for the flow field. This solution is obtained by following these basic guidelines:

    (a) An accurate second order finite difference marching technique is used to numerically integrate the governing partial differential equations;

    (b) Shock waves in the flow field are followed and the Rankine-Hugoniot conditions are satisfied across them;

    (c) The intersection of two shocks of the same family is computed explicitly;

    (d) Conformal mappings are used to develop a computational grid;

    (e) Body boundary conditions are satisfied by recasting the equations according to the concept of characteristics;

    (f) The edge of the entropy layer on blunt nose vehicles is followed from its origin and the derivatives across the layer formed;

    (g) Real gas effects are included when appropriate, by using fits of Mollier charts; and

    (h) Sharp leading edge wings are computed using a local two-dimensional solution.

    The only limitation to this solution technique is that the Mach number in the marching direction (nose to tail) must be supersonic at every point in the flow field. The region around the nose of blunt nosed vehicles must be computed by another technique (see description of BLUNT below) and once the flow becomes supersonic, STEIN can proceed with its calculations. This program has been used extensively to compute external flow fields and has been found to yield accurate results for a wide variety of vehicle configurations flying at Mach numbers between 2 and 26 and having angles of attack to plus/minus 30 degrees. The program BLUNT is used to find flow fields about blunt nosed portions of the vehicle. BLUNT uses a time dependent computational technique to asymptote to a steady transonic solution. Output from this program can be used by STEIN to define the flow field points where supersonic flow begins. The program QUICK provides the user with a geometry system to model a complex vehicle geometry in a quick, straight-forward fashion. QUICK consists of an initial defining and logical checkout group of routines, which actually set up the mathematical model, and a second group of routines which are used to interrogate the model for cross sectional information. QUICK supplies all geometrical information about the vehicle to STEIN. These programs were developed by A.F. Vachris, L.S. Yaeger, F. Marconi, and M.Salas of Grumman Aerospace for the NASA Langley Research Center. **/shifarc**

75. **Circuit Analysis (SNEAK)** *work-in-progress* Input to this program consists of data representing the circuit to be analyzed. The data is prepared by converting the schematic of the circuit into a "wire list". In this wire list all switches are assumed closed with special circumstances, e.g. double throw switches, being noted as switchable continuity. The output consists of any paths that meet the criteria for sneak circuits. These areas of suspicion must then be submitted to manual analysis, but the number of paths to be analyzed is greatly reduced by the criterion of opposing power and ground. Post-analysis consists of checking switch logic to sift out paths that cannot be switched on and then determining any systems effects of the remaining possible sneak circuits. The computer output is designed to present the path tracing information in a format that readily assists manual analysis of the suspected sneak circuits. The automated sneak circuit analysis is accomplished in three processing phases. The first phase is the data reduction phase. In this phase the wire list is generated. Input may be in several different formats and even segmented such that separate groups or contractors may prepare wire lists covering subsystems with discontinuities at interfaces. The wire list is merged with an in-line disconnect table establishing continuity at the interface between any subsystems. This wire list is then reduced to an Indexed Sequential Access Method (ISAM) file containing a branch cross-reference table, in which each to-node/from-node branch is uniquely identified and stored with its associated characteristics. The second phase is the path derivation phase. In this process the data in the branch cross-reference table is used to examine all possible paths to see which meet the above mentioned two-fold criteria for a possible sneak circuit. The third phase is the path regeneration phase. The paths flagged are listed in branch sequence number and then in to-from connector sequence. The output report generated is in a highly useable format that allows the engineer to verify the suspected sneak circuit path by locating the wire segments on the circuit schematic drawings. (Boeing Co.) **/sneak**

76. **Space Shuttle Synthesis Program (SSSP)** *work-in-progress* This program automates the trajectory, weights and performance computations essential to predesign of the Space Shuttle system for earth-to-orbit operations. The two-stage Space Shuttle system is a completely reusable space transportation system consisting of a booster and an orbiter element. The SSSP'S major parts are a detailed weight/volume routine, a precision three-dimensional trajectory simulation, and the iteration and synthesis logic necessary to satisfy the hardware and trajectory constraints. The SSSP is a highly useful tool in conceptual design studies where the effects of various trajectory configuration and shuttle subsystem parameters must be evaluated relatively rapidly and economically. The program furnishes sensitivity and tradeoff data for proper selection of configuration and trajectory predesign parameters. Emphasis is placed upon pre-design simplicity and minimum input preparation. Characteristic equations for describing aerodynamic and propulsion models and for computing weights and volumes are kept relatively simple. The synthesis program is designed for a relatively large number of two-stage Space Shuttle configurations and mission types, but avoids the complexity of a completely generalized computer program that would be unwieldy to use and/or modify. This program was developed by Convair (part of General Dynamics) for the NASA Marshall Space Flight Center. **/sssp**

77. **Velocities and streamlines on a blade-to-blade stream surface of a tandem blade turbomachine (TANDEM)** *work-in-progress* This computer program gives the blade-to-blade solution of the two-dimensional, subsonic, compressible (or incompressible), non-viscous flow problem for a circular or straight infinite cascade of tandem or slotted turbomachine blades. The blades may be fixed or rotating. The flow may be axial, radial, or mixed. The method of solution is based on the stream function using an iterative solution of nonlinear finite-difference equations. These equations are solved using two major levels of iteration. The inner iteration consists of the solution of simultaneous linear equations by successive over-relaxation, using an estimated optimum over-relaxation factor. The outer iteration then changes the coefficients of the simultaneous equations in order to correct for compressibility. The program input consists of the basic blade geometry, the meridional stream channel coordinates, fluid stagnation conditions, weight flow and flow split through the slot, and inlet and outlet flow angles. The output includes blade surface velocities, velocity magnitude and direction throughout the passage, and the streamline coordinates. This program is from the NASA Glenn Research Center. **/tandem**

78. **One-dimensional numerical analysis of the transient thermal response of multilayer insulative systems (THERM1D)** *work-in-progress* This program performs a one-dimensional numerical analysis of the transient thermal response of multi-layer insulative systems. The analysis can determine the temperature distribution through a system consisting of from one to four layers, one of which can be an air gap. Concentrated heat sinks at any interface can be included. The

computer program based on the analysis will determine the thickness of a specified layer that will satisfy a temperature limit criterion at any point in the insulative system. The program will also automatically calculate the thickness at several points on a system and determine the total system mass. This program was developed as a tool for designing thermal protection systems for high speed aerospace vehicles but could be adapted to many areas of industry involved in thermal insulation systems. In this package, the equations describing the transient thermal response of a system are developed. The governing differential equation for each layer and boundary condition are put in finite-difference form using a Taylor's series expansion. These equations yield an essentially tridiagonal matrix of unknown temperatures. A procedure based on Gauss' elimination method is used to solve the matrix. This program is from the NASA Langley Research Center. **/therm1d**

79. **Thermal Protection System multidimensional heat conduction program (TPS)** *work-in-progress* The Thermal Protection System (TPS) for the Space Shuttle consists of an outer layer of rigid surface insulation tiles. It is important that an accurate understanding of the thermal behavior of this system be obtained prior to usage. This computer program was developed to compute the transient temperature history and the steady-state temperatures of complex body geometries in three dimensions. Emphasis has been placed on the type of problems associated with the TPS, but the program could be used in the thermal analysis of most three-dimensional systems. The thermal model is subdivided into sections, or nodes, to a level of approximation which yields the desired level of accuracy. Input to the program consists of a geometrical description of the physical system, the material properties, and selected boundary conditions. The boundary conditions are used to account for heat flux, reradiation, radiation interchange, convection, fixed temperatures, and phase changes. The program will accommodate a thermal model with as many as 500 nodes, 4000 conductors, 3600 radiation interchange conductors, and 75 of each type of boundary condition. The program solves the differential equations describing the transient and steady state behavior of the model using finite difference techniques. For the transient analysis, the user may select either a forward difference method, a midpoint difference (Crank-Nicolson) method, a backward difference method, or an alternating direction method to numerically solve the governing equations. For the steady-state analysis, a modified backward difference method is available. Program output is in the form of temperature versus time histories for each section of the thermal model. This program was developed by Rockwell International for the NASA Marshall Space Flight Center. **/tps**

80. **Airfoil Smoothing**

    This report contains detailed descriptions of the theoretical methods and associated computer codes of a program to smooth and a program to scale arbitrary airfoil coordinates. The smoothing pro- gram utilizes both least-squares polynomial and least-squares cubic spline techniques to smooth iteratively the second derivatives of the y-axis airfoil coordinates with respect to a transformed x-axis system which unwraps the airfoil and stretches the nose and trailing-edge regions. The corresponding smooth airfoil coordinates are then determined by solving a tridiagonal matrix of simultaneous cubic spline equations relating the y-axis coordinates and their corresponding second derivatives. A technique for computing the camber and thickness distribution of the smoothed airfoil is also discussed.

The scaling program can then be used to scale the thickness distribution generated by the smoothing program to a specified maxi- mum thickness which is then combined with the camber distribution to obtain the final scaled airfoil contour.

/afsmo and **/profile**

81. **Doublet Lattice**

Aircraft flutter is a destructive phenomenon which requires special attention in the design process. The elements of flutter are structural dynamics and unsteady aerodynamics. Of these, it is generally recognized that unsteady aerodynamics are the more difficult to model and the least reliable. In 1935, Theodorsen was the first to develop a practical unsteady incompressible aerodynamic formula! for a flutter analysis of a two dimensional airfoil. It was fifty years ago that Smilg and Wasserman of the Aircraft Laboratory of the Wright Air Development Center wrote their landmark report on flutter clearance using the K-method and strip theory. Of course such methods can be addressed with manual calculations. Compressibility is normally associated with the flutter of high speed aircraft. It is impractical to solve the compressible unsteady aerodynamic equations by hand. The doublet lattice method" was developed along with improvements in digital computer technology. Hopefully, the doublet lattice method represents the most rudimentary unsteady aerodynamic technique in practice where subsonic compressible flow is a consideration. With the introduction of today's supercomputers, non-linear aerodynamics are now being addressed, in spite of the high cost. It is because of the high cost and technical complications associated with non-linear Computational Fluid Dynamics (CFD) that the doublet lattice method is still used almost exclusively for the subsonic flutter clearance of flight vehicles being designed today. It is difficult to imagine the day when non-linear CFD will replace the doublet lattice method in the preliminary design environment. **/doubletlattice**

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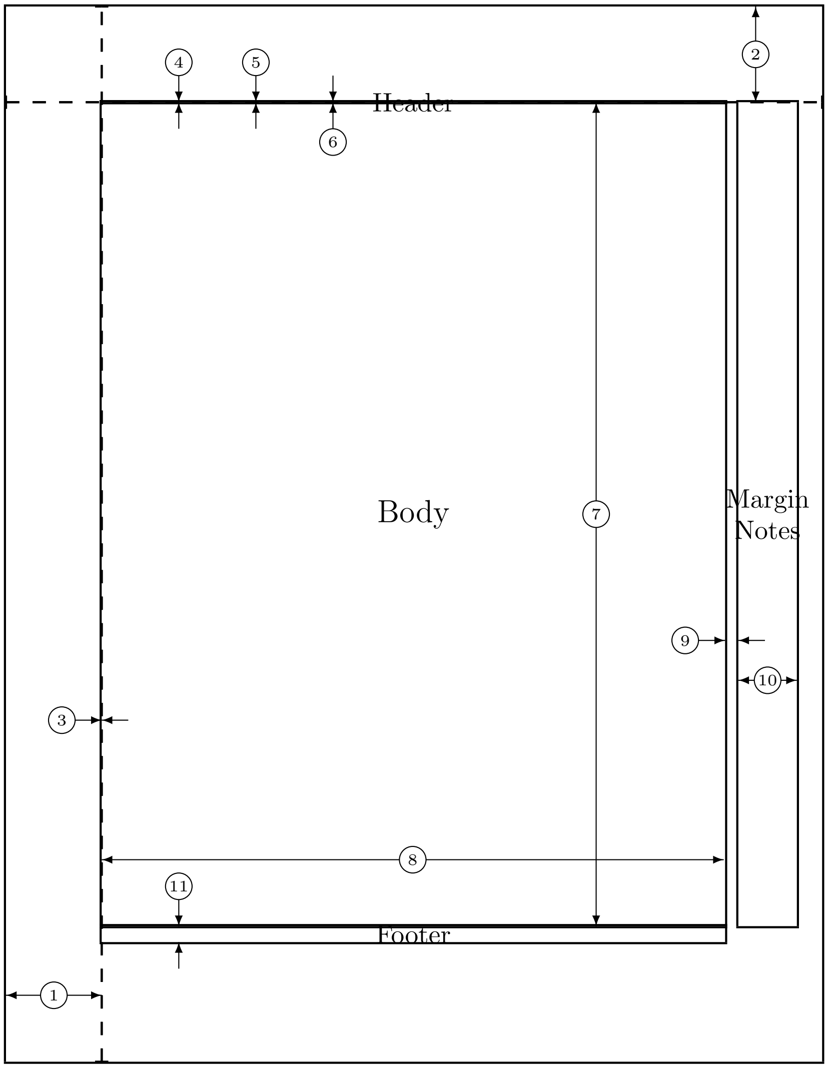
Ralph Carmichael
Public Domain Aeronautical Software
248 Meadow Road Santa Cruz CA 95060-2040 USA
Web: http://www.pdas.com e-mail: pdaerowebmaster@gmail.com



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