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User's Manual for AeroFcn: A FORTRAN Program to Compute Aerodynamic Parameters

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To obtain a copy of this code, please call Joe Conley at FTS (415) 464-3677 or write to Joe Conley, Ames Research Center, Mail Stop 269-4, Moffett Field, CA 94035.

ABSTRACT

This report documents the computer program **AeroFcn**, a utility program that computes the following 18 aerodynamic parameters: geopotential altitude, Mach number, true velocity, dynamic pressure, calibrated airspeed, equivalent airspeed, impact pressure, total pressure, total temperature, Reynolds number, speed of sound, static density, static pressure, static temperature, coefficient of dynamic viscosity, kinematic viscosity, geometric altitude, and specific energy for a standard or a modified standard day atmosphere using compressible flow and normal shock relations. Any two parameters that define a unique flight condition are selected and their values are entered interactively. The remaining parameters are computed and the solutions stored in an output file. Multiple cases can be run and the multiple case solutions can be stored in another output file for plotting. Parameter units, the output format, and primary constants in the atmospheric and aerodynamic equations can also be changed.

NOMENCLATURE

AeroAux.f	subprogram of AeroFcn FORTRAN code
AeroEqns.f	subprogram of AeroFcn FORTRAN code
AeroFcn	aerodynamic function FORTRAN program
AeroIO.f	subprogram of AeroFcn FORTRAN code
altfun	subroutine
ampchp	function
ANSI	American National Standards Institute
aro.dat	output file
aroplt.dat	output file
badstr	variable
brkfn	logical function
choose	subroutine
chrchk	subroutine
cmp3	compressed data file format
<cr>	carriage return
exprss	subroutine
fnalt	subroutine
FORTRAN	formula translation
fstchk	subroutine
initil	subroutine
inpchk	subroutine
iod	subroutine
lis1	ASCII data file format
lpalt	variable
lplt	variable
nhrng	variable

ntrp1z	interpolation subroutine
selchk	logical function
solve	subroutine
zamchp	subroutine

Symbols

a	speed of sound
a_0	sea level speed of sound
E_s	specific energy
g	acceleration due to gravity
g_0'	geopotential gravity length constant
H	geopotential altitude
H_b	breakpoints for geopotential altitude
$L_{M,b}$	breakpoints for temperature gradient
l	characteristic length
M	Mach number
M	molecular air mean weight
M_0	molecular air mean weight at sea level
m	mass
mgH	potential energy
m'	geopotential meter
P	static pressure
P_b	breakpoints for static pressure
P_0	sea level static pressure
P_t	total pressure
$\bar{q}$	dynamic pressure
q_c	impact pressure
R^*	gas constant
Re	Reynolds number
r_0	effective Earth radius
S	Sutherland's constant
T	static temperature
$T_{M,b}$	breakpoints for static temperature
T_0	sea level static temperature
T_t	total temperature
V	true airspeed
V_c	calibrated airspeed

V_e	equivalent airspeed
Z	geometric altitude
$\frac{1}{2}mV^2$	kinetic energy
β	primary constant used in coefficient of viscosity formula
γ	ratio of specific heats
η	kinematic viscosity, ratio of coefficient of dynamic viscosity and density
μ	coefficient of dynamic viscosity
ρ	static density
ρ_0	sea level static density
Γ	conversion constant

INTRODUCTION

Aerospace engineers, scientists, and students are often confronted with many highly interrelated aerodynamic parameters such as Mach number (M), calibrated airspeed (V_c), and dynamic pressure ($\bar{q}$). The tables, graphs, and formulas used by the aerospace community frequently do not contain the desired parameters or the relationships between parameters in a tractable form. Furthermore, computing a particular parameter is often complicated by inconvenient units and conversion factors. Therefore, the computer program **AeroFcn** was written to compute aerodynamic parameters easily in a convenient set of units given an independent pair of parameters.

The **AeroFcn** program incorporates a flexible model of the U.S. Standard Atmosphere, 1976 (ref. 1) that describes the atmospheric parameters as a function of geopotential altitude (h) accurately from sea level to 84.5 kilometers. A nonlinear equation solver was implemented to solve the transcendental relationships that occur in computing many of the parameters. This report presents a user's and programmer's guide to the formula translation (FORTRAN) program **AeroFcn**. The aerodynamic equations incorporated in the program are compressible flow and normal shock relations for subsonic and supersonic conditions. Modifications to the atmospheric and aerodynamic equations can be made by changing the primary constants found in those equations.

PROGRAM OVERVIEW

The **AeroFcn** is a menu driven interactive FORTRAN program that computes 16 aerodynamic parameters from 2 specified parameters that define a unique flight condition. The user interface provides a flexible structure that allows for the easy manipulation of the atmospheric and aerodynamic equations, output units, and output formats including provisions for plotting multiple cases. The FORTRAN code for **AeroFcn** may be obtained upon request.

Menu options are selected by typing the number corresponding to the desired option followed by a carriage return (<cr>). Normally 2 parameters are selected, the units and output formats defined, the values entered, and the remaining 16 parameters are computed. In addition, primary constants that exist in the atmospheric and aerodynamic equations (e.g., ratio of specific heats of air (γ)) can be changed. Each set of 18 parameters, along with the corresponding primary constants, define a single case. Single cases and multiple, parameter variation cases for plotting can be run and stored in output files.

PROGRAM OPERATION

After typing **AeroFcn**, the program introduction appears on the screen. This is followed by the program's main menu

```
*** Program Options Menu ***   (default = 1)

1   Select parameters
2   Enter/Change parameter values
3   Compute solution
4   Examine parameter values
5   Change parameter units
6   Change output format
7   Change primary constants
8   Multiple case/Plot file

9   End program
```

Any option can be chosen at any time from this menu. The normal sequence is to choose option 1 and select 2 parameters, such as Reynolds number (Re) and dynamic pressure ($\bar{q}$), from the list of 18. Next, option 2 is chosen and the values for the selected parameters are entered. Then option 3 is chosen and the remaining parameters are computed. The solutions are displayed on the terminal screen and can be saved in an output file with the default name **aro.dat** at the end of the session. The default menu choice changes from 1 to 2 and then to 3 respectively, to reflect this sequence.

Whenever option 3 is chosen, a solution will be computed based on the current values of selected parameters. The program initializes Mach number (M) and geopotential altitude (h) as the selected parameters with values of 1.0 and 0.0 ft respectively.

The parameter values can be examined at any time by choosing option 4 from the main menu. In addition, the parameter units can be changed by choosing option 5. Option 6 allows the format of the information displayed to the terminal screen and output file to be altered. The values of the primary constants that appear in the atmospheric and aerodynamic equations can be modified by choosing option 7. Option 8 introduces the Multiple Case/Plot Option Menu where multiple cases are run and the solutions can be stored in an output file for plotting called **aroplt.dat**. The two output files are referred to as **aro.dat** and **aroplt.dat**. However, these files can be assigned any name (assuming they are legal file names as defined by the local operating system). Option 9 terminates the program after giving the option to save the computed solutions in the output file **aro.dat**.

The program prevents information from scrolling past the screen's available window by requiring a <cr>. The places where a <cr> is necessary should be obvious. The main menu options are described in more detail in the following sections.

Option 1 - Select Parameters

The atmospheric and aerodynamic parameters are selected from the following menu by choosing option 1 on the main menu:

```
*** Parameter Selection Menu ***   (default = 20)
Select (individually) 2 known parameters
(* [ ] - currently chosen parameter(s))

*  1   [Geopotential altitude          ]
*  2   [Mach number                    ]
   3   True velocity
```

4 Dynamic pressure
5 Calibrated airspeed
6 Equivalent airspeed
7 Impact pressure
8 Total pressure
9 Total temperature
10 Reynolds number
11 Speed of sound
12 Static density
13 Static pressure
14 Static temperature
15 Coefficient of viscosity
16 Kinematic viscosity
17 Geometric altitude
18 Specific energy
19 Erase selections
20 Return to Program Options Menu

Two parameters are selected to describe a flight condition. Geopotential altitude and Mach number are shown in the previous menu as the currently selected parameters and remain so until chosen otherwise. Parameters are selected one at a time and the currently selected parameters are marked by an asterisk and surrounded by square brackets.

The following pairs of parameters do not describe a unique flight condition: impact pressure (q_c) and calibrated airspeed (V_c), dynamic pressure ($\bar{q}$) and equivalent airspeed (V_e), and any combination of geopotential altitude, geometric altitude, and the atmospheric parameters (parameters 1, 11, 12, 13, 14, 15, 16, and 17). If a nonunique pair has been selected, an error message appears. If a third parameter is selected while two parameters are currently selected, the first two selections are erased and the third choice becomes the only selected parameter. In addition, option 19 erases the currently selected parameter(s). Option 20, the default option on this menu, is used to return to the main menu. This menu is displayed until two unique parameters have been selected.

Option 2 - Enter/Change Parameter Values

Values for the selected parameters can be entered or changed by choosing the Enter/Change parameter values option from the main menu. The default value for the selected parameter is displayed with the current units and with a prompt for a new value. If a number is entered (followed by a <cr>), then that number becomes the current value for that selected parameter. If just a <cr> is entered, then the default value is retained. Any other type of input will not be accepted and an error message will appear.

There are four ways to change the parameter values, the first two are straightforward, whereas the third and fourth ways are more subtle. The first is to select option 2 from the main menu and change the parameter values as described in the previous paragraph. The second way is to choose option 3 from the main menu and compute the parameter values (see Option 3 - Compute Solution). This will change the values of the parameters not selected only if the values of the selected parameters have changed since the last time solutions were computed. The third way to change the parameter values is to select option 5 from the main menu, convert the units of one or more parameters,

and choose the corresponding parameter value(s) to be converted to the new units as described in Option 5 - Change parameter units. The fourth way is to again select option 5 from the main menu and convert the units of one or both the selected parameters without converting the corresponding values. Then, choosing option 3 from the main menu will compute the remaining 16 parameters based on the old parameter values that now have new units. Obviously, any combination of the four methods described previously also change the parameter values.

Option 3 - Compute Solution

Once the parameters are selected and their values entered, the Compute solution option, number 3 on the main menu, will compute the values of the remaining 16 parameters in the current units. For example:

```
   Case  1
Parameter Values:
(* [ ] - selected parameters)

*  [Geopotential altitude  ]  =        30000.0  (ft)
*  [Mach number            ]  =           .800
   True velocity              =          471.5  (knots)
   Dynamic pressure           =          281.5  (lbf/ft^2)
   Calibrated airspeed        =          303.9  (knots)
   Equivalent airspeed        =          288.4  (knots)
   Impact pressure            =          329.5  (lbf/ft^2)
   Total pressure             =          957.9  (lbf/ft^2)
   Total temperature          =          464.4  (deg R)
   Reynolds number            =   2.27828E+06
   Speed of sound             =          589.3  (knots)
   Static density             =   8.89272E-04   (slug/ft^3)
   Static pressure            =          628.4  (lbf/ft^2)
   Static temperature         =          411.7  (deg R)
   Coefficient of viscosity   =   3.10595E-07   (slug/ft-s)
   Kinematic viscosity        =   .349269E-04   (ft^2/s)
   Geometric altitude         =        30043.2  (ft)
   Specific energy            =        39868.4  (ft)
```

Computed solutions are numbered sequentially and are called cases. Parameter values are displayed to the terminal screen in either the default standard format or scientific notation (see Option 6 - Change output format). The computed solution in the given example was the first case from the output file **aro.dat**. The parameters were displayed in the standard format. The selected parameters were geopotential altitude and Mach number with values of 30,000 ft and 0.8 respectively. The units for the parameter values are the default units and can be modified using option 5 of the main menu (see Option 5 - Change parameter units).

Certain parameter pairs require the selection of a geopotential altitude range from which geopotential altitude is computed (see Derivations of Geopotential Altitude). For these cases, appropriate geopotential altitude ranges are displayed, a range is selected, and the geopotential altitude corresponding to the specified flight condition is calculated.

Option 4 - Examine Parameter Values

By choosing option 4 from the main menu, Examine parameter values, the selected parameters, the parameter values, and the parameter units can be conveniently examined. The information displayed is the same as a computed solution except for the menu title.

Option 5 - Change Parameter Units

Choosing option 5 from the main menu leads to the following menu, where the units of any or all the parameters can be changed.

*** Change Parameter Units Menu ***
Select parameters for unit change: (default = 22)

1	Geopotential altitude	(ft)
2	Mach number	
3	True velocity	(knots)
4	Dynamic pressure	(lbf/ft^2)
5	Calibrated airspeed	(knots)
6	Equivalent airspeed	(knots)
7	Impact pressure	(lbf/ft^2)
8	Total pressure	(lbf/ft^2)
9	Total temperature	(deg R)
10	Reynolds number	
11	Speed of sound	(knots)
12	Static density	($slug/ft^3$)
13	Static pressure	(lbf/ft^2)
14	Static temperature	(deg R)
15	Coefficient of viscosity	(slug/ft-s)
16	Kinematic viscosity	(ft^2/s)
17	Geometric altitude	(ft)
18	Specific energy	(ft)

19	Flight test units	21	Metric units
20	English units	22	Return to Program Options Menu

Parameter units remain fixed until changed by using options from this menu. The units shown are option 19, flight test units. English and metric units are also offered as options (20 and 21) on this menu. These three options will globally change the units of all the parameters to the chosen type. English units differ from flight test units in the velocity parameters. The velocity parameters are defined as ft/s in English units and knots in flight test units. The metric units option configures the parameters in the international system or SI units. Case 2 shows a solution in metric units for the selected parameters, impact pressure, and Reynolds number:

Case 2
Parameter Values:
(* [ ] - selected parameters)

	Geopotential altitude	=	9144.0	(m)
	Mach number	=	.800	
	True velocity	=	242.5	(m/s)
	Dynamic pressure	=	13480.1	(N/m^2)
	Calibrated airspeed	=	156.3	(m/s)
	Equivalent airspeed	=	148.4	(m/s)
*	[Impact pressure]	=	15777.1	(N/m^2)
	Total pressure	=	45866.7	(N/m^2)
	Total temperature	=	258.0	(deg K)
*	[Reynolds number]	=	$2.27828E+06$	
	Speed of sound	=	303.2	(m/s)
	Static density	=	$4.58313E-01$	(kg/m^3)
	Static pressure	=	30089.5	(N/m^2)
	Static temperature	=	228.7	(deg K)
	Coefficient of viscosity	=	$1.48714E-05$	(kg/m-s)
	Kinematic viscosity	=	$3.24482E-05$	(m^2/s)
	Geometric altitude	=	9157.2	(m)
	Specific energy	=	12151.9	(m)

Note that Case 2 is equivalent to Case 1 from the Option 3 - Compute Solution section.

Parameter units can also be changed individually by selecting the corresponding parameter from the menu. The parameters that have dimensions of length (geopotential altitude, geometric altitude, and specific energy (E_s)) can be expressed in feet, meters, miles, nautical miles, or kilometers. The parameters that have dimensions of velocity (true velocity, calibrated airspeed, equivalent airspeed, and speed of sound) can be expressed in nautical miles per hour (knots), feet per second, miles per hour, meters per second, or kilometers per hour. The parameters that have dimensions of pressure (dynamic pressure ($\bar{q}$), impact pressure (q_c), total pressure (P_t), and static pressure (P)) can be expressed in pounds force per foot^2, pounds force per inch^2, atmospheres, newtons per meter^2, inches of mercury (in-Hg), centimeters of mercury (cm-Hg), inches of water (in-H_2O), or millibars (newtons per 100.0 meters^2). The parameters that have dimensions of temperature (total temperature (T_t) and static temperature (T)) can be expressed in degrees Rankine, degrees Fahrenheit, degrees Kelvin, or degrees Celsius. Static density (ρ) can be expressed in slugs per foot^3, kilograms per meter^3, or pounds mass per foot^3. The coefficient of dynamic viscosity (μ) can be expressed in slugs per foot-second, pounds mass per foot-second, or kilograms per meter-second. Kinematic viscosity (η) can be expressed in feet^2 per second, inches^2 per second, meters^2 per second, or centimeters^2 per second. Mach number and Reynolds number are dimensionless quantities.

Changing the parameter units, either globally or individually, does not directly change the parameter values. Once the units have been changed, the current parameter values can be retained or multiplied by a conversion factor corresponding to the new units. If the units are changed globally, a message appears asking if the parameter values should be converted to the new units. When the units of a single parameter are changed, a message is displayed

showing the current parameter value and the value if it were to be converted to the new units. A selection is made between the current value and the converted value. Generally, values should be converted when units are changed.

Option 6 - Change Output Format

Option 6 from the main menu, Change output format, controls the format in the output file **aro.dat** and the format displayed to the terminal screen. The Change Output Format Menu is as follows:

*** Change Output Format Menu *** (current value = 1)

1 Standard format

2 Scientific notation

The default standard format is based on the default units for the atmospheric and aerodynamic parameters for most input values. If more precision is required, the output can be displayed in scientific notation by choosing the Scientific notation option as shown in the following example, Case 3.

Case 3
Parameter Values:
(* [ ] - selected parameters)

*	[Geopotential altitude]	=	1.50000E + 05	(ft)
*	[Mach number]	=	1.20000E + 01	
	True velocity	=	7.64183E + 03	(knots)
	Dynamic pressure	=	2.74722E + 02	(lbf/ft^2)
	Calibrated airspeed	=	3.71015E + 02	(knots)
	Equivalent airspeed	=	2.84861E + 02	(knots)
	Impact pressure	=	5.03845E + 02	(lbf/ft^2)
	Total pressure	=	5.06571E + 02	(lbf/ft^2)
	Total temperature	=	1.43254E + 04	(deg R)
	Reynolds number	=	1.20990E + 05	
	Speed of sound	=	6.36819E + 02	(knots)
	Static density	=	3.30279E − 06	(slug/ft^3)
	Static pressure	=	2.72541E + 00	(lbf/ft^2)
	Static temperature	=	4.80719E + 02	(deg R)
	Coefficient of viscosity	=	3.52088E − 07	(slug/ft-s)
	Kinematic viscosity	=	1.06603E − 01	(ft^2/s)
	Geometric altitude	=	1.51087E + 05	(ft)
	Specific energy	=	2.77286E + 06	(ft)

The current format type is displayed and retained until the other format is chosen.

Option 7 - Change Primary Constants

This option modifies the constants that appear in the atmospheric and aerodynamic equations described in the Atmospheric Model and Aerodynamic Equations sections. When option 7 is chosen from the main menu, the following menu will appear

*** Change Primary Constants Menu *** (default = 18)
Constants are currently defined in English units

1	Ratio of specific heats of air (γ)	=	1.40000	
2	Gas constant (R^*)	=	1545.31812	(ft-lbm/(lbm-mol-deg R))
3	Molecular air mean weight, sea level (M_0)	=	28.96440	
4	Reynolds number characteristic length (l)	=	1.00000	(ft)
5	Coefficient of viscosity constant (β)	=	$7.3025000E-07$	
			(lbm/(ft-s-(deg R)$^{0.5}$))	
6	Sutherland's constant (S)	=	198.72000	(deg R)
7	Number of atmospheric layers (nal)	=	8	
8	Geopotential altitude breakpoints (H_b)	=		(ft)
9	Temperature atmospheric breakpoints ($T_{M,b}$)	=		(deg R)
10	Pressure atmospheric breakpoints (P_b)	=		(lbf/ft^2)
11	Temperature gradients in atmosphere ($L_{M,b}$)	=		(deg R/ft)
12	Effective Earth radius (r_0)	=	$2.0855532E+07$	(ft)
13	Acceleration due to gravity, sea level (g_0)	=	32.17410	(ft/s^2)
14	Geopotential gravity length constant (g_0')	=	32.17410	(ft/s^2)

15 Convert to Metric units

16 Examine atmospheric breakpoints

17 Reset to original values

18 Return to Program Options Menu

Changing these constants will change the corresponding values in the atmospheric and aerodynamic equations. The primary constants can be displayed and modified in either English or metric units by choosing option 15. Primary constant units are changed as a set, not individually. Therefore, the menu label for option 15 is set to Convert to Metric units when English units are in use and set to Convert to English units when metric units are used.

The atmospheric model can be modified by changing the number of layers or the breakpoints (altitude, temperature, pressure, and temperature gradient), using options 7 through 11. The standard day model, presented in the Atmospheric Model section, is defined by the atmospheric equations and the breakpoints for the eight atmospheric layers between sea level and 84.5 kilometers. Option 16 allows the atmospheric breakpoints to be examined. All the primary constants except Reynolds number characteristic length affect the atmospheric model. In addition, option 17 will restore all the primary constants including the atmospheric breakpoints to their original values.

The sea level constants ρ_0, P_0, and a_0 that appear in the aerodynamic equations are defined as the value of that parameter at an altitude of 0 ft. Therefore, changing the primary constants can change the corresponding value of the sea level parameters.

Option 8 - Multiple Case/Plot File

The Multiple case/Plot file option from the main menu produces the following menu, which allows multiple cases to be run. The output from multiple cases can be stored in a file for plotting.

* * * Multiple Case/Plot File Menu * * * (default = 8)

1 Select constant parameter

2 Select varying parameter

3 Input constant parameter value

4 Input varying parameter min, max, and delta

5 Compute multiple cases only

6 Compute multiple cases and Create plot file

7 Change plot file format

8 Return to Program Options Menu

A constant and a varying parameter are selected to run multiple cases. These parameters are selected by choosing option 1 or 2 from the menu shown above and entering the corresponding values. The constant and varying parameters are chosen in the same way the individual case parameters were chosen as described in Option 1 - Selecting Parameters. A parameter cannot be selected to be both the constant and varying parameter. The varying parameter values require a minimum, maximum, and delta value, creating a parameter array from which solutions are computed.

Options 5 and 6 from the Multiple Case/Plot File Menu compute the parameter solutions for the multiple cases. Option 5 displays the multiple case solutions to the terminal screen. Multiple case sets are numbered sequentially as well as the individual cases inside each multiple case set. Option 6 writes the multiple case solutions to the plot file **aroplt.dat** and will also display a message asking whether or not to display the solutions to the terminal screen. Each time option 6 is chosen, a file name for the multiple case set should be entered. Different file names for each set of multiple cases are necessary to prevent the data sets from being overwritten.

Option 7 from this menu allows the output format to be specified for the plotting output file, **aroplt.dat**. The first format, **cmp3**, is a compressed format read by the plotting program Ezplot (ref. 2). The second format type, **lis1**, is a less efficient but more readable ASCII format that may be desirable for viewing data or for other plotting routines. Reading and writing data in **cmp3** and **lis1** formats are documented in the GetData reference manual (ref. 3).

Option 9 - End Program

Option 9 from the main menu terminates the program after allowing the entire session to be saved. If the case information is saved, single and multiple cases are stored sequentially in the output file **aro.dat**. The plotting output file, **aroplt.dat**, is written whenever that option is chosen under the Multiple Case/Plot File Menu as described in the previous section. There is no default to the End Program Menu since a mistake at this point could mean a significant loss of data.

PROGRAMMER'S REFERENCE GUIDE

The purpose of the program was to solve for 16 atmospheric and aerodynamic parameters given the values of any 2 selected parameters that define a unique flight condition. The problem was divided into two parts. The first

part used subroutine solve to compute geopotential altitude and Mach number from two selected parameters. The second part used subroutine exprss to compute the remaining 16 parameters from geopotential altitude and Mach number. The following sections discuss the atmospheric model, aerodynamic equations, equation solver, derivations of geopotential altitude, program structure, and error protection.

Atmospheric Model

The 1976 U.S. Standard Atmosphere was used as the reference for the atmospheric model in AeroFcn. Six atmospheric parameters are functions of geopotential altitude: static temperature, static pressure, static density, speed of sound, coefficient of dynamic viscosity, and kinematic viscosity. The acceleration due to gravity and geometric altitude are also functions of geopotential altitude and are included in this section.

The standard day atmospheric model is divided into a series of spherical layers of air. Equations describing the atmospheric properties inside each layer are based on breakpoints of geopotential altitude (H_b), static temperature ($T_{M,b}$), static pressure (P_b), and temperature gradient ($L_{M,b}$), where the subscript b represents the layer number. The following equations are implemented in AeroFcn and are valid for the geopotential altitude range from 5.0 kilometers below sea level to 84.5 kilometers above sea level.

Molecular scale temperature, T_M, is a function of geopotential altitude, H.

$$T = T_{M,b} + L_{M,b}(H - H_b) \tag{1}$$

Molecular scale temperature (T_M) is related to (kinetic) static temperature (T) by a ratio of the molecular air mean weight at sea level (M_0) and the molecular air mean weight (M).

$$T_M = T\frac{M_0}{M} \tag{2}$$

From sea level to 79-km geopotential altitude, the molecular air mean weight is constant and equal to M_0. From 79- to 84.5-km geopotential altitude, the molecular air mean weight is virtually equal to the sea level value. Therefore, the molecular scale temperature and static temperature are treated as equivalent in this atmospheric model. Static temperature can then be expressed as a function of geopotential altitude using equations (1) and (2):

$$T = T_{M,b} + L_{M,b}(H - H_b) \tag{3}$$

For an isothermal atmospheric layer, where temperature gradient equals zero, static temperature reduces to:

$$T = T_{M,b} \tag{4}$$

Static pressure (P) is also a function of geopotential altitude. For a nonisothermal layer, static pressure can be expressed as:

$$P = P_b\left[\frac{T_{M,b}}{T_{M,b} + L_{M,b}(H - H_b)}\right]^{\left[\frac{g_0' M_0}{R^* L_{M,b}}\right]} \tag{5}$$

where R^* is the gas constant and g_0' is the geopotential gravity length constant. The units of R^* differ in this and the following equations from those in the primary constant menu (see Option 7 - Change Primary Constant) by a lbm/slug conversion factor. If the atmospheric layer is isothermal, then static pressure is defined as:

$$P = P_{b^e}\left[\frac{-g_0' M_0(H - H_b)}{R^* T_{M,b}}\right] \tag{6}$$

From the perfect gas law, static density (ρ) can be expressed as a function of static pressure to static temperature.

$$\rho = \frac{P\,M_0}{R^*\Gamma} \tag{7}$$

Speed of sound in the atmosphere (a) is a function of the square root of static temperature:

$$a = \sqrt{\frac{\gamma R^* T}{M_0}} \tag{8}$$

where γ is the ratio of specific heats of air constant. Coefficient of dynamic viscosity (μ) is a function of static temperature:

$$\mu = \frac{\beta T^{\frac{3}{2}}}{T + S} \tag{9}$$

where S is Sutherland's constant and β is a primary constant. The units of β also differ in this equation from those in the primary constant menu by a lbm/slug conversion factor. Kinematic viscosity (η) is defined as the ratio of coefficient of dynamic viscosity to static density.

$$\eta = \frac{\mu}{\rho} \tag{10}$$

The standard day atmosphere between sea level and 84.5 km (or 277230.97 ft) is divided into 8 layers. The standard day breakpoints in English units for the eight atmospheric layers are:

Atmospheric Breakpoints

Layer, b (#)	Geopotential altitude, H_b (ft)	Temperature, $T_{M,b}$ (deg R)	Pressure, P_b (lbf/ft^2)	Temp gradient, $L_{M,b}$ (deg R/ft)
1	0.0000000	518.6700	2116.2199995	−0.0035662
2	36089.2388450	389.9700	472.6799016	0.0000000
3	65616.7979000	389.9700	114.3437577	0.0005486
4	104986.8766400	411.5700	18.1287947	0.0015362
5	154199.4750650	487.1700	2.3161984	0.0000000
6	167322.8346450	487.1700	1.3980314	−0.0015362
7	232939.6325450	386.3700	0.0826313	−0.0010973
8	277230.9711275	337.7700	0.0083153	−0.0010973

Note that the breakpoints are defined at the bottom of each layer and in the atmospheric reference, b is defined as 0 for the first layer.

Two other functions of geopotential altitude are also presented in this section. Geometric altitude (Z) can be expressed as a function of geopotential altitude:

$$Z = \frac{r_0 H}{\Gamma r_0 - H} \tag{11}$$

where r_0 is the effective Earth radius constant. The conversion constant Γ is defined as:

$$\Gamma = \frac{g_0}{g_0'} \tag{12}$$

where g_0 is the sea level acceleration due to gravity constant. Gravitational acceleration (g) can be expressed as a function of geometric altitude or geopotential altitude by using equation (11).

$$g = g_0 \left(\frac{r_0}{r_0 + Z}\right)^2 = g_0 \left(\frac{\Gamma r_0 - H}{\Gamma r_0}\right)^2 \tag{13}$$

Aerodynamic Equations

The aerodynamic parameters are defined in equations (14) through (24). Equations (14) through (21) were taken from reference 4 and can be found in various forms, along with the remaining aerodynamic parameters, in many standard aerodynamic texts.

Total pressure (P_t) is defined as the sum of static pressure (P) and impact pressure (q_c).

$$P_t = P + q_c \tag{14}$$

Dynamic pressure ($\bar{q}$) is defined as one half the product of static density (ρ) and true airspeed (V), squared.

$$\bar{q} = \frac{1}{2}\rho V^2 \tag{15}$$

Mach number (M) is defined as the ratio of true airspeed (V) to the speed of sound (a).

$$M = \frac{V}{a} \tag{16}$$

Total pressure can also be defined as a function of static pressure and Mach number. The total pressure equation for $M \leq 1$ is

$$P_t = P\left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} \tag{17}$$

Total pressure for $M \geq 1$ is

$$P_t = \frac{1+\gamma}{2} M^2 P \left[\frac{(1+\gamma)^2 M^2}{4\gamma M^2 - 2(\gamma - 1)}\right]^{\frac{1}{\gamma-1}} \tag{18}$$

Equivalent airspeed (V_e) is a function of the product of true airspeed and the square root of static density

$$V_e = V\sqrt{\frac{\rho}{\rho_0}} \tag{19}$$

where ρ_0 is the sea level static density constant. Impact pressure is a complicated function of calibrated airspeed (V_c). For $V_c \leq a_0$, impact pressure is defined as

$$q_c = P_0 \left[\left(1 + \frac{\gamma - 1}{2\gamma}\frac{\rho_0}{P_0} V_c^2\right)^{\frac{\gamma}{\gamma-1}} - 1\right] \tag{20}$$

where P_0 and a_0 are sea level constants of static pressure and speed of sound, respectively. The impact pressure equation for $V_c \geq a_0$ is

$$q_c = \frac{1+\gamma}{2}\left(\frac{V_c}{a_0}\right)^2 P_0 \left[\frac{(\gamma+1)^2}{4\gamma - 2(\gamma - 1)\left(\frac{a_0}{V_c}\right)^2}\right]^{\frac{1}{\gamma-1}} - P_0 \tag{21}$$

Total temperature (T_t) is a function of static temperature and Mach number.

$$T_t = T(1 + \frac{\gamma - 1}{2} M^2) \tag{22}$$

Reynolds number (Re) can be expressed as the ratio of static density and true airspeed to coefficient of dynamic viscosity:

$$Re = \frac{\rho V l}{\mu} \tag{23}$$

where l is the Reynolds number characteristic length constant. Energy height or specific energy (E_s) is the sum of potential energy (mgH) and kinetic energy ($\frac{1}{2} m V^2$) divided by unit weight,

$$E_s = H + \frac{1}{2} \frac{V^2}{g} \tag{24}$$

where m is mass.

Equation Solver

To solve the transcendental equations inherent in computing many of the parameters, a nonlinear equation solver was used. The equation solver varies a single parameter to zero a general function. The routine that calls the equation solver specifies the convergence criteria, the parameter to be varied along with an initial estimate, and any auxiliary parameters that are necessary in solving the atmospheric and aerodynamic equations. The following routine **amchp**, which computes Mach number given total and static pressure, demonstrates how the equation solver is implemented.

```
      Double precision function amchp (pt,pa)
c
c.... function computes Mach number given total and static pressure
c
      implicit double precision (a-h)
      implicit double precision (o-z)
c
      double precision x(1),wk(182),par(2)
      logical lofile,lstfmt
c
      common /outfil/ nunit1,lofile,lstfmt,nunit2,nunit3
c
      external zamchp
c
c.... equation solver variables
c
      nsig  =  5
      neqns  =  1
      itmax  =  500
c
c.... total and static pressure are passed as parameters
c
      par(1)  =  pt
      par(2)  =  pa
c
c.... initial estimate for Mach number
c
```

```
      x(1)  =  1.0
c
c.... nonlinear equation solver
c
      call zscnt (zamchp,nsig,neqns,itmax,par,x,fnorm,wk,ier)
c
c.... solution for Mach number
c
      amchp  =  x(1)
c
c.... error protection
c
      if (ier .ne. 0) then
        write (*,1000) pt,pa
        write (nunit3,1000) pt,pa
        read (*,*)
      endif
c
1000 format (/,2x,'ZSCNT did not converge.  The values given for the',
     . ' input parameters may ',/,2x,'not produce a physically ',
     . 'realizable system.  ',
     . /,2x,'Total pressure  = ',1pe15.5,' (lbf/ft^2)',
     . /,2x,'Static pressure = ',1pe15.5,' (lbf/ft^2)')
c
      return
      end
```

A corresponding subroutine is called by the equation solver that contains the nonlinear function to be set to zero. For this example, the equation solver calls the subroutine **zamchp** and varies Mach number ($x(1)$), given total pressure ($par(1)$), and static pressure ($par(2)$) until the function $f(1)$ converges to zero. Therefore, the Mach number at convergence is the Mach number which satisfies the flight condition determined by the selected parameters. The code for subroutine **zamchp** is as follows:

```
      Subroutine zamchp (x,f,n,par)
c
c.... routine finds the Mach number for a given static and total pressure
c
      implicit double precision (a-h)
      implicit double precision (o-z)
c
      double precision x(1),f(1),par(2)
      double precision M0
c
      common /prmcon/ gam   ,Rstar   ,M0      ,Rel   ,beta     ,S ,
     .                r0    ,g0      ,g0prm
c
c.... set Mach number and pressure parameters
c
      amch = x(1)
      pt = par(1)
      pa = par(2)
c
c.... employ penalty function for Mach less than zero
```

```
c
      if (amch .le. 0.0) then
        f(1) = - 10.0 * amch + pt
      elseif (amch .gt. 0.0 .and. amch .le. 1.0) then
        c1 = gam / (gam - 1.0)
        c2 = (1.0 + (gam - 1.0) / 2.0 * amch**2)**c1
        f(1) = pt - pa * c2
      else
        c1 = (gam + 1.0) / 2.0 * amch**2 * pa
        c2 = (gam + 1.0)**2 * amch**2
        c3 = 4.0 * gam * amch**2 - 2.0 * (gam - 1.0)
        f(1) = pt - c1 * (c2 / c3)**(1.0 / (gam - 1.0))
      endif
c
      return
      end
```

Notice that a penalty function is employed for Mach numbers less than zero. Penalty functions are implemented in all subroutines called by the equation solver to limit the algorithm to a search space appropriate to the atmospheric model and aerodynamic equations. Since computational speed was not a problem, terms such as $gam/(gam-1)$ were not computed outside the iterative process.

Derivations of Geopotential Altitude

An explicit solution was derived for many of the selected parameters without the use of the equation solver. The equations presented in this section represent the more complicated derivations, all of which consist of geopotential altitude as a function of an atmospheric parameter. The remaining explicit solutions are trivial and can be found in the subroutine solve or in functions that are called within solve. The following equations, derived from the atmospheric and aerodynamic equations from the previous sections, are expressions of geopotential altitude as a function of one atmospheric parameter and various primary constants.

From equation (3), geopotential altitude can be expressed as a function of static temperature for a nonisothermal layer.

$$H = H_b + \frac{T - T_{M,b}}{L_{M,b}} \tag{25}$$

From equation (5), geopotential altitude can be expressed as a function of static pressure for a nonisothermal layer.

$$H = H_b + \frac{T_{M,b}}{L_{M,b}} \left[\left(\frac{P}{P_b} \right)^{\left[\frac{-R^* L_{M,b}}{g_0' M_0} \right]} - 1 \right] \tag{26}$$

From equation (6), geopotential altitude can be expressed as a function of static pressure for an isothermal layer.

$$H = H_b - \frac{R^* T_{M,b}}{g_0' M_0} \ell n \left(\frac{P}{P_b} \right) \tag{27}$$

From equations (3), (5), and (7), geopotential altitude can be expressed as a function of static density for a nonisothermal layer.

$$H = H_b + \frac{T_{M,b}}{L_{M,b}} \left[\left(\frac{\rho R^* T_{M,b}}{P_b M_0} \right)^{\left[\frac{-R^* L_{M,b}}{g_0' M_0 + R^* L_{M,b}} \right]} - 1 \right] \tag{28}$$

From equations (3), (6), and (7), geopotential altitude can be expressed as a function of static density for an isothermal layer.

$$H = H_b - \frac{R^* T_{M,b}}{g_0' M_0} \ell n \left(\frac{\rho R^* T_{M,b}}{P_{M,b} M_0} \right) \tag{29}$$

From equations (3) and (8), geopotential altitude can be expressed as a function of atmospheric speed of sound for a nonisothermal layer.

$$H = H_b + \frac{a^2 M_0 - \gamma R^* T_{M,b}}{\gamma R^* L_{M,b}} \tag{30}$$

From equation (12), geopotential altitude can be expressed as a function of gravitational acceleration.

$$H = \Gamma r_0 \left(1 - \sqrt{\frac{g}{g_0}} \right) \tag{31}$$

Three parameters are not monotonic functions of geopotential altitude: static temperature, atmospheric speed of sound, and coefficient of dynamic viscosity. To compute geopotential altitude from one of these three parameters, geopotential altitude ranges based on the atmospheric layers where the parameter to be found is either strictly increasing or decreasing are displayed. A geopotential altitude range is then selected and geopotential altitude is calculated. The geopotential altitude ranges for isothermal atmospheric layers are also displayed, but cannot be selected.

The multiple case option uses a logical **lplt** that prevents having to choose the desired geopotential altitude range for each iteration when the multiple case option is chosen. The logical **lplt** is set true after the first case of a multiple case run is computed and the geopotential altitude range is stored as the variable **nhrng** and used for each case in the multiple case solution. These plotting variables are contained in the following common blocks:

```
common /aroplt/ conpar,xplt(kplt)
common /nlplt /nplt   ,lplt  ,nhrng
```

Program Structure

The **AeroFcn** FORTRAN code is divided into three subprograms: **AeroIO.f**, **AeroEqns.f**, and **AeroAux.f**. Routines that execute the program logic, sequencing, and provide for the user interface are contained in **AeroIO.f**. The software that describes the aerodynamic equations and mathematical relationships of the atmospheric model is contained in **AeroEqns.f**. **AeroAux.f** consists of auxiliary code such as interpolation routines and character string manipulation functions. The software package is written in American National Standards Institute (ANSI) FORTRAN 77 except for the following items:

- lowercase letters were used extensively throughout the program, and
- double precision constants were often written in single precision (for example, 20.0 instead of 2.0D + 01).

The nonstandard code was used to increase the readability of the code. The output files **aro.dat** and **aroplt.dat** use the file unit numbers 13 and 14 respectively. A scratch file is used by the program and is assigned the file unit number 15. The program was written in a modular style with the assumption that some of the subroutines and functions would probably be modified or replaced in the future.

Program dimension limits, described in the following, can easily be changed through parameter statements. The following is a list of the dimension limit names, brief descriptions, and sizes that set the size of the arrays used in **AeroFcn**:

kc	Number of primary constants	14
kdu	Default units (1 = flight test, 2 = English, 3 = metric)	1
kp	Number of atmospheric and aerodynamic parameters	18
kplt	Maximum number of elements in varying parameter	10001
kal	Maximum number of atmospheric layers	20

The parameter kdu specifies to which set of default units the program initializes in subroutine **initil**. English, flight test, or metric units can be set as the default by modifying kdu to 1, 2, or 3 respectively. Of course, the units can also be changed interactively as described in Option 5 - Change Parameter Units.

Error Protection

Error protection is built into the code to protect against improper input. The types of error protection include user interface errors, unreasonable numerical values, nonunique parameter selection, and numerical computing problems. Unless otherwise specified, error messages describe the problems in this section and allow recovery.

Every input that is read interactively by the program is passed through subroutine **iod**, which ensures that the variable type read was the type expected. Menu choices are protected by the subroutine **choose**, which allows only the options available on the current menu.

Filenames for the output files are checked for illegal characters in subroutines **chrchk** and **fstchk**. This error protection is highly dependent on the operating system where **Aerofcn** is installed. Currently, there are no characters that are specified as illegal. This, however, can be changed as shown in the following example where the number of illegal characters is the dimension of variable **badstr** and the data statement contains the following illegal characters

```
      character*27  badstr
c
      data badstr /'!@#$^&*()_=+'~[]{}",:;?><|\'/
```

The local compiler, however, may not allow some of these nonstandard characters in the character string.

Values of the selected parameters are checked in subroutine **inpchk** for unreasonable inputs, such as negative Mach numbers. The minimum, maximum, and delta values that create the vector for the multiple case option is created and checked in logical function **brkfn**.

The selected parameters are checked in logical function **selchk**. This function insures that there are two parameters selected and that the pair defines a unique flight condition. The function is set to false if an error is detected. The problem is described in an error message and allows the parameters to be reselected.

If a zero velocity condition is entered, a solution is computed from the current geopotential altitude and zero Mach number. Because the selected parameters, which may be different from the current geopotential altitude and Mach number, are retained in the solution, inconsistencies may appear in these solutions. Zero velocity conditions are detected and a caution is issued, but it is not considered to be an error.

The atmospheric and aerodynamic functions described in Atmospheric Model and Aerodynamic Equations are mostly smooth and well behaved. The equation solver almost always converges quickly to a solution, if one exists. Occasionally, there exists more than one solution for a given pair of selected parameters. In this case, the program will simply converge to the nearest solution. If a solution does not exist or the equation solver does not converge within the proper tolerance or the maximum number of iterations specified, an error message is displayed. In addition, many of the functions will restart the search algorithm with a different initial estimate if the equation solver fails to converge, in an attempt to circumvent local minima and convergence problems.

CONCLUDING REMARKS

This report documents the utility and limitations of the computer program **AeroFcn**. A section on program operations describes the various menu options and overall capabilities. A section for programmers is included that documents the atmospheric model, aerodynamic relations, and how the FORTRAN code is structured to solve for the unknown variables. Comments on error protection are also included in this section.

In summary, **AeroFcn** is a flexible FORTRAN software package wherein commonly used aerodynamic and atmospheric variables are related to each other using well known compressible flow and normal shock equations and a modifiable standard day atmospheric model. Once two unique variables are selected from interactive menus and their values entered, the remaining variables are computed and the solutions stored in an output file. Further options allow multiple cases to be run and the solutions to be stored in an output file for plotting as well as options that change parameter units, the output format, and primary constants.

Dryden Flight Research Facility
National Aeronautics and Space Administration
Edwards, California, March 15, 1991

REFERENCES

1. "U.S. Standard Atmosphere, 1976" National Oceanic and Atmospheric Administration, NASA, United States Air Force, Washington, D.C., Oct. 1976.

2. Garbinski, Charles, Paul C. Redin, and Gerald D. Budd, *User's Manual for EZPLOT Version 5.5 A FORTRAN Program for Two-dimensional Graphics Display of Data,* NASA TM-88293, 1988.

3. Maine, Richard E., *Manual for GetData Version 3.1 A FORTRAN Utility Program for Time History Data,* NASA TM-88288, 1987.

4. Gracey, William, *Measurement of Aircraft Speed and Altitude,* NASA RP-1046, 1980.

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13. ABSTRACT *(Maximum 200 words)*

This report documents the computer program **AeroFcn**, a utility program that computes the following 18 aerodynamic parameters: geopotential altitude, Mach number, true velocity, dynamic pressure, calibrated airspeed, equivalent airspeed, impact pressure, total pressure, total temperature, Reynolds number, speed of sound, static density, static pressure, static temperature, coefficient of dynamic viscosity, kinematic viscosity, geometric altitude, and specific energy for a standard or a modified standard day atmosphere using compressible flow and normal shock relations. Any two parameters that define a unique flight condition are selected and their values are entered interactively. The remaining parameters are computed and the solutions stored in an output file. Multiple cases can be run and the multiple case solutions can be stored in another output file for plotting. Parameter units, the output format, and primary constants in the atmospheric and aerodynamic equations can also be changed.

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