ATMOSPHERIC THERMODYNAMICS
HP48 Calculator Program Documentation
Louis Michaud
Revised: October, 2015

1.0 PROGRAM DESCRIPTION

HP48 calculator program Atmospheric Thermodynamics (AT1) calculates the properties of air containing water in any phase; given pressure, temperature and a humidity parameter. The program can calculate a wide range of parameters including:

1. Thermodynamic properties for individual air masses or of complete sounding.
2. Work produced when small air masses are moved isentropically.
3. Work produced when large masses of dry air change position.
4. Properties of mixtures of air and water.
5. Pressure drop and work loss for laminar and turbulent flow in tubes, work loss and terminal velocity for bubble flow.

The program uses the power and versatility of the Hewlett-Packard HP48 object oriented programming language. The HP48SX calculator came out in 1990 and is now out of production. The HP48SX is a programmable scientific calculator using object oriented programming, programmable keys, Reverse Polish Notation (RPN) or Algebraic Notation. When it came out the HP48SX was the leading scientific calculator and has not been surpassed. A community of HP48SX adepts developed. When HP stopped producing the calculator the community developed an HP48SX emulator for PC's which is available free of charge on the internet. The PC emulator runs approximately 100 times faster than the original calculator on a medium speed desktop. A calculation taking 10 minutes on the original calculator can be completed in less than 2 seconds on a PC.

HP48 emulators for IPod and IPad are now available for $15 at the Apple Application store. On the IPod/IPad emulators the key can be pressed directly like on the original calculators. In addition the IPad emulator provides visual and audible feedback when key are pressed resulting in a fabulous user interface. HP48 emulators are also available for Android devices.

For some unexplained reason the skin for the PC version of the HP48SX calculator reversed the color of the orange and blue shift keys. The skin for the HP48SX IPad emulator reverted to the original colors which match those of the HP48SX Manual.

The AT1 program can be run on the HP48SX or HP48GX original calculators, on windows PC's, on IPod, on IPad and on Android devices. AT1 requires 160 kBytes of memory. HP48SX PC emulator memory can be increased from 30 kB to 292 kB by merging two 128 kB memory cards. HP48GX PC emulator memory can be increased from 128 kB to 259 kB by merging one 128 kB memory card. The IPod/IPad applications now support the second memory card and therefore their maximum memory is 292 kB for the HP48SX app and 256 kB for the HP48GX app.

According to Vaclav Smil, a well programmed calculator is probably the most cost and time effective investment an inquisitive mind can make in a life time. Calculations relating to the Atmospheric Vortex Engine (AVE) can be carried out on the HP48SX. The calculations were independently checked on an equivalent MathCad program and on chemical engineering process simulator PROII.

HP48SX programs are called objects. Calculator programs are difficult to document and therefore are rarely shared. The labelled programmable key features of the HP48SX facilitate the use of the calculator. The directories and the programmable keys of the directory are organized to help one remember the name of function and sequence of use. The programs can be viewed using the VISIT key as a supplements to this documentation. Objects are usually kept short to make it easier to understand the programs. Parameters required to run a program are usually listed at the beginning of the program code. RPN and algebraic programming mode are both used. The algebraic mode is used to show equations their familiar form. Using the HP48SX calculator requires an understanding of its two volumes User Manual. Using the search function of your file reader can be an effective way of finding the topic or the object you are looking for in this program documentation.

The AT program can be modified to test scenarios not anticipated when the program was conceived. The program and its documentation are a work in progress. The purpose of infrequently used old objects may no longer be clear to the author. An attempt has been made to remove unused and duplicate objects. Some of the objects whose usefulness is in doubt or that may be used by other objects have been retained. Questions marks are used for the descriptions of objects that have not yet been documented.

Calculated thermodynamic properties list

Partial Pressure of Water,
Partial Pressure of Air,
Mixing Ratio for Water in any Phase,
Specific Humidity
Mole fraction of water
Relative Humidity,
Wet Bulb Temperature,
Density,
Virtual Temperature,
Potential Virtual Temperature,
Entropy,
Enthalpy,
Free Enthalpy
Potential Temperature at 100 kPa,
Double Potential Temperature (potential temperature at 10 kPa)
Isentropic Desiccation Temperature
Potential Isentropic Desiccation Temperature
Equivalent Temperature (Isenthalpic Desiccation Temperature),
Equivalent Potential Temperature
Lifting Condensation Pressure
Freezing Level
Level of Free Convection
True-Adiabatic Expansion Temperatures,
Pseudo-Adiabatic Expansion Temperature,
Potential pseudo wet-bulb Temperature,
Affinity,
Static Energy.

The calculations are based on Thermodynamique de l'Atmosphère by Louis Dufour and Jacques Van Mieghem. Thermodynamic functions are generally based on the equations listed in: http://vortexengine.ca/misc/AT1_Equations.pdf

The program uses rigorous definitions of thermodynamic properties and avoids algebraic approximations. The HP48 solver is used to calculate properties that cannot be isolated by algebraic manipulation rather than by using approximate equations. As a result running the calculation backwards reproduces the original inputs.

HP48 functions are written in algebraic notation so that the user can see the equations used to calculate a property and the parameters required by the program by visiting the program. Calculator programs can be extremely useful but are notoriously difficult to document. For this reason the use of calculator programs is frequently limited to the program creator. This documentation is an attempt to explain the major features of the program. This documentation is organized by directory. Object in directories are usually listed in the order they appear in the calculator. A good way to find what you are looking for is to use your pdf reader search function. The program and its documentation are works in progress.

The program uses SI units. Directory AT1 contains objects for converting non SI units to the base SI unit. Calculations are usually based on absolute temperature in degree Kelvin. Temperature can be entered in degree Celsius or Kelvin. Extensive properties are per unit mass of dry air. Enthalpy of moist air is in Joules per kilogram of dry air and includes the enthalpy of the air and its water content in any phase. Engineering multiples of the basic SI unit are used when appropriate; pressure is in kPa, mixing ratio is in g-water/kg-air. Units are not shown except in directory AT5F. Program PROP in AT5F calculates 28 properties of the air mass defined in AT4 and tag the values with the appropriate SI unit.

The program can plot arrays of properties calculated from atmospheric soundings. The program is designed so that the calculated properties can be used in subsequent calculations including plots based on arrays of sounding properties. Entropy calculations were checked against Randall, mixing calculations were checked against Lilly.

2.0 PROGRAM INSTALLATION

The compete Atmospheric Thermodynamics program is contained in object AT1. The program is installed by putting object AT1 on the stack and saving it as AT1 in the Home directory.

AT1 requires 155 kbytes of memory. A real HP48SX calculator requires at least one 128 kbytes memory card. This memory card must be merged in the built in 32 kBytes main memory to give a total memory of 160 kbytes.

An HP48SX can have up to 290 kbytes of memory by merging two 128 kbytes memory card with its basic 30 kbytes of memory. The HP48SX emulator should be set up with 290 kbytes of memory.

The AT1 program will run on either the HP48SX or the HP48GX or on their PC emulators. AT1 was written for the HP48SX. The HP48SX has a more consistent user interface than the HP48GX and is recommended. On a PC, the use of the Casey touch screen HP48SX skin is recommended.

2.1 DIRECTORY ORGANIZATION

Sub-directory AT2 is accessed by pressing the AT1 key in the home directory.

The left hand key in each directory is usually the next directory down. The ↑AT4 key in sub-directory AT2 gets one directly to the AT4 directory from which most of the functions are available.

The name of the current directory and the path from the Home directory are indicated at the top of the calculator screen. The name of the left hand key after you press VAR is the next directory down. When you see the AT5 key you are in the AT4 directory.

Sub-directories: AT2, AT3, AT4, AT5, and AT6 form a chain.
The objects in the upper level directories are available from any underlying directory. The constants in AT2 are available in AT3, AT4, and AT5, the data in AT5 can be plotted in AT6. The objects not in in-line directories are not accessible without changing directory. The functions in AT4 can be accessed from AT5. AT5B can access the objects in AT4, AT3, and AT2 but not the objects in AT5A. When the program encounters a new object, it looks for it first in the current directory and then in its parent directories. The constant values are entered only once, usually in AT2, therefore results are consistent and repeatable.

Directory Structure

Parent Directories	Sub Directories
HOME	AT1
AT1	AT2 AT2A AT2B AT2C AT2D ATDAT
AT2	AT3 AT3A AT3B AT3C AT3D, AT3E
AT3	AT4 AT4A AT4B AT4C
AT4	AT5 AT5A AT5B AT5C AT5D AT5E AT5F AT5G AT5H AT5J AT5K AT5L AT5M AT5P, AT5Q
AT5	AT6 AT6A AT6B AT6C AT6D AT6E
AT6	AT7

2.2 Main In-Line directories.

HOME	**Complete AT1 Program** - Atmospheric Themodynamics Program AT1.
AT1	**Conversion** between customary units and base SI unit; and energy content of common fuels. Press ATM↓ to jump directly to primary directory AT4
AT2	Thermodynamic **constants**.
AT3	Thermodynamic properties of **pure air and pure water**, virtual temperature, lapse rate, and the distance between sounding pressure

levels.

AT4	Thermodynamic properties of **moist air**. The condition of the unit mass of air is specified by entering pressure, temperature, and a humidity parameter. The directory uses the HP48 solver to calculate adiabatic expansion temperature, dew point, wet bulb, and equivalent temperature.
AT5	Thermodynamic properties of **complete soundings** and work produced when air masses are moved.
AT6	Programs to **plot** data from arrays.

2.3 Side sub-directories

Side sub-directories are used where the data is not likely to be used further down. The name of side-directories terminates with a letter.

AT2A	**Energy usage and reserves**
AT2B	Conversion **MPG to Km/hr** to L/100 km
AT2C	**Energy cost**
AT2D	**Hurricane categories and velocities**
ATDAT	Atmospheric **sounding data**

AT3A	**Clappeyron equation** coefficients calculation.
AT3B	Constants relating to the **Earth energy budget**: percent of radiation reflected and absorbed by the atmosphere and the earth surface, the solar constant, the Stefan-Boltzman law, and conversion factors from Langley.
AT3C	Thermodynamic properties of **propane**.
AT3D	**Circulation from earth rotation**
AT3E	Lambton College Prototype Parameters

AT4A	**Subsidence velocity** required to compensate for radiative cooling.
AT4B	**Carnot efficiency** and ultimate efficiency
AT4C	**Efficiency** of aimple and combined cycles.

AT5A	**Tables of adiabatic temperatures** for both true and pseudo adiabatic expansion, the freezing temperatures is adjustable.
AT5B	Properties of isenthalpically **mixed air and water**.
A5B1-A5B4	Data for the **four cases** described in: "Thermodynamic Cycle of the Atmospheric process".
A5B1	Case 1, air column with an adiabatic lapse rate, pure air.
A5B2	Case 2, air column with a 6.5 K/km lapse rate, pure air.
A5B3-A5B4	Case 3 and 4, air column with a 6.5 K/km lapse rate, moist parcel.
A5B6	Properties of air rising with entrainment and detrainment. Used for Tellus paper (currently broken).
A5B7	?
A5B8	?
AT5C	**Margules** type air masses change of position.

AT5D	Independent check of adiabatic expansion temperature using a standard equation for the entropy of moist air during adiabatic expansion (not used).
AT5E	Pressure drop and work loss for continuous **flow in a tube**. Drag, terminal velocity and work loss for **spherical air parcels**. **Air-to-sea heat transfer**.
ATE1	Tube flow calculations with stored data.
AT5F	Thermodynamic properties with tags, symbol and **units.**
AT5G	HP48 differentiation function test (unused).
AT5H	**CAPE** from sounding data.
AT5J	**Hurricane intensity - AVE Ideal process – Total energy equation**
AT5J1	Sarnia constants
AT5J2	Emperical energy equations
AT5J3	Hurricane & AVE total work
AT5K	Exergy
AT5L	Hurricane intensity - **Emanuel** method
AT5M	**Solar chimney**
AT5N	Pseudoadiabatic expansion temperatures – **Equivalent Potential temperatures** by step and by Bolton
AT5P	Sounding **arrays** and array conversion programs
AT5Q	AT5J with addition of WK=WB+WPP. (recognises that WP reduces WB)
AT6A	**Plots** array data using the HP48 parametric plot rather than MLINE.
AT6B	Sounding CAPE.
AT6C	Subsidence.
AT6D	Average properties of a sounding.
AT6E	?

AT4 PROGRAMS DESCRIPTION

Directory AT4 is described first because it is the most important and most frequently used directory. Pressing ATM↓ in the HOME directory makes AT4 the current directory. AT4 makes use of the constants in AT2 and of the pure air properties of AT3.

Air properties can be entered in many ways:

PKM	Pressure in kPa, dry bulb in K, and mixing ratio in g/kg.
PKU	Pressure in kPa, dry bulb in K, and relative humidity in %.
PCD	Pressure in kPa, dry bulb and dew point in degC with respect to liquid water.
PCM	Pressure in kPa, dry bulb in C, and mixing ratio in g/kg.
PCU	Pressure in kPa, dry bulb in degC and RH in %.
PCW	Pressure in kPa, dry and wet bulb in degC.
PCDF	Pressure in kPa, dry bulb and dew point in degC with respect to ice.
PθM	Pressure in kPa, potential temperature in K, and mixing ratio in g/kg-dry air.
PθQ	Pressure in kPa, potential temperature in K, and humidity in g/kg-substance.

To specify the air property, put the appropriate three properties on the stack and press the corresponding key. Irrespective of which three parameters are entered the properties are returned to the stack in the PKM format. Pressure is stored in variable PP, absolute temperature in variable TT, and mixing ratio is stored in variable MM.

MM is the total quantity of water per unit mass of air, the mixing ratio. MM includes the water in any phase, its unit is g-water/kg-air. Water beyond the saturation amount is considered to be in a condensed phase and in equilibrium with the air. If there is condensed water, the water in the vapour phase is the saturation amount. The condensed water is in the liquid phase if the temperature is above the freezing temperature TF. Properties per unit mass of dry air (mixing ratio) are used in preference to properties per total mass of substance because in many processes air content is conserved while water content can change - for example in processes where condensed water is separated from expanding air (pseudo adiabatic expansion). Open pseudo-adiabatic expansion is handled by removing the condensed water at regular interval.

Example:
Pressure: P = 0 kPa, Dry Bulb Temperature C = 20°C, Dew point: D=15°C
PP=90 kPA, TT=293.15 K, MM=12.00 g/kg

Arguments: 3:90 2:20 1:15
Function: PCD
Results: 3:90 2:293.15 1:12.00

Program 'R' recalls the three standard properties to the stack. Calculation of the thermodynamic properties is based on having the three standard air property variables on the stack and then pressing the key for the desired property. The ending digit 3 in the program name is used to indicate properties calculated from the three standard parameters.

R	Recall PP, TT, and MM to stack (TT in °K – PKM format)
C	Recall PP, TT, and MM to stack (Display in °C – PCM format)

Y	Toggle temperature in level 2 from °C to K
X	Recall PP, TT, and MM to stack (Display in °C – PCU format)
Q	Convert 3 stack properties from PKM format to PCU format
S	Convert 3 stack properties from PCU format to PKM format
E	Equivalent temperature air expanded to 10 kPa and compressed 100 kPa isentropically.
B	Backup PP, TT, MM in PPP, TTT, MMM.
A	Store PP, TT, MM, in PPP, TTT, MMM, Calculate and store SS.
A1	Recall PPP, TTT, MMM to the stack.

PV3	Vapour pressure (kPa)
U3	Relative humidity from mass ratio – saturation value relative to water (%)
UP3	Relative humidity from partial pressure ratio (%)
UI3	Relative humidity from mass ratio – saturation value relative to ice(%)

MS3	Mixing ratio at saturation (g/kg)
MV3	Mixing ratio of water in the vapour phase (g/kg)
ML3	Mixing ratio of water in the liquid phase (g/kg)
MI3	Mixing ratio of water in the ice phase (g/kg)
ρ3	Density (kg/m3) (Valid for moist air and for saturated air containing condensed water)
ρD3	Density (kg/m3) (Moist air only, Dufour and Van Mieghen equation 8.63)
ρL3	Density (kg/m3) (Moist air only, Leonard density of air plus density of water)
TV3	Virtual temperature (K) (Valid for moist air and for saturated air containing condensed water)
TV3S	Virtual temperature of saturated air without condensed water (K)
ST3	Entropy per unit mass of air (J/kg.K)
SM3	Entropy per unit mass of substance (J/kg.K)
SE3	Entropy from a common equation (equation possibly from Emanuel?) Equivalent to ST3 (Enter PKM)
AA3	Entropy if water is in condensed phase. (Enter PKM)

HT3	Enthalpy per unit mass of air (J/kg)
HM3	Enthalpy per unit mass of substance (J/kg)
EE3	Enthalpy when water is in condensed state (Dufour Equivalent Temperature 12.39).
HW4	Enthalpy at wet bulb temperature.

μ3	Free enthalpy [H –TS] (J/kg)
μAL3	Free enthalpy – all water in liquid phase (J/kg)
T→θ	Temperature to Potential Temperature
θ→T	Potential temperature to Temperature
θ3D	Potential Temperature of dry or unsaturated air
θ3M	Potential Temperature of any air including air with condensed water (solver)

θε	Equivalent Temperature from Memory PTM
θε3	Equivalent Temperature from entered PTM
θW3	Wet bulb from entered PTM

θL3	Liquid water potential temperature

θV3	Virtual potential temperature (K) *
TA3	Isentropic Desiccation Temperature (K)
θA3	Potential Isentropic Desiccation Temperature – (Dufour 14.23) (K)
θE3	Equivalent Potential Temperature
TE3	Equivalent (Isenthalpic Desiccation) Temperature (K)
θθ3	Temperature at 10 kPa (K) and equivalent potential temperature for true adiabatic expansion with water separation at the 10 kPa level.
θθθ	?? Equivalent Temperature using θθ3, enter PCU
θθE3	?? Equivalent Temperature using θθ3, uses PP, TT, MM.
HUX	Canadian Humidex – Equation taken from Wikipedia
EMA3	?? Equivalent Temperature based on an equation from Emanuel, enter PKM
EMAU	?? Equivalent Temperature based on an equation from Emanuel, enter PKU
τ4	Isentropic expansion temperature for moist air. (not valid for saturated air)

LCL3	Level of Condensation (kPa)
LFZ3	Freezing pressure (kPa)
Q3	Specific humidity (g/kg)
AFFK	Affinity of air at PKM for liquid water at the temperature of the air
AFFC	Affinity of air at PCU for liquid water at the temperature of the air
AC	Affinity of pure water vapour at pressure FF for water at temperature (in °C)
FF	Vapor pressure in kPa. FF calculated by either AFFK or AFFC

Example:
Arguments: 1:90 2:293.15 3:12.00
Function: ST3
Result: 212.47
Entropy is: 212.47 J/kg.K

The program is valid for 3 kinds of air:

1. Dry air where the moisture content is zero,
2. Moist air where the moisture is less than the saturated amount,
3. Saturated air where the water content is equal or greater than the saturation amount.

The three standard properties are used for the three kinds of air. Two properties are required to describe dry air, three properties are required to describe moist or saturated air. The phase rule allows three properties be specified to describe humid air but limits the number of properties that can be specified to two for saturated air. When the air is dry the third property is zero. When the air is saturated, the third property is used to determine the quantity of condensed water. The program checks if MM is beyond the saturation amount, if so the water beyond the saturated amount is taken to be all in the liquid phase if the temperature is above freezing temperature TF, or to be all in the ice phase if the temperature is below freezing temperature TF minus the freezing band FB. The calculations are based on the air and the water in any phase being at equilibrium. The calculated properties include the contribution of the condensed water. Air masses can have water in two condensed phases.

Once the required two or three properties are known all other thermodynamic properties of the air mass are readily calculated.

Example of program structure:

Visiting U3 shows that P, T, M must be on the stack to calculate relative humidity and that the program MVS is used in calculating the saturation mixing ratio.
Visiting MVS (in AT3) shows that pressure and temperature must be on the stack to calculate saturation mixing ratio and that the program PV is used in calculating the vapour pressure.
Visiting PV shows temperature must be on the stack to calculate vapour pressure and that the program PVL or PVI are used to calculate vapour pressure depending on whether the temperature is above or below the freeze point temperature, TF.

Freezing temperature TF (default 273.15 K) and freezing band FB (default 20 K) are stored in constant directory AT2 and can be changed to check their effect. The freezing band must be at least 5 K to avoid solver singularity problem.

AT4 HP48SX SOLVERS

The HP48 solver is used to solve for variables that cannot be isolated and to avoid having to manipulate equations.

Program 'S.EQ' is an equation calculating the total entropy from PP,TT, and MM. The temperature during true adiabatic expansion is calculated by entering PP and solving for TT. Program TSOL invokes the solver to solve for TT given PP.

The MEQ directory contains the following equations:

A.EQ	Entropy moisture is condensed.
E.EQ	Enthalpy moisture content condensed.
EM.EQ	Enthalpy Emanuel PKM equation
EU.EQ	Enthalpy Emanuel PKU equation
G.EQ	Gas Law.
H.EQ	Enthalpy.
L.EQ	Humidity minus 100 (Used by LCL3 to calcualte lifting condensation level)
M.EQ	Entropy for two conditons equation
S.EQ	Entropy.
TV.EQ	Virtual temperature equation
V.EQ	Vapour Pressure.
W.EQ	Enthalpy at Wet Bulb.
W2.EQ	?? Enthalpy & wet bulb

The solver will solve for any missing variable. The following programs invoke the solver directly to calculate frequently need variables:

ASOL	Isentropic desiccation temperature - enter P - Solve A.EQ.
DSOL	Dew Point Temperature - enter partial pressure of water - Solve the V.EQ
HSOL	Mixture temperatures - Enter P - Solve H.EQ. for TT
USOL	Solve H.EQ for MM, Enter HH
MSOL	Mixing ratio from wet bulb - Solve W.EQ.
PSOL	Isentropic expansion <u>pressure</u> – Enter T - Solve S.EQ for P given S, T and M.
SSOL	Isentropic expansion <u>temperature</u> – Enter P - Solve S.EQ. Solve for T given S, P, and M.

TCAL	Isentropic expansion temperature – equation – no condensation allowed
TSOL	Isentropic expansion temperature – Enter P – Invoke SSOL after calculating SS . Solve for T given S, P, and M.
VSOL	Temperature from Virtual temperature - Enter TV – Solve TV.EQ
WSOL	Wet bulb temperature - Solve W.EQ.

The following xxx-3 properties programs invoke the solver:
TA3, θA3, TE3, θE3, θθ3, LCL3, LFZ3. Properties calculated using the solver which require up to a minute to calculate on the original HP48SX calculator can be calculated in under 1 second on the emulator. The solver adds variables to the current directory. The use of the solver should be restricted to the directories where the variables PP,TT, and MM exist, namely AT4, AT5, AT5B, AT5F. The solver can overwrite the values of PP, TT, MM, SS, and HH. Results are always stored in the current directory. New variables appear at the front of the current directory before the name of the first sub-directory and can be purged once they are no longer required. Programs B (Backup) and R (Restore) can be used to restore the standard properties before the next calculations.

θ3D calculates potential temperature using a formula for the potential temperature of air with no condensed water content. θ3M uses the solver to calculate the potential temperature of air containing condensed water. Potential temperature can also be calculated using TSOL. TSOL uses the solver to calculate the temperature at the end of an isentropic process. θ3D is much faster than TSOL, but TSOL is more fundamental, entropy is conserved in isentropic processes. θ3M is valid for any kind of air including air containing condensed water. θ3D is only valid when there is no water in a condensed phase. TSOL is valid for compression or expansion.

The program makes extensive use of Gibb's rule that states that knowing three properties is sufficient to calculate all thermodynamic properties of a two component system. The three properties need not be one of the set listed at the beginning of section 3.1. For example the three properties can be: entropy, mixing ratio and pressure. TSOL calculates temperature from entropy, mixing ratio and pressure. When TSOL is used it is only necessary to enter the pressure (PP) because the values of entropy and the mixing ratio are taken from the calculator memory (SS, MM). The high resolution of the HP48SX makes possible to reverse a calculation to get back the originals input.

AT4 Miscellaneous objects

SET	Store stack in PP, TT, MM.
IS	Initialize by calculating entropy and storing it in SS.
GF	Accelleration of gravity factor of air water mixture - enter MM
KM	Poisson ratio of air water mixture – enter MM
RM	Gas constant of air water mixture – enter MM
CPM	Specific heat at constant pressure of air water mixture – enter MM
CST	Custom menu

AT4 CUSTOM MENU (CST)

The custom menu provides access to the most commonly used functions by using the A to F keys in the unshifted, left shifted, and right shifted mode.

KEY	LABEL	UNSHIFTED	LEFT-SHIFTED	RIGHT-SHIFTED
A	RUM	R	PCU	PCM
B	SHρ	ST3	HT3	ρ3
C	SCF	MS3	LCL3	LFZ3
D	PUV	PV3	U3	TV3
E	DWθ	DSOL	WSOL	TSOL
F	KCF	Z	ZF	ZC

There are two custom menus (CST) one in AT1 and one in AT4. The AT1 custom menu is available in all subdirectory of AT1 down to AT4. The AT4 custom menu is available from all subdirectory of AT4. The AT1 custom menu converts between non SI and SI units.

The AT4 custom menu can be accessed from the AT1 directory with the ↑AT4 key and pressing CST. The ↑AT4 key switches to directory AT4. Pressing ↑AT4 is a good way to get in the program, it puts you in the middle of the program where the commonly used functions and no more then two directories away.

AT1 Conversion factors, times, and utilities.

The purpose of the conversion factors is primarily to replace incoherent units into rational SI unit. Energy units should be converted to the base energy SI unit, the Joules. Prefixes are not used. Prefixes can be seen by going to engineering mode and looking at the exponent.

Temperature Conversion

ZC	Degree F to C
ZF	Degree C to F

Power Conversion

YPPH	PPH steam to Watt
ZPPH	Watt to PPH steam
YQPY	Quadrillion BTU/yr to Watt
ZQPY	Watt to quadrillion BTU/yr
YTR	Ton of refrigerant to Watt
ZTR	Watt to Ton of refrigerant
YHR	Heat Rate to Efficiency
ZHR	Efficiency to Heat Rate (BTU/kW-hr)

Energy Conversion

YMO	Cubic meter of crude oil to Joule
ZMO	Joule to cubic meter of crude oil
YMG	Cubic meter of natural gas to Joule
ZMG	Joule to cubic meter of natural gas
YBBL	Barrel of crude to Joule
ZBBL	Joule to barrel of crude oil

YTOE	Tonne of crude oil to Joule
ZTOE	Joule to tonne of crude oil
YTC	Tonne of coal to Joule
ZTC	Joule to tonne of coal
ZTNT	Joule to tonne of TNT
YTNT	Tonne of TNT to Joule

Miscellaneous conversions

TO→B	Tonne of crude oil to barrel
B→TO	Barrel of crude oil to tonne
G→KG	US gallons to kilogram of water
KG→G	Kilogram of water to US gallon
G→P	US gallon of water to pound
P→G	Pound of water to US gallon
KS→G	Kilogram per second water to US gallon per minute
GM→K	US gallon per minute water to kilogram per second
CF→KG	Standard cubic feet of air to kilogram
KG→KCF	Kilogram of air to standard cubic feet
ρM→	Density lb/ft^3 to kg/m^3.
ρI→	Density kg/m^3 to lb/ft^3 .

Conversion Factors

WPH	Watts per pound per hour steam
WQ	Watts per quadrillion BTU per year
WTR	Watt per ton of refrigerant
BKH	BTU per kilowatt-hour
GP	Pound per Gallon
JMO	Joule per cubic meter of oil
JMG	Joules per cubic meter natural gas
JTOE	Joules per ton of crude oil
JBBL	Joules per barrel of oil
JTC	Joules per ton of coal
JTT	Joules per tonne of TNT
TOB	Ton of oil per barrel

Time Conversion Factors

N	Seconds per day
NS	Seconds per sidereal day
MD	Minutes per day
HY	Hours per year
SY	Seconds per year

Miscellaneous Utilities

TICK	Short audible.
DONE	Long audible.
MLINE	Plotting program.
GRAPHER	A program to transform an array to a string for transfer to a PC.
AUTHOR	Program author name
SYMB	Calculator keyboard index

AT1 Custom Menu

The converts between SI and traditional units and works like the calculator's built in unit converter. To use the converter enter the value and press the key for the old unit. To convert to an other unit press the left shift key and the key for the new unit. Press UVAL to remove the unit tag.

The AT1 custom menu has the following user defined keys. Conversion only works within a category.

Category	UVAL			
Energy Units	J	KW*H	BTU	
Power Units	W	BTU/H		
Temperature Units	C	K	F	R
Volumetric flow	L/S	GPM		
Density	KG/M^3	LB/FT^3		
Energy Density	G/GJ	T/GW-h		

AT2 FREEZING BAND

Condensed water can freeze between 0℃ K and -40℃. Condensed water can be made to freeze over a band of temperature (FB) starting at a specified freezing temperature (TF). Freezing temperature TF and freezing band FB are stored in directory AT2. Default freezing temperature is 273.15 K; default freezing band is 20 K but these values can be changed by the user. For the default values, condensed water is all liquid temperatures above 0℃, all ice at temperatures under -20℃, and 50% liquid at -10℃. Objects MV3, ML3, and MI3 in AT4 can be used to calculate how much of the water is in each of the three phases.

A freezing band is equivalent to the transition phase suggested by Ooyama both approaches eliminates a singularity solver problem when all the condensate freezes suddenly. If the condensate were to all to freeze suddenly during adiabatic expansion the air temperature would rise and some of the condensate would have to re-evaporate to conserve entropy. The freezing band can be removed by setting FB to zero. Using a freezing band is preferable to using sudden freezing even if the point where freezing starts or end is not known. A freezing band of 5 K is sufficient to eliminate the solver singularity problems. The program assumes that water in the vapour phase is in equilibrium with liquid water if the temperature is above the bottom of the freezing band and in equilibrium with ice otherwise.

AT2 DIRECTORY

↑AT4	Make sub-directory AT4 the current directory

Directory AT2 contains constants:

Z	Converts degK to degC and vice versa (formerly named KC). If the number on the stack is less than 150, T0 (273.15) is added, if the number on the stack is greater than 150 T0 is subtracted. Pressing KC repeatedly toggles between degK and degC.

T0	Temperature base, 273.15.
TQ	Triple point temperature, 273.16

Flags 1 and 2 are used to set Freezing Temperature.
Flag 3 is used to set Freezing Band.
Flags are used because the flag status is visible in the calculator screen and because flags can be changed from any directory while objects can only be stored in the current directory.

I	Toggle between freezing temperature of 273.15 K (Ice - Flags 1 and 2 clear) and 173.15 K (No Ice – Flags 1 and 2 set)
II	Toggle between freezing bans of 20 K (flag 3 clear) and freezing band of 5 K (Flag 3 set)
SFT	Set Freezing Temperature
TF	Freezing temperature, 273.15 K

F1	F2	TF	SFT argument
Clear	Clear	0 °C	0
Set	Clear	-10 °C	10
Clear	Set	-40 °C	40
Set	Set	-100°C	100

The Freezing Temperature can be selected by setting the flags manually or by preceding the the SFT object with the argument of the above table.

FB	Freezing band, 20 K

The Freezing Band can be selected by setting flag 3 manually or toggled by pressing the SFB without argument. The default FB with flag 3 clear is 20. FB is 5 when flag 3 is set.

CPA	Specific heat of air at constant pressure
CVA	Specific heat of air at constant volume
RA	Gas constant for air
KA	RA/CPA
MA	Molecular weight of air

CPV	Specific heat of water vapour at constant pressure
RV	Gas constant for water vapour
CW	Specific heat of water
CI	Specific heat of ice
LV0	Latent heat of vaporization at T0
LVQ	Latent heat of vaporization at the triple point of water
LF0	Latent heat of fusion at T0
LSQ	Latent heat of sublimation at the triple point of water
MW	Molecular weight of water

G	Acceleration of gravity, 9.8 m/s^{-2}
GM	Accelleration of gravity 9.80665 m/s^{-2}
D	Dry adiabatic lapse rate (G/CPV)
ε	RA/RV
K	Kilo, One thousand, 1000

P0	Base pressure for air, 100 kPa
PS	Standard pressure 101.325 kPa
PV0	Base pressure for water vapour, 0.61070 kPa
PQ	Triple point pressure, 0.61114 kPa
PU	Standard atmosphere tropopause (11,000 m) pressure, 22.65kPa
PW1	Winter standard atmosphere tropopause (8000 m) pressure, 77.37 kPA.
PW2	Winter standard atmosphere pressure (2000 m), 32.29 kPA.
PE2	Equatorial standard atmosphere tropopause (15,000 m) pressure, 12.95 kPA.
TS	Standard atmosphere bottom temperature, 288.15 K.
TU	Standard atmosphere top temperature, 216.65 K.
TW1	Standard Winter atmosphere bottom temperature, 253.15 K.
TE1	Equatorial standard atmosphere bottom temperature, 301.15 K.
TE2	Equatorial standard atmosphere top temperature, 203.15 K.
AS	Standard Atmosphere Lapse Rate, 0.00650 K/m.
AW	Winter Atmosphere lapse rate, 0.00608 K/m.
AE	Equatorial Atmosphere lapse rate, 0.00653 K/m.
ZU	Elevation of the top of the Standard Troposphere, 11,000 m.
ZW1	Winter Atmosphere height, 2000 m.
ZW2	Winter Atmosphere height, 8000 m.
ZE2	Equatorial Atmosphere height, 15000 m.
αL	Clapeyron equation coefficient for saturation with respect to liquid water
βL	Clapeyron equation coefficient for saturation with respect to liquid water
γL	Clapeyron equation coefficient for saturation with respect to liquid water
αI	Clapeyron equation coefficient for saturation with respect to ice
βI	Clapeyron equation coefficient for saturation with respect to ice
γI	Clapeyron equation coefficient for saturation with respect to ice
UKEY	? User keys – No longer used
FC	Coriolis Factor ($2\pi/N$)
μA	Viscosity of air
μW	Viscosity of water
PRA	Prandt Number of air
PRW	Prandt Number of water
KAIR	Conductivity of air
KWA	Conductivity of water
αAIR	Diffusivity of air
αW	Diffusivity of water
ρAIR	Density of air at standard conditions
VAIR	Kinematic viscosity of air at standard conditions
HVC	Heating value of coal (J/kg)
HVL	Heating value of liquid fuel (J/kg)

AT2A Energy usage and reserves in Joules

All values are in Joules the base SI unit. Unit with SI prefixes can easily be inferred by going to ENG mode.

WPY	World primary energy usage per year
WEY	World electrical energy usage per year
WOY	World oil energy usage per year
WGY	World gas energy usage per year
WCY	World coal energy usage per year
USEY	US electrical energy usage per year
USOY	US oil energy usage per year
USGY	US gas energy usage per year
SUNS	Solar radiation received by the earth per second
SUND	Solar radiation received by the earth per day
SUNY	Solar radiation received by the earth per year
HHS	Hurricane thermal energy (heat) per second
HHD	Hurricane thermal energy per day
WFR	World fuel reserves
WOR	World oil reserves
WGR	World gas reserves
WCR	World coal reserves
WUR	World uranium reserves

AT2B Car mileage conversions

GALC	Toggle between Litres per 100 km to miles per Canadian gallon
GALU	Toggle between Litres per 100 km to miles per US gallon
KPM	Toggle between Litres per 100 km and kilometres per Litre

AT2C Energy price (Values based on September 2013 EIA)

$GJE	Electricity per Giga Joule ($33.33)
$JE	Electricity per Joule ($33.33E-9)
$KE	Electricity per kilowatt-hour - used to calculate others ($0.12)
$GJO	Crude oil per Giga Joule ($15.5)
$JO	Crude oil per Joule ($15.5E-9)
$MTO	Crude oil per metric ton ($650)
$BO	Crude oil per Barrel - used to calculate others ($95)
$GJG	Natural gas per Giga Joule ($5.29)
$JG	Natural Gas oil per Joule ($5.29E-9)

$MG	Natural gas per standard cubic meter ($0.203)
$TFG	Natural gas per standard thousand cubic feet - used to calculate others ($5.74)

$GJC	Coal per Giga Joule ($1.74)
$JC	Coal per Joule ($1.74E-9)
$MTC	Coal per metric ton ($45.10)
$TC	Coal per US ton - used to calculate others ($41.00)

$GJZ	Gasoline per Giga Joule ($26.5)
$JZ	Gasoline per Joule ($26.5E-9)
$LZ	Gasoline per litre ($0.92)
$GZ	Gasoline per US gallon - used to calculate others ($3.50)

AT2D Hurricane categories minimum velocity in m/s

VTS	Tropical storm
VH1	Category 1 hurricane
VH2	Category 2 hurricane
VH3	Category 3 hurricane
VH4	Category 4 hurricane
VH5	Category 5 hurricane
KPH	Convert m/s to km/hr
MPH	Convert m/s to mph
KT	Convert m/s to knot
VIA	76 m/s
VIM	170 m/s
EFO	Enhanced Fujita category 0
EF1	Enhanced Fujita category 1
EF2	Enhanced Fujita category 2
EF3	Enhanced Fujita category 3
EF4	Enhanced Fujita category 4
EF5	Enhanced Fujita category 5
FUJ	Old Fujita tornado class to m/s
TOC	Tropical Cyclone (135 m/s)

AT1 ATDAT Data directory.

ATDAT contains data relating to specific soundings

STDA	Standard atmosphere
EQUA	Standard equatorial atmosphere
POLE	Standard high latitude atmosphere

WILLIS	Willis island sounding
JOR	Jordan mean Caribbean hurricane season sounding
BRA1	Roscoe Braham pre lake Michigan sounding.
FM3	Fawbush and Miller type #3 tornado sounding
GATE	GATE sounding

HAW	? Sounding
LEE	Lee's convergence line sounding
LEMO	LeMoyne sounding
LUCAS	Lucas sounding
MK1	Makung pre severe squall sounding
PFLD	Plainfield tornado sounding
RW	Randal and Wang sounding
TEL	TELLUS sounding ?
TRIER	Trier sounding
WAT	Watonga pre-tornado sounding
WEI	WEI sounding
WSPO	? sounding
AEXP	Expansion data generated in AT5A. PAP, TAT, TAP?

The data directories can contains arrays of raw sounding data: SNC, SNK, SNU and arrays of calculated data: SNZ, SNT, SNP. The arrays have the same names as the arrays of AT5. There are programs in AT4 to convert raw data arrays from one format to another. You can store the SNC data in AT5 and recalculate the other arrays, or move all five arrays back to AT5. Program SAV recall the five arrays and their names to the stack. To move all arrays back to the AT5 directory, recall SAV to the stack and press EVAL, switch to the AT5 directory (FM3) and press STO 5 times. The opposite procedure can be used to move the arrays from AT5 to ATDAT. Arrow-down-AT5 changes to the AT5 directory.

SEN ??? Arrays summarizing the result of sensitivity analysis for the sounding. The second, third, and fourth columns contain the potential energy of the condensed water, the residual work, and the total work. The number in the first column is a code indicating the type of expansion, the freezing temperature, the parcel temperature excess, and the parcel mixing ratio excess.

Column 1 code: 1 true-adiabatic expansion
2 pseudo-adiabatic expansion
Column 2 code: 0 freezing at 0 C
1 freezing at -10 C
4 freezing at -40 C
9 no freezing
Column 3 code: parcel temperature excess (K) beyond base of sounding value
Column 4 code: parcel mixing ratio excess beyond base of sounding value (g/kg or 1/10 g/kg)

AT3 PROGRAM DESCRIPTION

Directory AT3 contains programs to calculate the thermodynamic properties of pure air and pure water, the virtual temperature of moist air, lapse rate and distance between two sounding levels.

PV	Partial pressure of water from T.
PVL	Partial pressure of liquid water from T. (same as PGL)
PVI	Partial pressure of ice from T. (same as PGI)

PV2	Partial pressure of water from P and M.
PA	Partial pressure of air from P and T (dew point).
MVS	Saturation mixing ratio from P and T. – Vapor in equilibrium with liquid or ice
MVL	Saturation mixing ratio from P and T. – Vapor in equilibrium with liquid

ρA	Density of pure air from P and T
ρV	Density of pure water from P and T

SA	Entropy of air from P and T per kg air.
SV	Entropy of vapour from P and T per kg vapour.
sL	Entropy of liquid water from T per kg liquid water. (lower case to distinguish from built-in “shift-left”)
SL3	Entropy of liquid water from P, T, M per kg of water. Uses sL and throws out P and M.
SI	Entropy of ice from T per kg of ice.
SC	Entropy of condensed water from T per kg liquid water.
SC3	Entropy of condensed water from P, T, M per kg of water. Uses SC and throws out P and M.

HA	Enthalpy of air from T per kg air.
HV	Enthalpy of vapour from T per kg water.
HL	Enthalpy of liquid water from T per kg water.
HI	Enthalpy of ice from T per kg ice.
HC	Enthalpy of condensed waater from T, per kg water.
HC3	Enthalpy of condensed water from P, T, M, per kg of water. Uses HC and throws out P and M.

µAIR	Free enthalpy of air from P and T per kg air.
µV	Free enthalpy of vapour from P and T per kg vapor.
µL	Free enthalpy of liquid water from T, per kg water.
µI	Free enthalpy of ice from T, per kg ice.
AFF	Affinity of liquid water from P and T.

TV	Virtual temperature from T and M.
LV	Latent heat of vaporization from t.
LS	Latent heat of sublimation from t.

ZTA	Height from T1,T2, and lapse rate.
ZPT	Height from P1, P2, T1, T2.
ZPTA	Height from P1, P2, T1, and lapse rate.
ZPTD	Height from P2 and T1 (P1 = 100 kPa, Lapse rate adiabatic)
PTAZ	P2 from P1, T1 (in K), lapse rate, and height (solar chimney)
PCAZ	P2 from P1, T1 (in °C), lapse rate, and height (solar chimney)
TPTA	Temperature from P1, P2, T1, and lapse rate.

Z.EQ	Equation relating PX1, PX2, CX1, aX, ZX
PX1	Ambient/Conduit bottom pressure
PX2	Ambient/Conduit top pressure
CX1	Ambient bottom temperature (°C)
aX	Ambient lapse rate (K/km)

ZX	Ambient/Conduit top pressure

α4	Lapse rate from P1, P2, TV1, TV2.
γ4	Poison exponent from P1, P2, TV1, TV2.
γxα	Poison exponent from Lapse rate.
αxγ	Lapse rate from Poison ratio.
NXγ	N from Poison ratio
γXN	poison ratio rate from N
CNα	Specific heat from lapse rate
CNγ	Specific heat from Poison ratio

ZS	Height in the Standard Atmosphere from P2.
ZTS	Height and temperature in the Standard Atmosphere from P2.
ΔZS	Height difference in the Standard Atmosphere from P1 and P2.
ZW	Height in the Winter Atmosphere from P2.
ZTW	Height and temperature in the Winter Atmosphere from p2.
ÄZW	Height difference in the Winter Atmosphere from P1 and p2.
ZE	Height in the Summer Atmosphere from p2.
ZTE	Height and temperature in the Summer Atmosphere from p2.
ÄZE	Height difference in the Summer Atmosphere from P1 and p2.

NCC	Carnot efficiency from Th and Tc in °C
NCK	Carnot efficiency from Th and Tc in K
MOL	Mole fraction from m.
Q	Ratio mass of air to total mass from M.
R→Q	Mixing ratio to specific humidity
Q→R	Specific humidity to mixing ratio

POP	Restrained and unrestrained cylinder/piston system. Inputs: P1, P2, T1 (in °C). (Van Ness type analysis). Outputs: initial temperature, isentropic expansion temperature, and unrestrained expansion temperature. RPN version.
POPA	Same as POP. Algebraic version
POP1	Restrained and unrestrained cylinder/piston system. Input pressure ratio (P2/P1). Output: Percent of isentropic expansion work loss as a result of the expansion not being fully restrained. Note: The loss work is 23.63% for P2/P1 of 0.95 and approaches 22.25% as P2/P1 approaches 1, i.e. 0.999.

θZPθ	Potential temperature lapse rate from P and lapse rate
θZθT	Potential temperature lapse rate from θ, T, α

PGL	Vapor pressure of water in kPa – slightly more accurate than XVL, Affinity A = 0
PGI	Vapor pressure of water in kPa – slightly more accurate than XVI, Affinity A = 0
XVL	Vapor pressure of water in kPa – slightly less accurate than PVL, Dufour eq: 9.87
XVI	Vapor pressure of water in kPa – slightly less accurate than PVI, Dufour eq: 9.87

ωBV	?
τBV	?
TAU	?
ER	?

AT3A CLAPEYRON EQUATION COEFFICIENTS (from Dufour and Van Mieghem)

AT3B SOLAR AND INFRARED RADIATION

AT3B contains the nominal percent of radiation reflected and absorbed by the atmosphere and the earth surface, the solar constant, the Stefan-Boltzman law, and earth surface area.

Source: Earth's Annual Global Mean Energy Budget. J. T. Kiehl and Kevin E. Trenberth. *Bulletin of the American Meteorological Society.* Volume 78, Issue 2 (February 1997) pp. 197-208.

Units are in W/m^2.

SCON	Solar constant (342 W/m^2)
STR	Solar radiation reflected by atmosphere and earth's surface (107)
SAR	Solar radiation reflected by air and clouds (77)
SGR	Solar radiation reflected by ground (30)
SAB	Solar radiation absorbed by air and clouds (67)
SGB	Solar radiation absorbed by ground (168)
IGE	Infrared emitted by the earth's surface (390)
IGB	Infrared absorbed by the earth's surface (324)
IGN	Infrared net from the earth's surface (66)
CVT	Convection from then earth's surface (102)
LGC	Latent from ground (78)
HGE	Sensible from ground (24)
IRT	Infrared total (235)
IGU	Infrared upward from the earth's surface (40)
ICU	Infrared upward from cloud (30)
IAU	Infrared upward from air (165)

W->P	Watts to percent
P->W	Percent to Watt

SBC	Stefan-Boltzman constant
WR	Radiative flux from temperature
TR	Temperature from Watts

ESUR	Earth's surface
ERAD	Earth radius (km)
R^A	Radius (km) to area (km^2)

FDO	Forcing as a result of doubling CO_2 concentration (4 W/m^2)
FBB	Forcing for Black Body (0.3 °C/(W/m^2))
FHA	Forcing including all feedback from James Hansen (0.75 °C/(W/m^2))

AT3C THERMODYNAMIC PROPERTIES OF PROPANE

ρv	Density of propane gas in kg/m3 – enter P in kPa and T in K
PC	Vapor pressure of propane in kPa – Enter T in K
RC	Propane gas constant - 188.7

HC	Propane heat of combustion - 50,292,000 J/kg
LV0	Propane heat of vaporization – 430,310 J/kg
MW	Propane molecular weight
PC0	
CW	Propane liquid sensible heat
CP	Propane gas specific heat at constant pressure
ρL	Propane liquid density – 510 kg/m3
αC	Propane vapour pressure equation coefficient
βC	Propane vapour pressure equation coefficient
γC	Propane vapour pressure equation coefficient

AT3D CIRCULATION PRODUCED FROM THE EARTH'S ROTATION

^R1	Enter annulus radius to initiate calculation
^V1	Enter annulus velocity for storage in V1
R1	Result annulus radius
V1	Result annulus velocity
R2	Result radial distance where C2 = C1
V2	Tangential velocity at radius where C2 = C1
C1	Circulation, C1 = R1 * V1 = R2 * V2
RAT	Radius and velocity ration RAT = V2 / V1 = R2 / R1
ω1	vorticity at radius 1
ω1S	vorticity at radius 1 solid body rotation
ω2	vorticity at radius 2
ω2S	vorticity at radius 2 solid body rotation
FΩ	Coriolis factor from latitude
MOM	Angular momentum – absolute
MOMR	Angular momentum – relative to earth surface
MOME	Angular momentum – earth surface
POTR	Potential Radius – Emanuel (1999)

AT3E LAMBTON COLLEGE PROTOTYPE PARAMETERS

λA8	Area of central 8" diameter hot air inlet – 0.0324 m^2
λA24	Area of central 24" diameter circle – 0.29 m^2
λAS1	Area of one 6" x 48" deflector slot – 0.37 m^2
λD	Area of 8 - 6" x 24" tangential deflector entry slots – 0.74 m^2
λF1	Heat capacity of small salamander 44,000 W
λF2	Heat capacity of large salamander 110,000 W
λRD	? Ratio of diamerter – 3.89
λRV	? Ratio of velocity – 0.15
λAS1	Area of 8 - 6" x 24" tangential deflector entry slots

AT4 MAIN PROGRAM – See description at beginning of program description

AT4A ? Subsidence velocity

AT4B ?

AT4C EFFICIENCY OF COMBINED CYCLES

Efficiency calculations for three stages combined cycle: Gas turbine, steam, AVE. Cycles can be omitted by making hot and cold source temperatures the same.

TSTO	Store up to four source temperatures in °C. Example 1600, 600, 30, -50.
TRCL	Recall up to four source temperatures in °C
COTA	Calculate actual cycle efficiency, initiates COMN
COMT	Calculate Carnot efficiency, initiates COMN
COMP	Calculate percent contribution of each cycle and percent increment due to AVE cycle
COMW	Display W1, W2, W3, W4.
COMN	Calculate percent contribution of each cycle from individual efficiency, enter the three efficiencies from COTA or COMT (delete x). Also calculate W1, W2, W3, W4.
EFF	Carnot efficiency – Enter Th and Tc in °C
EFF2	Carnot efficiency – Enter Th and Tc in °C with exchanger Delta-T
EFH	Carnot efficiency – Enter Th in K and use default TH
EFF	Carnot efficiency – Enter Tc in K and use default TC
EFU	Ultimate efficiency when work is dissipated at hot source temperature – Enter Carnot efficiency – from 7 terms of series.
EFL	Ultimate efficiency when work is dissipated at hot source temperature – Enter Carnot efficiency – from series ultimate limit
TH	Default hot source temperature
TC	Default cold source temperature
△TH	Steam cycle hot source Delta-T
△TC	Steam cycle cold source Delta-T
Q1,Q2, Q3,, Q4	Heat input to each cycle and waste heat - (Joule or Watt)
W1, W2, W3, W123	Work from each cycle and total work _ (Joule or Watt)
A1, A2, A3	Actual efficiency to Carnot efficiency ratio.

AT5 PROGRAM DESCRIPTION

AT5 contains programs to calculate properties for a whole sounding including how much work is produced when a parcel is raised true adiabatically or pseudo adiabatically. Caution parcel properties PP, TT, MM, SS etc... use in AT5 are not the same as used in AT4.

αGET	Gets the original sounding data in PKM format for the specified sounding level.
βGET	Gets the properties of pseudo adiabatic expanded air in PKM format for the specified sounding level.
ωGET	Gets the properties of true adiabatic expanded air in PKM format for the specified expansion level.
ρGET	Get parcel properties.
MIX	Mixing calculator
σ3	Calculates the static energy per unit mass of air, ZB and SNZ are used to calculate height.
σM3	Calculates the static energy per unit mass of substance, ZB and SNZ are used to calculate height.

NW1	Kinetic Energy produced when a parcel from base level is raised true adiabatically to pressure P. Enter upper level P. Kinetic energy equals total energy minus WPP.
NW2	Kinetic Energy when the parcel is moved to another sounding level. Enter upper level row number. Kinetic energy equals total energy minus WPP.
NW4	Kinetic Energy produced when a parcel recalled using Alpha-GET is raised true adiabatically to pressure P. (The work becomes positive at the Level of Free Convection, LFC.). Kinetic energy equals total energy minus WPP.
WPP	Potential energy of condensed water for typical pseudo adiabatic expansion, default value 1000 J/kg.
W1	Total Mechanical Energy produced when a parcel from base level is raised true adiabatically to pressure P. Enter upper level P.
W2	Total Mechanical Energy produced when the parcel is moved to another sounding level. Enter upper level row number.
W4	Total Mechanical Energy produced when a parcel recalled using Alpha-GET is raised true adiabatically to pressure P. (The work becomes positive at the Level of Free Convection, LFC.)
SNC	Sounding in PCD format
SNK	Sounding in PKM format
SNZ	Sounding in PKM plus elevation
SNT	Sounding – True adiabatic expansion
SNP	Sounding – Pseudo adiabatic expansion
GSA	Generate soundings al (GST GSP)l
GSZ	Generate sounding heights
Sσ	Toggle between reversible (constant entropy) and irreversible (constant static energy) expansion by setting flag 4
Pβ	Pressure array
Pβ5	Pressure array with 5 kPa intervals
GST	Generate sounding temperatures true-adiabatic expansion
GSP	Generate sounding temperatures pseudo-adiabatic expansion
ZB	Calculates the height of any pressure from the SNZ data.
TB	Calculates the virtual temperature at any pressure from the SNZ data.
WKT	Calculates work produced when a parcel is lifted from h1,h2,mv,z.
WP	Calculates potential energy of condensed water from m1,mv,z.
σ.EQ	Moist static energy equation
σSOL	Solve moist static energy equation for temperature
AVS	Average sounding entropy
AVH	Total and Average sounding enthalpy
AVM	Total and Average sounding water (mm H2O)

SNTs	Results array reversible no separation (true adiabatic – constant entropy)
SNTσ	Results array irreversible no separation (constant static energy)
SNPs	Results array reversible with separation (Pseudo adiabatic – constant entropy)
SNTσ	Results array reversible with separation (constant static energy)
SAVs	Copy result arrays SNT and SNP in SNTs and SNPs
SAVσ	Copy result arrays SNT and SNP in SNTσ and SNPσ
GρC	Generate parcel properties parcel properties in PCU format
GρK	Generate parcel properties parcel properties in PKM format
GρR	Generate parcel properties relative to sounding base enter ∆T and ∆M
Pρ	Parcel Presure
Tρ	Parcel Temperature
Mρ	Parcel mixing ratio
Sρ	Parcel entropy
Hρ	Parcel enthalpy
ZZ4 to ZZ8	Subsoutines used in calculating SNZ
WT1 to WT5	Subroutines used in calculating SNT
PD2 to PD9	Subroutines used in calculating SNP

SNZ contains the following sounding data:

Column	Content
1.	Pressure (kPa)
2.	Temperature (K)
3.	Mixing ratio (g/kg)
4.	Entropy (J/kg/K)
5.	Virtual Temperature (K)
6.	Lapse rate to next level down (K/m)
7.	Distance to the next level down (m)
8.	Height of current level (m)

SNT contains data relating to work produced when a parcel from the base level is raised true-adiabatically to the current level:

1. Pressure (kPa)
2. True adiabatic expansion temperature (K).
3. Potential energy of condensed water (J/kg-air).
4. Total mechanical energy (WB)
5. Kinetic energy (WK=WB-WPP).

SNP contains data relating to work produced when a parcel from the base level is raised pseudo-adiabatically to the current level:

1. Pressure (kPA)
2. Pseudo Adiabatic expansion temperature (K)
3. Water vapour content (g/kg)
4. Entropy of parcel excluding condensed water (J/kg/K)

5.	Water condensed in current expansion step (g/kg)
6.	Accumulated potential energy of condensed water (WP)
7.	Enthalpy of condensed water
8.	Enthalpy of vapour phase
9	Height z
10.	Work of buoyancy ΔWB in current step
11.	Cummulative work of buoyancy WB
12	Work of buoyancy minus potential energy of concensed water (WK=WB-WP)

AT5A ADIABATIC EXPANSION TEMPERATURES ??

The condition of the air to be expanded is stored in Matrix Beta and moved to the stack with Beta-GET. GTA generates the adiabatic expansion temperatures for 6 types of expansion and puts the result in a seven column array. The array ends up on the stack but is moved to AT6A and called VT for plotting. The array columns are:

Col Number	Parameter
1	Pressure
2	True adiabatic freezing at 0 degC.
3	True adiabatic freezing at -40 degC.
4	True adiabatic no freezing.
5	Pseudo-adiabatic freezing at 0 degC.
6	Pseudo-adiabatic freezing at -10 degC.
7	Pseudo-adiabatic no freezing.

GTA uses GT1, GT2, and GT3. GT1 produces the pressure column.
GT2 produces true adiabatic expansion temperatures. GT3 produces pseudo-adiabatic expansion temperatures. GTA calculates expansion temperatures at 5 kPa pressure interval.

PT-Delta in AT6A plots the differences between the various adiabatic expansion temperatures in VT. ET-delta equation can be edited plot the difference between any two type of expansion, lines can be added to the plot.

Programs TAT, TAP, and PAP list adiabatic expansion temperatures on the stack for a single type of expansion.

TAT	True-adiabatic at specified pressure interval.
TAP	Pseudo-adiabatic at specified pressure interval.
PAP	Pseudo-adiabatic at specified temperature interval.

Sample arrays are stored in the program name preceded by a left arrow. PAP produces an array that correspond to the Smithsonian Pseudo-expansion tables. Theta-WB calculates the potential pseudo wet bulb temperature which is stored at the bottom of the array. The Potential Pseudo wet-bulb are in agreement with the Smithsonian tables, within 0.2 K.

AT5B MIXTURE PROPERTIES

AT5B calculates the properties of a mixture of two air masses or of a mixture of an air mass and of condensed water. Mixing is an isenthalpic process.

The calculation is based on the fact that the enthalpy of the mixture and the water content of the mixture must be equal to the sum of the enthalpy and water content of the initial masses.

The program is primarily intended air masses initially at the same pressure but can also be used for air masses at different pressures provided M2 has the higher pressure. The pressure of the mixture is the lowest of P1 and P2. The higher pressure air mass in expanded isentropically before mixing. Air masses can have water in condensed states.

PCU1	Stores properties of air mass #1 in PCU format in PP1, TT1, and MM1.
PCU2	Stores properties of air mass #2 in PCU format in PP2, TT2, and MM2.
PCM1	Stores properties of air mass #1 in PKM format in PP1, TT1, and MM1.
PCM2	Stores properties of air mass #2 in PKM format in PP2, TT2, and MM2.
RC1	Recall air mass #1 properties in PCM format
RC2	Recall air mass #2 properties in PCM format
RC3	Recall air mass #3 properties in PCM format
RK1	Recall air mass #1 properties in PKM format
RK1	Recall air mass #2 properties in PKM format
PCT1	Calculates mixture property given percent of mass #1.
SIA	Calculate mixing internally generated entropy (mix air masses 1 and 2)
PCTA	Produces an array DA of mixture properties at 10% mass #1 increments; Cloumns: PCTA, C, M, U, TV, entropy increase.
DA	Mixing result array
TMW	Calculates the property of a mixture of mass #1 and of the MM2 water part of mass #2 where MM2 is in liquid state. TT2 and MM2 must be entered prior to pressing TMW and are used to specify the temperature and quantity of condensed water added to the humid air mass.
SAW	Entropy of air water mixture
WTW	Calculates to quantity of water required to saturate mass 1 air at T by mixing with water at temperature W. Enter the temperature of the water W and air mass 3 temperature T prior to pressing WTW.
WTU	Calculates to quantity of water required to produce saturated air of relative humidity U at T with water at temperature W. (Water outlet temperature equal to final air dry bulb temperature.) Enter the temperature of the water W, air mass 3 temperature T and relative humidity U prior to pressing WTU.
WTUW	Calculates to quantity of water that must be mixed with air mass 1 to produce saturated air of relative humidity U at temperature T with water at temperature

	W. Enter air mass 1 properties using PCU1 or PCM1 prior to running WTUW. The temperature of the liquid water in the mixture is the wet bulb temperature of the air mixture. Enter: W the temperature of the water (T2), T the temperature of the mixture, U the relative humidity of the mixture. The mixture is assumed to be at pressure P1; there is no change in pressure. Result in mass of water MM2 in grams per kg of air
WTUP	Calculates to quantity of water that must be mixed with air mass 1 to produce saturated air of relative humidity U at temperature T with water at temperature W. Enter air mass 1 properties using PCU1 or PCM1 prior to running WTUW. Tthe temperature of the liquid water in the mixture is the wet bulb temperature of the air mixture. Enter: W the temperature of the water, T the temperature of the mixture, U the relative humidity of the mixture. P3 the pressure of the mixture. The mixture is assumed to be at pressure P3; M1 air is expanded isentropically to from P1 to P3 prior to mixing. Result in mass of water MM2 in grams of water per kg air.
HCK	Enthalpy check after running WTUW - no parameters required just press HCK Results consist of four numbers: Enthalpy of gas phase in final state Enthalpy of liquid phase in final state Enthalpy of gas phase in initial state Enthalpy of liquid phase in final state Total enthalpy in the final state equals total enthalpy in the initial state.
SCK	Entropy check after running WTUW - no parameters required just press SCK entered. Results consist of four numbers: Entropy of gas phase in final state Entropy of liquid phase in final state Entropy of gas phase in initial state Entropy of liquid phase in final state Total entropy in the final state is greater than total entropy in the initial state because internally generated entropy is generated during the irreversible mixing process.

GCK	Gibb free energy check after running WTUW - no parameters required just press SCK entered. Results consist of four numbers: Gibb free energy of gas phase in final state Gibb free energy of liquid phase in final state Gibb free energy of gas phase in initial state Gibb free energy of liquid phase in final state Change in total Gibb free energy is the maximum energy that would be produced if the mixing process were carried out reversibly.
TMS	Calculates the property of a mixture of mass #1 and of the MM2 water part of mass #2 where MM2 is in vapour state. TT2 and MM2 are used to specify the quantity of vaporized water added to the humid air mass. PP2 is ignored.
PRO2	Surface pressure capability of saturated air water mixture?
PRO3	Surface pressure capability of air water mixture?
ΔSA	Change in entropy of air during mxing ?
ΔSW	Change of entropy of water during Mixing ?
ΔμA	Change in free enthalpy – For two air masses mixture
ΔμW	Change in free enthalpy – For air and condensed water mixture
WI	Work loss due to irreversible heating
THE	Effective temperature of the hot source
TCE	Effective temperature of the cold source
F1	Fraction air mass #1
TPLT	Plots the virtual temperature of the mixture array.
RPLT	Plots the relative humidity of the mixture array.
TVL1	?

AT5C Margules large air mass

1. Two forms of the Margules equations for calculating the total enthalpy of large air masses.
2. Programs to calculate the work produced when thin layer of dry air are raised, including the efficiency of the process and the height of air columns of uniform potential temperature.

ZPθ	Calculate the height of a layer of air of uniform potential temperature. Enter P1, P2, and θ.
MA-Alpha	Margules equation for the total enthalpy of large air masses from bottom and top pressure, bottom temperature, and lapse rate.
MA-Theta	Margules equation for the total enthalpy of large air masses from bottom and top pressure and potential temperature.
W-Theta-TZ	Work produced when a thin layer of dry air is raised, from potential

	temperature, parcel temperature, and height.
WP-Theta-T	Work produced when a thin layer of dry air is raised, from bottom and top pressure, potential temperature, and parcel temperature.
N-Theta-Z	Efficiency from potential temperature and height.
ZP-Theta	Height from bottom and top pressure and potential temperature.

Subdirectory AT5C1 contains a program for calculating the area that two air equal air masses of different potential temperature would require so that they have the same height. Invoke the solver, enter Theta-1, Theta-2, and PT the pressure at the top of the air mass. Solve for height ZZ, press A1 and P1 to obtain the area of air mass #1 and the pressure at the base of A1.

10.0 AT5D contains the equation given by Dufour and also by Iribarne and Godson for the entropy of humid air expanding isentropically to show that the result is the same as the simpler ST3 program approach.

SD2W	Entropy of air containing water in the liquid phase.
SD2I	Entropy of air containing water in the ice phase.

Four equations are required to calculate the adiabatic expansion temperature of rising air: one for the moist air stage, one for the stage where the air contains water in the liquid phase, one for the transition from liquid to ice, and one for the ice stage.
The constant entropy approach used in AT4 is simpler, a single equation covers all four stages.

AT5E TUBULAR AND SPHERICAL FLOW

Tubular flow

A5E1	TUBULAR FLOW USING STORED DATA Input data identified with suffix "5" Output data identified with suffix "6"

ΔPF	Pressure drop due to friction when fluid flows in a horizontal tube. From d, v, z, rho, f.
ΔPTA	Frictional delta-P for turbulent air. From d, v, z, rho.
DPL	Frictional delta-P laminar air
ΔPLA	Frictional delta-P for laminar air. From d, v, z, rho.
ΔPTW	Frictional delta-P turbulent water
ΔPLW	Frictional delta-P laminar water
DVZW	Delta P turbulent and laminar water flow
ΔPW	Calculate pressure reduction at the base of a vertical tube from pressure, the temperature, and the work (p, k, w).
ΔPA	Calculate pressure reduction at the base of a vertical tube from the work only (w), approximation.
WF	Work per unit mass loss through friction when a fluid flows in a horizontal tube. From d, v, z, f.

DVZρ	Work loss (J/kg) for turbulent and laminar flows. Enter DVZρ

WLA	Work per unit mass loss through friction in a horizontal tube for laminar air. From: d, v, z, rho.
WTA	Work per unit mass loss through friction in a horizontal tube for turbulent air. From: d, v, z, rho.

AREA	Circular conduit area from: d
TVFL	Volumetric flow (m3/s), from d, v.
TMFL	Mass flow (kg/s), from d, v rho
RE	Reynold number for turbulent air. From d,v rho.
REW	Reynold number for water. From d, v, rho.

FL	Friction Factor laminar flow.
FT	Friction Factor turbulent flow air. From d, v, rho.
FTW	Friction Factor turbulent water. From d, v, rho.
FLW	Friction Factor laminar water. From d, v, rho.

Buoyant air bubble flow.

FBUO	Buoyancy force from: d, rho ambient, b. b=rho ambient – rho parcel
FDRG	Drag force from: d, v, rho.
DDRG	?
WDRG	Drag work from: d, v, z.
VTER	Terminal velocity from: d, b.
VJS	?
SVOL	Sphere volume
SMAS	Sphere mass
CD	Drag coefficient, constant = 0.5.

CK	Sea to Air heat transfer coefficient. Enter v.

HFX	Sea to Air heat transfer, in W m^{-2}. Enter ρ (air density), hs (air saturation enthalpy at water temperature), ha (air enthalpy), v (velocity) - Dalton equation
HFS	Sea to Air heat transfer, in W m^{-2}. Enter ρ (air density), hs (air saturation enthalpy at water temperature), ha (air enthalpy), v (velocity) - Dalton equation plus lm spray term.
HFSA	Sea to Air heat transfer, in W m^{-2}. Enter P, C, U, W v, air saturation enthalpy at water temperature and enthalpy of surface air. Dalton Equation plus lm spray term.

CEO	Enthalpy transfer coefficient from = CD * 0.7, Ooyama (1969) and CBLAST
CDO	Drag coefficient from Ooyama (1969)
CEDR	CE to CD Ratio = 0.7 from CBLAST
CDD	Drag coefficient according to Dalton = 0.0018 from CBLAST
CDP	Drag coefficient according to Powell = 0.002 from CBLAST
CS	Spray power of five heat transfer coefficient.

QHT	Hurricane total heat from sea removal rate from ocean cooling in Watt Enter:

	ΔT Ocean cooling due to hurricane passage (℃) d Depth of cooled layer (m) w Width of cooled layer (m) v Velocity of hurricane (m/s) Result is total sea to air heat transfer in watts. (Assumes all cooling occurs under eyewall)
QHU	Hurricane heat removal rate per unit area of eyewall (W/m^2). Enter: Hurricane total heat from sea removal rate (result of QHT. l Eyewall length w Eyewall width Result is eyewall sea to air heat transfer in W/m^2.
QHV	Hurricane heat required to produce hurricane precipitation. Enter rain rate in mm/hr, and diameter of rain area in meters
DREN	Heat flux from eddy calculation. Enter CE, U10, Q0 and Q10. Results are <w'q'> and Qv. Used Drennan eddy correlation heat flux calculation in Table 1 of French and Drennan – Part1, 2007

Heat from sea removal rate

RAY	Rayleigh Number for free convection of air in a tube – enter: Delta T, mean T, Diameter
GR	Grashof Number for - free convection of air in a tube – enter: Delta T, mean T, Diameter

	Calculations
CALL	Calculate all output data from input data
ΔPT	Calculate: Delta pressure for turbulent flow
ΔPL	Calculate: Delta pressure for laminar flow
ΔPF	Calculate: Delta pressure using friction factor F5
WT	Calculate: Work loss per unit mass turbulent flow
WL	Calculate: Work loss per unit mass laminar flow
Re	Calculate: Reynolds Number
FT	Calculate: Friction factor turbulent flow
FL	Calculate: Friction factor laminar flow
AREA	Calculate: Tube cross sectional area
QV	Calculate: Volumetric flow
QM	Calculate: Mass flow
TWT	Calculate: Total work loss turbulent flow
TWL	Calculate: Total work loss laminar flow
CD	Calculate: Ideal work from T, delta T, Z5 – adiabatic lapse rate
PCE	Calculate: Ideal delta P from PCE

	Input Data
D5	Tube diameter
V5	Velocity
Z5	Tube length

μ5	Fluid viscosity
ρ5	Fluid density
F5	Friction factor
	Output data
PT6	Pressure drop turbulent flow
PL6	Pressure drop laminar flow
WT6	Work loss per unit mass turbulent flow
WL6	Work loss per unit mass laminar flow
FT6	Friction factor turbulent flow
FL6	Friction factor laminar flow
FR6	Ratio of Turbulent to Laminar friction factors
Re6	Reynolds Number
A6	Tube area
QV6	Volumetric flow
QM6	Mass flow
TWT6	Total work loss turbulent flow
TWL6	Total work loss laminar flow

AT5F Properties with unit

AT5F contains one program called PROP. PROP calculates the properties of the air specified in AT4 and tags each property with a name and unit. It is a quick way to check units used by the program.

12.2 AT5G

12.3 AT5H Upflow process calculations.

WC	Work Calculate – Enter P3 and Z3
HC	Enthalpy calculate – Calculate air conditions at the base of the updraft in PCD format. Calculates P1, T1, and H1.
ZC	Height Calculate – Calculate Z1, the height of the P1 level. Used to calculate the elevation at the base of a sounding when the station elevation is not provided.

AT5J Hurricane intensity – Total Energy Equation method

AT5J contains objects for calculating work production when air is raised both reversibly and irreversibly for a variety for conditions. Calculations are based on the total energy equation method and on the four state ideal process shown in Fig.1 of the Isabel intensity paper. Calculation results at the four states are stored in variables: P1…P4, T1…T4, M1-M3, S1-S3, H1…H4. Other results include WB - work of buoyancy, WP - potential energy of condensed water, Q - heat received, and maximum hurricane intensity in kPa and m/s.

The AT5J directory contains valuable programs. AT5J can be used to show that work is equal to heat received times Carnot efficiency. AT5J can be used to calculate the final temperature of air raised reversibly and irreversibly and to show that the final temperature is slightly higher for irreversible upflow than for reversible upflow. All calculation are based on updraft without separation (commonly called true adiabatic). The freezing temperature and the freezing bands are 0°C and 20°C by default but can be changed.

AT5J can calculate the maximum intensity (MPI) of hurricanes and the work produced in an atmospheric Vortex Engine (AVE) work based on ideal process including a heater/humidifier.

AT5J calculation prerequisites include entering the properties of ambient air at state 1 using either PCM1 or PCU1, entering the upper level pressure and level with PZ4.

PCM1	Enter surface air conditions in PCM format
PCU1	Enter surface air conditions in PCU format
PJ4	Enter pressure -> Jordan Caribbean sounding hurricane height from lookup table
PJ4S	Enter pressure -> Jordan Caribbean sounding hurricane height by interpolation
P4	Upper level pressure
Z4	upper level elevation
R1	Recall state 1 conditions in PCM format

Several of the objects use the two guesses method wherein the user enters one guess and the program provides a second guess and then extrapolates to find the solution. Program using the two guess method are identified with a “2” in their names. Results show the extrapolated value and the residual error. The two guess programs can be rerun to reduce the residual error.

Convection Energy wirhout heater/humidifier

The following four CE (Convection Energy) programs are for a three states process where there is no heater/humidifier. Results are stored in parameters X1, X3 and X4. There is no state 2. The calculation can usually be carried out directly without any guess indicated by the “1” in the program name or by providing one guess indicated by “2” in the program name. “R” stands for reversible expansion and “I” stands for irreversible expansion. There is no separation of the condensate in either case.

Convective Energy reversible process

CE1R Calculate the work produced when surface air is raised reversibly. Results shown are T4, P3, thetaE and WB. (Calculates P3 and T3, only valid if there is no condensation at state 3).

Convective Energy irreversible process Convective Energy reversible process

CE1% Calculate the work produced when surface air is semi reversibly. Enter turbine efficiency. Results shown are T4, P3, and WB. (Calculates P3 and T3, only valid if there is no condensation at state 3).

CE1I Calculate the work produced when surface air is raised irreversibly. Result T4, and P3.

CER Subroutine used by CE2R.

CE2R Calculate the work produced when surface air is raised reversibly. Enter a P3 guess. Results P3 and residual error. Can be rerun to reduce residual. (minor bug run CE1R first to correct)

CE1R and CE2R results correspond to the CAPE of a true adiabatic updraft. When there is no condensation at state 3 the two programs give the same result.

CEI	Subroutine used by CE2I.
CE2I	Calculate the work produced when surface air is raised irreversibly. Enter a P3 guess. Results P3 and residual error. Can be rerun to reduce residual.

CE1I and CE2I. Note that T4 is higher in the irreversible case than in the reversible case by W_{23rev}/C_{pa}.

Convection Energy with heater/humidifier

WA2 Calculate P3 given T3 and U3.

WA	Calculate reversible work for entered for P3 guess, given T3 and U3. (Wet heat)
TU	Enter temperature and relative humidity downstream of heater/humidifier before running WA or WA2.
WA2	Calculate P3 using two guesses method, given T3 and U3. Provide one P3 guess

WD2 Calculate P3 given T3 and M3.

WD	Calculate reversible work for entered for P3 guess, given T3 and M3. (Dry heat)
TM	Enter temperature and mixing ratio humidity downstream of heater/humidifier before running WD or WD2.
WD2	Calculate P3 using two guesses method, given T3 and M3. Provide one P3 guess

WTA2 Calculate C3 required to produce work given W0 and U3.

WTA	Calculate work for temperature C3 (in °C) given W0 and U3. Provide C3 guess.
WU	Enter work of buoyancy (W0) and relative humidity (RH3) in state 3 before running WTA or WTA2. Set W0 to zero to find datum temperature for which W = 0.
WTA2	Calculate C3 required to make the work zero given U3 using two guesses method. Provide C3 guess.

* OK for zero work - Needs fixing when work > 0.

WUA2 Calculate relative humidity required to produce work given W0 and T3.

WUA	Calculate relative humidity given W0 and C3. Provide relative humidity guess.
WC	Enter work of buoyancy (W0) and temperatrue (T3) in state 3 before running WUA or WUA2. Set W0 to zero to find datum relative humidity for which W = 0.
WUA2	Calculate relative humidity U3 required to make the work zero given C3 using two guesses method. Provide relative humidity guess.

* OK for zero work - Needs fixing when work > 0.

WPU2 Calculate temperature C3 required to produce pressure P3 at relative humidity RH3

WPU	Calculate work for U3 given T3.
PU	Enter Pressure (P3) and relative humidity (RH3) in state 3 before running WPU or WPU.
WPU2	Calculate T3 required to make the work zero given C3 using two guesses method. Provide one C3 guess.

Note: The four W?2 solvers give result in y-register error in x-register. The error can be deleted and W?2 can be pressed again to produce more accuracy. Results can be displayed in more detail by deleting the results and pressing X1 or X2.

S97	Hurricane Maximum Potential Intensity (MPI) from SST – 97% eyewall relative humidity & with freezing
S100	Hurricane Maximum Potential Intensity (MPI) from SST – 100% eyewall relative humidity & without freezing (PROII equivalent)
SSA	Hurricane air temperature from SST --- (T3 = 24.5 + (SST – SSI) / SSW
SSI	Hurricane Intercept (SST at which T3=24.5 °C, default 27 °C) – used in SSA
SSW	SST Weighing (Delta T3 / Delta SST, default 0.75) – used in SSA

X1	Hurricane Potential Intensity T3, WP, WB, WT
X2	Hurricane Potential Intensity T3, P3, Pc, WB, v.

WM3	Work calculated Using Michaud enthalpy – reversible updraft
WM4	Work calculated Using Michaud enthalpy – reversible updraft of given temperature and RH
WM5	Work calculated Using Michaud enthalpy – irreversible updraft

Miscellaneous AT5J objects

SAB	Enter Sea surface temperature (SST), temperature approach (AAP), and humidity approach (BAP). Store in SST, AAP and BAP. This is an alternate to PZ4.
T2C	Calculate temperature T2 and net work . Store W12 and Q23.
EXT	Interpolate using work for two P3 guesses to determine P3 which makes W34=0

SST	Sea surface temperature in °C.
AAP	Air temperature approach to SST in °C.
BAP	Air humidity approach to 100% in %.

PCαP	Z4 calculation based on P1, T1 (°C) and lapse rate α (°C/m) and P4. Results are stored in P4 and Z4.
PCαZ	Z4 calculation based on P1, T1 (°C) and lapse rate α (°C/m) and Z4. Results are stored in P4 and Z4.
PS4	Enter pressure -> Standard atmosphere height.
PW4	Enter pressure -> Standard winter atmosphere height.
PE4	enter pressure -> Standard equatorial atmosphere height
W95	Work calculation based on 95% RH. Enter SST

HM	Michaud enthalpy – Enthalpy of air producing zero work. 66900 J/kg when air is raised to Jordan 12 kPa level (15500m).
HM0	Michaud enthalpy – Enthalpy of air producing zero work. 59500 J/kg when dry air is raised to Jordan 12 kPa level (15500m).

T4	Temperature of parcel at level 4
T4E	Temperature of parcel at level 4, from P4JS.
BUO	Buoyancy of parcel at level 4 with condensed water in and out.

Extrapolation subroutine EXT variables

PY	P3 for guess 1
WY	Work 34 for guess 1
PZ	P3 for guess 2
WZ	Work 34 for guess 2

Work and heat calculated in T2C and used in WA2 and WD2

W12	Work of expansion process 12 for CE1R
Q01	Heat input required to reach state 1 assuming that the water is initially in the condensed state and that the air and water are initially at temperature ‘t0’. Enter ‘t0’ the temperature of air and water in °C (typically 20 °C), This is a good representation of the heat input for deep atmospheric cycle wherein essentially all the water separates from the air. Relevant to CE1R
Q03	Heat input required to reach state 3 assuming that the water is initially in the condensed state and that the air and water are initially at temperature ‘t0’. Enter ‘t0’ the temperature of air and water in °C (typically 20 °C), This is a good representation of the heat input for deep atmospheric cycle wherein essentially all the water separates from the air and where in the air is subsequently sprayed with sea water.
Q23	Heat received in process 23 for reversible expansion (CE1R)
Q13I	Heat received in process 23 for irreversible expansion (CE1I)

Work calculated in CE1R

WB	Work of buoyancy – Convective Energy (CE corresponds to CAPE)
MV	Maximum velocity from WB
WP	Potential energy of condensed water for true adiabatic expansion
WPP	Potential energy of condensed water for pseudo adiabatid expansion – Default 1000 J/kg
HCU1	Isabel Distant environment surface air conditions – 101.1 kPa, 27.8 °C, 75% RH
HCU2	Jordan sounding surface air for which WB is zero for P4 = 12 kPa 101.1 kPa, 27.8 °C, 63.8% RH
HCU3	Jordan sounding surface air for which WB is zero for P4 = 12 kPa 101.1 kPa, 28 °C, 62.63% RH
HCM4	Jordan sounding surface air for which T4 = T4E for P4 = 12kPa 101.51 kPa, 31.09 °C, 17.79 g/kg
HCM5	Jordan sounding surface air for which T4 = T4E for P4 = 13kPa 101.51 kPa, 26.25 °C, 17.79 g/kg
PC	?
PJ	Jordan sounding base pressure

A5J1 Subdirectory of AT5J

Pressure at solar chimney top – P200, P1K

A5J2 Subdirectory of AT5J – Work correlations moved out of AT5J

W2U	Equation derived from correlation for calculating work produced when surface air is raised reversibly to the 20 kPa level without need for using slow solver. (Enter surface air conditions in PCU format).

W2M	Equation derived from correlation for calculating work produced when surface air is raised reversibly to the 20 kPa level without need for using slow slover. (Enter surface air conditions in PCM format).

TEE	MPI from SST - Isabel correlation
DEM	MPI from SST - Isabel correlation
EMA	MPI from SST - Emanuel correlation.
ΔPE	Calculate delta P from CAPE ??
ΔPM	Calculate turbine delta-P given P1, K1, W12, M1

A5J3 Total work calculations

VD↑	Enter upward velocity (V) at the base of chimney and chimney diameter(D): calculate power. Calculates ρ1 and MU.
CHI	Work calculation – Press after V↑D↑ L osses based on turbulent flow (W) - Based on AT5J WB in J/kg. Results are: WR, WX, WF, and WT.
VOR	Work Calculation – Press after V↑D↑ Losses based on laminar flow (W) - Based on AT5J WB in J/kg. Results are: WR, WX, WF, and WT.
DDD	Calculate turbine loss (WT) and display WII, WAA, WX, WF, and WT
DVZρ	Friction loss calculation for turbulent and laminar flow (J/kg). Enter: diameter, velocity, length and density.

VCH	Upward velocity at base of updraft (m/s)
DCH	Diameter of updraft or solar chimney (m)
ρ1	Density of air at state 1 (kg/m^3)
MU	Updraft flow (kg/s)
WR	Reversible process work (W)
WX	Exit velocity losses (W)
WF	Friction losses (W)
WT	Turbine losses (W)
EF	Exit kinetic energy loss divider (Default 10)
FF	Laminar flow friction multiplier (Default 10)
NT	Turbine efficiency (%)

Total work

WI	Ideal work (W)
WN	Net work (W)
WX	Exit losses (W)
WF	Friction losses (W)
WT	Turbine losses (W)

Specific work

ωI	Specific work – ideal/reversible(J/kg)
ωX	Specific work – Turbine loss (J/kg)
ωF	Specific work – Friction loss (J/kg)
ωT	Specific work – Turbine loss (J/kg)
ωC	Specific work – Work of compression (J/kg)
ωE	Specific work – Work of expansion (J/kg)

AT5K Energy calculations using Exergy

IRR	Given p, t, m, pj, tj, and z Calculates loss work
WEX6	Given p, t, m, pj, tj, and z Calculates delta-h, delta-h – mgz, exergy
WEXZ	Given p, t, m, pj, and z Calculates work from delta-h -mgz
EXR5	Given p, t, m, pj, and tj Calculates exergy
EXRZ	Given p, t, m, pj, tj, and z Calculates: delta-h, tj*delta-s, ideal work
GIBB	> Given p t m Calculates Gibb free energy

AT5L Hurricane Intensity – Renno / Emanuel equations

Renno Equation (A simple theory for Dust Devils 1998 eq. 16)

PΘC	Calculate base pressure
PCUα	Enter base pressure, temperature and humidity
Pα	Far Environment Pressure
Tα	Far environment Temperature
TΘ	Central Temperature (°C)
Tσ	SST temperature (°C)
Mα	Far Environment mixing ratio
MαS	Far environment saturation mixing ratio
MΘ	Central mixing ratio
Uα	Far environment Relative Humidity
Λη	Efficiency multiplied by fractional dissipation in boundary layer

PCUA	Enter surface condition in PCU format. Use SST for C.
VK	Maximum velocity – without frictional reheat (K=Kerry)
VKB	Maximum velocity – with frictional reheat (KB= Kerry/Bister) Bister and Emanuel (1998) eq. (21) Emanuel (1999) eq. (1)
EK	Efficiency without frictional reheat

EKB	Efficiency with frictional reheat
V86	Maximum velocity – Emanuel (1986) eq. (43)
VKD	V86 denominator term
VKN	V86 Numerator term
B86	V86 beta term

PC	Central pressure – Emanuel (1986) eq. (26)
LPA, LPB, LPC, LPD	PC terms
PE, TE, ME, MES, UE	Surface conditions

HS	Enthalpy of saturated air at SST
HE	Enthalpy of surface air
TO	Outflow temperature
CD	Drag coefficient
CK	Heat transfer coefficient
R0	Outer radius (km)
FK	Coriolis factor
UC	Central relative humidity

DEMA	DeMaria (1994) hurricane velocity correlation – enter SST in °C

<u>AT5M SOLAR CHIMNEY</u>

ATMC	Solar chimney cases – see list of case at ene of this section
ΔT↑	Enter chimney base delta (ΔT). Calculate ideal work per unit mass (J/kg). Ex: Manzanares : 17°C -> 109.91 J/kg
V↑	Enter upward velocity (V) at the base of chimney; calculate power. Ex: Manzanares 8 m/s -> power ideal 75147 W, actual power 41802 W, Exit losses 21879 W, Friction losses 3952 W, Turbine losses 7514 W. Ex: Manzanares: 8
Q(down)	Calculate heat input from chimney flow and from collector area

CHI	Chimney mode power calculation
VOR	Vortex mode power calculation
LOR	Friction loss increased by a factor of 5000 (per Lorenz)

ZDD	Enter chimney height (Z), chimney diameter, and collector diameter. Ex: Manzanares: 200, 10, 244
P1Tτ	Enter chimney base pressure (P1) (default 100 kPa), base ambient temperature in °C and lapse rate (τ) (default 0.00975°C/m stored in variable D). EX: Manzanares: 100, 30, 0.00975
FNN	Enter Insolation heat flux (F), collector efficiency (N) in percent; and turbine efficiency in percent. Calculate total heat received and collector delta T Ex: Manzanares 10800 W/m2, 31% , 80%
MU	Calculated upward mass flow of air in kg/s

VUD	?
DDD	Calculate turbine loss (WT) and display QQo, WI, WN, WX, WF, and WT
FF	Vortex mode friction loss multiplier, default = 10
VF	Vortex mode exit velocity divider , default = 10
THP	Calculate enthalpy and entropy
ENR	Calculate heat, work, average source temperatures, and efficiency.
HYD	Calculate air density
Z4	Chimney height
τ	Lapse rate
VCH	Upward velocity at the bottom of the chimney
DCH	Chimney diameter

DCO	Diameter of collector (ie 244 m)
FCO	Heat flux on collector (ie 800 W/m2)
NCO	Efficiency of collector (ie 31%)
NT	Turbine efficiency in % (default 80%)
ρ2	Density of air at the base of the collector outlet
P1-P4	Pressures (kPa)
T1-T4	Temperatures (K)
H1-H4	Enthalpies (J/kg)
S1-S2	Entropy (J/K kg)
μ3-μ4	Moist static energy

Specific work

ωI	Specific work – ideal/reversible(J/kg)
ωX	Specific work – Turbine loss (J/kg)
ωF	Specific work – Friction loss (J/kg)
ωT	Specific work – Turbine loss (J/kg)
ωC	Specific work – Work of compression (J/kg)
ωE	Specific work – Work of expansion (J/kg)

Total work

QQI	Heat input (W)
WI	Ideal work (W)
WN	Net work (W)
WX	Exit losses (W)
WF	Friction losses (W)
WT	Turbine losses (W)

Specific heat

QI	Heat in (J/kg)
QO	Heat out (J/kg)

EF%	Efficiency
TCA	Effective temperature of the cold source
THA	Effective temperature of hot source
D400	Manzanares velocity delta T correlation at 400 W/m^2 insolation
D800	Manzanares velocity delta T correlation at 800 W/m^2 insolation

HT	Enter height and base temperature in (℃); caculates efficiency from simple solar chimney equation.
HTΔT	Enter chimney height (Z), chimney base temperature (℃), and chimney base delta T (ΔT). Calculate ideal work per unit mass (J/kg) from simple solar chimney equation. Ex: Manzanares 200 m, 30℃, 17℃ -> 109.91 J/kg

PP	Pressure (kPa)
TT	Temperature (K)
MM	Mixing ratio (g/kg)

BJW	Adrian Bejan Work equation
BJP	Adrian Bejan Power equation
DJR	Flatness Factor used in DJV
DJV	Diameter of Rankine vortex based on radial delta-P

ATMC	Input Conditons for various cases
MAN	Manzanares – 200 m, 10 m, 20 ℃, 8 m/s
MAN2	Manzanares – 1000 m, 10 m, 3.4 ℃, 8 m/s
EMI	EnviroMission – 1000 m, 150 m, 28 ℃, 16 m/s
EMI2	EnviroMission – 1000 m, 180 m, 20 ℃, 16 m/s

DEV2	Dust Devil – 1000 m, 2 m, 5 ℃, 12 m/s
DEV10	Dust Devil – 1000 m, 10 m, 5 ℃, 12 m/s
FWH	Fire Whirl – 1000 m, 2 m, 100 ℃, 20 m/s
ESC	Eskom AVE – 10,000 m. 50 m, 20 ℃, 20 m/s
DCT	Dry cooling tower – 10,000 m, 35 m, 20 ℃, 20 m/s
DCT8	Dry cooling tower – 10,000 m, 18 m, 20 ℃, 80 m/s
DCTα	Dry cooling tower – 10,000 m, 35 m, 20 ℃, 20 m/s, 8.09 ℃/km
DCTβ	Dry cooling tower – 10,000 m, 18 m, 20 ℃, 80 m/s, 8.09 ℃/km
DCTε	Dry cooling tower – 2,000 m, 35 m, 20 ℃, 20 m/s, 5 ℃/km
KEN	Kendall (Eskom) - 165 m, 145 m, 20 ℃, 4 m/s
GAR	Garage prototype – 2 m, 0.05 m, 100 ℃, 1 m/s
LAM	Lambton College - 5 m, 0.25 m, 30 ℃, 5 m/s
ZARV	ELZARA – 10000, 25 m, 20 ℃, 40 m/s
ZARA	ELZARA – 150, 60 m, 20 ℃, 8 m/s
GR1	Grotvlei – 120 m, 83 m, 31.5 ℃, 2.07 m/s, 9.75 ℃/km
GR2	Grotvlei – 120 m, 83 m, 31.5 ℃, 2.07 m/s, 6.5 ℃/km
GR20	Grotvlei – 2400 m, 83 m, 31.5 ℃, 2.07 m/s, 6.5 ℃/km
GR21	Grotvlei – 2400 m, 17 m, 30.5 ℃, 50 m/s, 6.5 ℃/km
GR21	Grotvlei – 2400 m, 30 m, 15 ℃, 30 m/s, 6.5 ℃/km
GT	Grptvlei – 120 m, 58 m, 31.5 ℃, 4.24 m/s, 6.5 ℃/km

AT5N PSEUDO ADIABATIC EXPANSION TEMPERATURE AND EQUIVALENT TEMPERATURE

PKM1	Enter initial air properties in PKM format store in P1, T1, M1
PCM1	Enter initial air properties in PCM format store in P1, T1, M1
PCU1	Enter initial air properties in PCU format store in P1, T1, M1
P4	Enter final pressure, default 10 kPa.
TθEN	Calculate pseudo adiabatic expansion temperature and equivalent temperature No argument required. Results are final temperature in ℃, in K, and θe. No freezing of condensed water – Freezing temperature 173.15 K.
TθEF	Calculate pseudo adiabatic expansion temperature and equivalent temperature No argument required. Results are final temperature in ℃, in K, and θe. With With freezing of condensed water – Freezing temperature 273.15 K.
Θε33	Equivalent temperature based on raising air to 10 kPa level.
Θε,eq	Equivalent potential temperature equation – no separation
SL3	Entropy when water is in liquid phase
BOL3	Equivalent temperature using Bolton equation
BOL4	Bolton equation from Holland 1997
θL	Potential temperature
PL	Lifting condensation level pressure
TL	Lifting condensation level temperature

Expansion temperature is calculated in step of 2 kPa. Condensed water is separated after each step. Freezing temperature is set to -100 ℃; the condensed water does not freeze. A P4 default of 10 kPa is sufficient to reduce water content to negligible level. Pseudo adiabatic expansion temperatures at intermediate pressures can be calculated by varying P4 in which case θe is not valid. TPSE calculation requires up to 40 solver operation and can take 30 seconds to run on a fast PC.

AT5P Sounding array and array conversion programs

The AT4 directory contains five arrays of sounding data:

SNK	Sounding data in PKM format
SNKU	Sounding data in PKU format
SNC	Raw sounding data in PCD format
SNCM	Raw sounding data in PCM format
SNU	Sounding data in PCU format

There are five programs to store and generate the five arrays.

K>U	Generate SNU from SNK
KU>K	Generate SNK from SNKU
K>C	Generate SNC from SNK
C>K	Generate SNK from SNC
U>K	Generate SNK from SNU
CM>K	Generate SNK from PCM

AT6 Plot using MLINE

AT6 uses program MLINE of AT1 to plot the date in the arrays of AT5. The array to be plotted is stored in array DA.
The samples in the directory can be copied and modified to plot other properties. Plotting range and axis labelling can be redefined.

The built in plots are:

PPLT	Pseudo-adiabatic expansion work
RPLT	True-adiabatic expansion work
SPLT	Sounding Temperature-Entropy Diagram
WPLT	Virtual Temperature Excess of the parcel
TPLT	Sounding Pressure-Entropy Plot
XPLT	Potential and Equivalent Potential Temperatures
YPLT	Virtual and Potential Virtual Temperatures
ZPLT	Double Potential Temperature

AT6A Plot using HP48 parametric plot.

AT6B plots equations based on the data in arrays. The result of the equation must be a complex number, the real part is plotted on the horizontal axis and the complex part is plotted on the vertical axis. The complex number may be taken directly from arrays or calculated from array data. Plot is more flexible than MLINE, the X and Y can come from different arrays, the data plotted not need to be in an array, it can be calculated from data in arrays. You can invoke the plotter, edit the equation and add more line to a plot. Parametric plot is slower than MLINE. MLINE takes 10 seconds to plot a single line. Parametric plot can take 1 minute to plot a line from an array without any calculation, calculating and plotting a property can take 5 minutes.

The plots can be exported to a PC and printed with Word Perfect.

REFERENCES

1. Dufour, L., et J. Van Mieghem, 1975: Thermodynamique de l'Atmosphere. Institut Royal Meteorologique de Belgique, Bruxelles.

2. Randall, D.A., J. Wang, 1992: The moist available energy of a conditionally unstable atmosphere. J. Atmos. Sci., 49, 240-255.

3. Ooyama, K.V., 1990: A thermodynamic foundation for modelling the moist atmosphere. J. Atmos. Sci., 47, 2580-2593.

4. Lilly, D.K., T. Gal-Chen, 1990: Can dryline mixing create buoyancy? J. Atmos. Sci., 47, 1170-1171.