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ASTEM-A COLLECTION OF FORTRAN SUBROUTINES
TO EVALUATE THE 1967 ASME EQUATIONS OF STATE
FOR WATER/STEAM AND DERIVATIVES OF THESE
EQUATIONS

by
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ABSTRACT

ASTEM is a modular set of FORTRAN IV subroutines to evaluate the state equations of liquid water and steam as published by the American Society of Mechanical Engineers (1967). Any thermodynamic quantity including derivative properties can be obtained from these routines by a user supplied main program.

As provided the ASTEM package includes a sample main program and requires 68K bytes of core storage (double precision) on the IBM 360/75.

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ASTEM - A COLLECTION OF FORTRAN SUBROUTINES
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WATER/STEAM AND DERIVATIVES OF THESE EQUATIONS

I. INTRODUCTION

This collection of subroutines called ASTEM (ASME Steam Tables) forms a self-contained modular set to evaluate the Gibbs, Helmholtz and saturation line functions as published by the American Society of Mechanical Engineers^[1]. Any thermodynamic quantity can be computed by these routines from a main program supplied by the user. The ability to obtain derivatives of any order makes ASTEM somewhat unique.

This package is written in FORTRAN IV for the IBM 360/75 and requires 68K bytes of storage. As programmed, all variables are double precision for computing accuracy on the 360 system. Conversions to other computers and conversion to single precision can be easily accomplished by the user.

Fundamental to this report is the ASME publication "Thermodynamic and Transport Properties of Steam" (1967 ASME Steam Tables), the American Society of Mechanical Engineers, 1967. The equations and constants from this book are not reproduced nor stated within this report because of their rather complex form and the possibility of typographical errors. Also, all symbols used in this report are the more standard English symbols for thermodynamic quantities whereas the ASME uses a set of Greek symbols for the reduced dimensionless variables. In this report a symbol is used for a particular physical quantity immaterial of units. Unless specifically noted or when numbers are quoted without units, they are assumed to be "reduced dimensionless" as used by the ASME.

This report assumes that the reader has a working knowledge of thermodynamics and their derivative relationships. A good classical thermodynamics textbook and the ASME Steam Tables are necessary references for use in conjunction with this document.

II. SYMBOL DEFINITIONS

The following table gives the symbol definitions as used in this report as well as the corresponding ASME symbol.

TABLE 1

SYMBOLS

This Report	ASME	Quantity
P	β	Pressure
T	θ	Temperature
v	χ	Specific volume
h	ε	Specific enthalpy
u	-	Specific internal energy
s	σ	Specific entropy
x	-	Mass quality
g	ξ	Gibbs function
f	ψ	Helmholtz function
β	-	Coefficient of thermal expansion $\frac{1}{v} \left(\frac{\partial v}{\partial T} \right)_P$
C_p	-	Specific heat capacity at constant pressure $(\partial h / \partial T)_P$
C_v	-	Specific heat capacity at constant volume $(\partial u / \partial T)_v$
κ	-	$-\frac{1}{v} \left(\frac{\partial v}{\partial P} \right)_T$ isothermal compressibility
a_s	-	Isentropic sonic velocity $a_s^2 = -v^2 \left(\frac{\partial P}{\partial v} \right)_s$
δ	-	$(\partial v / \partial T)_x$
γ	-	Ratio of specific heat capacities C_p/C_v

III. ASME SUBREGIONS

The published ASME equations are defined for limited ranges of pressure and temperature. All thermodynamic quantities in these equations are expressed in a normalized (reduced dimensionless) form such that at the critical point pressure, specific volume and temperature are unity. The subregions for each equation is shown in Figure 1, the equation forms are given in Table 2 and boundary values are listed in Table 3.

Figure 1. ASME subregions.

TABLE 2

ASME STATE EQUATION FORMS

Subregion	Equation Form	Limits
1 (liquid)	$g_1(P,T)$	$P_K(T) < P \leq P_2, \quad T_t \leq T \leq T_1$
2 (steam)	$g_2(P,T)$	$0 \leq P < P_K(T), \quad T_t \leq T \leq T_1$ $0 \leq P \leq P_L(T), \quad T_1 < T < T_2$ $0 \leq P \leq P_2, \quad T_2 \leq T \leq T_3$
3 (steam)	$f_3(v,T)$	$P_L < P < P_K(T), \quad T_1 < T < 1$ $P_L < P < P_2, \quad 1 \leq T < T_2$
4 (liquid)	$f_4(v,T)$	$P_K < P \leq P_2, \quad T_1 < T < 1$
5 (two-phase)	$P_K(T), f_3(v_g, T),$ $f_4(v_f, T)$	$T_1 < T < 1$
6 (two-phase)	$P_K(T), g_2(P_K, T)$ $g_1(P_K, T)$	$T_t \leq T \leq T_1$
Boundary between 2 and 3	$P_L(T)$	$T_1 < T < T_2$

TABLE 3

ASME BOUNDARY VALUES FOR SUBREGIONS

Quantity	ASME Normalized Value	Specific Value
T_t (triple point)	$27316/64730 \approx 0.421999$	$\sim 32.018^\circ\text{F}$
T_1	$62315/64730 \approx 0.96269$	662°F
T_c (critical point)	1	$647.3\text{K}, 705.47^\circ\text{F}$
T_2	$86315/64730 \approx 1.33346$	1094°F
T_3	$107315/64730 \approx 1.65788$	1472°F
P_t (triple point)	$P_K(T_t) \approx 2.7633 \times 10^{-5}$	$\sim 0.08865 \text{ psia}$
P_1	$P_K(T_1) \approx 0.747519$	$\sim 2398.2 \text{ psia}$
P_c (critical point)	1	$22120000\text{N/m}^2, \sim 3208.23 \text{ psia}$
P_2	$10000/2212 \approx 4.52$	14503.77 psia
v_c (critical point)	1	$0.00317 \text{ m}^3/\text{kg}, \sim 0.050778 \text{ ft}^3/\text{lbm}$

IV. THERMODYNAMICS

Many excellent references exist in the field of thermodynamics and it is not the purpose of this report to tabulate a comprehensive review of well known material. Within this framework we shall tabulate several of the more useful relations and their derivatives.

The four fundamental differential equations are:

$$du = Tds - Pd v \quad (1)$$

$$dh = Tds + vdP \quad (2)$$

$$df = -sdT - PdV \quad (3)$$

$$dg = -sdT + vdP \quad (4)$$

and in two-phase
$$\frac{dP}{dT} = \frac{1}{T} \frac{h_g - h_f}{v_g - v_f} \quad (5)$$

and the general relations between these thermodynamic variables are:

$$h = u + Pv \quad (6)$$

$$f = u - Ts \quad (7)$$

$$g = h - Ts. \quad (8)$$

Thermodynamic derivatives can be expressed in terms of any three independent derivatives and an appropriate set of state properties. The generally accepted standard form is to express the derivatives in terms of β , κ , and C_p along with P , v , and T in single phase. For homogeneous two-phase material, Bridgman^[2] uses dP/dT (P'), C_v , v_f , v_g , s , v , T , P , and $\phi(x, 1-x)$ where

$$\phi = (\partial v / \partial T)_x = xv_g(\beta_g - \kappa_g P') + (1-x)v_f(\beta_f - \kappa_f P') \quad (9)$$

and

$$C_v = x\{C_{pg} - TP'v_g(2\beta_g - \kappa_g P')\} + (1-x)\{C_{pf} - TP'v_f(2\beta_f - \kappa_f P')\}. \quad (10)$$

(Subscripts g and f refer to gas and fluid, respectively.)

Various thermodynamic quantities and standard derivatives are listed in Table 4 in terms of $g(P, T)$, $f(v, T)$, and the saturation pressure $P(T)$. This table along with derivatives as tabulated by Bridgman^[2] form a working set with which any thermodynamic quantity can be calculated algebraically.

To simplify writing, a shorthand notation of the explicit partial derivatives is used in Table 4. For instance, define g to be an explicit function of (P, T) ,

then $g_P \equiv \left(\frac{\partial g}{\partial P}\right)_T$, $g_T \equiv \left(\frac{\partial g}{\partial T}\right)_P$, and $g_{PT} \equiv \frac{\partial}{\partial P} \left[\left(\frac{\partial g}{\partial T}\right)_P \right]_T$.

TABLE 4.

THERMODYNAMIC VARIABLES EXPRESSED IN TERMS OF g , f , and P' Single-Phase: $g(P,T)$ and $f(v,T)$; Two-Phase $P(T)$

Variable		Single-Phase		Two-Phase
		Gibbs Equivalent	Helmholtz Equivalent	
P	Pressure	P	$-f_v$	$P = -(f_v)_g = -(f_v)_f$
h	Specific Enthalpy	$g - Tg_T$	$f - vf_v - Tf_T$	$xh_g + (1-x)h_f$
u	Specific Internal Energy	$g - Tg_T - Pg_P$	$f - Tf_T$	$xu_g + (1-x)u_f$
v	Specific Volume	g_P	v	$xv_g + (1-x)v_f$
s	Specific Entropy	$-g_T$	$-f_T$	$xs_g + (1-x)s_f$
g	Gibbs Function h-Ts	g	$f - vf_v$	$g_f = g_g$
f	Helmholtz Function u-Ts	$g - Pg_P$	f	$xf_g + (1-x)f_f$
β	$\frac{1}{v} \left(\frac{\partial v}{\partial T} \right)_P$	g_{PT}/g_P	$-f_{vT}/vf_{vv}$	not defined
C_P	$\left(\frac{\partial h}{\partial T} \right)_P$	$-Tg_{TT}$	$-T \left[f_{TT} - f_{vT}^2 / f_{vv} \right]$	not defined
C_V	$\left(\frac{\partial u}{\partial T} \right)_v$	$-T \left[g_{TT} - g_{PT}^2 / g_{PP} \right]$	$-Tf_{TT}$	$x \left[C_{P-TP'v(2\beta-\kappa P')} \right]_g + (1-x) \left[C_{P-TP'v(2\beta-\kappa P')} \right]_f$
κ	$-\frac{1}{v} \left(\frac{\partial v}{\partial P} \right)_T$	$-g_{PP}/g_P$	$1/vf_{vv}$	not defined
α_s^2	$-v^2 \left(\frac{\partial P}{\partial v} \right)_s$	$g_{PT}^2 g_{TT} / \left[g_{PT}^2 - g_{TT} g_{PP} \right]$	$v^2 \left[f_{vv} - f_{vT}^2 / f_{TT} \right]$	$Tv^2 P'^2 / C_V$
γ	C_P / C_V	$g_{TT} g_{PP} / \left[g_{PP} g_{TT} - g_{PT}^2 \right]$	$\left[f_{vv} f_{TT} - f_{vT}^2 \right] / f_{TT} f_{vv}$	not defined
δ	$\left(\frac{\partial v}{\partial T} \right)_x$	not defined	not defined	$x \left[v(\beta - \kappa P') \right]_g + (1-x) \left[v(\beta - \kappa P') \right]_f$

* Subscripts g and f mean that the quantity is evaluated on the gas and liquid side, respectively.

Note: $dP/dT = \frac{1}{T} \left(\frac{h_g - h_f}{v_g - v_f} \right)$

V. ASTEM ROUTINES AND COMMON BLOCKS

ASTEM is a package of 16 routines and 12 common blocks. Ten of the common blocks are block data and the other two transmit information between subroutines. Unless redimensioned by the user, the highest derivative allowed is order 9.

Since all arrays within ASTEM are one-dimensional to save storage area, the user must understand the equivalence of an "effective two-dimensional" array as explained in INDEX.

1. USER ROUTINES

The routines normally available to users are described in alphabetical order: CONA, CONU, GIBBAB, HELMCD, IASME, INDEX, PSATK, PSATL, ROOT, UNITS, and WRITEA.

1.1 CONA

Converts units of array AA.

Usage: CALL CONA(AA,IOA,A,IB,JB,CA,CI,CJ)

Input: AA, a single dimensioned array equivalent to AA(L,L)

where L = IOA+1

IB and JB are index biases

IOA is the order of array AA

CA is units conversion for numerator

CI is units conversion for denominator II

CJ is units conversion for denominator JJ

Output: Single dimensional array equivalent to A(LA,LA)

where LA = IOA+1-IB-JB

Example: Let AA be a 4 x 4 array of the Gibbs function and its (P,T) derivatives to third order. Set up the v array to second order.

CALL CONA (AA,3,A,1,0,CRV,CRP,CRT)

Output: A(1) = AA(2)*CRV = v

$$A(2) = AA(3)*CRV/CRP = \left(\frac{\partial v}{\partial P} \right)_T$$

$$A(3) = AA(4) * CRV / CRP^2 = \left(\frac{\partial^2 v}{\partial P^2} \right)_T$$

$$A(4) = AA(6) * CRV / CRT = \left(\frac{\partial v}{\partial T} \right)_P$$

etc.

1.2 CONU

Converts units of up to 10 variables

Usage: CALL CONU (J,C,X1,I1,X2,I2,X3,I3...X10,I10)

J = Number of X arguments

C = Array of six conversion factors

C(1) = critical pressure

C(2) = critical absolute temperature

C(3) = critical specific volume

C(4) = enthalpy conversion factor

C(5) = entropy conversion factor

C(6) = "zero" temperature

The array C can be obtained by a call to UNITS.

X's and I's are input variables to be converted where if

I = 1, X = pressure

I = 2, X = change in temperature

I = 3, X = specific volume

I = 4, X = enthalpy, specific internal energy, Gibbs
or Helmholtz

I = 5, X = entropy

I = 6, X = nonincremental temperature.

If I is positive, convert from reduced units to units
defined by the C array.

For I > 0, X is returned after multiplying by C(I).

If I is negative, convert from C array units to reduced
units.

For I < 0, X is returned after dividing by C(|I|).

1.3 GIBBAB

Given (P,T) compute the Gibbs function and all derivatives to order N.

Usage: CALL GIBBAB(G,P,T,N,I)

Input: P = pressure

T = temperature

N = derivatives to order N, $0 \leq N \leq 9$

I = ASME subregion either 1 or 2.

Output: G array containing the Gibbs function and its derivatives evaluated at (P,T)

Dimension G at least $(N+1)(N+2)/2$

(See INDEX for arrangement of output array.)

1.4 HELMCD

Given (v,T) compute the Helmholtz function and all derivatives to order N.

Usage: CALL HELMCD(F,V,T,N,I)

Input: V = specific volume

T = temperature

N = derivatives to order N, $0 \leq N \leq 9$

Output: F array containing the Helmholtz function and its derivatives evaluated at (v,T)

Dimension F at least $(N+1)(N+2)/2$

(See INDEX for the arrangement of the output array.)

1.5 IASME

Initial condition subroutine that must be called once to set values of binomial coefficients and factorials into /BINFAC/ and to initialize computer dependent residuals α_0 and α_1 ^[1] in /ASMCON/.

Usage: CALL IASME(I)

where I is the maximum order of derivatives to be calculated.

Limit: $1 \leq I \leq 9$

1.6 INDEX

Computes the FORTRAN location index of a packed single-dimensioned array that corresponds to a double-dimensioned triangular array A(I,J).

In ASTEM, two-dimensional (ie, functions of two independent variables) quantities are used within this program as packed, single-dimensioned quantities. For example, let G be the FORTRAN symbol to denote the Gibbs function and its P and T derivatives, then if we wish to compute the Gibbs derivatives to order n, G would have to be dimensioned $(n+1)(n+2)/2$ for a packed array. For a numerical example say that we require derivatives to the third order, then $(3+1)(4+1)/2 = 10$.

When calculated by a call to GIBBAB, the array G is returned with the following values:

$\begin{smallmatrix} I \\ \backslash J \end{smallmatrix}$	1	2	3	4
1	G(1) ε	G(2) ε_P	G(3) ε_{PP}	G(4) ε_{PPP}
2	G(5) ε_T	G(6) ε_{PT}	G(7) ε_{PPT}	
3	G(8) ε_{TT}	G(9) ε_{PTT}		
4	G(10) ε_{TTT}			

Rather than sketch this type of array to obtain the equivalence, a call to INDEX will compute the proper index value when supplied with the array size and the double FORTRAN index. For example, compute the index, L, for ε_{PPT}

$$L = \text{INDEX}(I, IM, J, JM, IP)$$

where $I = 3$

$J = 2$

$IM = JM = 4$

then $L = \text{INDEX}(3, 4, 2, 4, \text{IDUMMY}) = 7$

and $\text{IDUMMY} = IP = \text{maximum number of elements in the } J\text{th row} = 3.$

1.7 PSATK

Computes saturation pressure and derivatives to order n as a function of temperature.

Usage: CALL PSATK(P,T,N)

Input: T = temperature

N = derivatives to order N, $0 \leq N \leq 9$

Output: P(1) = P_{sat}

P(2) = P' (dP/dT)

P(3) = P'' (d^2P/dT^2)

etc.

Dimension P array at least (N+1).

1.8 PSATL

Computes the pressure boundary, P_L , between ASME regions 2 and 3 and its derivatives to order n as a function of T .

Usage: CALL PSATL(P,T,N)

Input: T = temperature

N = derivatives to order N , $0 \leq N \leq 9$

(Note: Derivatives of order 3 or higher are zero.)

(Note: Derivatives of order 3 or higher are zero.)

Output: $P(1) = P_L$

$P(2) = P'_L$

$\vdots$

1.9 ROOT

Computes iteratively a root of the Gibbs, Helmholtz, or saturation pressure function.

CALL ROOT(XROOT,A,B,C,D,I, NOGO)

where I = type of root and NOGO = .TRUE. if iteration failure occurs.

$|I|$ = ASME subregion number

TABLE 5

SUBROUTINE ROOT ARGUMENTS

I	ASME Subregion	Input		Output		
		A	B	XROOT	C	D
1	1	v	T	P	u	
2	2	v	T	P	u	
3	3	P	T	v	u	s
4	4	P	T	v	u	s
6	6	u	v	T_{sat}	x	P_{sat}
-1	1	P	u	T	v	
-2	2	P	u	T	v	
-3	3	u	v	T	P	
-4	4	u	v	T	P	
-5	5	P		T_{sat}		
-6	6	P		T_{sat}		

1.10 UNITS

A call to UNITS returns to the user the conversion constants for English or metric (MKS) units.

Usage: CALL UNITS(C,I)

Input: I = 1, English constants from /EUNITS/

I = 2, MKS constants from /MUNITS/

Output: Array C dimensioned by 10.

		English	Metric
C(1)	Critical pressure	CRP, lbf/in ²	CRPM, N/m ²
C(2)	Critical temperature	CRT,R	CRTM, K
C(3)	Critical specific volume	CRV, ft ³ /lbm	CRVM, m ³ /kg
C(4)	Enthalpy conversion	CRH, Btu/lbm (CRH=CRV*CRP*SQJC)	CRHM, J/kg (CRHM=CRVM*CRPM)
C(5)	Entropy conversion	CRS, Btu/lbm-R (CRS=CRH/CRT)	CRSM, J/kg-K (CRSM=SRHM/CRTM)
C(6)	"Zero" temperature	TO, 459.67 R	TOM, 274.15 K
C(7)	Mechanical equivalent to heat energy	JC, ft-lbf/Btu	JCM, Unity
C(8)	Gravitational conversion factor	GC, ft-lbm/sec ² -lbf	GCM, m/sec ²
C(9)	Pressure conversion	SQJC, (in ² /ft ²)/(ft-lbf/Btu) (SQJC = 144/JC)	SQJCM, Unity
C(10)	Conversion for normalized sonic velocity squared	SONIC2, (ft ² /sec ²)/(lbf-ft ³ /in ² -lbm)	SONICM, Unity

1.11 WRITEA

Write the array (or portions thereof) in triangular form when A is single-dimensioned.

Usage: CALL WRITE(A,I,J,IPAGE)

Input: array A

I,J effective dimensions of A

IPAGE is the current page number (both input and output).

If negative, no paginating.

Output example: I = J = 4; IB = JB = 0

A(1) A(2) A(3) A(4)

A(5) A(6) A(7)

A(8) A(9)

A(10)

Example: $I = 4, J = -4; IB = JB = 0$

A(1)

A(2) A(3)

A(4) A(5) A(6)

A(7) A(8) A(10)

(If $J < 0$, the binomial array is written.)

2. INTERNAL ROUTINES

The following subroutines are normally not called by the user.

2.1 BINOMX

Let $G(x,y)$ $H(x,y) = F(x,y)$, then given (a) $H(x,y)$, $F(x,y)$; compute $G(x,y)$ and its derivatives or (b) $H(x,y)$, $G(x,y)$; compute $F(x,y)$ and its derivatives.

Usage: CALL BINOMX(G,IGX,IGY,H,IHX,IHY,F,IFX,IFY,JI,JF,MGX,MGY,
MHX,MHY,MFX,MFY,LTYPE)

Input: A. LTYPE = 0, Compute G

H = array in packed single dimensional form
equivalent to double dimensions IHX,IHY

$H(1) = H(1,1) = H$

$H(2) = H(2,1) = \partial H / \partial x$

$H(1,2) = \partial H / \partial y$

etc.

F = array F in packed single dimension

F, $\partial F / \partial x$, $\partial F / \partial y$

equivalent array F(IHX,IHY)

JI = order of initial computation

(JO = 0, compute $G = F/H$)

JF = highest order

(Example: If JF = 2, compute derivatives to
2nd order) MGX,MGY: MHX,MHY: MFX,MFY are
index biases for G, H, and F.

Example: For the array F, elements are biased
 $F(I+MFX,J+MFY)$.

B. LTYPE = 0, Compute F given G and H

(Input description similar to A.)

2.2 EDER

Calculate the derivatives with respect to t of

$$z = \sum_{i=1}^M b_i e^{\lambda(1-t)n_i}$$

Usage: CALL EDER(Z,X,B,BL,M,M,IO)

Input: IO = highest order for derivatives

M = number of terms in sum

$$(1 \leq M \leq 7)$$

BL = λ

X = $e^{\lambda(1-t)}$

N = n_i (dimension M)

B = b_i (dimension M)

Output: Z array (dimension IO+1)

Z(1) = Z

Z(2) = dZ/dt .

2.3 FUNX

Defines and computes the functions for subroutine ROOT described in Section 1.9.

2.4 POLATT

Interpolates the straight lines in a table of Y,X.

Usage: Function POLATT(XY,XX,N,K)

Input: XY = Array of Y,X: Y(1), X(1), Y(2), X(2) . . .

where $X(N+1) > X(N)$

XX = input value of X

N = number of pairs of X,Y in XY array

K = memory index

Output: Interpolated value of Y and K, memory index.

2.5 POLYN

Compute the derivatives with respect to X of

$$z = \sum_{i=1}^M a_i X^{n_i}$$

Usage: CALL POLYN(X,Z,A,NI,M,L)

Input: X = value of main variable

M = number of terms in sum

$(1 \leq M \leq 20)$

A = a_i , dimensioned M

NI = integer n_i , dimensioned M

L = dimension of Z

(derivatives computed to order L-1)

Output: Z array.

3. COMMON BLOCKS

3.1 /ASMCON/

Contains $T_t, T_1, T_2, T_3, P_t, P_1, P_2, \alpha_0, \alpha_1, I_1$.

/ASMCON/ must be initialized by a call to IASME.

(Note: /ASMCON/ appears in block data DA12 with approximate values which are recalculated in IASME using precise values from /ASMCox/.)

3.2 /ASMCox/

Set in block data DA11 with values to calculate /ASMCON/.

3.3 /ASME1/

Set in block data DAT2; contains constants for the Gibbs functions.

3.4 /ASME34/

Set in block data DAT3; contains the constants for the Helmholtz functions.

3.5 /ASMESL/

Set in block data DAT4; contains the constants for saturation pressure line and P_L line separating subregions 2 and 3.

3.6 /BINFAC/

Contains an array of binomial coefficients and an array of factorials which are calculated in IASME.

(Note: The dimensions of this array limit the derivative calculations to 9th order or less.)

3.7 /DUMZZZ/

An intermediate storage area.

(Note: The dimensions of this array limit the derivative calculations to 9th order or less.)

3.8 /ERRPVT/

Contains arrays of iteration error requirements and search limits for subroutine ROOT. Values set in block data DAT7.

3.9 /EUNITS/ CRP,CRT,CRV,CRH,CRS,TO,JC,GC,SQJC,SONIC2

Contains conversion constants set in block data for English units.

This common block is available to users by calling UNITS.

$$CRP \approx 3208 \text{ psia}$$

$$P \text{ (reduced)} = P(\text{psia})/CRP$$

$$CRT \approx 1165.14 \text{ R}$$

$$T \text{ (reduced)} = [T(F)+TO]/CRT$$

$$CRV \approx 0.0578 \text{ ft}^3/\text{lbm}$$

$$v \text{ (reduced)} = v(\text{ft}^3/\text{lbm})/CRV$$

$$CRH \approx 30.14 \text{ Btu/lbm}$$

$$g, f, h, \text{ or } u \text{ (reduced)} = [h \text{ or } u \text{ (Btu/lbm)}]/CRH$$

CRS = entropy normalization

$$s \text{ (reduced)} = s(\text{Btu/lbm-F})/CRS$$

$$TO = 459.67 \text{ R (difference between absolute temperature)}$$

Scale (R) and Fahrenheit (F)

$$JC \approx 778.16 \text{ ft-lb}_f/\text{Btu (mechanical equivalent to heat energy)}$$

$$GC \approx 32.174 \text{ ft-lbm/sec}^2\text{-lb}_f$$

$$SQJC = 144/JC, \text{ pressure conversion from lb}_f/\text{in}^2 \text{ to Btu/ft}^3$$

SONIC2 = conversion for normalized sonic velocity squared

$$a_s^2(\text{ft}^2/\text{sec}^2) = a_n^2 \text{ (normalized)} * \text{SONIC2}$$

3.10 /MUNITS/ CRPM,CRTM,CRVM,CRSM,TOM,JCM,GCM,SQJCM,SONICM

Contains conversion for metric (MKS) units. Available by calling UNITS.

$$CRPM = 2.212 \times 10^7 \text{ N/m}^2$$

$$CRTM = 647.3 \text{ K}$$

$$CRVM = 0.00317 \text{ m}^3/\text{kg}$$

$$CRHM = 70120.4 \text{ J/kg}$$

$$CRSM \approx 108.3275 \text{ J/kg-K}$$

$$TOM = 273.15 \text{ K}$$

$$JCM = 1. \text{ N-m}^2/\text{J}$$

$$GCM = 9.80665 \text{ m/sec}^2$$

$$SQJC = 1. \text{ N-m}^2/\text{J}$$

$$\text{SONICM} = 1. (\text{m}^2/\text{sec}^2)/(\text{N-m}^2/\text{kg})$$

3.11 /ROOTLM/

Contains pairs of (v,T) which define the approximate boundaries of ASME subregions 3 and 4 or for subroutine ROOT. Values set in block data DAT8.

3.12 /SATLIN/

Contains approximate values of T_{sat} as a function of P for subroutine ROOT. Values set in block data DAT9.

The following table is a cross-reference for subroutines, functions, and name common blocks within ASTEM.

TABLE 6

CROSS-REFERENCE OF SUBROUTINES, FUNCTIONS AND NAME COMMON BLOCKS

Subroutine(S) or Function(F)																	Common Blocks with Block Data Name												
	S	S	S	S	F	S	S	S	F	F	S	S	S	S	S	S		DAT2	DAT1	DAT2	DAT3	DAT4	**	**	DAT7	DAT4		DAT8	DAT9
	CONA	CONU	BINOMX	EDER	FUNX	GIBBAB	HELMCD	IASME	INDEX	POLATT	POLYN	PSATK	PSATL	ROOT	UNITS	WRITEA	ZPOWER	/ASMCN/	/ASMCX/	/ASME1/	/ASME34/	/ASMESL/	/BINFAC/	/DUMZZZ/	/ERRPVT/	/EUNITS/	/MUNITS/	/ROOTIM/	/SATLIN/
CONA			X																										
CONU																													
BINOMX									X														X						
EDER***																													
FUNX						X	X					X																	
GIBBAB			X	X					X		X		X				X		X					X					
HELMCD			X								X							X			X			X					
IASME						X						X						X	X				X						
INDEX																													
POLATT																													
POLYN																													
PSATK			X								X												X	X					
PSATL											X												X						
ROOT*					X					X		X	X												X			X	X
UNITS																										X	X		
WRITEA*									X																				

* Contains a write statement and format.

** Contains dimensions that restrict maximum order.

*** Contains dimensions that limit number of summation terms.

VI. SAMPLE PROBLEM

The following sample problem is designed to test all routines in the ASTEM package.

Case	Given	ASME Region	Compute
1	T=250F, X=0.3	6	P, P', and v (English units)
2	T=680F, X=0.3	5	P, P', v, and P_L (English units)
3	P=400 psia, T=150F	1	<p>g and its (P,T) derivatives to 9th order.</p> <p>Write g, v, κ, s, β, a_s, and C_p in English units.</p> <p>Write g array in reduced units.</p> <p>Write v array in English, MKS, and reduced units.</p>

COMPILER OPTIONS - NAME= MAIN,OPT=02,LINES=58,SIZE=0000K,
SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOID,XREF

ISN 0002	IMPLICIT REAL*8(A-H,O-Z)	MAIN0010
ISN 0003	DIMENSION G(55), GV(45)	MAIN0020
ISN 0004	DIMENSION CE(10), CM(10)	MAIN0030
ISN 0005	LOGICAL NOGO	MAIN0040
	C	MAIN0050
	C INITIALIZE	MAIN0060
ISN 0006	CALL IASME(9)	MAIN0070
ISN 0007	CALL UNITS(CE,1)	MAIN0080
ISN 0008	CALL UNITS(CM,2)	MAIN0090
ISN 0009	JPAGE = 1	MAIN0100
ISN 0010	WRITE(6,101) JPAGE	MAIN0110
ISN 0011	101 FORMAT(1H1,23HASTEM/H0002,06/25/71KV4,10X,14HSAMPLE PROBLEM, 1 70X,54PAGE ,13)	MAIN0120
ISN 0012	WRITE(6,102)	MAIN0130
ISN 0013	102 FORMAT(1H0,6X,8HP (PSIA),13X,54F (F),8X,10MV (FT3/L3),15X,1HX, 1 10X,14HDP/DT (PSIA/F),5X,9HPL (PSIA))	MAIN0140
	C	MAIN0150
	C - CASE 1	MAIN0160
ISN 0014	L = 1	MAIN0170
ISN 0015	T = 250.00	MAIN0180
ISN 0016	X = .300	MAIN0190
ISN 0017	PL = 0.00	MAIN0200
ISN 0018	5 CALL CONU(1,CE,T,-5)	MAIN0210
ISN 0019	CALL PSATK(G,T,1)	MAIN0220
ISN 0020	P = G(1)	MAIN0230
ISN 0021	DPDT = G(2)*CE(1)/CE(2)	MAIN0240
ISN 0022	IF(L.EQ.2) GO TO 10	MAIN0250
ISN 0024	CALL GIBBAB(G,P,T,1,1)	MAIN0260
ISN 0025	VF = G(2)	MAIN0270
ISN 0026	CALL GIBBAB(G,P,T,1,2)	MAIN0280
ISN 0027	VG = G(2)	MAIN0290
ISN 0028	GO TO 15	MAIN0300
ISN 0029	10 CALL ROOT(VF,P,T,UF,SF,4,NOGO)	MAIN0310
ISN 0030	CALL ROOT(VG,P,T,UG,SG,3,NOGO)	MAIN0320
ISN 0031	CALL PSATL(PL,T,0)	MAIN0330
ISN 0032	15 V = X*(VG-VF) + VF	MAIN0340
ISN 0033	CALL CONU(4,CE,P,1,T,6,V,3,PL,1)	MAIN0350
ISN 0034	WRITE(5,103) P,T,V,X,DPDT,PL	MAIN0360
ISN 0035	103 FORMAT(1H ,6E18.8)	MAIN0370
ISN 0036	GO TO (20,30),L	MAIN0380
	C	MAIN0390
	C CASE 2	MAIN0400
ISN 0037	20 L = 2	MAIN0410
ISN 0038	T = 580.00	MAIN0420
ISN 0039	GO TO 5	MAIN0430
	C	MAIN0440
	C CASE 3	MAIN0450
ISN 0040	30 P = 400.00	MAIN0460
ISN 0041	T = 150.00	MAIN0470
ISN 0042	CALL CONU(2,CE,P,-1,T,-6)	MAIN0480
ISN 0043	CALL GIBBAB(G,P,T,9,1)	MAIN0490
ISN 0044	GI = G(1)	MAIN0500
ISN 0045	V = G(2)	MAIN0510
ISN 0046	GK = -G(3)/G(2)	MAIN0520
ISN 0047	I = INDEX(1,10,2,10,10)	MAIN0530
		MAIN0540
		MAIN0550

ISN 0048	S = -G(I)	MAIN0560
ISN 0049	B = G(I+1)/G(2)	MAIN0570
ISN 0050	I = INDEX(1,10,3,10,10)	MAIN0580
ISN 0051	CP = -T*G(I)	MAIN0590
ISN 0052	AS = DSQRT(CP*CE(10)/(CP*GK/V - T*B*B))	MAIN0600
ISN 0053	CALL CONU(8,CE,GI,4,V,3,GK,-1,S,5,8,-2,CP,5,P,1,T,6)	MAIN0610
ISN 0054	WRITE(6,104) P,T,GI,V,GK,S,B,CP,AS	MAIN0620
ISN 0055	104 FORMAT(1H0,3HP =,E18.8,5H PSIA,13X,3HT =,E18.8,2H F,16X,34G =, 1 E18.8,7H BTU/LB/1H ,3HV =,E18.8,7H FT3/LB,11X,3HC =,E18.8, 2 7H PSIA-1,11X,3HS =,E18.8,9H BTU/LB-F/1H ,3HB =,E18.8,4H F-1, 3 14X,3HCP=,E18.8,9H BTU/LB-F, 9X,3HAS=,E18.8,7H FT/SEC)	MAIN0630
	105 FORMAT(1H0,10X,33HGIBBS ARRAY IN ASME REDUCED UNITS)	MAIN0640
	WRITE(6,105)	MAIN0650
	CALL WRITEA(G,10,10,-1)	MAIN0660
ISN 0056	106 FORMAT(1H0,10X,43HSPECIFIC VOLUME ARRAY IN ASME REDUCED UNITS)	MAIN0670
ISN 0057	WRITE(6,106)	MAIN0680
ISN 0058	CALL CONA(G,9,GV,1,0,1.00,1.00,1.00)	MAIN0690
ISN 0059	CALL WRITEA(GV,9,9,-1)	MAIN0700
ISN 0060	107 FORMAT(1H0,10X,38HSPECIFIC VOLUME ARRAY IN ENGLISH UNITS)	MAIN0710
ISN 0061	WRITE(6,107)	MAIN0720
ISN 0062	CALL CONA(G,9,GV,1,0,CE(3),CE(1),CE(2))	MAIN0730
ISN 0063	CALL WRITEA(GV,9,9,-1)	MAIN0740
ISN 0064	108 FORMAT(1H0,10X,34HSPECIFIC VOLUME ARRAY IN MKS UNITS)	MAIN0750
ISN 0065	WRITE(6,108)	MAIN0760
ISN 0066	CALL CONA(G,9,GV,1,0,CM(3),CM(1),CM(2))	MAIN0770
ISN 0067	CALL WRITEA(GV,9,9,-1)	MAIN0780
ISN 0068	STOP	MAIN0790
ISN 0069	END	MAIN0800
ISN 0070		MAIN0810
ISN 0071		MAIN0820
ISN 0072		MAIN0830

ASTEM/MOD02,06/25/71KVM

SAMPLE PROBLEM

P (PSIA)	T (F)	V (FT3/LB)	X	DP/DT (PSIA/F)	PL (PSIA)
0.298246510 02	0.250000000 03	0.415767950 01	0.300000000 00	0.521613540 00	0.0
0.270858980 04	0.680000000 03	0.545081830-01	0.300000000 03	0.181618490 02	0.256248070 04

P =	0.400000000 03 PSIA	T =	0.150000000 03 F	G =	-0.119389880 02 BTU/LB
V =	0.163223530-01 FT3/LB	K =	0.310989220-05 PSIA-1	S =	0.214638640 00 RTU/LB-F
B =	0.311602050-03 F-1	CP =	0.998724700 00 BTU/LB-F	AS =	0.507957790 04 FT/SEC

GIBBS ARRAY IN ASME REDUCED UNITS

J / I	1	2	3	4	5	5	7	8	9	10
1	-3.980340-01	3.214420-01	3.207110-03	2.722280-04	-6.015190-05	1.857690-05	-7.704890-05	4.050260-06	-2.587710-06	1.955810-06
2	-8.295570 00	1.167030-01	-5.334170-03	1.267480-03	-3.707120-04	1.407300-04	-7.291000-05	4.615930-05	-3.469650-05	
3	-7.376880 01	8.515330-01	-1.031200-01	1.294670-02	-4.555260-03	2.490800-03	-1.429900-03	9.957230-04		
4	1.349450 02	-2.918380 00	5.857610-01	1.595290-01	-8.844270-02	3.145010-02	-2.294680-02			
5	-6.156110 02	5.997050 01	-2.664500 01	1.438860 00	3.192200-01	8.385140-01				
6	2.418580 03	-3.247860 02	4.717410 02	3.214160 01	-8.948240 01					
7	-5.131970 04	3.923940 04	-1.307280 04	1.201240 03						
8	2.830380 06	-6.897180 06	2.278880 05							
9	-7.493870 07	5.792910 08								
10	3.901420 09									

SPECIFIC VOLUME ARRAY IN ASME REDUCED UNITS

J / I	1	2	3	4	5	5	7	8	9
1	3.214420-01	3.207110-03	2.722280-04	-6.015190-05	1.857690-05	-7.704890-06	4.050260-06	-2.587710-06	1.955810-06
2	1.167030-01	-5.334170-03	1.267480-03	-3.707120-04	1.407300-04	-7.291000-05	4.615930-05	-3.469650-05	
3	8.515330-01	-1.031200-01	1.294670-02	-4.555260-03	2.490800-03	-1.429900-03	9.957230-04		
4	-2.918380 00	5.857610-01	1.595290-01	-8.844270-02	3.145010-02	-2.294680-02			
5	6.997050 01	-2.664500 01	1.438860 00	3.192200-01	8.385140-01				
6	-3.247860 02	4.717410 02	3.214160 01	-8.948240 01					
7	3.923940 04	-1.307280 04	1.201240 03						
8	-5.897180 06	2.278880 05							
9	5.792910 08								

SPECIFIC VOLUME ARRAY IN ENGLISH UNITS

J / I	1	2	3	4	5	6	7	8	9
1	1.632240-02	-5.076080-08	1.343010-12	-9.249770-17	8.904060-21	-1.151110-24	1.886100-28	-3.756060-32	8.848650-36
2	5.086030-05	-7.246070-11	5.366730-15	-4.892600-19	5.789270-23	-9.348850-27	1.844870-30	-4.322390-34	
3	3.185120-08	-1.202260-12	4.704900-17	-5.159870-21	8.794240-25	-1.573620-28	3.415590-32		
4	-9.368860-11	5.861380-15	4.975690-19	-8.598240-23	9.530230-27	-2.157390-30			
5	1.927890-12	-2.288330-16	3.851720-21	2.663540-25	2.180790-28				
6	-7.680460-15	3.477180-18	7.384570-23	-6.408090-25					
7	7.964050-16	-8.270160-20	2.368690-24						
8	-1.201450-15	1.237340-21							
9	8.660690-18								

SPECIFIC VOLUME ARRAY IN MKS UNITS

J / I	1	2	3	4	5	6	7	8	9
1	1.018970-03	-4.596090-13	1.763690-21	-1.761790-29	2.459750-37	-4.612110-45	1.096050-52	-3.165770-60	1.081690-67
2	5.715240-07	-1.180960-15	1.268600-23	-1.677390-31	2.878720-39	-6.742410-47	1.929760-54	-6.557570-62	
3	5.442420-09	-3.526990-17	2.001870-25	-3.184240-33	7.871310-41	-2.042810-48	6.430960-56		
4	-3.411010-11	3.095120-19	3.810760-27	-9.551010-35	1.535410-42	-5.064520-50			
5	1.263430-12	-2.175040-20	5.309890-29	5.325640-37	6.324220-44				
6	-9.060020-15	5.949080-22	1.832440-30	-2.306290-37					
7	1.691020-15	-2.546880-23	1.058000-31						
8	-4.591890-16	6.858940-25							
9	5.958150-17								

VII. REFERENCES

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