SYTBL2 / Notes

2006-12-10

Contents

'Thermodynamic Table for Performance Calculations in Gas Turbine Engine'
[IGTC2003Tokyo TS-093]

[SYTBL2/ Summary]

- ◉ Thermodynamic Table integrated with Flow Function Table to cover;
  - ① Temperature; T=0 — 5000 (K)
  - ② Fuel-Air Ratio; F/A= Air — Stoichiometric {F/A < 0.06824}
  - ③ Much Number; 0 — 25
  - ④ Systems of Units; S I, Metric, British
  - ⑤ Constant κ; (for educational purpose)

- ◉ VB Version for Hand Calculation.
- ◉ The Program written in Fortran for a Sub-routine Program.
- ◉ Dissociation was not taken into account.

Introduction

A subroutine program,, named as 'SYTBL2', was arranged for programming works relating to performance calculations in turbomachineries. This study on 'SYTBL' was presented in the IGTC'03Tokyo, of which the coefficients for the temperature less than 200(K) has been revised in 'SYTBL2' by using the JANAF table as shown in p.14. This notes are a guide to explain how to use the subroutine program, 'SYTBL2.for' in a main programming work.. The reference files will be contained in 'ExSY2.lzh', as shown in Table 1.

[Hand Cal.] Visual Basic version of the 'SYTBL2' shown in [Fig. 1]/p.3, was arranged for the convenience to hand calculations. The attached files 'ExSY2' contains the folder [VB] which has three files in it.. Move the folder [VB] to an appropriate place in your PC, then click SYTBL2.exe, so that it will start to work. Firstly, Unit and Option button to be chosen.. The upper half is for thermodynamic table and lower half for flow function table. Viscosity; μ is also shown in Air-option. To clarify the too small or big values, .'Exponential' expression is arranged as shown in [Fig-1].

[Programming /Symbols] The 'SYTBL2' consists of two functions, i.e. Thermodynamic table [Table 12]/p.11 and Flow function table [Table 14]/p.12. To utilize the subroutine program :'SYTBL2.for', the format shown in [Table-11]/p.10 have to be added into the top of main program. Practically, it will be done by means of copy & paste to main program from the listing of CPCAL1, for example.

Compiling of main program will be done as:

C::¥MSDEV¥BIN>fl32 a:¥ Main.for a;¥Sytbl2.for.

The related files will be attached in the folder; [ExSY2]. The examples of utilizing thermodynamic table are shown in CPCAL1 [Table 4]/p.7, CPCAL [Table 6]/p.8 and CPCHK1 [Table 7]/p.8.

And, FLCAL1 [Table 8]/p.9, FLCAL [Table 9]/p.9 and FLCHK [Table 10]/p.10 are for the examples of flow function table. All these files are operative on DOS prompt. The listings of the attached programs will explain how to call these sub-functions.

[Tables] The Air Table [Table 20] corresponds to CPAIR1.exe, similarly Cp Table [Table 21] to CPTBL1.exe and Flow Table [Table 22] to FLTBL1.exe. By modifying those listings slightly, any tables required will be generated.

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Table 1 Attached Files ---The all files in (A),(B) are operative on DOS Prompt

[1] Hand Cal.	(A) Thermodynmic Table	[4] Tables
	CPCAL1.for	
SYTBL2.exe-----------(Fig. 1)	CPCAL1.exe-------------(Table 4)	CPAIR1.ans------(Table 20)
SY6UNST.log	CPCAL.for	CPAIR1.for
ReadMe.txt	CPCAL.exe--------------(Table 6)	CPAIR1.exe
	CPCHK1.for	
[2] Subroutine Program	CPCHK1.exe------------(Table 7)	CPTBL1.ans------(Table 21)
	(B) Flow Function Table	CPTBL1.for
SYTBL2.for	FLCAL1.for	CPTBL1.exe
	FLCAL1.exe------------(Table 8)	
	FLCAL.for	FLTBL1.ans-------(Table 22)
	FLCAL.exe--------------(Table 9)	FLTBL1.for
	FLCHK.for	FLTBL1.exe
	FLCHK.exe-------------(Table 10)	

[1]　Hand　Cal.

[1-1] VB-Version / Symbols

VB-Version [Fig. 1] is arranged for Hand Cal.

Upper side＝Thermodynamic table.

Lower side＝Flow function table.

◉ Unit (SI,　Metric or　British) and

Option (Gas, Air or　κ) to be chosen first.

Option　κ is for the Cal. with　κ=Const.

Thermodynamic table

- T;　Temperature
- H;　Enthalpy
- U;　Internal energy
- Pr:　Relative pressure
- Vr;　Relative volume
- F/A;　Fuel/Air ratio
- Cp;　Specific heat
- φ;　Entropy function
- κ;　Specific heat ratio

Flow Function table

- Mn ;　Mach number
- Ps/Pt; Pressure ratio (static to total)
- Pt/Ps; Pressure ratio (total to static)
- Ts/Tt; Temperature ratio (static to total)
- Rs/Rt=ρ_s/ρ_t; Density ratio (static to total)
- V/Sqr(T)=V/√T, Velocity normalized
- Q=G√T/AP$_t$; Volume flow rate normalized (total, subsonic)
- S= G√T/AP$_t$; Volume flow rate normalized (total,supersonic)
- Q$_s$= G√T/AP$_s$; Volume flow rate normalized (static, subsonic)
- A/Ach; Area ratio (Laval nozzle, subsonic)
- S= A/Ach; Area ratio (Laval nozzle, for supersonic)
- Cpm;　Specific heat (mean)
- κ_m;　Specific heat ratio (mean)

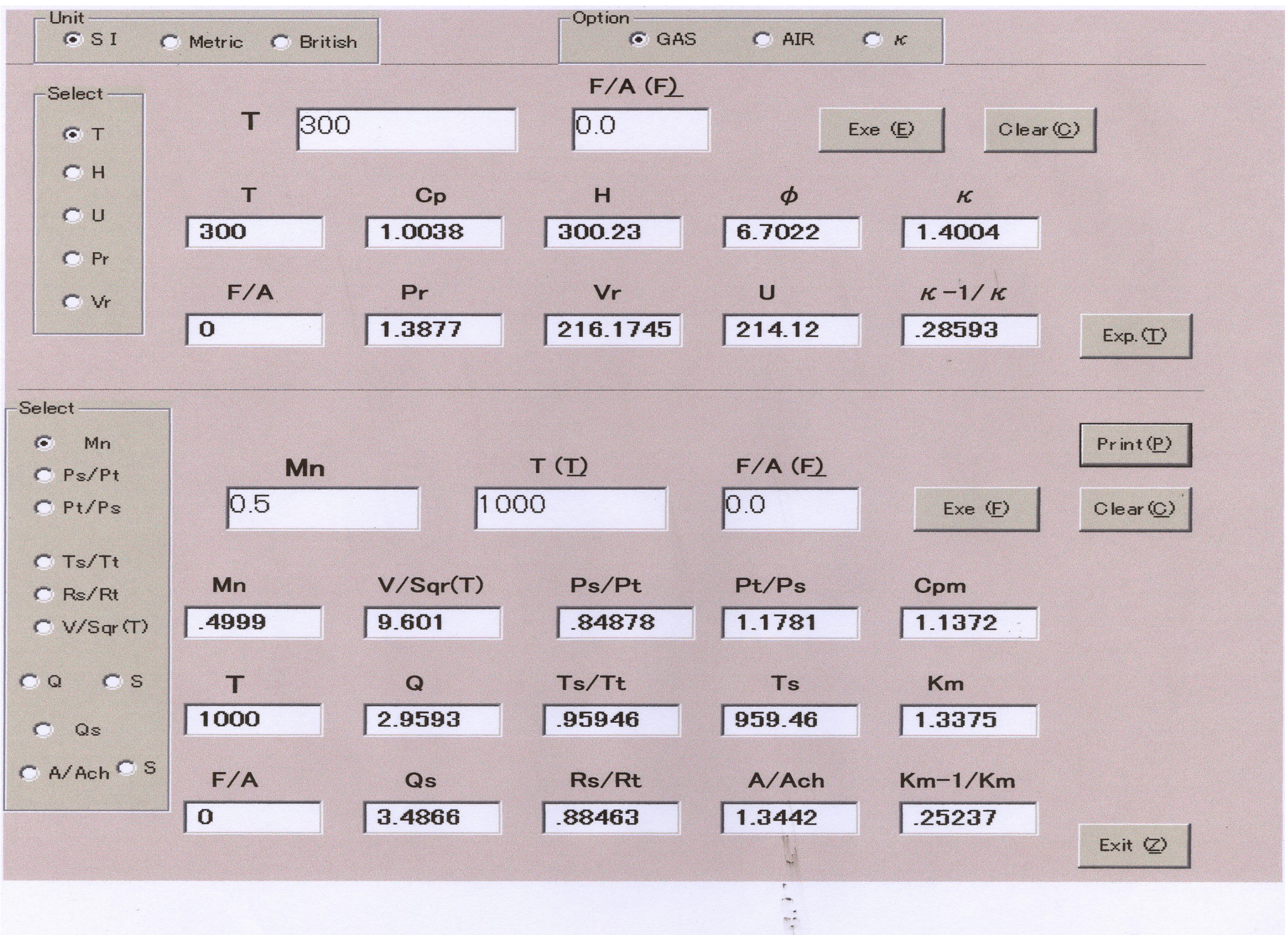


Fig. 1　　VB- Version

Fuel/Air Ratio; F

- Fuel/Air ratio :F will be taken as shown in [Table 2] ,depending upon the values inputted.

Table 2 Fuel/Air Ratio; F

①; $F = f/a$ ------for $0 \leqq F < 0.1$
②; $F = \phi \equiv (f/a)/(f/a)_{st}$ -----for $0.1 \leqq F \leqq 1.4$
③; $F = a/f$ ----- for $1.4 < F$

Three Systems of Units

- The SYTBL works for the three systems of units, SI , Metric and British, as shown below.

Table 3 Three Systems of Units

ND	1	2	3
Unit	S I	Metric	British
A	cm^2	cm^2	in^2
Cp, Cv, ϕ	kJ/kg K	kcal/kg K	Btu/lb R
G	kg/sec	kg/sec	lb/sec
h, u	kJ/kg	kcal/kg	Btu/lb
L	m	m	ft
P	MPa	kg/cm^2	lb/in^2 (psi)
T	K	K	R
V	m/sec	m/sec	ft/sec
$\frac{V}{\sqrt{T}}$	$\frac{m/sec}{\sqrt{K}}$	$\frac{m/sec}{\sqrt{K}}$	$\frac{ft/sec}{\sqrt{R}}$
$q, q_s = \frac{G\sqrt{T}}{A\ P}$	$\frac{(kg/sec)\sqrt{K}}{cm^2\ MPa}$	$\frac{(kg/sec)\sqrt{K}}{cm^2\ kg/cm^2}$	$\frac{(lb/sec)\sqrt{R}}{in^2\ psi}$

Viscosity of Air ; μ

The units for the viscosity of air ; μ are defined as below.

--- see Sec.[3-6], p.18---

S I Unit;	[Pa sec]
Metric Unit;	$[kg_f\ sec/m^2]$
British Unit;	$[lb_f\ sec/ft^2]$

κ= Const. Option --- See [Ex.2]/p.6---

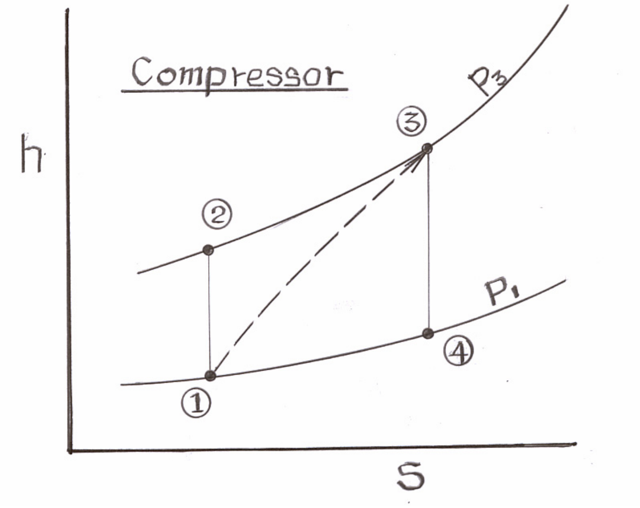
- It works for the input value of: $\kappa > 1.0$.

[1-2] Example cal.

[Ex.-1] Relative Pressure; Pr

Obtain efficiency; η of the air compressor operating at:

---- T1= 288.15, P1= 0.101325, P3/P1= 5.0, T3= 530.0 (K) ---



Notes on Pr Cal.

Data given; T1, P1, T3, P3
h3= f(T3)

At T1; h1= f(T1), Pr1= f(T1)
Pr2= Pr1 * (P3/P1)

At Pr2; h2= f(Pr2)

Efficiency; η =(h2− h1)/(h3− h1)

Compressor Efficiency Cal., ND=1 (S I unit)						
Stn.	T	P	h	ϕ	Pr	s
1	① 288.15	0.101325	288.33	6.66174	1.2052	7.31887
2	455.26	0.506625	457.21	7.12366	② 6.0260	7.31884
3	③ 530.00	0.506625	534.03	7.27987	10.3838	7.47505
4	336.60	0.101325	337.02	6.81790	④ 2.07676	7.47504

Station Cal.
① (Stn1); T= 288.15 (K)
② (Stn2); Pr2= Pr1*(P3/P1)= 1.2052*5= 6.026
③ (Stn3); T3= 530. (K)
④ (Stn4); Pr4= Pr3/(P3/P1)= 10.3838/5= 2.07676

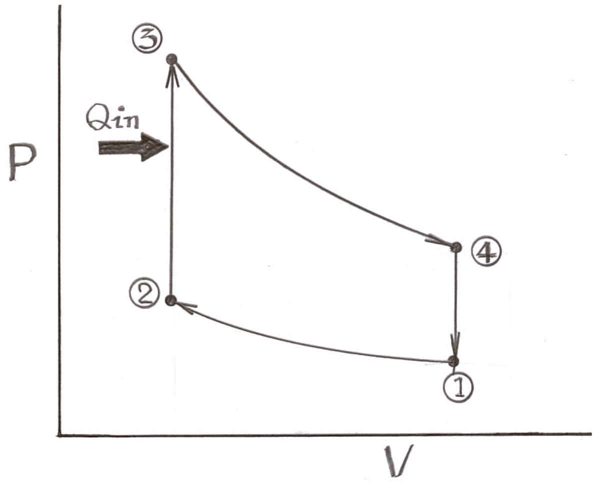
Output Cal.
Adiabatic efficiency: η = (h2−h1)/(h3−h1)= (457.21−288.33)/(534.03−288.33)= 168.88/245.70= **0.6873**
Input energy = h3−h1= 534.03−288.33= 245.70 (kJ/kg)
Potential energy= h3−h4= 534.03−337.02= 197.01 (kJ/kg)
Loss energy= Input energy− Potential energy= 245.70− 197.01= 48.69 (kJ/kg)

Loss Energy / Check Cal .; [s=entropy, ϕ= Entropy function]
S1= ϕ 1−R*Ln(P1)= ϕ 1−R*Ln(0.10132)=6.66174−0.28703*(−2.2894)=7.31887 (kJ/kg K)
S3= ϕ 3−R ln(P3)= 7.27987−0.28703*ln(0.506625)= 7.47505 (kJ/kg K)
ΔS=S3−S1=7.47505−7.31887=0.15618 (kJ/kg K)
Tm=(T1+T4)/2= (288.15+336.6)/2= 312.375 (K)
Loss Power= G*Tm*ΔS = 1.0*312.375*0.15618 = **48.78** (kJ/kg)

[Ex.-2] Relative Volume; Vr (κ =1.2)

Obtain the efficiency; η of an engine operating at;

--- T1= 288.15, P1= 0.101325, ε = 10., Qin= 1000 ---



Notes on Vr Cal.

Data given; T1, P1, ε , Qin

At ①; U1, Vr1 = f(T1) , Vr2= Vr1 / ε

At ②; U2= f(Vr2), U3= U2+ Qin

At ③; Vr3=f(U3) , Vr4= Vr3 * ε

At ④; U4= f(Vr4)

W_{OUT}=(U3- U4)/ (U2- U1)

η = W_{OUT}／Q_{IN}

h6= U4 ＋R*T1

T6 = f(h6)

*** Piston Engine Cycle Cal with K=1.2, ND=1, (SI unit) ***

Stn.	T(K)	P(MPa)	h	u	ϕ	Pr	Vr	SS	v=RT/1000P
1	① 288.15	0.10132	496.22	413.52	10.7534	1.3779	209.117	11.41110	0.81630
2	456.67	1.60580	786.46	655.38	11.5465	21.8377	② 20.9117	11.41041	0.08163
3	1153.46	4.05594	1986.45	③1655.38	13.1422	5670.3150	0.203	12.73991	0.08163
4	727.78	0.25590	1253.36	1044.46	12.3491	357.7609	④ 2.0342	12.74061	0.81629
6(Exh)	654.50	0.10132	⑤ 1127.17	939.30	12.1663	189.2562	3.458	12.82401	1.85412

*** ⑤Exhaust Gas; h6= U4+P1V1=U4+RT1= 1044.46+0.287(288.15)= 1044.46+82.707= 1127.167 (kJ/kg) ***

Station Cal.
① (Stn1); T= 288.15 (K)
② (Stn2); Vr2=Vr1/ε =209.117/10=20.9117
③ (Stn3); U3= U2*Qin= 655.38+1000= 1655.38 (kJ/kg)
④ (Stn4): Vr4= Vr3*ε = 0.20342*10= 2.0342

Output Cal.
Compression Work= U2−U1= 655.38−413.52= 241.86 (kJ/kg)
Expansion Work= U3−U4= 1655.38−1044.46= 610.92 (kJ/kg)
Engine Output= Exp.W−Comp.W= 610.92−241.86= 369.06 (kJ/kg)
Thermal Efficiency= Output/Input= 369.06/1000= 0.36906

(Note): Efficiency= 1−i/ε ^(1.2−1)= 1−1/10^0.2= 1−0.63096= 0.36904

Pressure Cal.
P2= P1*(Pr2/Pr1)= 0.10132*(21.8377/1.3779)= 1.6058 (MPa)
P3=P2*(T3/T2)=1.6058*(1153.46/456.67)=4.05594 (MPa)
P4= P3*(Pr4/Pr3)= 4.05594*(357.761/5670.315)= 0.2559 (MPa)

Energy Balance
Energy−In= h1+Qin= 496.22+1000= 1496.22 (kJ/kg)
Energy−Out= Output+h6= 369.06+1253.36= 1496.22 (kJ/kg)

Entropy; S = f (ϕ ,P), --- ϕ =entropy function
S=ϕ−R*ln(P)= ϕ−0.2870277*ln(P) ---for ND=1 (SI unit)
S=ϕ−RC*ln(P)= ϕ−0.0685554*ln(P) ---for ND=2 (Metric unit) and ND=3 (British unit)

[2]　Programming / Symbols

[2-1]　Example Calculations.(Operative on DOS Prompt)

[Ex.-1]　CPCAL1　---Thermodynamic table for　[CK=0.0, ND=1]

INPUT DATA

I = Option No.

= 1,　T:　Temperature [K]

= 2,　H:　Enthalpy [kJ/kg]

= 3,　U:　Internal energy [kJ/kg]

= 4,　Pr:　Relative pressure

= 5,　Vr:　Relative volume

F = Fuel/ Air ratio—see [Table 5]

OUTPUT DATA

Table 4 shows the output for;

[I=1 ,　T= 300 (K),　F=0.]

Table 4　Example. Cal./ **CPCAL1**

```
C:¥FOR¥BINB>CPCAL1
    I,    ( T: H: U: Pr: Vr ),      F    ???
    1      300      0.0

    T= 300.000    CP=1.003821     H= 300.235    VR=   .21617E+03     U = 214.126
F/A=   .00000    K = 1.40043   PHI= 6.70222    PR=   .1388E+01     (K-1)/K=.285935
```

Notes;

（1）　The options in CPCAL1 are defined as　[CK=0.0, ND=1]. The　CK stands for **C**onstant **K**appa Option,　If CK=1.3 inputted, the table will show the characteristics for　$\kappa = 1.3$.

（2）　The option: ND stands for **N**umber of **D**imensions.
ND=1 for SI unit, ＮＤ=2　for Metric unit　and　ND=3 for British unit.

（3）Ｆ　stands for　Fuel / Air ratio which will be taken as below depending upon the value inputted.

Table 5　Fuel/Air Ratio

F = f / a	for	$0 \leqq F < 0.10$
F= $\phi \equiv$ f/a / (f/a)st	for	$0.10 \leqq F \leqq 1.4$
F = a / f	for	$1.4 < F$

That is, F=0.06825-- (f/a),　F=1.0--$(f/a)_{st}$　and F=14.653--(a/f) , all for the characteristics at Stoichiometric Condition, same meaning..

（4 ）There are examples utilizing the following sub-functions of Thermodynamic functions in the listins of　‘CPCAL1.for’.

CPT,　HFT,　SFT,　UFT,　PRT,　and　VRT.

[Ex.-2] CPCAL ---Thermodynamic table

Table 6 Example Cal. / CPCAL (Operative on DOS prompt)

```
C:¥FOR¥BINB>CPCAL
 CK,   ND,    I,    ( T: H: U: Pr: Vr ),      F   ???
  0.0    1      2      300.235       0.0

   T= 300.000     CP=1.003821      H= 300.235     VR=   .21617E+03      U = 214.127
   F/A=   .00000     K = 1.40043    PHI= 6.70222     PR=   .1388E+01 (K-1)/K=.285935
```

Notes

(1) CPCAL[Table 6] is the same program as CPCAL1[Table 4], but the options of CK and ND are arranged as input data. in CPCAL. [Table 6] shows the characteristics corresponding to the enthalpy of: h=300.235 by using the option :I=2.

(2) Option [CK=0.0, ND=1] were chosen for CPCAL1 in the listing of CPCAL.for.

[Ex.-3] CPCHK1 ---Thermodynamic table for [CK=0.0, ND=1]

Table 7 Example Cal./ CPCHK.1

```
C:¥FOR¥BINB>CPCHK1
   T,          F   ???
 300          0.0
   T= 300.000     CP=1.003821      H= 300.235     VR=   .2162E+03       U = 214.126
 F/A=   .00000     K =1.400433    PHI= 6.70222     PR=   .1388E+01 (K-1)/K=.285935

          ( 5 ) TFH     H=         300.234500     T=        300.000000
          ( 6 ) TPR    PR=           1.387768     T=        300.000000
          ( 9 ) TFU     U=         214.126200     T=        300.000000
         ( 14 ) TVR    VR=         216.174500     T=        300.000000
         ( 10 ) HVR    VR=         216.174500     H=        300.234500
         ( 11 ) HPR    PR=           1.387768     H=        300.234500

         ( 12 ) UPR    PR=           1.387768     U=        214.126200
         ( 13 ) UVR    VR=         216.174500     U=        214.126200
         ( 15 ) PRH     H=         300.234500    PR=          1.387768
         ( 18 ) PRU     U=         214.126200    PR=          1.387768
         ( 16 ) VRH     H=         300.234500    VR=        216.174500
         ( 17 ) VRU     U=         214.126200    VR=        216.174500
```

Note;

Thermodynamic table contains 18 sub-functions as shown in [Table 12]/ p.11. The all sub-functions are used in CPCHK1. ---See the listings of CPCHK1.for.---

[Ex.-4] <u>FLCAL1</u> (Operative on DOS prompt.) ---Flow function table [CK=0.0, ND=1]

INPUT DATA

J = Option No.

- = 1, Mn; Mach number
- = 2, PsR; pressure ratio: Ps/Pt
- = 3, PtR, pressure ratio: Pt/Ps
- = 4, TsR, temperature ratio: Ts/Tt
- = 5, RsR, density ratio: ρ_s / ρ_t
- = 6, VfT, velocity normalized: V/$\sqrt{Tt}$
- = 7, Q, volume flow rate(subsonic) $\frac{G\sqrt{T_t}}{AP_t}$
- = 8; Qs volume flow rate: $\frac{G\sqrt{T_t}}{AP_s}$
- = 9; AsR; area ratio(subsonic):A/Ach
- =10; SQ: volume flow rate(supersonic) $\frac{G\sqrt{T_t}}{AP_t}$
- =11; SAs; area ratio(supersonic): A/Ach

OUTPUT

V/RTt; velocity normalized: V/$\sqrt{Tt}$

RO/ROt; density ratio: ρ_s / ρ_t

Table 8 Example Cal. / FLCAL1 ---see Table 3/p.4 for units.

```
C:¥FOR¥BINB>FLCAL1
J,( Mn:PsR:PtR:  TsR:RsR:VfT:  Q:Qs:AsR:  SQ:SAsR ),  T,   F   ???
  1    0.5   300   0.0

   Tt= 300.000  Ts= 285.691   CPm = 1.00345   Km=1.40064 (Km-1)/Km=.28604
   Mn=  .500  P/Pt=  .84294   Ts/T = .95230  V/RTt=  9.7839   Q = 3.01724
  F/A=  .00000 Pt/P=    1.1863 RO/ROt= .885 16 A/At=  1.3397   Qs= 3.57943
```

[Notes]

(1) FLCAL1is the table for [CK=0.0, ND=1], i.e. for SI unit.

(2) [Table 8] shows the flow table for the INPUT DATA: J=1(Mn), Mn=1, T=300(K),F=0.0(Air).

[Ex. 5] <u>FLCAL</u> (Operative on DOS prompt.)---Flow function table

Table 9 Example Cal. / FLCAL

```
C:¥FOR¥BINB>FLCAL
CK,ND,J,( Mn:PsR:PtR:  TsR:RsR:VfT:  Q:Qs:AsR:  SQ:SAs R ),  T,   F   ???
  0.0   1   1    0.5    300.    0.0

   Tt= 300.000  Ts= 285.691   CPm = 1.00345   Km=1.40064 (Km-1)/Km=.28604
   Mn=  .500  P/Pt=  .84294   Ts/T = .95230  V/RTt=  9.7839   Q = 3.01724
   F/A=  .00000 Pt/P=    1.1863 RO/ROt= .88516 A/At=   1.3397 Qs=   3.57943
```

[Note] Options ; CK and ND are arranged as INPUT DATA in FLCAL/Table 9.

[Ex-6] FLCHK(Operative on DOS prompt) ---Flow function check program

Flow function table consists of 9 sub-functions as shown in [Table 14]/ p.12.
The all sub-functions are used in FLCHK. ---See the listings of FLCHK.for.

Table 10 Example Cal. / FLCHK

```
C:¥FOR¥BINB>FLCHK
  CK,   ND,   Mn,     T     ,F   ???
 0.0    1      0.5     300.      0.0

    Tt= 300.000   Ts= 285.691     CPm = 1.00345     Km=1.40064 (Km-1)/Km=.28604
    Mn=   .500   P/Pt=   .84294     Ts/T = .95230   V/RTt=   9.7839     Q = 3.01724
  F/A=   .00000 Pt/P=   1.18632 RO/ROt= .88516     A/At=   1.3397     Qs= 3.57943

    (22)  PSR;    PSPT=    8.429400E-01        Mn =     5.000015E-01
    (23)  PTR;    PTPS=         1.186324        Mn =     5.000015E-01
    (24)  TSR;    TSTT=    9.523023E-01        Mn =     4.999910E-01
    (25)  RSR;    RSRT=    8.851597E-01        Mn =     5.005257E-01

    (26)  VFT;     VRT=         9.783910        Mn =     5.000523E-01
    (27)  FQT;     Q    =        3.017244        Mn =     4.999988E-01
    (28)  FQS;     QS =         3.579430        Mn =     5.000289E-01
    (29)  ASR;    ASR =         1.339727        Mn =     5.000005E-01
```

[Ex.-7] Format Table 11 Format

```
$DEBUG
          COMMON/SYIAE/RC,R,AFST,CK,ND,G,CJK,AKR
          COMMON/SHEN/TSX,CPMX,AKMX,AKRMX
          COMMON/YANG/AMNX,PSPTX,PTPSX,TSTTX,RSRTX,VRTX,QX,QSX,ASATX
C
          UR=8.31433           ! (kJ/kmol K)
          AM=28.967            ! (kg/kmol)
          G=9.80665
          CJK=4.1868           ! (kJ/kcal)
           R=UR/AM             !=0.2870277 (kJ/kg K)
          RC=R/CJK             !=0.0685554 (kcal/kg K) or (Btu/lb R)
          ND=1                 !   ND=1 for SI, 2 for Metric , 3 for British
```

[2-2] Subroutine / Formats

'SYTBL2' consists of two tables; Thermodynamic table and Flow–function table.

(1) Thermodynamic Table

Thermodynamic table consists of 18 sub-functions. —— [Table 13] .

Table 12 Thermodynamic table / Function Names

		To Obtain						
		T	Cp	h	Φ	u	Pr	Vr
From	T		① CPT	② HFT	③ SFT	⑦ UFT	④ PRT	⑧ VRT
	Cp							
	h	⑤ TFH					⑮ PRH	⑯ VRH
	Φ							
	u	⑨ TFU					⑱ PRU	⑰ VRU
	Pr	⑥ TPR		⑪ HPR		⑫ UPR		
	Vr	⑭ TVR		⑩ HVR		⑬ UVR		

Table 13 Thermodynamic table / Formats

No	Functions	Names	Related
1	Cp=f(T)	CPT(T,F,Cp,AK)	--
2	h=f(T)	HFT(T,F,H)	--
3	S=f(T)	SFT(T,F,S)	--
4	Pr=f(T)	PRT(T,F,Pr)	(3)
5	T=f(h)	TFH(H,F,T)	(2)
6	T=f(Pr)	TPR(PR,F,T)	(4)
7	U=f(T)	UFT(T,F,U)	(2)
8	Vr=f(T)	VRT(T,F,Vr)	(4)
9	T=f(U)	TFU(U,F,T)	(5)

No	Functions	Names	Related
10	h=f(Vr)	HVR(VR,F,H)	(2),(8)
11	h=f(Pr)	HPR(PR,F,H)	(2),(6)
12	U=f(Pr)	UPR(PR,F,U)	(6),(7)
13	U=f(Vr)	UVR(VR,F,U)	(7),(14)
14	T=f(Vr)	TVR(VR,F,T)	(5),(10)
15	Pr=f(h)	PRH(H,F,Pr)	(5),(9)
16	Vr=f(h)	VRH(H,F,Vr)	(5),(8)
17	Vr=f(U)	VRU(U,F,Vr)	(8),(9)
18	Pr=f(U)	PRU(U,F,Pr)	(4),(9)

(Note) The values written in red are for the characteristics to be obtained.

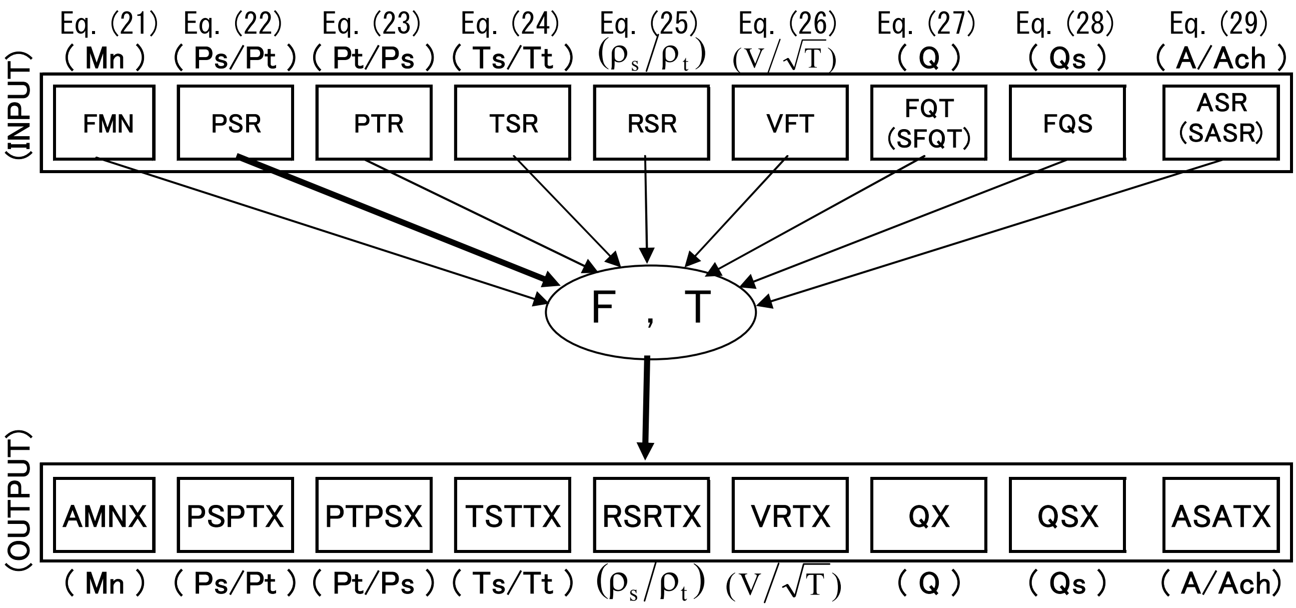
（2） Flow-Function Table

Flow-function table consists of 9 sub-functions. ――［Table 14］.

Table 14　　Function Names & OUTPUT

Eq. No.	Input Format		Output Format ; (Y)	
	Equation	Formats	Output	Symbols
21	Y = f (Mn)	FMN (Mn, F, T)	Mn	AMNX
22	Y = f (Ps/Pt)	PSR (Ps/Pt, F, T)	Ps/Pt	PSPTX
23	Y = f (Pt/Ps)	PTR (Pt/Ps, F, T)	Pt/Ps	PTPSX
24	Y = f (Ts/Tt)	TSR (Ts/Tt, F, T)	Ts/Tt	TSTTX
25	Y = f (ρ_s/ρ_t)	RSR (ρ_s/ρ_t, F, T)	ρ_s/ρ_t	RSRTX
26	Y = f ($V/\sqrt{Tt}$)	VFT ($V/\sqrt{Tt}$, F, T)	$V/\sqrt{Tt}$	VRTX
27	Y = f (Qt)	FQT (Qt, F, T) SFQT (Qt, F, T)	Qt	QX
28	Y = f (Qs)	FQS (Qs, F, T)	Qs	QSX
29	Y = f (A/Ach)	ASR (A/Ach, F, T) SASR (Mn, F, T)	A/Ach	ASATX

Table 15　Flow-function table /Schematics



[3] Related Equations

[3-1] Constants

Universal gas constant; UR=**8.31433** [kJ/kmol K]

Molecular weight of air ; M=**28.967** [kg/kmol]

Acceleration of gravity; g=**9.80665** [m/sec^2]

Conversion factor CJK=**4.1868** [kJ/kcal]

1[lb] =0.4535924 =**0.4536** [kg], 1[ft]=**0.3048** [m]

Acceleration of gravity [British]; **32.174** [ft/sec^2]

=9.80665 /0.3048

Units;

1[kgf] =9.80665 [N], [N-m] = [J], [J/sec]=[w],

[J/kg] =[m/sec]^2

Gas constant;

R=UR/M=8.31433/28.967=0.2870277

=(**0.287**) [kJ/kg K]--forSI unit.

RC=R/CJK=8.31433/28.967/4.1868=0.0685554

=(**0.06856**) [kcal/kg-K], or{Btu/lb-R} = RM/J =RB/JB

RM=UR*1000/ M /g =8314.33/ 28.967 /9.80665

=29.2691227 = (**29.27**) [kg-m/kg-K] --Metric unit

RB=RM/ 1.8/ 0.3048 =53.3476871

=(**53.35**) [ft-lb/lb-R] –British unit

Mechanical equivalent of heat;

J=CJK*10^3 /g =4186.8/9.80665= 426.934784

=(**426.9**) [kg-m/kcal]

JB=CJK*10^3/g/1.8/0.3048= 4186.8/0.80665/1.8/0.3048

=778.1692622 = (**778.2**) [ft-lb/lb-R]

Pressure;

1[kg/cm^2] =1{kg/cm^2}***g / 100** =9.80665 /100

=(0.0980665)[MPa]

=1[kg/cm^2]*2.54^2/0.4535924=14.2233424=(**14.223**) [psi]

Standard ambient pressure;

P_0 =**1.0332** [kg/cm^2] –for Metric unit

=1.0332*g/100=1.0332*9.80665/100=0.101322308

=(**0.10132**) [MPa]

=1.0332*2.54^2/0.4535924=14.6955573=(**14.696**) [psi]

Entropy; s at $T_{0,}$ P_0 (Standard ambient condition.)

[SI]; s= ϕ - R*ln(P)=6.66174-0.287*ln(0.10132)

=6.66174-0.287*(-2.2894715)=7.31888 「J/kg-K]

[Metric]; =1.59112-RC*ln(1.0332)

=1.59112-0.06856*0.0326608=1.58888 [kcal/kg- K]

[British]; = 1.59113-RC*ln(14.696)

=1.59112-0.06856*2.6875753=1.40689 [Btu/lb-R]

Specific Weight; γ

— at $T_{0,}$ P_0 (Standard Ambient Condition.)

[SI] γ =P/(R*T)=0.101322*10^3/0.287/288.15

=1.2251 [kg/m^3]

[Metric] γ =P/(RM*T)=1.0332*10^4/29.27/288.15

=1.2251 [kg/m^3]

[British] γ = P/(RB*T)

=14.696*144/53.35/518.67 =0.07648 [lb/ft^3]

(Note);[lb/ft^3]=1[kg/m^3]*(0.3048)^3/0.4536

=1/16.018 [lb/ft^3]

Horsepower ;

[Metric] PS =75 [kg-m/sec]

=75*g [w] =75*9.80665/10^3 =0.7355 [kw]

[British]HP=550[lb-ft/sec]

=(550*0.4536*0.3048)*9.80665/10^3=0.7457 [kw]

[3-2] Thermodynamic Table

Table 16 Thermodynamic functions

$$Cpa = C_0 + C_1T + C_2T^2 + C_3T^3 + C_4T^4 \quad \text{------------(1)}$$

$$ha = \int_0^T Cp\,dT = C_0T + \frac{C_1}{2}T^2 + \frac{C_2}{3}T^3 + \frac{C_3}{4}T^4 + \frac{C_4}{5}T^5 + CH \quad \text{------------(2)}$$

$$\phi a = \int_0^T \frac{Cp}{T}dT = C_0\ln(T) + C_1T + \frac{C_2}{2}T^2 + \frac{C_3}{3}T^3 + \frac{C_4}{4}T^4 + CF \quad \text{---------(3)}$$

$$\theta_{CP} = (1+a)(Cp_{ST} - Cpa) \quad \text{------------(4)}$$

$$\theta_h = (1+a)(h_{ST} - ha) \quad \text{------------------(5)}$$

$$\theta_\phi = (1+a)(\phi_{ST} - \phi a) \quad \text{------------------(6)}$$

$$Cp = Cpa + \frac{f}{1+f}\,\theta_{CP} \quad \text{---------------(7)}$$

$$h = ha + \frac{f}{1+f}\,\theta_h \quad \text{-------------------(8)}$$

$$\phi = \phi a + \frac{f}{1+f}\,\theta_\phi \quad \text{-------------------(9)}$$

$$\theta_{CP} = CP_0 + CP_1T + CP_2T^2 + CP_3T^3 + CP_4T^4 + CP_5T^5 \quad \text{-------(10)}$$

$$\theta_h = H_0 + H_1T + H_2T^2 + H_3T^3 + H_4T^4 + H_5T^5 \quad \text{----------------(11)}$$

$$\theta_\phi = F_0 + F_1T + F_2T^2 + F_3T^3 + F_4T^4 + F_5T^5 \quad \text{---------------------(12)}$$

Where: f = 0.06825 at stoichiometric
a = 1/ f =14.652 used for this table.

Table 17 Coefficients

SYTBL2 / Coefficients [kJ /kg K] 2005-1-19

Symbol	0 K - 300 K	200 K - 800 K	800 K - 2200 K	2200K - 5000 K	Equation
C_0	B1= .1001704E+01	DC0= .1018913E+01	CD10= .7986551E+00	A11= .8852846E+00	
C_1	B2= .3383075E−05	DC1=−.1378364E−03	CD11= .5339216E−03	A12= .3702210E−03	
C_2	B3= .5877607E−08	DC2= .1984340E−06	CD12=−.2288169E−06	A13=−.1349033E−06	1, 2, 3
C_3	B4=−.2643871E−09	DC3= .4239924E−09	CD13= .3742086E−10	A14= .2368343E−10	
C_4	B5= .1038620E−11	DC4=−.3763249E−12	CD14= .0000000E+00	A15=−.1580984E−14	
CH	B6=−.2180805E+00	DCH=−.1698463E+01	CD1H= .4738465E+02	A16= .1545856E+02	2
CF	B7= .9921631E+00	DCF= .9199264E+00	CD1F= .2019088E+01	A17= .1543854E+01	3
CP_0	G1= .7251687E−01	DP0=−.3594941E+00	CP10= .1088757E+01	D11= .3828289E−01	
CP_1	G2= .3532892E−02	DP1= .4516399E−02	CP11=−.1415883E−03	D12= .2714380E−02	
CP_2	G3=−.2248715E−04	DP2= .2811636E−05	CP12= .1916016E−05	D13=−.1017066E−05	11
CP_3	G4= .1136625E−06	DP3=−.2170873E−07	CP13=−.1240093E−08	D14= .1722610E−09	
CP_4	G5=−.1622836E−09	DP4= .2868878E−10	CP14= .3016695E−12	D15=−.1103124E−13	
CP_5	G6= .0000000E+00	DP5=−.1222634E−13	CP15=−.2611711E−16	D16= .0000000E+00	
H_0	VH= .9339293E+01	DH0= .6263742E+02	DH10=−.1768385E+03	P16= .7008344E+02	
H_1	V1= .7251687E−01	DH1=−.5286657E+00	DH11= .8369064E+00	P11= .3828289E−01	
H_2	V2= .1766446E−02	DH2= .3222623E−02	DH12= .3647621E−03	P12= .1357190E−02	12
H_3	V3=−.7495717E−05	DH3=−.2167025E−05	DH13= .2515545E−06	P13=−.3390221E−06	
H_4	V4= .2841561E−07	DH4= .2495170E−09	DH14=−.1254134E−09	P14= .4306526E−10	
H_5	V5=−.3245672E−10	DH5= .3489182E−12	DH15= .1640627E−13	P15=−.2206248E−14	
F_0	RA7=−.1117070E+01	DF0=−.7126983E+00	DF10=−.1264536E+01	QA17=−.7808500E+00	
F_1	RA1= .7320000E−02	DF1=−.2295019E−03	DF11= .4468673E−02	QA11= .2800000E−02	
F_2	RA2=−.4245800E−04	DF2= .1315413E−04	DF12=−.2853818E−05	QA12=−.5432150E−06	13
F_3	RA3= .1826960E−06	DF3=−.2553182E−07	DF13= .1640346E−08	QA13= .6632280E−10	
F_4	RA4=−.3737920E−09	DF4= .2239099E−10	DF14=−.5314314E−12	QA14=−.3973220E−14	
F_5	RA5= .2970480E−12	DF5=−.7607185E−14	DF15= .6988461E−16	QA15= .6744780E−19	

[3-3]   Flow Function Table

Table 18   Flow functions

$$Mn = v/a = \sqrt{2\Delta h}\Big/\sqrt{\kappa_s R T_s} \qquad \text{(1)}$$

$$\frac{P_s}{P_t} = \frac{1}{\left[1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_m - 1}{\kappa_m}\right) Mn^2\right]^{\frac{\kappa_m}{\kappa_m - 1}}} \qquad \text{(2)}$$

$$\frac{P_t}{P_s} = \left[1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_m - 1}{\kappa_m}\right) Mn^2\right]^{\frac{\kappa_m}{\kappa_m - 1}} \qquad \text{(3)}$$

$$\frac{T_s}{T_t} = \frac{1}{\left[1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_m - 1}{\kappa_m}\right) Mn^2\right]} \qquad \text{(4)}$$

$$\frac{\rho_s}{\rho_t} = \frac{1}{\left[1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_m - 1}{2}\right) Mn^2\right]^{\frac{1}{\kappa_m - 1}}} \qquad \text{(5)}$$

$$\frac{V}{\sqrt{T_t}} = \sqrt{\kappa_s R}\,\frac{Mn}{\left[1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_m - 1}{2}\right) Mn^2\right]} \qquad \text{(6)}$$

$$q \equiv \left(\frac{G\sqrt{T_t}}{A\ \ P_t}\right) = 10^2\sqrt{\frac{\kappa_s}{R}}\,\frac{Mn}{\left[1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_m - 1}{2}\right) Mn^2\right]^{\frac{\kappa_m + 1}{2(\kappa_m - 1)}}} \qquad \text{(7)}$$

$$q_s \equiv \left(\frac{G\sqrt{T_t}}{A\ P_s}\right) = 10^2\sqrt{\frac{\kappa_s}{R}}\,Mn\sqrt{1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_m - 1}{2}\right) Mn^2} \qquad \text{(8)}$$

$$\frac{\mathrm{A}}{\mathrm{Ach}} = \frac{1}{\mathrm{Mn}}\left[\frac{1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_m - 1}{2}\right)\mathrm{Mn}^2}{1 + \left(\frac{\kappa_s}{\kappa_m}\right)\left(\frac{\kappa_s - 1}{2}\right)}\right]^{\frac{\kappa_m - 1}{2(\kappa_m - 1)}} \qquad \text{(9)}$$

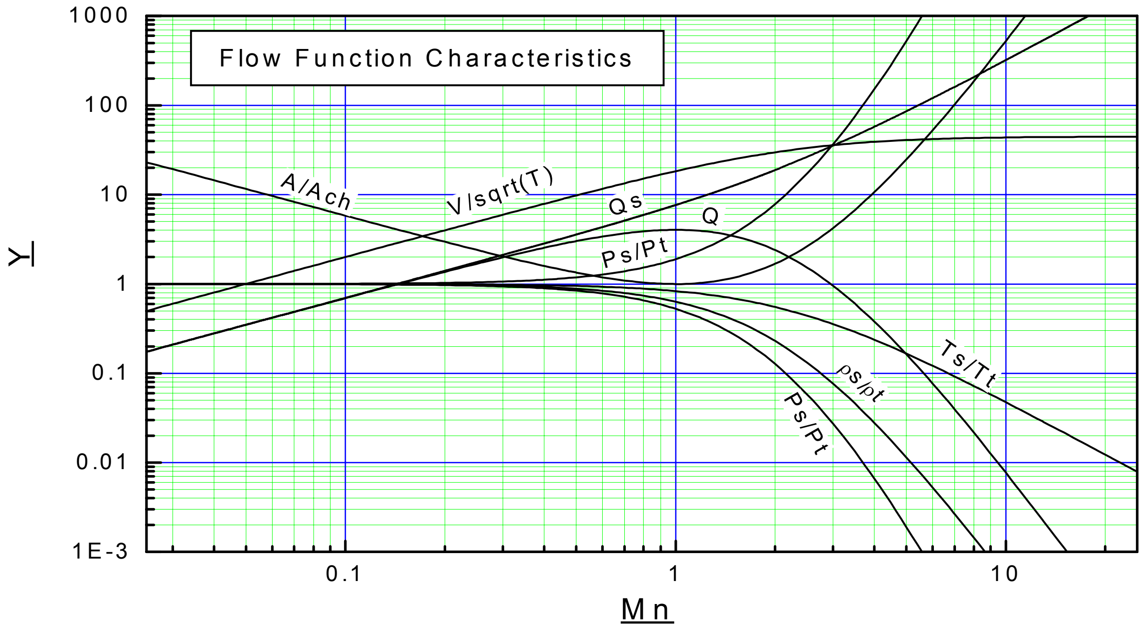


Fig. 2   Flow Functions / Characteristics

[3-4] Relative Pressure; Pr and Relative Volume; Vr

[A] Relative Pressure; Pr

From basic equations in thermodynamics:

$$dq = dh - vdp \quad \left[\frac{kJ}{Kg}\right] \quad \text{-------(1)}$$

$$ds = \frac{dq}{T} \quad \left[\frac{kJ}{KgK}\right] \quad \text{--------(2)}$$

$$\rightarrow \quad Tds = dh - vdp \quad \text{------ (3)}$$

For $ds = 0$ in Eq.(3)

$$dh = CpdT = vdp \quad \text{------(4)}$$

$$pv = RT \quad \rightarrow \quad v = \frac{RT}{p} \quad \text{------(5)}$$

With Eq.(5), Eq.(4) becomes:

$$Cp\, dT = \frac{RT}{p}dp$$

$$\rightarrow \frac{dp}{p} = \frac{1}{R}\frac{Cp}{T}dT$$

Integrating the above equation;

$$\int_0 \frac{dp}{p} = \frac{1}{R}\int_0 \frac{Cp}{T}dT$$

$$\ln\left(\frac{p}{p_0}\right) = \frac{1}{R}\int_0 \frac{Cp}{T}dT = \frac{1}{R}(\phi - \phi_0) \quad \text{-----(6)}$$

Note that;

$$\phi \equiv \int_0 \frac{Cp}{T}dT \quad = \text{Entropy Function}$$

Put $Pr = (\frac{p}{p_0})$ in Eq.(6), so that;

$$\ln Pr = \frac{1}{R}(\phi - \phi_0) \quad \text{----------- (7)}$$

Relative pressure; Pr may be obtained from Eq.(7) as;

$$Pr = Exp\left\{\frac{1}{R}(\phi - \phi_0)\right\} \quad \text{--------(8)}$$

where; $\phi_0 \equiv \phi$ at $T_0 = 273.15$ (K)

[B] Relative Volume; Vr

Basic equations;

$$Cp - Cv = R \quad \text{-----------------------(9)}$$

$$dQ = du + pdv \quad \text{---------------------(10)}$$

$$du = Tds - pdv \quad \text{---------------------(11)}$$

Eq.(11) at $ds = 0$;

$$du \equiv Cv\, dT = -\, pdv \quad \text{----------------(12)}$$

$pv = RT$

$$\rightarrow \quad p = \frac{RT}{v} \quad \text{--------------------(13)}$$

Eq.(12) may be written by using Eq.(13) as;

$$Cv\, dT = -RT\frac{dv}{v}$$

$$\rightarrow \frac{dv}{v} = -\frac{\mathbf{Cv}}{\mathbf{RT}}dT \quad \text{----------- (14)}$$

Integrationg Eq.(14);

$$\int_0 \frac{dv}{v} = -\frac{1}{R}\int_0 \frac{Cv}{T}dT$$

$$\rightarrow \ln\left(\frac{v}{v_0}\right) = -\frac{1}{R}\int_0 \frac{Cv}{T}dT \quad \text{------(15)}$$

$$\left(\frac{v}{v_0}\right) \equiv Vr = Exp\left\{-\frac{1}{R}\int_0 \frac{Cv}{T}dT\right\} \quad \text{--------(16)}$$

Based on Eq.(9);

$$\frac{Cv}{T}dT = \frac{Cp}{T}dT - R\frac{dT}{T}$$

$$\rightarrow \int_0 \frac{Cv}{T}dT = \int_0 \frac{Cp}{T}dT - R\int_0 \frac{dT}{T}$$

$$= (\phi - \phi_0) - R\ln\left(\frac{T}{T_0}\right) \quad \text{---(17)}$$

Relative volume; Vr may be obtained from Eq.(16) together with Eq.(17) as;

$$Vr = Exp\left\{-\frac{\phi - \phi_0}{R} + \ln\left(\frac{T}{T_0}\right)\right\} \quad \text{--------(18)}$$

$$Vr \equiv \frac{T}{Pr} \quad \text{-----(19)}$$ will be used in this table.

[3-5] Constant κ Option

Basic equations

$Cp - Cv = R$

$\kappa = 1/(1 - R/Cp)$

→ (R/Cp) =const. required.

Tc= 273.15 (K)

R=0.28703 {kJ/kg K} ------------------(1)

Cp =R* κ/(κ-1) ----------------------------(2)

h =CpT [kJ/kg] ---------(3)

u= h- R*T [kJ/kg] -----------(4)

ϕ= 1+Cp*ln(T) [kJ/kg K]----------(5)

s= ϕ –R*ln(P) [kJ/kg K] ----------(6)

Pr=Exp{(κ-1)/ κ *ln(T/T_c)}

= Exp{ (ϕ- ϕ_0) /R } ---------------------(7)

-- where ϕ_0= ϕ at T=Tc

Vr= T / Pr defined. --------------------(8)

T= h / Cp ---------------------------(9)

T= (h-u) / R -------------------------(10)

T=Exp{ (κ-1)/κ*ln(Pr)+ln(Tc) } -----------(11)

=Exp{ (κ-1)/κ*ln(Pr)+5.610 }

T=Exp{ κln(Tc)- (κ-1)ln(Vr) } -------------(12)-

Table 19 Compressible-Flow Function at Mn=1.0, T=300 (K)

κ	Cp	a	Ts/Tt	Pt/Ps	ρ_s/ρ_t	$V/\sqrt{T}$	Q	Qs
1.1	3.1573	300.35	0.95238	1.7103	0.61391	17.341	3.7089	6.3435
1.2	1.7222	306.49	0.90909	1.7716	0.62092	17.695	3.8280	6.7815
1.3	1.2438	311.99	0.86957	1.8324	0.62759	18.013	3.9385	7.2170
1.4	1.0046	316.95	0.83333	1.8929	0.63394	18.299	4.0417	7.6506
AIR	1.0028	317.04	0.83293	1.8942	0.63392	18.304	4.0427	7.6564
1.5	0.9611	321.45	0.80000	1.9531	0.64000	18.559	4.1382	8.0824

Note; Example Cal. at κ=1.2;

(1) a ; Sonic velocity $=\sqrt{\kappa R T_s}$ =Sqt{ $\kappa R T_t$ (T_s/T_t)}

= Sqt{ 1.2 (287.03) 300 (0.90909) }= 306.49 [m/sec]

(2) $V = (V/\sqrt{T})*\sqrt{T} = 17.695*\sqrt{300}$ =17. 695*17. 3205=306. 49 = a

(3) Ts/Tt = 2/(κ+1) , Pt/Ps ={(κ+ 1) /2}**{ κ/ (κ−1) }, ρ_s/ρ_t ={2/(κ+1)}**{1/(κ−1) }

(4) $\kappa \doteqdot (2n+3)/(2n+1)$ where n = numbers of atomics.

[3-6] Viscosity of Air; μ

Viscosity: μ is arranged in Option: Air in VB-Version.

The value of μ corresponds to static temperature: Ts. in Flow function table

Metric unit

Based on Sutherland's equation;

(JSME,Mech. handbook, Vol.5(1968),Sec.10, p.1)

$$\mu = 1.7580 * 10^{-6} \left(\frac{380}{380+t}\right)\left(\frac{273+t}{273}\right)^{3/2}$$

[kg_f sec/m^2]---------(1)

The Eq/(1) is for T(C), then it was rearranged for T(K) as below.

$$\mu = 1.7580 * 10^{-6} \left(\frac{380}{380+T-273.15}\right)\left(\frac{T}{273.15}\right)^{3/2}$$

--------------------(2)

The Eq.(2) shows a slightly different value from Eq.(1).

S I unit

$$1\left(\frac{kg_f \ \ sec}{m^2}\right) = \frac{9.80665(N)\ \ sec}{m^2} = 9.80665$$

[Pa sec] --------(3)

Note that:

1 [kg_f] =9.80665 (N), 1(N/m^2) =1 [Pa]

1 [kg_f sec / m^2]= 9.80665 [Pa sec]

British unit

$$1\left(\frac{kg_f \ sec}{m^2}\right) = \frac{\left(\frac{1}{0.453592}\right)[lb sec]}{\left(\frac{1}{0.3048}\right)^2 [ft]^2} = \frac{(0.3048)^2}{0.453592}$$

$$= 0.2048163 \left[\frac{lb_f \ sec}{ft^2}\right]$$ -----------(4)

Note that:

1 [lb_f] = 0.453592 [kg_f], 1 [ft] = 0.3048 [m]

1 [lb_f sec/ft^2]=32.17404 [lb_m/ft sec]

SUMMARY

[μ]$_{Metric}$ obtainable from Eq.(2)------[kg_f sec/m^2]

[μ]$_{SI}$ = 9.80665*[μ]$_{Metric}$ ---------------[Pa sec]

[μ]$_{British}$ =0.2048163*[μ]$_{Metrici}$-------[lb_f sec /ft^2]

--- for T(R)=1.8*T(K)

(Ref.): Sutherland's equation for British unit:

$$\mu * 10^6 = (0.3170 * 10^{-4}) * T_R^{1.5} * \left(\frac{734.6}{T_R + 216}\right)$$

[lb_f sec/ ft^2]-----(5)

[Notes]

Kinematic Viscosity; ν

Viscosity; μ will be obtained as below from he Option :Air in VB-Version at T=288.a5(K).

μ=17.97*10^{-6} [Pa sec] or {kg_m/m sec} ---for SI unit

μ= 1.832*10^{-6} [kg_f sec/m^2]---for Metric unit

At T=518.67(R);

μ=0.3753*10^{-6}[lb_fsec/ft^2]—for British unit.

Kinematic Viscosity: ν will be obtained as;

$$\nu = \mu / \rho \ [m^2/sec]$$

where:

ρ=P/RT =[Pa/(J/kg_m K)*K]

= 0.1013*10^6 /(287*288.15)=1.2249[kg_m/m^3]

∴ ν= μ/ ρ=17.97*10^{-6}/1.2249

=14.67*10^{-6} [m^2 /sec]

[4] Tables

[4-1] CPAIR1 Table 20 Air Table (SI unit)

*** Gas Table (SI Unit) *** CK= .000 ND= 1 F= .000

T(K)	CP	H	PHI	U	PR	VR	K	(K-1)/K
.00	1.00170	.000	.0000	.000	.10031E-09	.00000E+00	1.4016	.28654
20.00	1.00177	19.817	3.9931	14.076	.11045E-03	.18108E+06	1.4016	.28652
40.00	1.00183	39.853	4.6874	28.371	.12411E-02	.32228E+05	1.4015	.28650
60.00	1.00188	59.890	5.0937	42.668	.51104E-02	.11741E+05	1.4015	.28649
80.00	1.00192	79.928	5.3819	56.966	.13950E-01	.57348E+04	1.4015	.28648
100.00	1.00194	99.966	5.6055	71.263	.30398E-01	.32896E+04	1.4015	.28647
120.00	1.00195	120.005	5.7881	85.562	.57445E-01	.20889E+04	1.4015	.28647
140.00	1.00196	140.044	5.9426	99.860	.98390E-01	.14229E+04	1.4015	.28647
160.00	1.00199	160.084	6.0764	114.159	.15682E+00	.10203E+04	1.4015	.28646
180.00	1.00205	180.124	6.1944	128.459	.23657E+00	.76086E+03	1.4014	.28644
200.00	1.00207	200.002	6.2958	142.597	.33684E+00	.59375E+03	1.4014	.28643
220.00	1.00183	220.041	6.3913	156.895	.46980E+00	.46828E+03	1.4016	.28650
240.00	1.00187	240.077	6.4785	171.190	.63652E+00	.37705E+03	1.4015	.28649
260.00	1.00222	260.118	6.5587	185.490	.84172E+00	.30889E+03	1.4013	.28639
280.00	1.00287	280.168	6.6330	199.800	.10904E+01	.25679E+03	1.4010	.28621
300.00	1.00382	300.234	6.7022	214.126	.13878E+01	.21617E+03	1.4004	.28594
320.00	1.00507	320.323	6.7670	228.474	.17394E+01	.18397E+03	1.3997	.28558
340.00	1.00662	340.439	6.8280	242.850	.21511E+01	.15806E+03	1.3989	.28514
360.00	1.00847	360.590	6.8856	257.260	.26290E+01	.13693E+03	1.3979	.28462
380.00	1.01061	380.780	6.9402	271.710	.31797E+01	.11951E+03	1.3967	.28401
400.00	1.01303	401.016	6.9921	286.205	.38099E+01	.10499E+03	1.3954	.28334
420.00	1.01573	421.303	7.0416	300.751	.45268E+01	.92781E+02	1.3939	.28258
440.00	1.01869	441.647	7.0889	315.355	.53381E+01	.82426E+02	1.3923	.28176
460.00	1.02192	462.053	7.1342	330.020	.62519E+01	.73578E+02	1.3906	.28087
480.00	1.02538	482.525	7.1778	344.752	.72766E+01	.65965E+02	1.3887	.27992
500.00	1.02908	503.069	7.2197	359.556	.84212E+01	.59374E+02	1.3868	.27892
600.00	1.05046	607.011	7.4092	434.794	.16294E+02	.36824E+02	1.3760	.27324
700.00	1.07473	713.259	7.5729	512.339	.28825E+02	.24285E+02	1.3644	.26707
800.00	1.09851	821.944	7.7181	592.322	.47798E+02	.16737E+02	1.3537	.26129
900.00	1.12112	932.948	7.8488	674.623	.75369E+02	.11941E+02	1.3441	.25602
1000.00	1.14118	1046.083	7.9680	759.056	.11416E+03	.87594E+01	1.3360	.25152
1100.00	1.15891	1161.106	8.0776	845.376	.16726E+03	.65768E+01	1.3292	.24767
1200.00	1.17453	1277.795	8.1791	933.362	.23823E+03	.50372E+01	1.3234	.24438
1300.00	1.18827	1395.949	8.2737	1022.813	.33119E+03	.39252E+01	1.3185	.24155
1400.00	1.20035	1515.393	8.3622	1113.554	.45082E+03	.31055E+01	1.3143	.23912
1500.00	1.21099	1635.971	8.4454	1205.429	.60238E+03	.24901E+01	1.3106	.23702
1600.00	1.22043	1757.551	8.5239	1298.307	.79175E+03	.20208E+01	1.3075	.23518
1700.00	1.22889	1880.025	8.5981	1392.078	.10255E+04	.16577E+01	1.3047	.23357
1800.00	1.23659	2003.304	8.6686	1486.654	.13108E+04	.13732E+01	1.3023	.23211
1900.00	1.24375	2127.324	8.7356	1581.972	.16558E+04	.11475E+01	1.3000	.23078
2000.00	1.25060	2252.043	8.7996	1677.988	.20692E+04	.96658E+00	1.2979	.22951
2100.00	1.25736	2377.441	8.8608	1774.683	.25607E+04	.82008E+00	1.2958	.22828
2200.00	1.26198	2502.607	8.9200	1871.146	.31478E+04	.69889E+00	1.2944	.22744
2300.00	1.26707	2629.063	8.9762	1968.900	.38288E+04	.60071E+00	1.2929	.22653
2400.00	1.27172	2756.006	9.0303	2067.140	.46218E+04	.51928E+00	1.2915	.22570
2500.00	1.27599	2883.394	9.0823	2165.825	.55398E+04	.45128E+00	1.2902	.22495
2600.00	1.27993	3011.193	9.1324	2264.921	.65968E+04	.39413E+00	1.2891	.22425
2700.00	1.28358	3139.370	9.1807	2364.395	.78077E+04	.34581E+00	1.2880	.22362
2800.00	1.28698	3267.900	9.2275	2464.222	.91886E+04	.30473E+00	1.2870	.22302
2900.00	1.29018	3396.760	9.2727	2564.380	.10756E+05	.26961E+00	1.2861	.22247
3000.00	1.29321	3525.931	9.3165	2664.848	.12529E+05	.23944E+00	1.2853	.22195
3100.00	1.29609	3655.397	9.3590	2765.612	.14526E+05	.21340E+00	1.2844	.22146
3200.00	1.29886	3785.146	9.4001	2866.657	.16768E+05	.19084E+00	1.2837	.22098
3300.00	1.30154	3915.167	9.4402	2967.975	.19276E+05	.17119E+00	1.2829	.22053
3400.00	1.30413	4045.451	9.4790	3069.557	.22074E+05	.15403E+00	1.2822	.22009
3500.00	1.30667	4175.992	9.5169	3171.395	.25184E+05	.13898E+00	1.2815	.21966
3600.00	1.30916	4306.784	9.5537	3273.484	.28634E+05	.12573E+00	1.2808	.21925
3700.00	1.31161	4437.823	9.5896	3375.820	.32449E+05	.11402E+00	1.2801	.21884
3800.00	1.31402	4569.104	9.6246	3478.399	.36659E+05	.10366E+00	1.2795	.21843
3900.00	1.31639	4700.626	9.6588	3581.218	.41292E+05	.94449E-01	1.2788	.21804
4000.00	1.31872	4832.382	9.6922	3684.271	.46381E+05	.86242E-01	1.2782	.21766
4100.00	1.32100	4964.369	9.7248	3787.555	.51958E+05	.78910E-01	1.2776	.21728
4200.00	1.32322	5096.581	9.7566	3891.064	.58058E+05	.72342E-01	1.2770	.21692

[4-2] CPTBL1 Table 21 Cp Table (SI unit)

*** CP TABLE (SI Unit) *** ND = 1

T(K)	AIR	0.01	0.02	0.03	0.04	0.05	0.06	0.06825
.00	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
20.00	1.00177	1.00311	1.00442	1.00570	1.00696	1.00820	1.00941	1.01040
40.00	1.00183	1.00366	1.00545	1.00721	1.00893	1.01063	1.01229	1.01363
60.00	1.00188	1.00412	1.00631	1.00846	1.01057	1.01264	1.01467	1.01632
80.00	1.00192	1.00452	1.00707	1.00957	1.01202	1.01443	1.01679	1.01870
100.00	1.00194	1.00489	1.00779	1.01063	1.01341	1.01614	1.01883	1.02100
120.00	1.00195	1.00527	1.00853	1.01172	1.01485	1.01792	1.02093	1.02338
140.00	1.00196	1.00568	1.00933	1.01291	1.01642	1.01986	1.02324	1.02598
160.00	1.00199	1.00616	1.01025	1.01426	1.01819	1.02205	1.02584	1.02891
180.00	1.00205	1.00672	1.01131	1.01581	1.02022	1.02454	1.02879	1.03223
200.00	1.00207	1.00727	1.01236	1.01735	1.02225	1.02705	1.03177	1.03559
220.00	1.00183	1.00777	1.01359	1.01930	1.02490	1.03040	1.03579	1.04016
240.00	1.00187	1.00853	1.01505	1.02144	1.02771	1.03386	1.03990	1.04479
260.00	1.00222	1.00955	1.01673	1.02377	1.03068	1.03745	1.04410	1.04949
280.00	1.00287	1.01083	1.01864	1.02630	1.03380	1.04117	1.04840	1.05426
300.00	1.00382	1.01239	1.02078	1.02902	1.03709	1.04501	1.05278	1.05909
320.00	1.00507	1.01420	1.02315	1.03193	1.04054	1.04898	1.05727	1.06399
340.00	1.00662	1.01628	1.02575	1.03504	1.04415	1.05308	1.06185	1.06896
360.00	1.00847	1.01863	1.02859	1.03835	1.04793	1.05732	1.06654	1.07401
380.00	1.01061	1.02123	1.03164	1.04186	1.05187	1.06170	1.07134	1.07915
400.00	1.01303	1.02409	1.03493	1.04556	1.05598	1.06621	1.07624	1.08438
420.00	1.01573	1.02719	1.03843	1.04945	1.06026	1.07087	1.08127	1.08971
440.00	1.01869	1.03054	1.04215	1.05354	1.06471	1.07567	1.08642	1.09514
460.00	1.02192	1.03412	1.04609	1.05782	1.06933	1.08062	1.09169	1.10067
480.00	1.02538	1.03793	1.05022	1.06228	1.07411	1.08571	1.09709	1.10632
500.00	1.02908	1.04194	1.05455	1.06692	1.07904	1.09094	1.10261	1.11207
600.00	1.05046	1.06472	1.07871	1.09242	1.10587	1.11907	1.13201	1.14251
700.00	1.07473	1.09025	1.10546	1.12037	1.13500	1.14935	1.16343	1.17484
800.00	1.09851	1.11516	1.13149	1.14749	1.16319	1.17860	1.19371	1.20596
900.00	1.12112	1.13886	1.15626	1.17331	1.19004	1.20645	1.22254	1.23560
1000.00	1.14118	1.15998	1.17841	1.19648	1.21421	1.23159	1.24865	1.26248
1100.00	1.15891	1.17871	1.19813	1.21717	1.23585	1.25417	1.27214	1.28671
1200.00	1.17453	1.19528	1.21562	1.23556	1.25513	1.27432	1.29315	1.30841
1300.00	1.18827	1.20988	1.23107	1.25185	1.27222	1.29221	1.31183	1.32773
1400.00	1.20035	1.22274	1.24469	1.26622	1.28733	1.30804	1.32836	1.34484
1500.00	1.21099	1.23407	1.25670	1.27889	1.30065	1.32199	1.34294	1.35992
1600.00	1.22043	1.24411	1.26732	1.29007	1.31239	1.33429	1.35577	1.37319
1700.00	1.22889	1.25306	1.27676	1.30000	1.32279	1.34515	1.36709	1.38488
1800.00	1.23659	1.26117	1.28527	1.30890	1.33208	1.35482	1.37713	1.39522
1900.00	1.24375	1.26865	1.29307	1.31701	1.34050	1.36353	1.38613	1.40446
2000.00	1.25060	1.27574	1.30040	1.32457	1.34828	1.37154	1.39436	1.41287
2100.00	1.25736	1.28268	1.30750	1.33183	1.35570	1.37911	1.40209	1.42072
2200.00	1.26198	1.28835	1.31420	1.33955	1.36441	1.38880	1.41273	1.43213
2300.00	1.26707	1.29368	1.31978	1.34537	1.37046	1.39508	1.41923	1.43882
2400.00	1.27172	1.29855	1.32485	1.35065	1.37594	1.40076	1.42511	1.44485
2500.00	1.27599	1.30300	1.32948	1.35545	1.38092	1.40590	1.43042	1.45029
2600.00	1.27993	1.30709	1.33373	1.35984	1.38546	1.41059	1.43524	1.45523
2700.00	1.28358	1.31087	1.33764	1.36388	1.38962	1.41487	1.43964	1.45972
2800.00	1.28698	1.31439	1.34126	1.36761	1.39345	1.41880	1.44367	1.46384
2900.00	1.29018	1.31768	1.34465	1.37108	1.39701	1.42245	1.44740	1.46764
3000.00	1.29321	1.32079	1.34783	1.37434	1.40034	1.42585	1.45087	1.47117
3100.00	1.29609	1.32374	1.35084	1.37741	1.40348	1.42904	1.45413	1.47447
3200.00	1.29886	1.32656	1.35372	1.38034	1.40646	1.43208	1.45721	1.47759
3300.00	1.30154	1.32928	1.35648	1.38315	1.40931	1.43497	1.46015	1.48057
3400.00	1.30413	1.33192	1.35916	1.38587	1.41207	1.43777	1.46298	1.48343
3500.00	1.30667	1.33449	1.36177	1.38851	1.41475	1.44048	1.46572	1.48619
3600.00	1.30916	1.33702	1.36432	1.39110	1.41736	1.44312	1.46839	1.48889
3700.00	1.31161	1.33949	1.36683	1.39363	1.41992	1.44570	1.47100	1.49152
3800.00	1.31402	1.34193	1.36929	1.39612	1.42243	1.44824	1.47357	1.49410
3900.00	1.31639	1.34433	1.37171	1.39856	1.42490	1.45073	1.47608	1.49663
4000.00	1.31872	1.34668	1.37409	1.40096	1.42732	1.45317	1.47854	1.49911
4100.00	1.32100	1.34898	1.37641	1.40330	1.42968	1.45556	1.48094	1.50153
4200.00	1.32322	1.35122	1.37866	1.40558	1.43197	1.45787	1.48327	1.50387
4300.00	1.32536	1.35338	1.38084	1.40777	1.43418	1.46009	1.48551	1.50612
4400.00	1.32741	1.35543	1.38291	1.40985	1.43627	1.46219	1.48762	1.50824
4500.00	1.32934	1.35737	1.38485	1.41180	1.43823	1.46416	1.48959	1.51022
4600.00	1.33112	1.35915	1.38664	1.41358	1.44002	1.46594	1.49138	1.51201
4700.00	1.33272	1.36075	1.38823	1.41517	1.44160	1.46752	1.49295	1.51357
4800.00	1.33412	1.36213	1.38959	1.41652	1.44293	1.46883	1.49425	1.51486

[4-3] FLTBL1 Table 22 Air Flow Table at T=288.15 (SI unit)

*** One Dimentional Flow Functions (SI Unit) *** CK= .000 ND= 1 T= 288.150 F= .00000

Mn	Ps/Pt	Pt/Ps	Ts/Tt	RO/ROt	V/RTt	Q	Qs	A/Ach
.000	1.00000	1.0000	1.00000	1.00000	.00000	.00000	.00000	.00000
.100	.99303	1.0070	.99800	.99502	2.00311	.69440	.69928	5.82145
.120	.98998	1.0101	.99712	.99284	2.40272	.83111	.83952	4.86389
.140	.98639	1.0138	.99609	.99027	2.80174	.96662	.97996	4.18202
.160	.98227	1.0180	.99490	.98731	3.20008	1.10076	1.12062	3.67241
.180	.97763	1.0229	.99355	.98398	3.59765	1.23334	1.26155	3.27764
.200	.97248	1.0283	.99205	.98028	3.99439	1.36419	1.40279	2.96325
.220	.96683	1.0343	.99039	.97620	4.39018	1.49314	1.54437	2.70736
.240	.96068	1.0409	.98859	.97177	4.78493	1.62000	1.68631	2.49534
.260	.95406	1.0482	.98663	.96698	5.17859	1.74464	1.82866	2.31707
.280	.94697	1.0560	.98453	.96185	5.57102	1.86689	1.97143	2.16535
.300	.93943	1.0645	.98228	.95638	5.96216	1.98660	2.11468	2.03487
.320	.93146	1.0736	.97989	.95058	6.35193	2.10363	2.25842	1.92167
.340	.92307	1.0833	.97735	.94446	6.74022	2.21786	2.40269	1.82270
.360	.91428	1.0938	.97468	.93803	7.12698	2.32915	2.54753	1.73562
.380	.90510	1.1049	.97187	.93129	7.51213	2.43740	2.69297	1.65854
.400	.89555	1.1166	.96892	.92427	7.89555	2.54248	2.83902	1.58999
.420	.88565	1.1291	.96585	.91697	8.27722	2.64432	2.98574	1.52876
.440	.87542	1.1423	.96264	.90939	8.65703	2.74282	3.13315	1.47386
.460	.86487	1.1562	.95931	.90156	9.03492	2.83789	3.28128	1.42449
.480	.85403	1.1709	.95585	.89348	9.41081	2.92947	3.43016	1.37997
.500	.84292	1.1864	.95227	.88516	9.78463	3.01748	3.57981	1.33972
.520	.83154	1.2026	.94857	.87662	10.15632	3.10188	3.73028	1.30327
.540	.81993	1.2196	.94476	.86787	10.52582	3.18263	3.88159	1.27021
.560	.80810	1.2375	.94084	.85891	10.89305	3.25968	4.03376	1.24019
.580	.79607	1.2562	.93681	.84977	11.25798	3.33301	4.18684	1.21290
.600	.78386	1.2757	.93267	.84044	11.62053	3.40260	4.34084	1.18810
.620	.77149	1.2962	.92843	.83096	11.98065	3.46844	4.49580	1.16555
.640	.75897	1.3176	.92409	.82131	12.33829	3.53052	4.65173	1.14506
.660	.74633	1.3399	.91966	.81152	12.69339	3.58885	4.80869	1.12645
.680	.73358	1.3632	.91513	.80161	13.04591	3.64345	4.96668	1.10958
.700	.72074	1.3875	.91052	.79157	13.39581	3.69432	5.12574	1.09430
.720	.70783	1.4128	.90582	.78143	13.74303	3.74151	5.28589	1.08050
.740	.69486	1.4391	.90103	.77118	14.08753	3.78503	5.44716	1.06808
.760	.68186	1.4666	.89617	.76086	14.42929	3.82493	5.60957	1.05694
.780	.66883	1.4951	.89123	.75045	14.76825	3.86126	5.77315	1.04700
.800	.65580	1.5249	.88622	.73999	15.10438	3.89407	5.93793	1.03818
.820	.64277	1.5558	.88115	.72947	15.43766	3.92341	6.10394	1.03042
.840	.62976	1.5879	.87600	.71890	15.76805	3.94934	6.27118	1.02366
.860	.61679	1.6213	.87079	.70831	16.09552	3.97194	6.43970	1.01784
.880	.60387	1.6560	.86553	.69768	16.42005	3.99126	6.60951	1.01292
.900	.59100	1.6920	.86021	.68705	16.74162	4.00739	6.78063	1.00884
.920	.57822	1.7295	.85483	.67641	17.06019	4.02039	6.95310	1.00558
.940	.56551	1.7683	.84941	.66577	17.37576	4.03036	7.12692	1.00310
.960	.55290	1.8086	.84394	.65514	17.68831	4.03737	7.30214	1.00136
.980	.54040	1.8505	.83843	.64454	17.99783	4.04151	7.47876	1.00033
1.000	.52801	1.8939	.83288	.63396	18.30428	4.04287	7.65680	1.00000
1.100	.46808	2.1364	.80462	.58174	19.79044	4.01108	8.56918	1.00794
1.200	.41212	2.4265	.77580	.53122	21.19938	3.92348	9.52029	1.03045
1.300	.36068	2.7725	.74673	.48302	22.53137	3.79162	10.51240	1.06629
1.400	.31404	3.1843	.71769	.43758	23.78762	3.62646	11.54758	1.11486
1.500	.27236	3.6716	.68854	.39557	24.96276	3.44025	12.63114	1.17550
1.600	.23525	4.2509	.66023	.35631	26.07421	3.23678	13.75911	1.24937
1.700	.20258	4.9362	.63255	.32026	27.11712	3.02572	14.93559	1.33650
1.800	.17405	5.7456	.60562	.28738	28.09460	2.81295	16.16203	1.43757
1.900	.14926	6.6997	.57954	.25755	29.00993	2.60304	17.43966	1.55348
2.000	.12784	7.8224	.55438	.23060	29.86650	2.39946	18.76964	1.68527
3.000	.02728	36.6516	.35612	.07661	35.90676	.95843	35.12816	4.21891
4.000	.00662	151.0994	.23731	.02789	39.08175	.37973	57.37761	10.64819
5.000	.00190	525.0594	.16607	.01147	40.86720	.16329	85.73722	24.76236
6.000	.00064	1562.6190	.12149	.00527	41.94574	.07698	120.28880	52.52660
7.000	.00024	4086.8010	.09223	.00265	42.63882	.03941	161.06680	102.59550
8.000	.00010	9615.0800	.07217	.00144	43.10745	.02164	208.08750	186.83450
9.000	.00005	20738.5300	.05790	.00083	43.43782	.01260	261.35920	320.84080
10.000	.00002	41621.6100	.04742	.00051	43.67884	.00771	320.88640	524.46610