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INPUT GUIDE FOR COMPUTER PROGRAMS TO GENERATE THERMODYNAMIC DATA FOR AIR AND FREON (CF_4)

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by

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FOREWORD

This document was prepared by personnel of the Lockheed-Huntsville Research & Engineering Center for the Engineering Analysis Division of the NASA-Johnson Space Center, Houston, Texas and the Aerophysics Division of NASA-Marshall Space Flight Center, Huntsville, Alabama. The work was performed under Contract NAS9-13429 (Mr. Barney B. Roberts, technical monitor) in support of the Plume Simulation Technology Test Program.

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Section 1
INTRODUCTION

Scale model testing which requires simulation of the prototype plume shape generally employs a "cold flow" test approach in obtaining the scale model plume. Air is most commonly used since air supply systems are readily available at most test facilities. However air does not exhibit the desired flow properties under all test conditions which then in such cases necessitates the use of other simulant gases. Freon 14 (CF_4) has been found to exhibit expansion properties similar to those of the Space Shuttle main engines and thus is a candidate for use as a simulant gas in Space Shuttle scale model test programs.

Previous investigators (Refs. 1 and 2) have found these gases not to behave as an ideal gas (constant ratio of specific heats, etc.) nor obey the perfect gas law when expanded supersonically. Consequently, analytical studies which treat the supersonic expansion of these gases should include the effects of the non-standard equation of state as well as the variation of specific heat ratio with pressure and temperature.

Following the work of Refs. 1 and 2 FORTRAN computer codes have been developed to calculate the thermodynamic properties of these gases for isentropic expansions from given plenum conditions. Thermodynamic properties for air are calculated with equations derived from the Beattie-Bridgeman nonstandard equation of state (Ref. 1). Thermodynamic properties for Freon 14 are calculated with equations derived from the Redlich-Quang nonstandard equation of state (Ref. 2).

Utility of the programs for use in analytical prediction of model rocket nozzle flow fields was enhanced by arranging card or tape output of the data in a format compatible with a method-of-characteristics (MOC, Ref. 3) computer program. The nonstandard equation of state programs thus enhance the accuracy of the method-of-characteristics solution of supersonic flow fields.

Section 2
DISCUSSION OF THE NONSTANDARD EQUATION OF STATE PROGRAM FOR AIR

The nonstandard equation of state program for air consists of seven subroutines which perform the necessary calculations to expand air isentropically from given plenum conditions to a given pressure. Plenum temperature and pressure are input to establish an isentrope along which the expansion will be made. Along this isentrope the program iterates for temperature at points located at pressure increments of DELP. At each point thermodynamic properties are calculated with equations derived from the Beattie-Bridgeman equation of state (Ref. 1). The thermodynamic data is arranged into a format compatible with the method-of-characteristics (MOC) computer code (Ref. 3) and may be output on cards or a FORTRAN tape unit.

The input instructions and description of the input FORTRAN symbols are covered in the program input section. Interpretation of the output is discussed in the program output section.

2.1 PROGRAM INPUT

This subsection contains a detailed description of the program input as follows:

- Detailed input guide
- Detailed description of the input FORTRAN symbols.

2.1.1 Detailed Guide for Input Data

Card No. 1

Format 16I5 (right adjusted)

Column	Parameter	Identification
1-5	IWRITE	0 No intermediate printout 1 Intermediate printout
6-10	ITAB	Number of entropy cuts
11-15	IUNIT	0 No output for MOC program 7 Punched output for MOC program N FORTRAN unit for tape output for MOC program

Card No. 2

Format 5D10.6

Column	Parameter	Identification
1-10	PREF	Reference pressure corresponding to reference entropy and enthalpy, psia
11-20	TREF	Reference temperature corresponding to reference entropy and enthalpy, ^{o}F
21-30	SREF	Reference entropy, Btu/lbm-^{o}R,
31-40	HREF	Reference enthalpy, Btu/lbm
41-50	EMMAX	Maximum Mach number to be considered

Card No. 3

Format 5D10.6, 4A6, 1I1

Column	Parameter	Identification
1-10	PTU	Plenum pressure, psia
11-20	TT1	Plenum temperature, ^{o}F
21-30	DELP	Pressure increment at which calculations are made, psia

Card No. 3 (Cont'd)

Column	Parameter	Identification
31-40	PMINN	Minimum expansion pressure, psia
41-50	PS	Plenum pressure for calculation of second table, psia
51-74	HEADER	Gas identification for MOC input
75	ISTOP	1 Discontinue calculations with immediate case 0 Continue calculations with new plenum conditions

2.1.2 Input FORTRAN Symbols

Symbol	Description	Units
IWRITE	This flag controls the output of intermediate calculations during the iterative cycle for a convergent solution. If IWRITE=0, there is no intermediate printout. If IWRITE=1 intermediate printout will be generated.	N/A
ITAB	This flag determines the number of entropy cuts calculated by the program. If ITAB=1 there will be one entropy out. If ITAB=2 there will be two entropy cuts. If the thermochemistry data is to be used in a flow field containing shocks, ITAB should be set equal to 2.	N/A
IUNIT	The method of output of the program's thermochemistry data is controlled by this flag. If IUNIT=0, there is no output generated for the MOC program. If IUNIT=7, the output will be punched on cards in a format appropriate for input to the MOC. If IUNIT=N (N≠0, 7), the output will be written on FORTRAN tape unit N.	N/A
PREF	This variable is the pressure at which the reference entropy and enthalpy are evaluated.	psia
TREF	This variable is the temperature at which the reference entropy and enthalpy are evaluated.	^{o}F
SREF	A reference entropy for change of entropy calculations. It has a value defined for air at a pressure of PREF and a temperature of TREF.	Btu/lbm-^{o}R

Symbol	Description	Units
HREF	A reference enthalpy for change of enthalpy calculations. It has a value defined for air at a pressure of PREF and a temperature of TREF	Btu/lbm
EMMAX	The maximum Mach number which will be considered in the calculations of the isentropic expansion from the given plenum conditions.	N/A
PTU	The plenum pressure from which air will be isentropically expanded.	psia
TT1	The plenum temperature from which air will be isentropically expanded.	^oF
DELP	The pressure increment for succeeding calculations from plenum conditions.	psia
PMIN	The minimum static pressure which will be considered in the calculations of the isentropic expansion from the given plenum conditions.	psia
PS	Plenum pressure for calculation of a second table of thermodynamic data.	psia
HEADER	Identifies the set of computed gas properties when thermochemistry data is punched on cards or written on a tape for subsequent input to the MOC program. The MOC program compares column for column, this header and the gas identification data input to the MOC while searching a tape file for the proper set of thermochemistry data.	N/A
ISTOP	This flag is a run control parameter. If ISTOP = 1, the program discontinues calculations with the immediate set of plemum conditions. If ISTOP = 0, the program calculates another isentropic expansion with the next set of plenum conditions input via card No. 3. ISTOP allows for calculation of isentropic expansions from numerous plenum conditions with one computer run.	N/A

2.2 PROGRAM OUTPUT

This subsection contains a description of the output scheme utilized by the program and a description of the error messages printed out by the program.

2.2.1 Description of Program Data Output

The data output of the nonstandard equation of state program for air is organized into three horizontal lines for each pressure increment at which calculations are made. Data output includes plenum conditions, local fluid and thermodynamic properties and local Mach number and temperature assuming air to behave as an ideal gas.

The following guide consists of numbered flags on a sample printout sheet (page 8) which correspond to numbered comments listed below.

1	M	Mach number
2	R	Gas constant for air, ft-lbm/^{o}R-lb-mole
3	GAMA	Ratio of specific heats for air
4	T	Static temperature, ^{o}R
5	P	Static pressure, psia
6	A/A*	One-dimensional expansion ratio
7	H	Enthalpy, lbm
8	V	velocity, ft/sec
9	PGM	Mach number assuming perfect gas
10	PGT	Temperature assuming perfect gas, ^{o}R
11	PC	Plenum (total) pressure, psia
12	TC	Plenum (total) temperature, ^{o}R

13	ENTROPY	Entropy, Btu/lbm-°R
14	HC	Plenum enthalpy, Btu/lbm-°R
15	RHO	Density, lbm/ft^3
16	SS	Local speed of sound, ft/sec
17	RHO*U	Mass flow per unit area, $lbm/sec\text{-}ft^2$

2.2.2 Description of Program Error Message Output

1. DUE TO PROGRAM LIMITATIONS, THE PROGRAM IS ASSUMING MINIMUM PE=

   This statement occurs when the program is unable to solve for temperature at a pressure increment. The previous pressure is assumed to be the minimum expansion pressure.

2. NO CONVERGENCE AFTER 100 TRIES

   This statement occurs when the program is unable to converge on a solution at a given pressure after 100 iterations. The quantity generated by iteration 100 is accepted as the solution and the run continued.

3. ITSUB WILL NOT CONVERGE

   This statement originates in subroutine ITSUB which provides iteration control for any function. The statement indicates that the program is unable to converge on a solution.

```
 (1)               (2)                (3)                    (4)                (5)                  (6)                   (7)                (8)
 M=  .00000     R=   .17619+04 GAMA=  .15157+001 T=  .66600+003 P=  .17000+04 A/A*=   .00000     H=  .15372+003 V=  .00000
(9)PGM =  .000000000000   (10)PGT =  .666000000000+003
(11)PC= .17000+004 TC= .66600+003 ENTROPY=  .93410+00 HC= .15372+003 RHO=  .20862+00 SS=  .12817+04 RHO*U=  .00000
          (12)               (13)                   (14)                (15)                  (16)                  (17)
 M=  .87221+000 R=  .17192+04 GAMA=  .15051+001 T=  .57006+003 P=  .10050+04 A/A*=  .10142+01 H=  .13128+003 V=  .10593+04
 PGM =  .900130400064+000      PGT =  .573126586216+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14767+00 SS=  .12145+04 RHO*U=  .15643+03

 M=  .87686+000 R=  .17189+04 GAMA=  .15050+001 T=  .56922+003 P=  .10000+04 A/A*=  .10132+01 H=  .13109+003 V=  .10640+04
 PGM =  .904721113102+000      PGT =  .572310455669+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14718+00 SS=  .12135+04 RHO*U=  .15660+03

 M=  .88152+000 R=  .17186+04 GAMA=  .15049+001 T=  .56837+003 P=  .99500+03 A/A*=  .10121+01 H=  .13089+003 V=  .10688+04
 PGM =  .909318032583+000      PGT =  .571491405143+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14668+00 SS=  .12124+04 RHO*U=  .15677+03

 M=  .88619+000 R=  .17183+04 GAMA=  .15047+001 T=  .56753+003 P=  .99000+03 A/A*=  .10112+01 H=  .13070+003 V=  .10735+04
 PGM =  .913921401495+000      PGT =  .570669409437+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14619+00 SS=  .12114+04 RHO*U=  .15693+03

 M=  .89087+000 R=  .17181+04 GAMA=  .15046+001 T=  .56668+003 P=  .98500+03 A/A*=  .10102+01 H=  .13050+003 V=  .10782+04
 PGM =  .918531463719+000      PGT =  .569844443007+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14569+00 SS=  .12103+04 RHO*U=  .15709+03

 M=  .89556+000 R=  .17178+04 GAMA=  .15045+001 T=  .56582+003 P=  .98000+03 A/A*=  .10093+01 H=  .13031+003 V=  .10830+04
 PGM =  .923148463715+000      PGT =  .569016479953+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14519+00 SS=  .12093+04 RHO*U=  .15724+03

 M=  .90026+000 R=  .17175+04 GAMA=  .15044+001 T=  .56497+003 P=  .97500+03 A/A*=  .10085+01 H=  .13011+003 V=  .10877+04
 PGM =  .927772646696+000      PGT =  .568185494019+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14469+00 SS=  .12082+04 RHO*U=  .15738+03

 M=  .90496+000 R=  .17172+04 GAMA=  .15042+001 T=  .56411+003 P=  .97000+03 A/A*=  .10077+01 H=  .12991+003 V=  .10924+04
 PGM =  .932404258715+000      PGT =  .567351458580+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14419+00 SS=  .12071+04 RHO*U=  .15752+03

 M=  .90968+000 R=  .17170+04 GAMA=  .15041+001 T=  .56324+003 P=  .96500+03 A/A*=  .10069+01 H=  .12971+003 V=  .10971+04
 PGM =  .937043546755+000      PGT =  .566514346640+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14369+00 SS=  .12061+04 RHO*U=  .15765+03

 M=  .91441+000 R=  .17167+04 GAMA=  .15040+001 T=  .56238+003 P=  .96000+03 A/A*=  .10062+01 H=  .12952+003 V=  .11018+04
 PGM =  .941690758818+000      PGT =  .565674130821+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14319+00 SS=  .12050+04 RHO*U=  .15777+03

 M=  .91914+000 R=  .17164+04 GAMA=  .15039+001 T=  .56151+003 P=  .95500+03 A/A*=  .10055+01 H=  .12932+003 V=  .11066+04
 PGM =  .946346144016+000      PGT =  .564830783359+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14269+00 SS=  .12039+04 RHO*U=  .15789+03

 M=  .92389+000 R=  .17161+04 GAMA=  .15037+001 T=  .56064+003 P=  .95000+03 A/A*=  .10049+01 H=  .12911+003 V=  .11113+04
 PGM =  .951009952661+000      PGT =  .563984276092+003
 PC=  .17000+004 TC=  .66600+003 ENTROPY=  .93410+00 HC=  .15372+003 RHO=  .14218+00 SS=  .12028+04 RHO*U=  .15801+03

 M=  .92865+000 R=  .17159+04 GAMA=  .15036+001 T=  .55976+003 P=  .94500+03 A/A*=  .10043+01 H=  .12891+003 V=  .11160+04
 PGM =  .955682436354+000      PGT =  .563134580458+003
```

Section 3
DISCUSSION OF THE NONSTANDARD EQUATION OF STATE PROGRAM FOR FREON

The nonstandard equation of state program for Freon 14 (CF_4) consists of nine subroutines which perform the necessary calculations to expand Freon isentropically from given plenum conditions to a given pressure. Plenum temperature and pressure are input to establish an isentrope along which the expansion will be made. Along this isentrope the program iterates for pressure at points located at temperature increments of DELTT. At each point thermodynamic properties are calculated with equations derived from the Redlich-Quang equation of state (Ref. 2). The thermodynamic data is arranged into a format compatible with the method-of-characteristics (MOC) computer code (Ref. 3) and may be output on cards or a FORTRAN tape unit.

The input instructions and description of the input FORTRAN symbols are covered in the program input section. Interpretation of the output is discussed in the program output section.

3.1 PROGRAM INPUT

This subsection contains a detailed description of the program input as follows:

- Detailed input guide, and
- Detailed description of the input FORTRAN symbols.

3.1.1 Detailed Guide for Input Data

Card No. 1

Format 16I5 (right adjusted)

Column	Parameter	Identification
1-5	ITAB	Number of entropy cuts
6-10	IUNIT	0 No output for MOC program
		7 Punched output for MOC program
		N FORTRAN unit for tape output for MOC program

Card No. 2

Format 5E15.8

1-15	A2	Constant for nonstandard equation of state
16-30	A3	Constant for nonstandard equation of state
31-45	A4	Constant for nonstandard equation of state
46-60	A5	Constant for nonstandard equation of state
61-75	A6	Constant for nonstandard equation of state

Card No. 3

Format 5E15.8

1-15	B2	Constant for nonstandard equation of state
16-30	B3	Constant for nonstandard equation of state
31-45	B4	Constant for nonstandard equation of state
46-50	B5	Constant for nonstandard equation of state
61-75	B6	Constant for nonstandard equation of state

Card No. 4

Format 5E15.8

Column	Parameter	Identification
1-15	C2	Constant for nonstandard equation of state
16-30	C3	Constant for nonstandard equation of state
31-45	C5	Constant for nonstandard equation of state

Card No. 5

Format 5E15.8

1-15	BLIT	Constant in nonstandard equation of state
16-30	AK	Constant in nonstandard equation of state
31-45	ALPHA	Constant in nonstandard equation of state

Card No. 6

Format 5E15.8

1-15	AL4	Constant used in calculation of specific heat at zero pressure
16-30	BL4	Constant used in calculation of specific heat at zero pressure
31-45	CL4	Constant used in calculation of specific heat at zero pressure
46-60	DL4	Constant used in calculation of specific heat at zero pressure

Card No. 7

Format 5E15.8

Column	Parameter	Identification
1-15	R	Gas constant for Freon 14 (CF_4)
16-30	AJ	Constant used in the nonstandard equation of state

Card No. 8

Column	Parameter	Identification
1-10	TREF	Reference temperature corresponding to reference entropy and enthalpy, ^oF
11-20	PREF	Reference pressure corresponding to reference entropy and enthalpy, psia
21-30	VREF	Reference specific volume corresponding to reference entropy and enthalpy, ft^3/lbm
31-40	SREF	Reference entropy, Btu/lbm-^oR
41-50	HREF	Reference enthalpy, Btu/lbm
51-60	EMMAX	Maximum Mach number to be considered

Card No. 9

Column	Parameter	Identification
1-10	TO	Plenum temperature, ^oF
11-20	PO	Plenum pressure, psia
21-30	DELTT	Temperature increment at which calculations are made, ^oF
31-40	TMIN	Minimum expansion temperature, ^oF
41-50	PS	Plenum pressure for calculation of second table, psia
51-74	HEADER	Gas identification for MOC input

3.1.2 Input FORTRAN Symbols

Symbol	Description	Units
ITAB	This flag determines the number of entropy cuts calculated by the program. If ITAB=1 there will be one entropy cut. If ITAB=2 there will be two entropy cuts. If the thermo-chemistry data is to be used in a flow field containing shocks, ITAB should be set equal to 2.	N/A
IUNIT	The method of output of the program's thermo-chemistry data is controlled by this flag. If IUNIT=0, there is no output generated for the MOC program. If IUNIT=7, the output will be punched on cards in a format appropriate for input to the MOC. If IUNIT=N (N≠0, 7) the output will be written on FORTRAN tape unit N.	N/A
A2	Constant used in the calculation of the non-standard equation of state. A2 = -2.16259 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
A3	Constant used in the calculation of the non-standard equation of state. A3 = 4.404057E-03 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
A4	Constant used in the calculation of the non-standard equation of state. A4 = 1.921072E-04 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
A5	Constant used in the calculation of the non-standard equation of state. A5 = -4.481049E-06 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
A6	Constant used in the calculation of the non-standard equation of state. A6 = 5.8388E-07 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
B2	Constant used in the calculation of the non-standard equation of state. B2 = 2.135114E-03 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
B3	Constant used in the calculation of the non-standard equation of state. B3 = 1.282818E-05 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
B4	Constant used in the calculation of the non-standard equation of state. B4 = -3.918263E-07 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A

Symbol	Description	Units
B5	Constant used in the calculation of the non-standard equation of state. B5 = 9.062318E-09 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
B6	Constant used in the calculation of the non-standard equation of state. B6 = -9.263923E-04 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
C2	Constant used in the calculation of the non-standard equation of state. C2 = -18.94113 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
C3	Constant used in the calculation of the non-standard equation of state. C3 = 0.539776 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
C5	Constant used in the calculation of the non-standard equation of state. C5 = -4.836678E-05 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
BLIT	This constant is used in the nonstandard equation of state. BLIT = 0.0015 for Freon 14 (CF_4).	N/A
AK	This constant is used in the nonstandard equation of state. AK = 0.00976 for Freon 14 (CF_4).	N/A
ALPHA	This constant is used in the nonstandard equation of state. ALPHA = 6.61199 for Freon 14 (CF_4).	N/A
AL4	Constant used in the calculation of specific heat at zero pressure. AL4 = 0.0190458084 for Freon 14 (CF_4) in Eq. (A4) of Ref. 4.	N/A
BL4	Constant used in the calculation of specific heat at zero pressure. BL4 = 3.00892783E-04 for Freon 14 (CF_4) in Eq. (A4) of Ref. 4.	N/A
CL4	Constant used in the calculation of specific heat at zero pressure. CL4 = -1.30237441E-07 for Freon 14 (CF_4) in Eq. (A4) of Ref. 4.	N/A
DL4	Constant used in the calculation of specific heat at zero pressure. DL4 = 1.96802894E-11 for Freon 14 (CF_4) in Eq. (A4) of Ref. 4.	N/A
R	Gas constant used in the nonstandard equation of state. R = 0.1219336 for Freon 14 (CF_4).	$\frac{\text{ft-lbm}}{^{o}\text{R-lb-mole}}$

Symbol	Description	Units
AJ	This variable is used in calculations of the nonstandard equation of state. AJ = 0.185053 for Freon 14 (CF_4) in Eq. (A1) of Ref. 4.	N/A
TREF	This variable is the temperature at which the reference entropy and enthalpy are evaluated.	^oF
PREF	This variable is the pressure at which the reference entropy and enthalpy are evaluated.	psia
VREF	This variable is the specific volume at which the reference entropy and enthalpy are evaluated.	ft^3/lbm
SREF	This variable is a reference entropy for change of entropy calculations. It has a value defined for Freon 14 at a temperature of TREF, a pressure of PREF, and a specific volume of VREF.	Btu/lbm-^oR
HREF	This variable is a reference enthalpy for change of enthalpy calculations. It has a value defined for Freon 14 at a temperature of TREF, a pressure of PREF, and a specific volume of VREF.	Btu/lbm
EMMAX	The maximum Mach number which will be considered in the calculations of the isentropic expansion from the given plenum conditions.	N/A

3.2 PROGRAM OUTPUT

This subsection contains a description of the output scheme utilized by the program and a description of the error messages printed out by the program.

3.2.1 Description of Program Data Output

The data output of the nonstandard equation of state program for Freon is organized into two horizontal lines for each temperature increment at which calculations are made. Data output includes plenum conditions and local fluid and thermodynamic properties.

The following guide consists of numbered flags on a sample printout sheet (pp. 18) which correspond to numbered comments listed below.

1	PO	Plenum pressure, psia
2	TO	Plenum temperature, ^{o}R
3	VO	Specific volume for plenum conditions, ft^3/lbm
4	CVO	Specific heat at constant volume for plenum conditions
5	CPO	Specific heat at constant pressure for plenum conditions
6	GAMMA	Ratio of specific heats for plenum conditions
7	ENTROPY	Entropy for plenum conditions, Btu/lbm-^{o}R
8	ENTHALPY	Enthalpy for plenum conditions, Btu/lbm-^{o}R
9	SPEED OF SOUND	Local speed of sound for plenum conditions, ft/sec
10	TEMPERATURE	Static temperature, ^{o}R
11	VOLUME	Specific volume, ft^3/lbm
12	PRESSURE	Static pressure, psia
13	CSUBV	Specific heat at constant volume
14	CSUBP	Specific heat at constant pressure
15	GAMMA	Ratio of specific heats
16	RHO	Density, lbm/ft^3
17	ENTHALPY	Enthalpy, Btu/lbm
18	ENTROPY	Entropy, Btu/lbm-^{o}R
19	SOUND SPEED	Local speed of sound, ft/sec
20	VELOCITY	Velocity, ft/sec

21	MACH NO.	Mach number
22	COMP FACTOR	Compressibility factor
23	RHO*U	Mass flow per unit area, lbm/ft^2-sec

3.2.2 Description of Program Error Message Output

1. ITSUB WILL NOT CONVERGE

   This statement originates in subroutine ITSUB which provides iteration control for any function. The statement indicates that the program is unable to converge on a solution.

2. NO CONVERGENCE

   This statement originates in subroutine STATE or subroutine SOLVE. In subroutine SOLVE the statement indicates that the program will not converge on a solution for the local temperature. In subroutine STATE the statement indicates that the program will not converge.

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(1) P0= 0.20000304E 04PSIA (2) T0= 0.63500000E 03DEG.R (3) V0= 0.33358782E-01FT3/LB (4) CV0= 0.17036274E 00 (5) CP0= 0.24486377E 00

GAMMA= 0.14373257E 01 ENTROPY= 0.60596881E 00 ENTHALPY= 0.14837953E 03 SPEED OF SOUND= 0.68212561E 03

(6) (7) (8) (9)

(10) TEMPERATURE / (17) ENTHALPY	(11) VOLUME / (18) ENTROPY	(12) PRESSURE / (19) SOUND SPEED	(13) CSUBV / (20) VELOCITY	(14) CSUBP / (21) MACH NO.	(15) GAMMA / (22) COMP FACTOR	(16) RHO / (23) RHO*U	
0.62500000E 03	0.35975478E-01	0.17951223E 04	0.16918361E 00	0.24354490E 00	0.14395298E 01	0.86394953E 00	0.92726433E 00
0.14711514E 03	0.60596096E 00	0.65304954E 03	0.24453961E 03	0.37443482E 00	0.84741699E 00	0.21126986E 03	
0.61500000E 03	0.38812987E-01	0.16162947E 04	0.16796442E 00	0.24181646E 00	0.14396884E 01	0.80078852E 00	0.85947453E 00
0.14593228E 03	0.60595119E 00	0.63024996E 03	0.34499523E 03	0.54742896E 00	0.83656191E 00	0.27626819E 03	
0.60500000E 03	0.41898936E-01	0.14586665E 04	0.16670122E 00	0.23970991E 00	0.14379611E 01	0.74180865E 00	0.79617238E 00
0.14475682E 03	0.60585689E 00	0.61072558E 03	0.42175129E 03	0.69357381E 00	0.82847454E 00	0.31285858E 03	
0.59500000E 03	0.45492216E-01	0.13127285E 04	0.16536551E 00	0.23699021E 00	0.14331295E 01	0.68321573E 00	0.73328542E 00
0.14363946E 03	0.60584929E 00	0.59372351E 03	0.48354486E 03	0.81442761E 00	0.82313621E 00	0.33036541E 03	
0.58500000E 03	0.49514621E-01	0.11413610E 04	0.16394692E 00	0.23386052E 00	0.14262664E 01	0.62771344E 00	0.62321571E 00
0.14253640E 03	0.60586929E 00	0.57926013E 03	0.53762646E 03	0.92812609E 00	0.82004344E 00	0.33747534E 03	
0.57500000E 03	0.54134373E-01	0.10628544E 04	0.16248929E 00	0.23026257E 00	0.14170037E 01	0.57412409E 00	0.61619889E 00
0.14146267E 03	0.60593009E 00	0.56695446E 03	0.58549157E 03	0.10326957E 01	0.81913161E 00	0.33614477E 03	
0.56500000E 03	0.59285186E-01	0.95265200E 03	0.16094779E 00	0.22643473E 00	0.14068834E 01	0.52426242E 00	0.56268319E 00
0.14038439E 03	0.60596536E 00	0.55459024E 03	0.62002979E 03	0.11317114E 01	0.81980156E 00	0.33023797E 03	
0.55500000E 03	0.65642331E-01	0.85583771E 03	0.15934129E 00	0.22243753E 00	0.13950832E 01	0.47785794E 00	0.51287794E 00
0.13934904E 03	[illegible]	[illegible] 03	[illegible] 03	0.12258276E 01	0.82179772E 00	[illegible] 03	
[illegible] 03	[illegible]	[illegible] 03	[illegible] 00	[illegible] 00	0.13847063E 01	0.43467837E 00	0.46653335E 00
[illegible] 03	[illegible]	[illegible] 03	[illegible] 03	[illegible] 01	[illegible] 00	0.32076236E 03	

REFERENCES

1. Randall, R. E., "Thermodynamic Properties of Gases: Equations Devised from the Beattie-Bridgeman Equation of State Assuming Variable Specific Heats," AEDC TR-57-10, Arnold Engineering Development Center, Tullahoma, Tenn., August 1957.

2. Hunt, James L., and L. R. Boney, "Thermodynamic and Transport Properties of Gaseous Tetrafluoromethane in Chemical Equilibrium," NASA TN D-7181, Langley Research Center, Hampton, Va., August 1973.

3. Prozan, R. J., "Development of a Method-of-Characteristics Solution for Supersonic Flow of an Ideal, Frozen or Equilibrium Reacting Gas Mixture," LMSC-HREC A782535, Lockheed Missiles & Space Company, Huntsville, Ala., April 1966.

4. Hunt, James L., and Robert A. Jones, "Use of Tetrafluoromethane to Simulate Real-Gas Effects on the Hypersonic Aerodynamics of Blunt Vehicles," NASA TR R-312, Langley Research Center, Hampton, Va., June 1969.

Appendix A
LISTING OF THE NONSTANDARD EQUATION OF STATE PROGRAM FOR AIR

```
WFOR,US MAIN,MAIN
MSD 1IA -06/07/74-13:41:00 (0,1)

   MAIN PROGRAM

   STORAGE USED; CODE(1) 001556; DATA(0) 005402; BLANK COMMON(2) 000000

    COMMON BLOCKS:

    0003    INPUT  000030
    0004    FACTOR 000012
    0005    SFACT  000004

   EXTERNAL REFERENCES (BLOCK, NAME)

    0006    ICAL
    0007    PERGAS
    0010    ITSUO
    0011    ITSUB
    0012    NINTRS
    0013    NRDUS
    0014    NIO2S
    0015    NWDUS
    0016    NIO3S
    0017    NIO1S
    0020    XPDU
    0021    ALOG
    0022    SQRT
    0023    DSQRT
    0024    NERR2S
    0025    NWBUS
    0026    NSTOPS

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001    000472 1L      0000    005110 10F     0000    005076 100F    0000    005130 1050F   0000    005102 108F
    0001    000353 11L     0001    001236 115L    0000    005103 1151F   0000    005077 12F     0000    005075 13F
    0001    001323 130L    0001    001247 131L    0001    001270 132L    0000    005255 140F    0000    005261 145F
    0000    005264 148F    0001    001332 151L    0001    001351 152L    0001    001401 189L    0001    001203 190L
    0001    001410 191L    0001    000715 20L     0000    005112 200F    0001    000624 203L    0001    001477 210L
    0000    005266 215F    0000    005234 30F     0001    001425 400L    0001    001472 410L    0000    005154 50F
    0000    005175 55F     0001    001147 60L     0001    001312 601G    0001    000165 611L    0000    005132 619F
    0001    001371 636G    0000    005225 65F     0001    001067 714L    0001    001071 715L    0001    001134 797L
    0001    000061 90L     0001    000117 933L    0001    000122 936L    0001    001552 95L     0003 D 000012 A
    0000 R  005070 AF1     0000 R  005071 AF2     0003 D  000006 AU      0000 R  005047 ARATIO  0003 D 000014 B
    0003 D  000010 BU      0003 D  000016 C       0005 D  000000 CAPE    0005 D  000002 CAPF    0000 R 005056 CF
    0000 D  000106 CONHL   0000 R  005034 CONR    0000 D  000050 CONV    0000 R  005033 CONVR   0000 D 000024 DELP
    0000 R  005123 EM      0000 D  000030 EMMAX   0000 R  005066 EM2     0000 D  000034 ES      0000 D 000046 FOF
    0000 D  000036 FS      0000 D  000002 GAMA    0000 R  005051 GAMU    0000 R  004073 GAMZ    0000 R 005027 HEADER
    0000 D  000110 HLOC    0000 D  000062 HR      0000 D  000054 HREF    0000 D  000042 HTOT    0000 I 005042 I
    0000 I  005063 IBR     0000 I  005062 IERROR  0000 I  005072 IOF     0000 I  005043 IS      0000 I 005041 ISTOP
    0000 I  005036 ITAB    0000 I  005040 ITIME   0000 I  005037 IUNIT   0000 I  005035 IWRITE  0004 D 000000 II
    0000 I  005074 J       0004 D  000006 JI      0004 D  000002 JI      0004 D  000010 KT      0004 D 000004 KI
    0000 I  005064 MI      0000 I  005122 NRS     0000 D  000014 MI      0003 D  000024 OCV     0003 D 000022 OGAM
```

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```
0000 D 000060 OOGM1     0003 D 000004 PE        0000 R 005052 PEA       0000 R 005065 PEPSF     0000 R 005061 PFF
0000 D 000020 PGM       0000 D 000022 PGT       0000 R 005060 PMIN      0000 D 000026 PMINN     0000 R 004043 POT
0000 D 000052 PREF      0000 D 000056 PS        0000 D 000114 PSAV      0000 D 000112 PTU       0003 D 000000 PTI
0003 D 000020 R         0000 D 000000 RHO       0000 D 000040 RHOS      0000 R 005054 RHOU      0000 R 005055 RHU
0000 D 000064 SAVE      0000 R 005045 SLOC      0000 D 000104 SREF      0000 R 005057 SS        0000 R 005073 TAB
0003 D 000026 TE        0000 R 005053 TEA       0000 D 000010 TFAC      0000 R 003057 TOT       0000 D 000044 TRATIO
0000 D 000032 TREF      0003 D 000002 TTI       0000 R 005067 TXOGP1    0000 R 005050 VEL       0000 D 000004 XMFAC1
0000 D 000006 XMFAC2    0000 R 005044 XMU       0000 D 000116 XSAVE     0000 D 000012 Z         0000 R 001107 ZER
0000 D 000120 ZR        0000 R 005046 ZRR
```

```
00000  *DIAGNOSTIC*  THE NAME SSS APPEARS IN A DIMENSION OR TYPE STATEMENT BUT IS NEVER REFERENCED.
00100        C      THIS PROGRAM CALCULATES REAL GAS THERMODYNAMIC PROPERTIES FOR
00100        C      AIR USING THE BEATTIE-BRIDGEMAN EQUATION OF STATE FOR AN
00100        C      ISENTROPIC EXPANSION FROM SPECIFIED RESERVOIR CONDITIONS
00101               DOUBLE PRECISION RHO,GAMA,XMFAC1,XMFAC2,TFAC,Z,M1,PTI,TTI,PE,AO,BO
00101              1,A,B,C,R,OGAM,OCV,TE,II,JI,KI,JT,KT,PGM,PGT,DELP,PMINN
00101              *,EMMAX,TREF,ES,FS,RHOS,HTOT,TRATIO,FOF,CONV,PREF,HREF,PS,OOGM1,HR
00101              *,SAVE,CAPE,CAPF,SREF,CONHL,HLOC,PTU,PSAV,XSAVE,ZR,SSS
00103               DATAMKS/3HENG/
00105               DATA  AO,       BO,        A,        B,    .    C,          R
00105              1/     4906.5D0,0.738D0,0.3093100,-0.1763D00, 4.0543D0, 10.729D0/
00114               DATA   OGAM,      OCV
00114              1/      1.4D0,   0.1714100/
00117               DIMENSION M1(2)
00120               DIMENSIONSAVE(8),EM(500),ZER(500),GAMZ(500),TOT(500),POT(500)
00121               COMMON/INPUT/PTI,TTI,PE,AO,BO,A,B,C,R,OGAM,OCV,TE
00122               COMMON/FACTOR/II,JI,KI,JT,KT
00123               COMMON/SFACT/CAPE,CAPF
00124               DIMENSIONHEADER(4)
00125               CONVR=778.*32.174
00126               CONR=.068561
00127               CONHL=CONR*OGAM/(OGAM-1.D0)
00130               READ(5,13)IWRITE,ITAB,IUNIT
00135               READ(5,10)PREF,TREF,SREF,HREF,EMMAX
00144               TE=TREF
00145               PE=PREF
00146               ITIME=2
00147               CALLICAL(IWRITE,RHO,GAMA,ITIME)
00150               ES=CAPE
00151               FS=CAPF
00152               RHOS=RHO
00153            13 FORMAT(16I5)
00154            90 CONTINUE
00155           100 FORMAT(1H1)
00156               WRITE(6,100)
00160               READ(5,12)PTU,TTI,DELP,PMINN,PS,HEADER,ISTOP
00160        C      *************** THE NEXT 6 CARDS ARE A TEMPORARY INSERT TO READ DATA
00171         12    FORMAT(5D10.6,4A6,I11)
00172               TTI=TTI+460.D0
00173  *DIAGNOSTIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
00173               IF(PTU.NE.0.D0)GO TO 933
00175               PTI=PSAV
00176               GO TO 936
```

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```
00177        933 PSAV=PTO
00200            PTI=PTO
00201        936 CONTINUE
00201     C      ************* END OF INSERT
00201     C      **** THE FOLLOWING CARD  PREVIOUSLY READ IF(PTI.EQ.0.) GOTO95
00202            DELP=DELP/2.D0
00203            PMINN=PMINN/12.5D0
00204  *DIAGNOSTIC*  THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
00204            IF(PTI.EQ.0.) GO TO 95
00206            I=1
00207            IS=0
00210        108 FORMAT(4A6)
00211            ITIME=2
00212            TE=TTI
00213            PE=PTI
00214            CALL LICAL(IWRITE,RHO,GAMA,ITIME)
00215            HTOT=J1*OGAM*CONR*TE/(OGAM-1.D0)
00216        611 CONTINUE
00217            JT=JI
00220            KI=KI
00221            OOGMI=1.D0/(OGAM-1.D0)
00222            TRATIO=(TE/TREF)**OOGMI
00223            AMFACI=TRATIO*CAPE*RHOS*FS/(ES*RHO*CAPF)
00224            XMU=SNGL(AMFACI)
00225       1151 FORMAT(1X,8D12.5,/1X,2D12.5,E12.5)
00226            SLOC=SNGL(SREF)+CONR*ALOG(XMU)
00227            EM(I)=0.
00230            Z=R*(144./778.26)/.068561
00231            ZR=1545.2*32.174/Z
00232            ZRR=SNGL(ZR)
00233            GAMZ(I)=SNGL(GAMA)
00234            TOT(I)=SNGL(TTI)
00235            POT(I)=SNGL(PTI)*144.
00236            ARATIO=0.0
00237            MI(2)=0.0
00240            VEL=0.
00241            GAMU=SNGL(GAMA)
00242            PEA=SNGL(PTI)
00243            TEA=SNGL(TE)
00244            RHOU=0.
00245            RHO=SNGL(RHO)*28.966/32.174
00246            CF=PEA*144./(RHO*ZRR*TEA)
00247            ZRR=ZRR*CF
00250            SS=SQRT(1.4*ZRR*TEA)
00251            PGM=0.0D0
00252            ZER(I)=ZRR
00253            PGT=TTI
00254            WRITE(6,619)MI(2),ZRR,GAMA,TE,PE    ,ARATIO,HTOT,VEL
00266            WRITE(6,55)PGM,PGT,PTI,TTI,SLOC,HTOT,RHO,SS,RHOU
00301            PE=PTI
00302            PMIN = 0.0
00303         10 FORMAT(5D10.0 ,4A6)
00303     C      PRESSURES IN PSIA., TEMPERATURES IN DEG. RANKINE
00304         11 CONTINUE
00305            PE=PE-DELP
00306            IF(PE.LT.200.D0)DELP=10.D0D
```

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```
00310            IF(PE.LT.15.000)DELP=1.00
00312            IF(PE.LT.1.500)DELP=.100
00314            IF(PE.LT..1500)DELP=.0100
00316            IF(PE.LT.PMINN)GOTO190
00320            IF(PE.GE.PT1) GO TO 11
00322            PFF = PE
00323            IERROR = 0
00324        201 CONTINUE
00325            CALL PERGAS(PGM,PGT,IERROR,PMIN)
00326            IF(IERROR.GT.0)WRITE(6,200)PMIN
00332        200 FORMAT(1H0,66HDUE TO PROGRAM LIMITATIONS. THE PROGRAM IS ASSUMING
00332           1A MINIMUM PE =,D20.12)
00333            TE=PGT
00334            IF(PGM.LT.0.900)GOTO11
00336            MI(1)=PGM
00337            SAVE(2)=.0200*TE
00340            CONV=.00100*PE
00341            ITIME=2
00342            IBR=1
00343          1 CONTINUE
00344            CALL ICAL(IWRITE,RHO,GAMA,ITIME)
00345            IF(ITIME.EQ.100)GOTO190
00347            ITIME=ITIME+1
00350            IF(RHO.LT.0.000)GOTO11
00350      C     CALCULATION OF REAL GAS MACH NUMBER AND STATIC TEMPERATURE
00352            XMFAC1 = JT*((PT1*K1/(PE*KT))**((OGAM-1.)/OGAM))
00353            XMFAC2 = 1./(I1*(OGAM-1.)/2.)
00354            MI = 2
00355            IF(ITIME.EQ.1)MI=1
00357            MI(1)=MI(2)
00360            MI(MI) =DSQRT(ABS((XMFAC1-J1)*XMFAC2))
00360      C     CALCULATION OF TEMPERATURE
00361            TFAC = (0.5*(OGAM-1.)*I1*MI(MI)**2)+J1
00362            TE = TT1*JT/TFAC
00363            IF(TE.GT. 90.00) GO TO 203
00365            PE = PE + 0.0100
00366            PMIN = PE
00367            IERROR = 1
00370            GO TO 190
00371        203 CONTINUE
00372            TFAC=((TFAC/JT)**3.500*KT/K1
00373            XMFAC1=PT1/TFAC
00374            FOF=PE-XMFAC1
00375            XSAVE=TE
00376            CALLITS00(FOF,TE,SAVE,CONV, 50,IBR)
00377            IF(IBR.EQ.5)GOTO20
00401            IF(ITIME.GT.250)GOTO60
00403            IF(ITIME.LE.2)GOTO1
00405            IF(ABS(XSAVE-TE).LE..100)GOTO20
00407            GOTO(1,1,1,1,20,60),IBR
00410         20 CONTINUE
00411            I=I+1
00412            Z=R*(144./778.26)/0.068561
00413            PEPSF = PE
00414            ZR = 1545.0*32.174/Z
00415            EM2=SNGL(MI(2))
```

```
      ZRR=SNGL(ZR)
      GAMU=SNGL(GAMA)
      TEA=SNGL(TE)
      PEA=SNGL(PEPSF)
      RHO=SNGL(RHO)*28.966/32.174
      CF=PEA*144./(RHO*ZRR*TEA)
      ZRR=ZRR*CF
      SS=SQRT(GAMU*ZRR*TEA)
      VEL=EM2*SS
      RHOU=SNGL(RHO)*EM2*SS*28.966/32.174
      EM(I)=EM2
      ZER(I)=ZRR
      GAMZ(I)=GAMU
      TOT(I)=TEA
      POT(I)=PEA*144.
 1050 FORMAT(5E10.5)
      IF(MI(2).LE.1.) GO TO 714
      TWOGP1 = 2./(GAMA+1.)
      AF1 = 1.+0.5*(GAMA-1.)*MI(2)**2
      AF2 = (TWOGP1*AF1)**((GAMA+1.)/(GAMA-1.))
      ARATIO = SQRT((1./MI(2)**2)*AF2)
      GO TO 715
  714 CONTINUE
      ARATIO = 1.0
  715 CONTINUE
      HLOC=JI*TE*CONHL
      IF(IS.GT.0)GOTO797
      WRITE(6,619)MI(2),ZRR,GAMA,TE,PE    ,ARATIO,HLOC,VEL
  619 FORMAT(1H0,3H M=,D12.5,3H R=,E12.5,6H GAMA=,D12.5,3H T=,D12.5,
     1 3H P=,E12.5,6H A/A*=,E12.5,3H H=,D12.5,3H V=,E12.5)
   50 FORMAT(1H0,3HM =,D20.12,10X,25HMOL. WT.(LBM/LBM-MOLE) = ,D12.5,/
     16H GAMA=,D20.12,4H TE=,D20.12,4H PE=,D20.12)
      WRITE(6,55)PGM,PGT,PT1,TT1,SLOC,HTOT,RHO,SS,RHOU
   55 FORMAT(1H ,6HPGM = ,D20.12,5X,6HPGT = ,D20.12,/4H PC=,D12.5,4H TC=
     1,D12.5,9H ENTROPY=,E12.5,4H HC=,D12.5,6H RHO=,E12.5,4H SS=,E12.5,
     *7H RHO*U=,E12.5)
  797 CONTINUE
      IF(MI(2).GT.EMMAX)GOTO190
      IF(TE.LT.100.D0) GO TO 190
      GO TO 11
   60 CONTINUE
      WRITE(6,65)
   65 FORMAT(1H0,31HNO CONVERGENCE AFTER 100 TRIES.)
      WRITE(6,30)ITIME,MI(1),MI(2),TE,PE,XMFAC1
   30 FORMAT(1H0,21HFOR ITERATION NUMBER ,I3,   5HM1 = ,D15.8 ,   5HM2 =
     1 ,D15.8,    5HTE = ,D15.8 ,4H PE=,D15.8,4H P1=,D12.5)
      WRITE(6,55)PGM,PGT,PT1,TT1,SLOC,HTOT
      GOTO20
  190 CONTINUE
      IS=IS+1
      IOF=1
      TAB=1.
      IF(ISTOP.EQ.1) GO TO 95
      IF(ITAB)90,90,112
  112 GOTO(115,115,90),IS
  115 CONTINUE
```

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```
00552                 IF(IUNIT)189,189,125
00555             125 IF(IUNIT.NE.7)GOTO130
00557                 IF(IUNIT.EQ.0)GOTO90
00561                 GOTO(131,132),IS
00562             131 WRITE(7,140)HEADER,IOF,ITAB
00567                 WRITE(7,145)TAB
00572             132 SS=SLOC*CONVR
00573                 WRITE(7,145)SS,I
00577                 WRITE(7,148)((EM(J),ZER(J),GAMZ(J),TOT(J),POT(J)),J=1,I)
00611             140 FORMAT(4A6,5X,I3,7X,I1,4X,I1)
00612             145 FORMAT(E10.5,7X,I3)
00613             148 FORMAT(5E10.5)
00614                 GOTO189
00615             130 CONTINUE
00616                 GOTO(151,152),IS
00617             151 WRITE(IUNIT)HEADER,IOF,ITAB
00624                 WRITE(IUNIT)TAB
00627             152 SS=SLOC*CONVR
00630                 WRITE(IUNIT)SS,I
00634                 WRITE(IUNIT)((EM(J),ZER(J),GAMZ(J),TOT(J),POT(J)),J=1,I)
00646             189 GOTO(191,190),IS
00647             191 CONTINUE
00650                 PT1=PS
00651                 PE=PT1
00652                 TE=TT1
00653                 IBR=1
00654                 SAVE(2)= 1.0D0
00655                 CONV=.1D0
00656                 ITIME=2
00657             400 CALLICAL(IWRITE,RHO,GAMA,ITIME)
00660                 HR=JI*UGAM*CONR*TE/(UGAM-1.D0)
00661                 FOF=HTOT-HR
00662                 CALLITSUB(FOF,TE,SAVE,CONV,1D0,IBR)
00663                 GOTO(400,400,400,400,210,410),IBR
00664             410 WRITE(6,215)
00666             215 FORMAT(24H ITSUB WILL NOT CONVERGE    )
00667             210 CONTINUE
00670                 TT1=TE
00671                 ITIME=2
00672                 CALLICAL(IWRITE,RHO,GAMA,ITIME)
00673                 I=1
00674                 IF(PE.LT.200.D0)DELP=10.0D0
00676                 IF(PE.LT.15.0D0)DELP=1.D0
00700                 IF(PE.LT.1.5D0)DELP=.1D0
00702                 IF(PE.LT..15D0)DELP=.01D0
00704                 PMINN=.025D0
00705                 GOTO611
00706              40 CONTINUE
00707              95 CONTINUE
00710                 STOP
00711                 END

      END OF COMPILATION:          3 DIAGNOSTICS.
```

```
@FOR,S ITSUO,.TSUO
HSU IIA -02/19/74-13:31:24 (0,)

SUBROUTINE ITSUO      ENTRY POINT 000211

STORAGE USED: CODE(1) 000230; DATA(0) 000027; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   NERR2$
 0004   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000026 10L      0001    000164 100L     0001    000167 110L     0001    000177 120L     0001    000041 30L
 0001    000062 35L      0001    000071 50L      0000    000007 501F     0000    000011 502F     0001    000113 55L
 0001    000122 70L      0001    000136 75L      0001    000142 80L      0001    000153 90L      0000 D  000000 FOFX
 0000 D  000002 FOFXCK   0000    000021 INJP$    0000 I  000006 NI       0000 D  000004 X

00101              SUBROUTINE ITSUO (FOFY,Y,SAVE,CONV,NTIMES,ITIME)
00101        C     THIS SUBROUTINE PROVIDES ITERATION CONTROL FOR ANY FUNCTION     ITS00200
00101        C        SAVE(4-7)=STORAGE LOCATIONS FOR X AND FOFX                   ITS00300
00101        C     (CONV)-CONVERGENCE CRITERIA                                     ITS00400
00101        C     (NTIMES)-MAX NUMBER OF ITERATIONS                               ITS00500
00103              DOUBLEPRECISIONFOFY,Y,SAVE,CONV,FOFX,FOFXCK,X
00104              DIMENSIONSAVE(8)                                                ITS00600
00105              FOFXCK=SAVE(8)                                                  ITS00800
00105        C     FOFY AND Y ARE DUMMY INPUT ARGUMENTS                            ITS00900
00106              FOFX=FOFY                                                       ITS01000
00107              X=Y                                                             ITS01100
00107        C     CHECK FOR CONVERGENCE                                           ITS01200
00110              IF(ABS (FOFX)-CONV.LE.0.D0)GOTO110
00110        C     ITIME CONTROLS THE TYPE CALCULATION TO BE PERFORMED             ITS01500
00110        C        ITIME=1,FIRST TIME THROUGH                                   ITS01600
00110        C     ITIME=2,POS FIRST TIME THROUGH                                  ITS01700
00110        C       ITIME=3,NEG FIRST TIME THROUGH                                ITS01800
00110        C       ITIME=4,SOLUTION IS BRACKETED                                 ITS01900
00110        C       ITIME=5,SOLUTION HAS CONVERGED                                ITS02000
00110        C       ITIME=6,SOLUTION WILL NOT CONVERGE                            ITS02100
00112              GOTO(10,30,50,70),ITIME                                         ITS02200
00112        C     INITIALIZE                                                      ITS02300
00113           10 NI=1                                                            ITS02400
00114              ITIME=2                                                         ITS02500
00115              FOFXCK=FOFX                                                     ITS02600
00116              SAVE(8)=FOFXCK                                                  ITS02700
00117              IF(FOFX.LT.0.D0)GOTO50
00121           30 IF(FOFX.LT.0.D0)GOTO70
00123              IF(FOFXCK.GE.FOFX)GOTO35                                        ITS03000
00125              SAVE(2)=-1.D0*SAVE(2)
```

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```
00126               X=X-2.DO*SAVE(2)
00127               GOTO90                                                 ITS03300
00130            35 SAVE(4)=X                                              ITS03400
00131               SAVE(5)=FOFX                                           ITS03500
00132               X=X-SAVE(2)                                            ITS03600
00132       C       OF ONE VARIABLE                                        ITS03700
00132       C       (FOFX)-FUNCTION WHICH IS DRIVEN TO ZERO                ITS03800
00132       C       (X)-VARIABLE WHICH IS ITERATIVELY SOLVED FOR           ITS03900
00132       C       (SAVE)-PROGRAM CONTROL                                 ITS04000
00132       C           SAVE(2)=X INCREMENT                                ITS04200
00132       C           SAVE(3)=COUNTER DENOTING NTH ITERATION             ITS04300
00133               GOTO90                                                 ITS04400
00134            50 ITIME=3                                                ITS04500
00135               IF(FOFX.GT.0.D0)GOTO70
00137               IF(FOFXCK.LE.FOFX)GOTO55                               ITS04700
00141               SAVE(2)=-1.D0*SAVE(2)
00142               X=X+2.D0*SAVE(2)
00143               GOTO90                                                 ITS05000
00144            55 SAVE(6)=X                                              ITS05100
00145               SAVE(7)=FOFX                                           ITS05200
00146               X=X+SAVE(2)                                            ITS05300
00147               GOTO90                                                 ITS05400
00150            70 ITIME=4                                                ITS05500
00151               IF(FOFX.LT.0.D0)GOTO75
00153               SAVE(4)=X                                              ITS05800
00154               SAVE(5)=FOFX                                           ITS05900
00155               GOTO80                                                 ITS06000
00156            75 SAVE(6)=X                                              ITS06100
00157               SAVE(7)=FOFX                                           ITS06200
00157       C         PICK NEW GUESS FOR X ACCORDING TO TYPE CALCULATION   ITS06300
00160            80 X=SAVE(4)-SAVE(5)*((SAVE(6)-SAVE(4))/(SAVE(7)-SAVE(5)))  ITS06400
00161            90 IF(NI.GE.NTIMES)GOTO100                                ITS06500
00163               NI=NI+1                                                ITS06600
00164               GOTO120                                                ITS06800
00165           100 ITIME=6                                                ITS06900
00166               GOTO120                                                ITS07000
00167           110 ITIME=5                                                ITS07100
00170               SAVE(4)=X                                              ITS07200
00171               SAVE(5)=FOFX                                           ITS07300
00172               SAVE(6)=X                                              ITS07400
00173               SAVE(7)=FOFX                                           ITS07500
00174           120 CONTINUE
00175           501 FORMAT(1X,5I5)
00176           502 FORMAT(1X,4D12.5,/1X,8D12.5)
00177               Y=X                                                    ITS07700
00200               RETURN                                                 ITS07800
00201               END                                                    ITS07900

END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,S ITSUB,ITSUB
HSD IIA -02/19/74-13:31:25 (0,)

   SUBROUTINE ITSUB      ENTRY POINT 000211

   STORAGE USED: CODE(1) 000230; DATA(0) 000211; BLANK COMMON(2) 000000

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003     NERR2$
    0004     NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000026 10L       0001    000164 100L      0001    000167 110L      0001    000177 120L      0001     000041 30L
    0001     000062 35L       0001    000071 50L       0001    000113 55L       0001    000122 70L       0001     000136 75L
    0001     000142 80L       0001    000153 90L       0000 D  000000 FOFX      0000 D  000002 FOFXCK    0000     000013 INJP$
    0000 I   000006 NI        0000 D  000004 X


00101                  SUBROUTINE ITSUB (FOFY,Y,SAVE,CONV,NTIMES,ITIME)
00101        C         THIS SUBROUTINE PROVIDES ITERATION CONTROL FOR ANY FUNCTION          ITS00200
00101        C            SAVE(4-7)=STORAGE LOCATIONS FOR X AND FOFX                        ITS00300
00101        C         (CONV)-CONVERGENCE CRITERIA                                          ITS00400
00101        C         (NTIMES)-MAX NUMBER OF ITERATIONS                                    ITS00500
00103                  DOUBLEPRECISIONFOFY,Y,SAVE,CONV,FOFX,FOFXCK,X
00104                  DIMENSIONSAVE(8)                                                     ITS00600
00105                  FOFXCK=SAVE(8)                                                       ITS00800
00105        C         FOFY AND Y ARE DUMMY INPUT ARGUMENTS                                 ITS00900
00106                  FOFX=FOFY                                                            ITS01000
00107                  X=Y                                                                  ITS01100
00107        C         CHECK FOR CONVERGENCE                                                ITS01200
00110                  IF(ABS (FOFX)-CONV.LE.0.)GOTO110                                     ITS01300
00110        C         ITIME CONTROLS THE TYPE CALCULATION TO BE PERFORMED                  ITS01500
00110        C            ITIME=1,FIRST TIME THROUGH                                        ITS01600
00110        C         ITIME=2,POS FIRST TIME THROUGH                                       ITS01700
00110        C           ITIME=3,NEG FIRST TIME THROUGH.                                    ITS01800
00110        C           ITIME=4,SOLUTION IS BRACKETED                                      ITS01900
00110        C           ITIME=5,SOLUTION HAS CONVERGED                                     ITS02000
00110        C           ITIME=6,SOLUTION WILL NOT CONVERGE                                 ITS02100
00112                  GOTO(10,30,50,70),ITIME                                              ITS02200
00112        C         INITIALIZE                                                           ITS02300
00113              10  NI=1                                                                 ITS02400
00114                  ITIME=2                                                              ITS02500
00115                  FOFXCK=FOFX                                                          ITS02600
00116                  SAVE(8)=FOFXCK                                                       ITS02700
00117                  IF(FOFX.LT.0.)GOTO50                                                 ITS02800
00121              30  IF(FOFX.LT.0.)GOTO70                                                 ITS02900
00123                  IF(FOFXCK.GE.FOFX)GOTO35                                             ITS03000
00125                  SAVE(2)=-1.*SAVE(2)                                                  ITS03100
```

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00126            X=X-2.*SAVE(2)                                       ITS03200
00127            GOTO90                                               ITS03300
00130         35 SAVE(4)=X                                            ITS03400
00131            SAVE(5)=FOFX                                         ITS03500
00132            X=X-SAVE(2)                                          ITS03600
00132      C     OF ONE VARIABLE                                      ITS03700
00132      C     (FOFX)-FUNCTION WHICH IS DRIVEN TO ZERO              ITS03800
00132      C     (X)-VARIABLE WHICH IS ITERATIVELY SOLVED FOR         ITS03900
00132      C     (SAVE)-PROGRAM CONTROL                               ITS04000
00132      C        SAVE(2)=X INCREMENT                               ITS04200
00132      C        SAVE(3)=COUNTER DENOTING NTH ITERATION            ITS04300
00133            GOTO90                                               ITS04400
00134         50 ITIME=3                                              ITS04500
00135            IF(FOFX.GT.0.)GOTO70                                 ITS04600
00137            IF(FOFXCK.LE.FOFX)GOTO55                             ITS04700
00141            SAVE(2)=-1.*SAVE(2)                                  ITS04800
00142            X=X+2.*SAVE(2)                                       ITS04900
00143            GOTO90                                               ITS05000
00144         55 SAVE(6)=X                                            ITS05100
00145            SAVE(7)=FOFX                                         ITS05200
00146            X=X+SAVE(2)                                          ITS05300
00147            GOTO90                                               ITS05400
00150         70 ITIME=4                                              ITS05500
00151            IF(FOFX.LT.0.)GOTO75                                 ITS05700
00153            SAVE(4)=X                                            ITS05800
00154            SAVE(5)=FOFX                                         ITS05900
00155            GOTO80                                               ITS06000
00156         75 SAVE(6)=X                                            ITS06100
00157            SAVE(7)=FOFX                                         ITS06200
00157      C       PICK NEW GUESS FOR X ACCORDING TO TYPE CALCULATION ITS06300
00160         80 X=SAVE(4)-SAVE(5)*((SAVE(6)-SAVE(4))/(SAVE(7)-SAVE(5)))  ITS06400
00161         90 IF(NI.GE.NTIMES)GOTO100                              ITS06500
00163            NI=NI+1                                              ITS06600
00164            GOTO120                                              ITS06800
00165        100 ITIME=6                                              ITS06900
00166            GOTO120                                              ITS07000
00167        110 ITIME=5                                              ITS07100
00170            SAVE(4)=X                                            ITS07200
00171            SAVE(5)=FOFX                                         ITS07300
00172            SAVE(6)=X                                            ITS07400
00173            SAVE(7)=FOFX                                         ITS07500
00174        120 CONTINUE
00175            Y=X                                                  ITS07700
00176            RETURN                                               ITS07800
00177            END                                                  ITS07900

END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,S ITERAT,ITERAT
MSD IIA -02/19/74-13:31:28 (0,)

SUBROUTINE ITERAT     ENTRY POINT 000101

STORAGE USED: CODE(1) 000130; DATA(0) 000070; BLANK COMMON(2) 000000

COMMON BLOCKS:

0003   INPUT  000030

EXTERNAL REFERENCES (BLOCK, NAME)

0004   ITSUB
0005   NERR2$
0006   NRDU$
0007   NIO2$
0010   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0001     000013 1CL    0001     000071 15L    0001     000055 20L      0000     000027 25F    0003 D 000012 A
0003 D 000006 AO       0003 D 000014 B        0003 D 000010 BO         0003 D 000016 C       0000 D 000024 CONV
0000 D 000022 FOF      0000 I 000026 IBR      0000     000050 INJP$    0003 D 000024 OCV     0003 D 000022 OGAM
0000 D 000000 PA       0003 D 000004 PE       0003 D 000000 PT1        0003 D 000020 R       0000 D 000002 SAVE
0003 D 000026 TE       0003 D 000002 TT1


00101          SUBROUTINEITERAT(PR,T,E1,E2,E3,RHO,ITIME)
00103          COMMON/INPUT/PT1,TT1,PE,AO,BO,A,B,C,R,OGAM,OCV,TE
00104          DOUBLEPRECISIONPR,T,E1,E2,E3,RHO,PA,SAVE,FOF,CONV,R,PT1,TT1,PE,
00104         * AO,BO,A,B,C,OGAM,OCV,TE
00105          DIMENSIONSAVE(8)
00106          RHO=PR/(R*T)
00107          IBR=1
00110          SAVE(2)=.1D0
00111          CONV=.0000000001D0
00112       10 PA=RHO*R*T*(1.D0+RHO*(E1+RHO*(E2+RHO*E3)))
00113          FOF=PR-PA
00114          CALLITSUB(FOF,RHO,SAVE,CONV,100,IBR)
00115          GOTO(10,10,10,10,15,20),IBR
00116       20 WRITE(6,25)PR,R,T,RHO,FOF
00125       25 FORMAT(3X38HITSUB WILL NOT CONVERGE,P,R,T,RHO,FOF=,5D12.5)
00126          ITIME=1001
00127       15 CONTINUE
00130          RETURN
00131          END

END OF COMPILATION:        NO  DIAGNOSTICS.
```

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```
@FOR,S PERGAS,PERGAS
HSD IIA -02/19/74-13:31:30 (0,)

   SUBROUTINE PERGAS     ENTRY POINT 000073

   STORAGE USED: CODE(1) 000105; DATA(0) 000034; BLANK COMMON(2) 000000

    COMMON BLOCKS:

    0003   INPUT  000030

   EXTERNAL REFERENCES (BLOCK, NAME)

    0004    XPDD
    0005    DSQRT
    0006    NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001     000060 10L        0001     000015 20L        0003 D 000012 A       0003 D 000006 A0       0003 D 000014 B
    0003 D 000010 B0           0003 D 000016 C            0000 D 000006 FACT1   0000 D 000010 FACT2    0000 D 000014 FACT3
    0003 D 000022 GAMA         0000 D 000004 GM1OG        0000 D 000000 GM102   0000 D 000002 GM102I   0000   000026 INJP$
    0003 D 000024 OCV          0003 D 000004 P            0003 D 000000 P0      0003 D 000020 R        0003 D 000026 T
    0003 D 000002 T0           0000 D 000012 XM


            SUBROUTINE PERGAS(PM,PT,IERROR,PMIN)
            DOUBLE PRECISION PM,PT,P0,T0,P,A0,B0,A,B,C,R,GAMA,OCV,T,GM102,
           1GM102I,GM1OG,FACT1,FACT2,XM,FACT3
            COMMON/INPUT/P0,T0,P,A0,B0,A,B,C,R,GAMA,OCV,T
            GM102 =(GAMA-1.)/2.
            GM102I = 1./GM102
            GM1OG = (GAMA-1.)/GAMA
         20 CONTINUE
            FACT1 = ((P0/P)**GM1OG)-1.
            FACT2 = FACT1*GM102I
            XM =DSQRT(FACT2)
            FACT3 = (1.+GM102*XM**2)
            T = T0*(1./FACT3)
            IF(T.GT.70.0D0)GO TO 10
            P = P + 0.001D0
            IERROR = 1
            PMIN = P
            GO TO 20
         10 CONTINUE
            PM = XM
            PT = T
            RETURN
            END
```

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```
END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,S SINH,SINH
HSD 11A -02/19/74-13:31:31 (0,)

   FUNCTION SINH          ENTRY POINT 000030

   STORAGE USED: CODE(1) 000034; DATA(0) 000021; BLANK COMMON(2) 000000

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   DEXP
    0004   NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0000 D 000003 E1        0000 D 000005 E2        0000   000011 INJP$      0000 R 000000 SINH       0000 D 000001 SNHARG


00101                  FUNCTION SINH(A)
00103                  DOUBLE PRECISION A,SNHARG,E1,E2
00104                  SNHARG = A
00105                  E1 =DEXP(A)
00106                  E2 =DEXP(-A)
00107                  SINH = 0.5*(E1-E2)
00110                  RETURN
00111                  END

      END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,S ICAL,ICAL
HSD IIA -02/19/74-13:31:33 (0,)

SUBROUTINE ICAL       ENTRY POINT 001121

STORAGE USED: CODE(1) 001155; DATA(0) 000347; BLANK COMMON(2) 000000

 COMMON BLOCKS:

 0003    INPUT   000030
 0004    FACTOR  000012
 0005    SFACT   000004

EXTERNAL REFERENCES (BLOCK, NAME)

 0006    ITERAT
 0007    XPDI
 0010    DSINH
 0011    NWDU$
 0012    NI01$
 0013    NI02$
 0014    DEXP
 0015    XPDD
 0016    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000055 116G     0001     000213 133G     0000     000140 151F     0001     000442 173G     0001     000377 30L
 0001     000401 40L      0000     000142 50F      0000     000176 60F      0001     000501 65L      0000     000210 70F
 0001     001077 80L      0001     001103 90L      0003 D 000012 A        0003 D 000006 A0       0003 D 000014 B
 0003 D 000010 B0       0003 D 000016 C        0005 D 000000 CAPE     0000 D 000014 CAPEN2   0000 D 000016 CAPE02
 0005 D 000002 CAPF     0000 D 000074 CAPF1    0000 D 000076 CAPF2    0000 D 000100 CAPF3    0000 D 000062 CAPG
 0000 R 000137 CAPGN2   0000 D 000060 CAPG02   0000 D 000054 CP       0000 D 000050 CPFAC1   0000 D 000052 CPFAC2
 0000 D 000046 CV       0000 D 000044 CVVIB    0000 D 000034 EA       0000 D 000036 EB       0000 D 000040 EC
 0000 D 000006 EN2DEN   0000 D 000004 EN2NUM   0000 D 000012 E02DEN   0000 D 000010 E02NUM   0000 D 000020 E1
 0000 D 000022 E2       0000 D 000024 E3       0000 D 000120 G        0000 D 000026 GFAC     0000 I 000134 I
 0000 I 000136 ICOUNT   0000     000310 INJP$     0000 D 000056 IPROP    0004 D 000000 I1       0000 I 000135 J
 0000 D 000064 JFAC1    0000 D 000066 JFAC2    0000 D 000070 JFAC3    0000 D 000072 JPROP    0004 D 000006 JT
 0004 D 000002 J1       0000 D 000142 KPROP    0004 D 000010 KT       0004 D 000004 K1       0003 D 000024 OCV
 0003 D 000022 OGAM     0003 D 000004 PE       0003 D 000000 PT1      0003 D 000020 R        0000 D 000030 RHO
 0000 D 000104 RT1      0003 D 000026 TE       0003 D 000002 TT1      0000 D 000032 T1       0000 D 000000 XCPGN2
 0000 D 000002 XCPG02   0000 D 000042 Z

00000  *DIAGNOSTIC*  THE NAME CAPGN1 APPEARS IN A DIMENSION OR TYPE STATEMENT BUT IS NEVER REFERENCED.
00101      1*          SUBROUTINE ICAL(IWRITE,RHO1,GAMMA,ITIME)
00103      2*          DOUBLE PRECISION    XCPGN2,XCPG02,EN2NUM,EN2DEN,E02NUM,E02DEN,
00103      3*         $ CAPEN2,CAPE02
00104      4*          DOUBLE PRECISION E1,E2,E3,GFAC,RHO,T1,EA,EB,EC,Z,CVVIB,CV,CPFAC1,
00104      5*         1CPFAC2,CP,IPROP,CAPGN1,CAPG02,CAPG,JFAC1,JFAC2,JFAC3,JPROP,CAPE,
```

```
     2CAPF1,CAPF2,CAPF3,CAPF,KPROP,RTI,G,PTI,TTI,PE,AO,BO,A,B,C,R,OGAM,
     3OCV,TE,II,JI,KI,JT,KT,RHOI,GAMMA
      COMMON/INPUT/PTI,TTI,PE,AO,BO,A,B,C,R,OGAM,OCV,TE
      COMMON/FACTOR/II,JI,KI,JT,KT
      COMMON/SFACT/CAPE,CAPF
      DIMENSION RTI(6),G(6)
C     CALCULATION OF DENSITY
C     UNITS OF VARIABLES E ARE FT**3/LB-MOLE
C     UNITS OF VARIABLES G ARE IN**2/LBF
      E1 = BO-(AO/(R*TE))-C/TE**3
  151 FORMAT(1X,7D12.5)
      E2 = AO*A/(R*TE)-BO*B-BO*C/TE**3
      E3 = (BO*B*C)/TE**3
      DO 10 I=1,6
      RTI(I) = R*TE**I
   10 CONTINUE
      G(1)= -E1/RTI(1)
      G(2)= (2.0*E1**2-E2)/RTI(2)
      G(3)= (5.0*(E2-E1**2)-E3)/RTI(3)
      G(4)= (6.0*E1*E3+3.0*E2**2+(7.0*E1**2)*(2.0*E1**2-3.0*E2))/RTI(4)
      G(5)= 7.0*(E2*E3-4.0*E1*(E2**2+E1*E3)+(6.0*E1**3)*(2.0*E2-E1**2))
     $      /RTI(5)
      G(6)= (6.0*((10.0*E1**2)*(3.0*E2**2+2.0*E1*E3)+(11.0*E1**4)
     $      *(2.0*E1**2-5.0*E2)-2.0*E2**2)+E3*(4.0*E3-73.0*E1*E2))/RTI(6)
      GFAC = 1.0
      DO 20 I=1,6
      GFAC = GFAC + G(I)*PE**I
   20 CONTINUE
C     THE REAL GAS DENSITY IS NOW COMPUTED
                         CALLITERAT(PE,TE,E1,E2,E3,RHOI,ITIME)
      RHO=RHOI
      T7=TE
      EA=E1
      EB=E2
      EC=E3
C     THE RATIO OF SPECIFIC HEATS CALCULATION
C     VIBRATIONAL CONTRIBUTION FOR AIR
      IF(ITIME.EQ.1) GO TO 30
      Z=.06856100
      CVVIB = ((706.85DC/TE)/SINH(3054.9DO/TE))**2
     *           +((245.22DO/TE)/SINH(2046.1DO/TE))**2
      CV = OCV + CVVIB+(6.0*Z*C*RHO/TE**3) *(1.0+BO*RHO/2.0-BO*B*RHO**2
     $/3.0)
      CPFAC1 =((1.0+2.0*C*RHO/TE**3)*(1.0+BO*RHO-BO*B*RHO**2))**2
      CPFAC2 =(1.0+2.0*E1*RHO+3.0*E2*RHO**2+4.0*E3*RHO**3)
      CP = CV + Z*(CPFAC1/CPFAC2)
      GAMMA = CP/CV
      GO TO 40
   30 CONTINUE
      GAMMA = OGAM
   40 CONTINUE
C     CALCULATION OF IPROP
      IPROP = (GAMMA/OGAM)*(1.0+2.0*E1*RHO+3.0*E2*RHO**2+4.0*E3*RHO**3)
      IF(IWRITE.GT.0)WRITE(6,50)ITIME,E1,E2,E3,(G(J),J=1,6),GFAC,RHO,
     $GAMMA,IPROP
      IF(IWRITE.GT.0.AND.ITIME.GT.1)WRITE(6,60)CVVIB,CV,CP
```

```
C**** CALCULATION OF JPROP FACTOR USING CAPG
      ICOUNT = 0
   65 CONTINUE
C***  CAPG FOR AIR FROM REFERENCE EQ. 74
      CAPGN2 =  (-4770.9D0/TI)/(1.0-DEXP(6109.7D0/TI))
      CAPGO2 =  (-857.29D0/TI)/(1.0-DEXP(4092.1D0/TI))
      CAPG = CAPGN2+CAPGO2
      JFAC1 = RHO*(B0-(2.0*A0/(R*TI))-4.0*C/TI**3)
      JFAC2 = RHO**2*((3.0*A0*A/(2.0*R*TI))-5.0*B0*C/(2.0*TI**3)-B0*B)
      JFAC3 = RHO**3*(2.0*B0*B*C/TI**3)
      JPROP = 1.0+((OGAM-1.0)/OGAM)*(CAPG+JFAC1+JFAC2+JFAC3)
C**** CALCULATION OF KPROP FACTOR USING CAPE AND CAPF
C**   CAPE FROM REFERENCE EQ. 75
      XCPGN2 = CAPGN2/0.7808D0
      XCPGO2 = CAPGO2/0.2095D0
      EN2NUM = DEXP(XCPGN2)
      EN2DEN = 1.0-DEXP(-6109.7D0/TI)
      EO2NUM = DEXP(XCPGO2)
      EO2DEN = 1.0-DEXP(-4092.1D0/TI)
      CAPEN2 = (EN2NUM/EN2DEN)**(0.7808D0)
      CAPEO2 = (EO2NUM/EO2DEN)**(0.2095D0)
      CAPE = CAPEN2*CAPEO2
C**   CAPF FROM REFERENCE EQ. 38
      CAPF1 = RHO*(B0+2.0*C/TI**3)
      CAPF2 = RHO**2*((B0*C/TI**3)-B0*B/2.0)
      CAPF3 = RHO**3*2.0*B0*B*C/(3.0*TI**3)
      CAPF =DEXP(CAPF1+CAPF2-CAPF3)
      KPROP = (CAPE/CAPF)*(1.0+EA*RHO+EB*RHO**2+EC*RHO**3)
      IF(IWRITE.GT.0)WRITE(6,70)RHO,CAPG,JPROP,CAPE,CAPF,KPROP
   50 FORMAT(1H0,37HIN SUBROUTINE ICAL FOR ITERATION NO. ,I3,9HE(1-3) =
     1,3D20.12,/1H ,9HG(1-6) = ,6D20.12,/1H ,6H GFAC=,D20.12,5H RHO=,D20
     2.12,7H GAMMA=,D20.12,7H IPROP=,D20.12)
   60 FORMAT(1H0,7H CVVIB=,D20.12,2X,4H CV=,D20.12,2X,4H CP=,D20.12)
   70 FORMAT(1H0,5H RHO=,D20.12,6H CAPG=,D20.12,7H JPROP=,D20.12,6H CAPE
     1=,D20.12,6H CAPF=,D20.12,/7H KPROP=,D20.12)
      IF(ITIME.EQ.1.AND.ICOUNT.EQ.1) GO TO 80
      I1 = IPROP
      J1 = JPROP
      K1 = KPROP
      IF(ITIME.GT.1) GO TO 90
      RHO = PT1/(R*TT1)
      TI = TT1
      EA = B0*(A0/(R*TI))-C/TI**3
      EB =  A0*A/(R*TI)-B0*B-B0*C/TI**3
      EC = B0*B*C/TI**3
      ICOUNT=1
      GO TO 65
   80 CONTINUE
      JT = JPROP
      KT = KPROP
   90 CONTINUE
      RETURN
      END
```

END OF COMPILATION: 1 DIAGNOSTICS.

Appendix B

LISTING OF THE NONSTANDARD EQUATION OF STATE PROGRAM FOR FREON 14 (CF_4)

```
[illegible] MAIN,MAIN
[illegible] -02/20/74-21:26:45 (0,)

MAIN PROGRAM

STORAGE USED: CODE(1) 001017; DATA(0) 005150; BLANK COMMON(2) 000033

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   STATE
 0004   NEATS
 0005   DSR
 0006   SOUND
 0007   ETHAL
 0010   SOLVE
 0011   PRES
 0012   ITSUB
 0013   NINTR$
 0014   NRDU$
 0015   NIO2$
 0016   NIO3$
 0017   NERTS$
 0020   SQRT
 0021   NERR2$
 0022   NWDU$
 0023   NIO1$
 0024   NRBU$
 0025   NSTOP$
```



```
STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0000   004776 100F     0000   005000 101F     0001   000515 115L     0001   000610 130L     0001   000534 131L
 0001   000555 132L     0000   005111 140F     0000   005115 145F     0000   005120 148F     0001   000617 151L
 0001   000636 152L     0001   000666 189L     0001   000174 19L      0001   000473 190L     0001   000675 191L
 0000   005002 200F     0000   005101 201F     0000   005042 202F     0000   005043 203F     0000   005110 204F
 0000   005107 205F     0000   005100 206F     0001   000773 210L     0000   005122 215F     0001   000272 2626
 0001   000473 3L       0000   004775 300F     0000   005105 301F     0001   001013 303L     0001   000710 400L
 0001   000766 410L     0001   000577 4176     0001   000656 4546     0001   000457 5L       0001   000463 7L
 0001   000112 90L      0002 R 000025 AJ       0002 R 000016 AK       0002 R 000017 ALPHA    0002 R 000020 AL4
 0000 R 004746 AM       0002 R 000000 A2       0002 R 000001 A3       0002 R 000002 A4       0002 R 000003 A5
 0002 R 000004 A6       0002 R 000015 BLIT     0002 R 000021 BL4      0002 R 000005 B2       0002 R 000006 B3
 0002 R 000007 B4       0002 R 000010 B5       0002 R 000011 B6       0000 R 004744 CF       0002 R 000022 CL4
 0000 R 004771 CONV     0000 R 004720 CONVR    0000 R 004760 CP       0000 R 004735 CPO      0000 R 004757 CV
 0000 R 004734 CVO      0002 R 000012 C2       0002 R 000013 C3       0002 R 000014 C5       0000 R 004726 DELTT
 0002 R 000023 DL4      0005 R 000000 DSR      0000 R 000010 EM       0000 R 004723 EMMAX    0007 R 000000 ETHAL
 0000 R 004773 FOF      0000 R 004761 GAM      0000 R 004736 GAMQ     0000 R 001760 GAMZ     0000 R 004764 GAN
 0000 R 004745 GASR     0000 R 004751 GP       0000 R 004762 H        0000 R 004772 HC       0000 R 004714 HEADER
 0000 R 004741 HO       0002 R 000032 HREF     0000 I 004731 I        0000 I 004774 IBR      0000 I 004767 IOF
 0000 I 004732 IS       0000 I 004721 ITAB     0000 I 004722 IUNIT    0000 I 004766 J        0000 I 004753 L
 0000 I 004752 N        0000 R 004756 P        0000 R 004725 PO       0000 R 003730 POT      0002 R 000027 PREF
 [illegible] R 000000 PRES  0000 R 004730 PS   0000 R 004743 PSFA     0002 R 000024 R        0000 R 000000 SAVE
 [illegible] R [illegible]4763 [illegible]  0000 R 004742 SLOC  0000 R 004737 [illegible]  0006 R 000000 SOUND  0002 R 000031 SREF
 [illegible] R [illegible]4740 [illegible]  0000 R 004754 T     0000 R 004770 TAB      0000 R 004727 TMIN     0000 R 004724 TO
 [illegible] [illegible]2744 [illegible]  0000 R 004747 TP      0002 R 000026 TREF     0000 R 004765 U        0000 R 004755 V
```

```
0000 R 004733 VO        0000 R 004750 VP        0002 R 000030 VREF        0000 R 000774 ZER
```

```
      COMMON A2,A3,A4,A5,A6,B2,B3,B4,B5,B6,C2,C3,C5
      COMMON ELIT,AK,ALPHA,AL4,BL4,CL4,DL4,R,AJ
      COMMON TREF,PREF,VREF,SREF,HREF
      DIMENSION SAVE(8),EM(500),ZER(500),GAMZ(500),TOT(500),POT(500)
     *,HEADER(4)
      CONVF=32.174*778.2
      READ(5,300)ITAB,IUNIT
  300 FORMAT(1I5)
      READ(5,100)A2,A3,A4,A5,A6
  100 FORMAT(5E15.8)
      READ(5,100)B2,B3,B4,B5,B6
      READ(5,100)C2,C3,C5
      READ(5,100)ELIT,AK,ALPHA
      READ(5,100)AL4,BL4,CL4,DL4
      READ(5,100)R,AJ
      READ(5,100)TREF,PREF,VREF,SREF,HREF,EMMAX
   90 CONTINUE
    9 READ(5,101)TO,PO,DELTT,TMIN,PS,HEADER
  101 FORMAT(6F10.6)
      IF(TO.LT..5)GOTO303
      I=1
      IS=0
      CALL STATE(PO,TO,VO)
      CALL HEATS(TO,VO,CVO,CPO,GAMO)
      SOSR=OSR(TO,VO)
      SS=SOUND(TO,VO,GAMO)
      HO=HREF+ETHAL(TO,VO)
   19 CONTINUE
      PRINT 205
      SLCC=SOSR
      PRINT 200,PO,TO,VO,CVO,CPO,GAMO,SOSR,HO,SS
      PSFA=PO*144.
      CF=PO*VO/(R*TO)
      GASR=1545.2*32.174*CF/88.01
      AM=0.0
      EM(I)=AM
      ZER(I)=GASR
      GAMZ(I)=GAMO
      TOT(I)=TO
      POT(I)=PSFA
  200 FORMAT(1X,3HPO=,E15.8,4HPSIA,3X,3HTO=,E15.8,5HDEG R,3X,
     13HVO=,E15.8,6HFT3/LB,3X,4HCVO=,E15.8,3X,4HCPO=,E15.8,/
     21X,6HGAMMA=,E15.8,3X,8HENTROPY=,E15.8,3X,9HENTHALPY=,E15.8,
     33X,15HSPEED OF SOUND=,E15.8)
      PRINT 202
  202 FORMAT(//)
      PRINT 203
  203 FORMAT(2X,11HTEMPERATURE,5X,6HVOLUME,8X,8HPRESSURE,9X,
     15HDELTA,10X,5HCSUBF,10X,5HGAMMA,/4X,8HENTHALPY,6X,7HENTROPY,
     27X,11HSOUND SPEED,5X,8HVELOCITY,8X,8HMACH NO.,5X,11HCOMP FACTOR)
      PRINT 204
```

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```
  206 FORMAT(/)
      TP=TC
      VP=VC
      GP=GAMO
      M=1
      L=0
      DO 1 I=1,250
      T=TP-DELTT
      IF(T-TMIN)3,2,2
    2 CALL SOLVE(T,V,TP,VP,GP,SOSR)
      P=PRES(T,V)
      CALL HEATS(T,V,CV,CP,GAM)
      H=ETHAL(T,V)+HREF
      SISR=DSR(T,V)
      SS=SOUND(T,V,GAM)
      U=SQRT(2.0*32.17*778.16*(HO-H))
      AM=U/SS
      CF=P*V/(R*T)
      PRINT 201,T,V,P,CV,CP,GAM,H,SISR,SS,U,AM,CF
  201 FORMAT(1X,6E15.8,/1X,6E15.8)
      PSFA=P*144.
      CASR= 1545.2*32.174*CF/88.01
      M=M+1
      EM(M)=AM
      ZEP(M)=GASR
      GAM2(M)=GAM
      TOT(M)=T
      TOT(M)=T
      POT(M)=PSFA
      IF(AM.GT.EMMAX)GOTO3
  301 FORMAT(5E10.5,4A6)
      J=I-L
      IF(J-11)5,6,6
    6 PRINT 205
  205 FORMAT(1H1)
      PRINT 203
      L=I
      GO TO 7
    5 PRINT 204
  204 FORMAT(/)
    7 TP=T
      VP=V
    1 GP=GAM
    3 CONTINUE
  190 CONTINUE
      IS=IS+1
      IOF=1
      FAF=1.
      IF(ITAB)90,90,112
  112 GOTO(115,115,90),IS
  115 CONTINUE
      IF(IUNIT)189,189,125
  125 IF(IUNIT.NE.7)GOTO130
      IF(IUNIT.EQ.5)GOTO90
      GOTO(131,...,32),IS
  131 WRITE(7,140)FACER,IOF,ITAB
```

```
          WRITE(7,145)TAB
  132     SS=SLOC*CONVR
          WRITE(7,145)SS,M
          WRITE(7,148)((EM(J),ZER(J),GAMZ(J),TOT(J),POT(J)),J=1,M)
  140     FORMAT(4A6,5X,I3,7X,I1,4X,I1)
  145     FORMAT(E10.5,7X,I3)
  148     FORMAT(5E10.5)
          GOTO189
  130     CONTINUE
          GOTO(151,152),IS
  151     WRITE(IUNIT)HEADER,IOF,ITAB
          WRITE(IUNIT)TAB
  152     SS=SLOC*CONVR
          WRITE(IUNIT)SS,M
          WRITE(IUNIT)((EM(J),ZER(J),GAMZ(J),TOT(J),POT(J)),J=1,M)
  189     GOTO(191,190),IS
  191     CONTINUE
          IF(ITAB.EQ.1)GOTO90
          PO=PS
          SAVE(1)=1.
          SAVE(2)= 1.0
          CONV=.01
  400     CALLSTATE(PO,TO,VO)
          CALLHEATS(TO,VO,CVO,CPO,GAMO)
          HC=HREF+ ETHAL(TO,VO)
          FOF=HC-HO
          CALLITSUB(FOF,TO,SAVE,CONV,100)
          IBR=SAVE(1)
          GOTO(400,400,400,400,210,410),IBR
  410     WRITE(6,215)
  215     FORMAT(24H ITSUB WILL NOT CONVERGE    )
  210     CONTINUE
          I=1
          SOSF=BSR(TO,VO)
          SS=SOUND(TO,VO,GAMO)
          HO=HC
          GOTO19
  303     CONTINUE
          STOP
          END

END OF COMPILATION:        NO  DIAGNOSTICS.
```

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SUBROUTINE STATE ENTRY POINT 000167

STORAGE USED: CODE(1) 000207; DATA(0) 000055; BLANK COMMON(2) 000033

EXTERNAL REFERENCES (BLOCK, NAME)

0003	ITSUB
0004	EXP
0005	NERR2$
0006	NERR3$

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0001		000153	1L	0000		000022	15F	0001		000056	2L	0001		000153	3L	0002		000025	AJ
0002	R	000016	AK	0002	R	000017	ALPHA	0002		000020	AL4	0002	R	000000	A2	0002	R	000001	A3
0002	R	000002	A4	0002	R	000003	A5	0002	R	000004	A6	0002	R	000015	BLIT	0002		000021	BL4
0002	R	000005	B2	0002	R	000006	B3	0002	R	000007	B4	0002	R	000010	B5	0002	R	000011	B6
0002		000022	CL4	0000	R	000016	CONV	0002	R	000012	C2	0002	R	000013	C3	0002	R	000014	C5
0002		000023	DL4	0000	R	000010	EKT	0000	R	000020	FPTV	0002		000032	HREF	0000	I	000021	IBR
0000		000033	INJP$	0002		000027	PREF	0002	R	000024	R	0000	R	000000	SAVE	0002		000031	SREF
0000	R	000017	TD	0002		000026	TREF	0000	R	000011	T2	0000	R	000012	T3	0000	R	000013	T4
0000	R	000014	T5	0000	R	000015	T6	0002		000030	VREF								

```
00101          SUBROUTINE STATE(P,T,V)
00103          COMMON A2,A3,A4,A5,A6,B2,B3,B4,B5,B6,C2,C3,C5
00104          COMMON BLIT,AK,ALPHA,AL4,BL4,CL4,DL4,R,AJ
00105          COMMON TREF,PREF,VREF,SREF,HREF
00106          DIMENSIONSAVE(8)
00107          EKT=EXP(-AK*T)
00110          T2=A2+B2*T+C2*EKT
00111          T3=A3+B3*T+C3*EKT
00112          T4=A4+B4*T
00113          T5=A5+B5*T+C5*EKT
00114          T6=A6+B6*T
00115          V=R*T/P+BLIT
00116          SAVE(1)=1.
00117          SAVE(2)=.001
00120          CONV=.00001
00121        2 TD=V-BLIT
00122          FPTV=P-R*T/TD-T2/TD**2-T3/TD**3-T4/TD**4-T5/TD**5-T6*EXP(ALPHA*V)
00123          CALLITSUB(FPTV,V,SAVE,CONV,1000)
[illegible]    IBR=SAVE(1)
[illegible]    GOTO(2,2,2,2,1,3),IBR
[illegible]  3 CONTINUE
[illegible] 15 FORMAT(1H0,15H NO CONVERGENCE )
[illegible]  1 CONTINUE
```

```
      RETURN
      END

END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
..S HEATS,HEATS
..IA -02/20/74-21:26:50 (0,)

SUBROUTINE HEATS      ENTRY POINT 000233

STORAGE USED: CODE(1) 000255; DATA(0) 000041; BLANK COMMON(2) 000033

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   EXP
 0004   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0002 R 000025 AJ      0002 R 000016 AK     0002 R 000017 ALPHA   0002 R 000020 AL4    0002 R 000000 A2
 0002 R 000001 A3      0002 R 000002 A4     0002 R 000003 A5      0002 R 000004 A6     0002 R 000015 BLIT
 0002 R 000021 BL4     0002 R 000005 B2     0002 R 000006 B3      0002 R 000007 B4     0002 R 000010 B5
 0002 R 000011 B6      0002 R 000022 CL4    0000 R 000000 CVSTR   0002 R 000012 C2     0002 R 000013 C3
 0002 R 000014 C5      0002 R 000023 DL4    0000 R 000002 EKT     0002   000032 HREF   0000   000015 INJP$
 0000 R 000007 PPT     0000 R 000010 PPV    0002   000027 PREF    0002 R 000024 R      0002   000031 SREF
 0000 R 000001 TD      0002   000026 TREF   0000 R 000003 T2      0000 R 000004 T3     0000 R 000005 T5
 0000 R 000006 T6      0002   000030 VREF

      SUBROUTINE HEATS(T,V,CV,CP,GAM)
      COMMON A2,A3,A4,A5,A6,B2,B3,B4,B5,B6,C2,C3,C5
      COMMON BLIT,AK,ALPHA,AL4,BL4,CL4,DL4,R,AJ
      COMMON TREF,PREF,VREF,SREF,HREF
      CVSTR=AL4+BL4*T+CL4*T**2+DL4*T**3
      TD=V-BLIT
      EKT=EXP(-AK*T)
      T2=A2+B2*T+C2*EKT
      T3=A3+B3*T+C3*EKT
      T5=A5+B5*T+C5*EKT
      T6=ALPHA*(A6+B6*T)
      CV=CVSTR-AJ*T*AK*AK*EKT*(C2/TD+C3/(2.0*TD**2)+C5/(4.0*TD**4))
      PPT=R/TD+(B2-AK*C2*EKT)/TD**2+(B3-AK*C3*EKT)/TD**3+B4/TD**4+(B5-AK
     1*C5*EKT)/TD**5+B6*EXP(ALPHA*V)
      PPV=-R*T/TD**2-2.0*T2/TD**3-3.0*T3/TD**4-4.0*(A4+B4*T)/TD**5
     1-5.0*T5/TD**6+T6*EXP(ALPHA*V)
      CP=CV-T*AJ*PPT**2/PPV
      GAM=CP/CV
      RETURN
      END

END OF COMPILATION:      NO DIAGNOSTICS.
```

```
FUNCTION ETHAL        ENTRY POINT 000535

STORAGE USED: CODE(1) 000550; DATA(0) 000074; BLANK COMMON(2) 000033

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   EXP
 0004   ALOG
 0005   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0002 R 000025 AJ      0002 R 000016 AK      0002 R 000017 ALPHA   0002 R 000020 AL4     0002 R 000000 A2
 0002 R 000001 A3      0002 R 000002 A4      0002 R 000003 AS      0002 R 000004 A6      0002 R 000015 BLIT
 0002 R 000021 BL4     0002 R 000005 B2      0002 R 000006 B3      0002 R 000007 B4      0002 R 000010 B5
 0002 R 000011 B6      0002 R 000022 CL4     0002 R 000012 C2      0002 R 000013 C3      0002 R 000014 C5
 0002 R 000023 DL4     0000 R 000003 D1      0000 R 000004 D2      0000 R 000010 EAV     0000 R 000011 EAVR
 0000 R 000001 EKT     0000 R 000002 EKTR    0000 R 000000 ETHAL   0002   000032 HREF    0000   000037 INJP$
 0002   000027 PREF    0002 R 000024 R       0002   000031 SREF    0000 R 000005 TA      0000 R 000006 TB
 0000 R 000007 TC      0000 R 000020 TD      0000 R 000012 TDA     0000 R 000013 TDB     0000 R 000014 TDC
 0000 R 000015 TDD     0000 R 000016 TDE     0000 R 000017 TDF     0000 R 000026 TE      0000 R 000021 TEA
 0000 R 000022 TEB     0000 R 000023 TEC     0000 R 000024 TED     0000 R 000025 TEF     0002 R 000026 TREF
 0002 R 000030 VREF

00101      FUNCTION ETHAL(T,V)
00103      COMMON A2,A3,A4,AS,A6,B2,B3,B4,B5,B6,C2,C3,C5
00104      COMMON BLIT,AK,ALPHA,AL4,BL4,CL4,DL4,R,AJ
00105      COMMON TREF,PREF,VREF,SREF,HREF
00106      EKT=EXP(-AK*T)
00107      EKTR=EXP(-AK*TREF)
00110      D1=VREF-BLIT
00111      D2=V-BLIT
00112      TA=AL4*(T-TREF)+BL4*(T**2-TREF**2)/2.0+CL4*(T**3-TREF**3)/3.0+DL4*
00112     1(T**4-TREF**4)/4.0
00113      TB=AJ*(EKT*(AK*T+1.0)-EKTR*(AK*TREF+1.0))*(C2/D1+C3/(2.0*D1**2)
00113     1+C5/(4.0*D1**4))
00114      TC=R*(T-TREF)/D1+(B2*(T-TREF)+C2*(EKT-EKTR))/D1**2+(B3*(T-TREF)
00114     1+C3*(EKT-EKTR))/D1**3+B4*(T-TREF)/D1**4
00115      TC=AJ*VREF*(TC+(B5*(T-TREF)+C5*(EKT-EKTR))/D1**5+B6*(T-TREF)*
00115     1EXP(ALPHA*VREF))
00116      EAV=EXP(ALPHA*V)
00117      EAVR=EXP(ALPHA*VREF)
00120      TDA=R*T*(ALOG(D2/D1)-BLIT/D2+BLIT/D1)
00121      TDB=2.0*(A2+B2*T+C2*EKT)*(1.0/D1-1.0/D2+BLIT/(2.0*D1**2)-
00121     1BLIT/(2.0*D2**2))
00122      TDC=3.0*(A3+B3*T+C3*EKT)*(BLIT/(3.0*D1**3)-BLIT/(3.0*D2**3)+
```

```
     11.0/(2.0*D1**2)-1.0/(2.0*D2**2))
      TDD=4.0*(A4+B4*T)*(BLIT/(4.0*D1**4)-BLIT/(4.0*D2**4)+
     11.0/(3.0*D1**3)-1.0/(3.0*D2**3))
      TDE=5.0*(A5+B5*T+C5*EKT)*(BLIT/(5.0*D1**5)-BLIT/(5.0*D2**5)+
     11.0/(4.0*D1**4)-1.0/(4.0*D2**4))
      TDF=(A6+B6*T)*(EAV*(ALPHA*V -1.0)-EAVR*(ALPHA*VREF-1.0))/ALPHA
      TD=AJ*(TDA+TDB+TDC+TDD+TDE+TDF)
      TEA=R*T*ALOG(D2/D1)+T*(B2-AK*C2*EKT)*(1.0/D1-1.0/D2)
      TEB=T*(B3-AK*C3*EKT)*(0.5/D1**2-0.5/D2**2)
      TEC=T*B4*(1.0/D1**3-1.0/D2**3)/3.0
      TED=T*(B5-AK*C5*EKT)*(1.0/D1**4-1.0/D2**4)/4.0
      TEF=T*B6*(EAV-EAVR)/ALPHA
      TE=AJ*(TEA+TEB+TEC+TED+TEF)
      ETHAL=TA+TB+TC-TD+TE
      RETURN
      END

END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
FUNCTION DSR          ENTRY POINT 000254

STORAGE USED: CODE(1) 000265; DATA(0) 000033; BLANK COMMON(2) 000033

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   EXP
 0004   ALOG
 0005   NERR3S

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0002 R 000025 AJ      0002 R 000016 AK      0002 R 000017 ALPHA   0002 R 000020 AL4     0002   000000 A2
 0002   000001 A3      0002   000002 A4      0002   000003 A5      0002   000004 A6      0002 R 000015 BLIT
 0002 R 000021 BL4     0002 R 000005 B2      0002 R 000006 B3      0002 R 000007 B4      0002 R 000010 B5
 0002 R 000011 B6      0002 R 000022 CL4     0002 R 000012 C2      0002 R 000013 C3      0002 R 000014 C5
 0002 R 000023 DL4     0000 R 000000 DSR     0000 R 000002 D1      0000 R 000003 D2      0000 R 000001 EKT
 0002   000032 HREF    0000   000013 INJPS   0002   000027 PREF    0002 R 000024 R       0002 R 000031 SREF
 0000 R 000004 TEMP    0002 R 000026 TREF    0002 R 000030 VREF


00101          FUNCTION DSR(T,V)
00103          COMMON A2,A3,A4,A5,A6,B2,B3,B4,B5,B6,C2,C3,C5
00104          COMMON BLIT,AK,ALPHA,AL4,BL4,CL4,DL4,R,AJ
00105          COMMON TREF,PREF,VREF,SREF,HREF
00106          EKT=EXP(-AK*T)
00107          D1=VREF-BLIT
00110          D2=V-BLIT
00111          TEMP=AL4*ALOG(T/TREF)+BL4*(T-TREF)+CL4*(T**2-TREF**2)/2.0+DL4*
00111         1(T**3-TREF**3)/3.0
00112          TEMP=TEMP+AJ*AK*(EKT-EXP(-AK*TREF))*(C2/D2+C3/(2.0*D2**2)
00112         1+C5/(4.0*D2**4))+AJ*R*ALOG(D2/D1)
00113          TEMP=TEMP-AJ*(B2-AK*C2*EKT)*(1.0/D2-1.0/D1)
00113         1-AJ*(B3-AK*C3*EKT)*(1.0/D2**2-1.0/D1**2)/2.0
00114          TEMP=TEMP-AJ*(B5-AK*C5*EKT)*(1.0/D2**4-1.0/D1**4)/4.0-AJ*B4*
00114         1(1.0/D2**3-1.0/D1**3)/3.0
00115          DSR=TEMP+AJ*B6*(EXP(ALPHA*V)-EXP(ALPHA*VREF))/ALPHA+SREF
00116          RETURN
00117          END

   END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,S SOLVE,SOLVE
FOR 11A -02/20/74-21:26:56 (0,)

   SUBROUTINE SOLVE      ENTRY POINT 000110

   STORAGE USED: CODE(1) 000130; DATA(0) 000043; BLANK COMMON(2) 000033

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003   DSR
    0004   ITSUB
    0005   XPRR
    0006   EXP
    0007   NERR2$
    0010   NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0001   000077 1L      0000   000016 1SF     0001   000036 2L     0001   000077 3L     0002   000025 AJ
    0002 R 000016 AK      0002   000017 ALPHA   0002   000020 AL4    0002   000000 A2     0002   000001 A3
    0002   000002 A4      0002   000003 A5      0002   000004 A6     0002 R 000015 BLIT   0002   000021 BL4
    0002   000005 B2      0002   000006 B3      0002   000007 B4     0002   000010 B5     0002   000011 B6
    0002   000022 CL4     0000 R 000012 CONV    0002   000012 C2     0002   000013 C3     0002   000014 C5
    0002   000023 DL4     0003 R 000000 DSR     0000 R 000011 DI     0000 R 000010 EKT    0002   000032 HREF
    0000 I 000015 IBR     0000   000027 INJP$   0002   000027 PREF   0002   000024 R      0000 R 000000 SAVE
    0000 R 000013 SL      0000 R 000014 SOFX    0002   000031 SREF   0002   000026 TREF   0002 R 000030 VREF


00101             SUBROUTINE SOLVE(T,V,TP,VP,GP,SOSR)
00103             COMMON A2,A3,A4,A5,A6,B2,B3,B4,B5,B6,C2,C3,C5
00104             COMMON BLIT,AK,ALPHA,AL4,BL4,CL4,DL4,R,AJ
00105             COMMON TREF,PREF,VREF,SREF,HREF
00106             DIMENSIONSAVE(8)
00107             V=VP*(TP/T)**(1.0/(GP-1.0))
00110             EKT=EXP(-AK*T)
00111             DI=VREF-BLIT
00112             SAVE(1)=1.
00113             SAVE(2)=-DI
00114             CONV= 1.E-03
00115           2 SL=LSR(T,V)
00116             SOFX=SOSR-SL
00117             CALLITSUB(SOFX,V,SAVE,CONV,100)
00120             IBR=SAVE(1)
00121             GOTO(2,2,2,2,1,3),IBR
00122           3 CONTINUE
00123          15 FORMAT(1HOISH NO CONVERGENCE   )
00124           1 CONTINUE
00125             RETURN
00126             END
```

```
END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,S PRES,PRES
MSG 11A -02/20/74-21:26:58 (0,)

    FUNCTION PRES        ENTRY POINT 000105

    STORAGE USED: CODE(1) 000114; DATA(0) 000015; BLANK COMMON(2) 000033

    EXTERNAL REFERENCES (BLOCK, NAME)

     0003   EXP
     0004   NERR3$

    STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

     0002     000025 AJ         0002 R 000016 AK         0002 R 000017 ALPHA      0002   000020 AL4        0002 R 000000 A2
     0002 R   000001 A3         0002 R 000002 A4         0002 R 000003 A5         0002 R 000004 A6         0002 R 000015 BLIT
     0002     000021 BL4        0002 R 000005 B2         0002 R 000006 B3         0002 R 000007 B4         0002 R 000010 B5
     0002 R   000011 B6         0002   000022 CL4        0002 R 000012 C2         0002 R 000013 C3         0002 R 000014 C5
     0002     000023 DL4        0000 R 000001 EKT        0002   000032 HREF       0000   000003 INJPS      0002   000027 PREF
     0000 R   000000 PRES       0002 R 000024 R          0002   000031 SREF       0000 R 000002 TD         0002   000026 TREF
     0002     000030 VREF

  00101      1*            FUNCTION PRES(T,V)
  00103      2*            COMMON A2,A3,A4,A5,A6,B2,B3,B4,B5,B6,C2,C3,C5
  00104      3*            COMMON BLIT,AK,ALPHA,AL4,BL4,CL4,DL4,R,AJ
  00105      4*            COMMON TREF,PREF,VREF,SREF,HREF
  00106      5*            EKT=EXP(-AK*T)
  00107      6*            TD=V-BLIT
  00110      7*            PRES=R*T/TD+(A2+B2*T+C2*EKT)/TD**2+(A3+B3*T+C3*EKT)/TD**3+(A4+B4
  00110      8*           1*T)/TD**4+(A5+B5*T+C5*EKT)/TD**5+(A6+B6*T)*EXP(ALPHA*V)
  00111      9*            RETURN
  00112     10*            END

       END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
*FOR,S SOUND,SOUND
HSD IIA -02/20/79-21:26:59 (0,)

   FUNCTION SOUND        ENTRY POINT 000127

   STORAGE USED: CODE(1) 000140; DATA(0) 000024; BLANK COMMON(2) 000033

   EXTERNAL REFERENCES (BLOCK, NAME)

    0003    EXP
    0004    SQRT
    0005    NERR3$

   STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    0002    000025 AJ      0002 R 000016 AK      0002 R 000017 ALPHA   0002   000020 AL4     0002 R 000000 A2
    0002 R  000001 A3      0002 R 000002 A4      0002 R 000003 A5      0002 R 000004 A6      0002 R 000015 BLIT
    0002    000021 BL4     0002 R 000005 B2      0002 R 000006 B3      0002 R 000007 B4      0002 R 000010 B5
    0002 R  000011 B6      0002   000022 CL4     0002 R 000012 C2      0002 R 000013 C3      0002 R 000014 C5
    0002    000023 DL4     0000 R 000001 EKT     0002   000032 HREF    0000   000011 INJP$   0000 R 000003 PPV
    0002    000027 PREF    0002 R 000024 R       0000 R 000000 SOUND   0002   000031 SREF    0000 R 000002 TD
    0002    000026 TREF    0002   000030 VREF

00101          FUNCTION SOUND(T,V,GAMMA)
00103          COMMON A2,A3,A4,A5,A6,B2,B3,B4,B5,B6,C2,C3,C5
00104          COMMON BLIT,AK,ALPHA,AL4,BL4,CL4,DL4,R,AJ
00105          COMMON TREF,PREF,VREF,SREF,HREF
00106          EKT=EXP(-AK*T)
00107          TD=V-BLIT
00110          PPV=-R*T/TD**2-2.0*(A2+B2*T+C2*EKT)/TD**3-3.0*(A3+B3*T+C3*EKT)/
00110         1TD**4-4.0*(A4+B4*T)/TD**5-5.0*(A5+B5*T+C5*EKT)/TD**6+ALPHA*
00110         2(A6+B6*T)*EXP(ALPHA*V)
00111          SOUND=SQRT(-GAMMA*PPV*V**2)*68.062324
00112          RETURN
00113          END

    END OF COMPILATION:        NO  DIAGNOSTICS.
```

```
@FOR,S ITSUB,ITSUB
RSD IIA -02/20/74-21:27:01 (0,)

    SUBROUTINE ITSUB      ENTRY POINT 000245

    STORAGE USED: CODE(1) 000256; DATA(0) 000020; BLANK COMMON(2) 000000

    EXTERNAL REFERENCES (BLOCK, NAME)

     0003    NERR2$
     0004    NERR3$

    STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

     0001     000047 10L      0001    000212 100L     0001    000215 110L     0001    000225 120L     0001    000061 30L
     0001     000100 35L      0001    000107 50L      0001    000130 55L      0001    000137 70L      0001    000162 75L
     0001     000166 80L      0001    000176 90L      0000 R  000002 FOFX     0000 R  000001 FOFXCK   0000    000010 INJP$
     0000 I   000004 ITIME    0000 I  000000 NI       0000 R  000003 X

  00101           SUBROUTINE ITSUB (FOFY,Y,SAVE,CONV,NTIMES)                       ITS00100
  00101      C    THIS SUBROUTINE PROVIDES ITERATION CONTROL FOR ANY FUNCTION      ITS00200
  00101      C       SAVE(4-7)=STORAGE LOCATIONS FOR X AND FOFX                    ITS00300
  00101      C    (CONV)-CONVERGENCE CRITERIA                                      ITS00400
  00101      C    (NTIMES)=MAX NUMBER OF ITERATIONS                                ITS00500
  00103           DIMENSIONSAVE(8)                                                 ITS00600
  00104           NI=SAVE(3) +.1                                                   ITS00700
  00105           FOFXCK=SAVE(8)                                                   ITS00800
  00105      C    FOFY AND Y ARE DUMMY INPUT ARGUMENTS                             ITS00900
  00106           FOFX=FOFY                                                        ITS01000
  00107           X=Y                                                              ITS01100
  00107      C    CHECK FOR CONVERGENCE                                            ITS01200
  00110           IF(ABS (FOFX)-CONV.LE.0.)GOTO110                                 ITS01300
  00112           ITIME=SAVE(1)+.1                                                 ITS01400
  00112      C    ITIME CONTROLS THE TYPE CALCULATION TO BE PERFORMED              ITS01500
  00112      C       ITIME=1,FIRST TIME THROUGH                                    ITS01600
  00112      C    ITIME=2,POS FIRST TIME THROUGH                                   ITS01700
  00112      C      ITIME=3,NEG FIRST TIME THROUGH                                 ITS01800
  00112      C      ITIME=4,SOLUTION IS BRACKETED                                  ITS01900
  00112      C      ITIME=5,SOLUTION HAS CONVERGED                                 ITS02000
  00112      C      ITIME=6,SOLUTION WILL NOT CONVERGE                             ITS02100
  00113           GOTO(10,30,50,70),ITIME                                          ITS02200
  00113      C    INITIALIZE                                                       ITS02300
  00114        10 NI=1                                                             ITS02400
  00115           ITIME=2                                                          ITS02500
  00116           FOFXCK=FOFX                                                      ITS02600
  00117           SAVE(8)=FOFXCK                                                   ITS02700
  00120           IF(FOFX.LT.0.)GOTO50                                             ITS02800
  00122        30 IF(FOFX.LT.0.)GOTO70                                             ITS02900
  00124           IF(FOFXCK.GE.FOFX)GOTO35                                         ITS03000
```

```
00126                 SAVE(2)=-1.*SAVE(2)                                         ITS03100
00127                 X=X-2.*SAVE(2)                                              ITS03200
00130                 GOTO90                                                      ITS03300
00131              35 SAVE(4)=X                                                   ITS03400
00132                 SAVE(5)=FOFX                                                ITS03500
00133                 X=X-SAVE(2)                                                 ITS03600
00133       C         OF ONE VARIABLE                                             ITS03700
00133       C         (FOFX)-FUNCTION WHICH IS DRIVEN TO ZERO                     ITS03800
00133       C         (X)-VARIABLE WHICH IS ITERATIVELY SOLVED FOR                ITS03900
00133       C         (SAVE)-PROGRAM CONTROL                                      ITS04000
00133       C           SAVE(1)=ITIME                                             ITS04100
00133       C            SAVE(2)=X INCREMENT                                      ITS04200
00133       C            SAVE(3)=COUNTER DENOTING NTH ITERATION                   ITS04300
00134                 GOTO90                                                      ITS04400
00135              50 ITIME=3                                                     ITS04500
00136                 IF(FOFX.GT.0.)GOTO70                                        ITS04600
00140                 IF(FOFXCK.LE.FOFX)GOTO55                                    ITS04700
00142                 SAVE(2)=-1.*SAVE(2)                                         ITS04800
00143                 X=X+2.*SAVE(2)                                              ITS04900
00144                 GOTO90                                                      ITS05000
00145              55 SAVE(6)=X                                                   ITS05100
00146                 SAVE(7)=FOFX                                                ITS05200
00147                 X=X+SAVE(2)                                                 ITS05300
00150                 GOTO90                                                      ITS05400
00151              70 ITIME=4                                                     ITS05500
00152                 N1=SAVE(3)                                                  ITS05600
00153                 IF(FOFX.LT.0.)GOTO75                                        ITS05700
00155                 SAVE(4)=X                                                   ITS05800
00156                 SAVE(5)=FOFX                                                ITS05900
00157                 GOTO80                                                      ITS06000
00160              75 SAVE(6)=X                                                   ITS06100
00161                 SAVE(7)=FOFX                                                ITS06200
00161       C           PICK NEW GUESS FOR X ACCORDING TO TYPE CALCULATION        ITS06300
00162              80 X=SAVE(4)-SAVE(5)*((SAVE(6)-SAVE(4))/(SAVE(7)-SAVE(5)))     ITS06400
00163              90 IF(N1.GE.NTIMES)GOTO100                                     ITS06500
00165                 N1=N1+1                                                     ITS06600
00166                 SAVE(3)=N1                                                  ITS06700
00167                 GOTO120                                                     ITS06800
00170             100 ITIME=6                                                     ITS06900
00171                 GOTO120                                                     ITS07000
00172             110 ITIME=5                                                     ITS07100
00173                 SAVE(4)=X                                                   ITS07200
00174                 SAVE(5)=FOFX                                                ITS07300
00175                 SAVE(6)=X                                                   ITS07400
00176                 SAVE(7)=FOFX                                                ITS07500
00177             120 SAVE(1)=FLOAT(ITIME)+.1                                     ITS07600
00200                 Y=X                                                         ITS07700
00201                 RETURN                                                      ITS07800
00202                 END                                                         ITS07900

     END OF COMPILATION:        NO  DIAGNOSTICS.

+FIN
```