ADE400 051

AD

(12)

BRL

REPORT NO. 2018

A VERSATILE USER-ORIENTED CLOSED BOMB DATA REDUCTION PROGRAM (CBRED)

C. Price
A. Juhasz

September 1977

USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: (14) BRL [redacted]-2018
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): (6) A VERSATILE USER-ORIENTED CLOSED BOMB DATA REDUCTION PROGRAM (CBRED)
5. TYPE OF REPORT & PERIOD COVERED: BRL REPORT
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): (10) C. Price [redacted] A. Juhasz
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD 21005
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: (16) 1W161102AH43
11. CONTROLLING OFFICE NAME AND ADDRESS: US Army Materiel Development and Readiness Command, 5001 Eisenhower Avenue, Alexandria, VA 22333
12. REPORT DATE: (11) Sep[redacted] 1977
13. NUMBER OF PAGES: 175
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): (12) 158p.
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited. (18) SBIE

DDC RECEIVED FEB 6 1978 B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): (19) AD-E400 051
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number): Closed Bomb; Combustion; Burning Rates; Propellants - Burning Rates; Propellants - Closed Bomb Testing; Propellants - Combustion; Propellants - Artillery; Propellants - Small Arms.
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (jmk)

A versatile digital computer program was developed to provide linear burning rate information on propellants based on pressure-time records obtained from closed bomb firings. Some of the unique features of the program are: a treatment of heat loss based on radiative and convective heat transfer, capability of using single valued or tabular thermodynamic input, allowance for web deviation in the propellant sample, allowance for ignition deviation (flame spread) of the propellant sample, allowance for possible simultaneous burning of

DD FORM 1473, 1 JAN 73 — EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

050 750

propellant and ignition aid, allowance for tabular input of propellant surface versus mass fraction burned (to accommodate unusual geometries), and capability to treat vented vessel operations. The program was set up to operate on an interactive basis on a PDP 11/20 laboratory computer. In practice, once the program is called, the operator is guided in his choice of parameters (thermochemistry, heat loss, ignition deviation, etc.) by a series of prompts. A program overview is presented along with a description of equations, a derivation of the equations, and copies of program output and program listing.

TABLE OF CONTENTS

Page

LIST OF SYMBOLS

Fortran Symbol	Symbol	Definition	Units
CAID	c_a	starting weight of ignition aid	lb
CPROP CNGWT	c_p	starting weight of propellant	lb
	g	gravitational constant (used as a conversion factor)	ft/sec^2
H	h_c	convective heat transfer coefficient	$Btu/in.^2-{}^oR$
SPACE2(3)	h_r	radiative heat transfer coefficient	$Btu/in.^2-{}^oR^4$
TOTMOL	m_T	total moles of gas in chamber	lb-mol
RMOL	$\dot{m}_T$	rate of change of total moles of gas in the chamber	mol/sec
RATE	r	linear burning rate of the propellant	in./sec
TIGN	t_{ig}	time of propellant ignition	msec
TMAX	t_{pm}	time of maximum pressure	msec
Y(5)	w_a	weight of ignition aid burned	lb.
Y(3)	w_{al}	weight of ignition aid combustion products in the chamber	lb
DY(5)	$\dot{w}_a$	ignition aid mass burning rate ($\dot{w}_a = AP^n$)	lb/sec
DY(3)	$\dot{w}_{al}$	rate of change of ignition aid combustion products in the system ($\dot{w}_{al} = \dot{w}_a - w_a \dot{w}_n / w_s$)	lb/sec
Y(2)	w_i	weight of igniter combustion products in the chamber	lb

LIST OF SYMBOLS

FORTRAN Symbol	Symbol	Definition	Units
DY(2)	$\dot{w}_i$	rate of change of igniter combustion products ($\dot{w}_i = - w_i \dot{w}_n/w_s$)	lb/sec
DNN	$\dot{w}_n$	mass discharge rate through the nozzle	lb/sec
Y(6)	w_p	weight of propellant burned	lb
Y(4)	w_{pl}	weight of propellant combustion products in the chamber	lb
DY(6)	$\dot{w}_p$	mass burning rate of the propellant	lb/sec
DY(4)	$\dot{w}_{pl}$	rate of change of propellant combustion products in the chamber (vented chamber operation) ($\dot{w}_{pl} = \dot{w}_p - w_{pl} \dot{w}_n/w_s$)	lb/sec
Y(1)	w_r	weight of air in the chamber	lb
DY(1)	$\dot{w}_r$	rate of change of air in the system ($\dot{w}_r = - w_r \dot{w}_n/w_s$)	lb/sec
WSYS	w_s	weight of gases in the chamber $w_s = w_r + w_i + w_{al} + w_{pl}$	lb
DWSYS	$\dot{w}_s$	rate of change of the weight of gases in the system	lb/sec
DB	x	distance burned into the grain	in.
Y(8-12)	x_n	distance burned into the grain for the n-th charge increment (n has values of 1-5)	in.
SPACE1(10)	A_t	effective throat area(sonic control assumed)	in.^{2}
SPACE2(2)	A_w	bomb wall surface area	in.^{2}
CP	C_p	heat capacity at constant pressure	Btu/lb.^oF

LIST OF SYMBOLS

FORTRAN Symbol	Symbol	Definition	Units
CVP	C_v	heat capacity at constant volume	Btu/lb - ^oF
DCVP	$\dot{C}_v$	rate of change of heat capacity at constant volume	Btu/lb - ^oF-sec
CSTAR	C*	characteristic discharge velocity	ft/sec
OD	D	initial grain diameter	in.
PD	D_p	initial perforation diameter	in.
OOD	D'	instantaneous grain diameter (D' = D - 2x)	in.
PPD,PRFD	D'_p	instantaneous perforation diameter ($D'_p = D_p + 2x$)	in.
E	E	end area of grain	in.^{2}
	E^*_{cv}	energy of gases in the chamber	
	E^*_p	energy from combustion of the propellant	
HTL1	H_L	total heat loss to walls of the chamber	Btu
ARP	$\dot{H}_L$	instantaneous heat loss rate	Btu/sec
H	$\bar{\dot{H}}_L$	average heat loss rate	Btu/sec
G	$\dot{H}_{Lc}$	convective heat loss rate	Btu/sec
HTL	$\dot{H}_{Lr}$	radiative heat loss rate	Btu/sec
GL	L	initial grain length	in.
GGL	L'	instantaneous grain length	in.

* Variables used in derivation only

LIST OF SYMBOLS

FORTRAN Symbol	Symbol	Definition	Units
XMA	M_a	molecular weight of ignition aid combustion products	NA
XMI	M_i	molecular weight of igniter combustion products	NA
XMP	M_p	molecular weight of propellant combustion products	NA
	M_r	molecular weight of air (defined as 29)	NA
XMW	M_s	molecular weight of gases in the system	NA
Y(7),P	P	pressure	psia
DP	$\dot{P}$	rate of change of pressure with respect to time	psia/sec
PMAX	P_m	experimentally measured maximum pressure in the system	psia
P	P_{st}	stagnation pressure	psia
PTHEO	P_{0s}	theoretically computed maximum pressure in the system	psia
RSYS	R_s	gas constant for the system ($R_s = R_u m_T / w_s$)	in.-lb/lb^{o}F
DR	$\dot{R}_s$	rate of change of gas constant for the system ($\dot{R}_s = R_u / w_s (\dot{m}_T - m_T \dot{w}_s / w_s)$)	in.-lb/lb-^{o}F-sec
RU	R_u	universal gas constant	in.-lb/mol^{o}F
AAB,S	S_t	instantaneous propellant surface area	in.^{2}

LIST OF SYMBOLS

FORTRAN Symbol	Symbol	Definition	Units
AB	S_{tn}	instantaneous surface area of nth charge increment	$in.^2$
TSYS	T_s	gas temperature in the chamber (computed as ^oK; note also that $^oR=^oF$ +459.69)	^oR
TSYS	T_{st}	stagnation temperature	^oF
SPACE1(36)	T_w	bomb wall surface temperature	^oR
TAID, T5	T_{0a}	isochoric adiabatic flame temperature of the ignition aid	^oR
T6,TZD	T_{0p}	isochoric adiabatic flame temperature of the propellant	^oR
BVOL	V_b	empty bomb volume	$in.^3$
VSYS	V_s	system volume	$in.^3$
DVSYS	$\dot{V}_s$	rate of change of system volume $\dot{V}_s=-w_s\dot{\eta}-\eta\dot{w}_s+(\dot{w}_a+\dot{w}_p)/\rho$	$in.^3/sec$
WID,WOD	W	initial propellant web	in.
ALPHA	α	angle used in multiperforated grain surface calculations (MPGSC) defined in Appendix C	deg
BETA	β	angle used in MPGSC, defined in Appendix C	deg
GAM1	Γ	ratio of specific heats	NA
ETA	η	propellant covolume	$in.^3/lb$
DETA	$\dot{\eta}$	rate of change of propellant covolume	$in.^3/lb\text{-}sec$
THETA	θ	angle used in MPGSC, defined in Appendix C	deg

LIST OF SYMBOLS

Fortran Symbol	Symbol	Definition	Units
RHO	ρ	solid propellant density	$lb/in.^3$
CPGM2	Γ	a function of the specific heat ratio defined in Appendix D	NA

I. INTRODUCTION

Among the parameters of interest to the interior ballistician are the burning rate and chemical energy of the propellant used in propelling charges. These parameters must be known to predict the performance to be expected from a given gun-ammunition system.[1,2] Reliable data on the chemical energy of the propellant may be obtained from thermodynamic calculations based on the chemical composition and heats of formation of the propellant ingredients.[3,4] Propellant burning rates, however, cannot be predicted with similar reliability although various efforts at predicting burning rates from chemical compositions,[5,6,7] thermochemistry[8] and chemical kinetics have been and are being

---

[1] *J. Corner, M. A., PhD, Theory of the Interior Ballistics of Guns, New York, John Wiley and Sons, Inc., 1950.*

[2] *Paul G. Baer and Jerome M. Frankle, "The Simulation of Interior Ballistic Performance of Guns by Digital Computer Program," Ballistic Research Laboratories Report No. 1183, December 1962, AD #299980.*

[3] *A. C. Haukland and W. M. Burnett, "Sensitivity of Interior Ballistic Performance to Propellant Thermochemical Parameters," Proceedings of the Tri-Service Gun Propellant Symposium, 11-13 October 1972, Picatinny Arsenal, Dover, NJ, Vol 1, Section 7.3.*

[4] *Paul G. Baer, Ingo W. May, and Jerome M. Frankle, "A Comparison of Several Predictive Approaches in Charge Establishment for Large Caliber Artillery Systems," Proceedings of the 11th JANNAF Combustion Meeting, Jet Propulsion Laboratory, Pasadena, CA., September 1974, Vol 1; C.P.I.A. Publication 261, December 1974, The Chemical Propulsion Information Agency, Silver Spring, Md.*

[5] *William H. Tschappat, Lt.-Col, Ord. Dept., Text-Book of Ordnance and Gunnery, 1st Ed., New York, John Wiley and Sons, Inc., 1917, pp. 111-118.*

[6] *Albert A. Bennett, PhD, "Tables of Interior Ballistics," Ordnance Department Pamphlet No. 2039, April 1921.*

[7] *D. W. Riefler and D. J. Lowery, "Linear Burn Rates of Ball Propellants Based on Closed Bomb Firings," Ballistic Research Laboratories Contractor Report No. 172, August 1974.* (AD #921704L)

[8] *Henri Muraour, "Chemie Physique sur la Reaction Entre La Temperature de la Explosion d' une Poudre et sa Vitesse de Combustion," Comp. rend., Vol 187, 1928, pp. 289-294.*

pursued.[9-15] (See, footnote,*). Useful burning rate data, therefore, must still be obtained experimentally.

Classically, two principal methods have been used to obtain burning rate data for propellants. These are the strand burner and the closed bomb. Both involve the burning of propellant samples in steel containers of sufficient strength to withstand high pressures. In a strand burner, a single sample (strand) of propellant is burned cigarette fashion under essentially a constant pressure. In practice, this is achieved by connecting a ballast volume to the combustion chamber so that the gases given off by the propellant contribute negligibly to overall system pressure. The regression of the burning surface is measured by timing the intervals between breaking of fuse wires embedded along the length of the propellant sample. Thus each experiment yields a single average value of linear burning rate for a given pressure. To obtain burning rates for a propellant over a range of pressures, a number of experiments are required. The resultant data are fitted to some mathematical form which then allows computation of the values of the burning rate at intermediate points. The method is straight-forward (though time consuming) and has been used for many years, especially by the rocket community.

---

*Current Army efforts on combustion modeling are centered in the Fundamentals of Combustion Task of the Energetic Materials Technology Program of the US Army Materiel Development and Readiness Command, Alexandria, VA 22333.

[9] Ref 1, pp. 42-84 and reference therein.

[10] Bryce L. Crawford, Jr., Clayton Huggett, and J. J. McBrady, "The Mechanism of Burning of Double Base Propellants," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 854-862.

[11] Robert G. Parr and Bryce L. Crawford, Jr., "A Physical Theory of Burning of Double Base Rocket Propellants," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 929-954.

[12] O. K. Rice and Robert Ginell, "The Theory of Burning of Double Base Rocket Powders," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 885-917.

[13] R. E. Wilfong, S. S. Penner, and F. Daniels, "An Hypothesis for Propellant Burning," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 863-872.

[14] R. D. Geckler, "Mechanism of Combustion of Solid Propellants," Selected Combustion Problems, London, Butterworths Scientific Publications, 1954, pp. 289-339.

[15] D. B. Spalding, "The Theory of Solid and Liquid Propellants," Combustion and Flame, Vol 4, 1960, pp. 59-76.

The second method of obtaining propellant burning rate data involves the closed bomb. In the closed bomb, a statistically adequate number of propellant grains are ignited and allowed to burn in a fixed volume under the pressure exerted by the propellant combustion gases. The pressure in the chamber builds up rapidly and is recorded as a function of time. From the pressure-time data it is possible to derive linear burning rate information for the propellant over a range of pressures from a single experiment, a marked advantage over the repeated tests required with the strand burner.* But where the closed bomb technique gains in experimental economy, it loses in the complexity of the data reduction method. The problem has been attacked in a variety of ways by a number of authors.[17-20] The earlier papers were aimed at providing methods for computing the data by hand. This lead to the use of a variety of simplifying assumptions both in the development of the theory and the form functions used. The more recent papers were aimed at computer solutions to the problem and, in general, provide a more complete treatment of the phenomenon. A brief bibliography of closed bomb burn rate reduction methods is included at the end of this report.

**Alternately, the data recorded may be the first derivative of pressure with respect to time vs. pressure. This is generally reduced to an average value of dp/dt (obtained at 0.250, 0.3750, 0.500, and 0.625 of the maximum pressure) which when compared with the value for a reference propellant (obtained under identical conditions) gives an idea of the burning characteristic to be expected of the sample. The "quickness" and "relative quickness"[16] values so obtained can be quite useful for correlations with weapon performance characteristics.*

---

[16] *Method 801.1.1, "Quickness and Force Measurement of Propellant (Closed Bomb Method)," (Revised 21 Oct 75), Military Standard 286B, Department of Defense, Washington, DC 20301.*

[17] *C. M. Dickey, "Determination of Burning Characteristics of Propellant," E.I. duPont de Nemours and Company, Explosives Department, Burnside Laboratory, Memorandum Report No. 31 (File BL-135-101), March 1943.*

[18] *James H. Wiegand, "A Method of Calculation of the Burning Rate of Powders from dP/dt vs. P Records for closed Chambers," Ballistic Research Laboratories Report No. 546, June 1945.*

[19] *E. Haeuseler and W. Dehl, "State of Development of Testing Procedures for Propellants in the Closed Vessel," Explosivstoffe, Vol 18, 1970, pp. 41-52.*

[20] *H. Krier and S.A. Shimpis, "Predicting Uniform Gun Interior Ballistics: Part I - An Analysis of Closed-Bomb Testing," University of Illinois Technical Report AAE 74-5, July 1974. Contract DAAD-21-73-C-0540.*

The objective of the present work was to generate a comprehensive data reduction method providing more versatility than is available from any of the previous methods. The equations which were developed provide for the presence of igniter and ignition aid, as well as the ambient air present in the bomb. A more sophisticated heat loss treatment is included. Other unique features include allowance for changes in the thermodynamic characteristics of the combustion products and of web deviations in the propellant sample. In addition, the treatment allows for analysis of data from vented chamber experiments. The theory was implemented in a program written for an available laboratory computer. An attractive feature of the program is its user oriented "question and answer" format which allows the user to readily modify input variables and to make decisions on the various data reduction options. The reduced data are available for examination in easily interpretable format in a matter of minutes.

II. OVERVIEW AND PROGRAM CAPABILITIES

The program capabilities are outlined in the following section. In the form listed here it requires as input a suitable data file of pressure vs time and first derivative of pressure with respect to time and a "header" or set of parameters describing propellant geometry and physical characteristics, propellant thermochemistry and experimental parameters.*

A listing of the input requirements is contained in Appendix A, program operation is interactive and is controlled from a terminal keyboard. Two modes of operation are possible, standard and nonstandard. The standard option provides a "normal" burning rate analysis on a more or less routine basis. This analysis assumes full burning of all of the ignition aid before ignition of the propellant, simultaneous ignition of all the propellant grains, a fixed set of dimensions for all propellant grains, constant thermochemistry for the combustion products, and linear heat loss during the combustion of the propellant sample.

The second, nonstandard, mode of operation allows for operation of the program with a variety of options for special applications. A summary comparison of the "standard" and "nonstandard" modes of analysis is presented in Table I.

---

* *The data file is obtained by operating on the range data with a smoothing and differentiation program "SCHECK." The program and operations are to be described in a future report.*

Table I. Comparison of Standard and Nonstandard Data Reduction Modes

FACILITY	STANDARD MODE	OPTION NO.	NONSTANDARD MODE
Heat Loss	Constant heat loss rate throughout burning	1	Compute heat loss based on convective and radiative heat transfer coefficients.
Thermochemistry	Average values of impetus, covolume, molecular weight, and γ used.	2	Thermodynamic data input as table (function of pressure).
Propellant Geometry	Fixed web used in calculations	3	Statistical treatment of web deviations used in calculations
Ignition	Simultaneous ignition of whole propellant charge.	4	Allows definition of ignition deviation in terms of time to account for flame spread effects.
Ignition Aid	All ignition aid burned before propellant ignited.	5	Propellant ignited before all of ignition aid is consumed.
Vented Vessel	No provision.	6	Allows computation of mass discharge when pressure exceeds diaphragm burst pressure.
Burning Surface	Capabilities provided: sphere; cylinder; and single, seven, and nineteen-perforated cylinders.	7	Allows input of any surface area function in tabular form.

Use of the program in either the standard or nonstandard mode has been simplified by allowing the use of propellant, igniter, and experimental data all from the same input file. Data on propellant geometry, thermochemistry, and dimensions are all recorded as "header" information at the time that the data are taken. (This is achieved using a separate program, CBDAP, closed bomb data acquisition program. The program will be described in another report.) The result is that conversion of the pressure-time data to linear burning rates may be performed simply without detailed knowledge of program operations. In performing a standard analysis, once the operator has entered the input data file, he is freed from providing any additional input except for specifying whether only the central portion (from 10 to 80 percent of maximum pressure) or all of the curve is to be plotted.

If changes are to be made in some of the propellant or igniter data or if special handling of the data is required, the nonstandard mode of analysis is employed. In this mode, the pertinent propellant and igniter data in the data file are displayed and the opportunity for changing or accepting the respective value is presented. In addition, the opportunity of selecting each of the options in Table I is presented to the user. Once these decisions have been made, data reduction proceeds as before.

Program output consists of: (a) a summary sheet or header describing the sample, experimental parameters and data on the maximum pressure and selected values of the derivative of pressure with respect to time (dP/dt), (b) a tabular listing of pressure, time, dP/dt, burning rate, web and surface fraction data, (c) superimposed plots of pressure (P) versus time (t) and dP/dt versus t. (d) a plot of dP/dt versus reduced pressure (P/P_{max}), and (e) a log-log plot of burning rate as a function of pressure. The burning rate versus pressure plot includes a printout of the coefficient and the exponent in the equation

$$r = AP^n \quad , \tag{1}$$

where: r = linear burning rate,

P = pressure,

A = burning rate coefficient, and

n = burning rate exponent.

obtained by a least squares fit of the data over the desired pressure range as well as statistical data on the "goodness of fit." An example of program output is given in Appendix B.

III. THEORY

A. SIMPLIFIED DERIVATION

The basic objective of the analysis is to derive linear burning rate data for propellant samples from pressure-time histories of their burning process in a closed bomb. Simply, the event involves the conversion of a solid sample composed of a large number of grains of a given geometry and size to a gas having a given amount of energy. Since the vessel is closed, the products may not escape, the pressure builds up and the propellant sample burns in an environment of a continuously changing pressure.

A variety of factors influence the conversion rate of the solid sample to gas. Those of primary interest are the propellant surface area, the pressure, and the propellant chemical composition. For all propellants, the conversion rate of solids to gas (i.e., the mass burning rate) is directly proportional to surface. For all gun propellants (and many others) the rate of regression of the propellant surface (the so-called linear burning rate, r) is directly proportional to pressure. As a general rule, the linear burning rates of propellants at given pressures are a function of the energy content of the composition.

To describe the process it is necessary to describe the gas produced, the unburned propellant and the energy balance for the process as a function of time. The derivation which follows is limited to a single propellant of constant thermochemistry. Eliminating complicating factors such as the presence of the igniter, ignition aid, etc., allows the generation of a simple instructive set of equations demonstrating the logic used. The actual equations used in the program are discussed in a later section and their derivation is given in the appendix.

(1) Equation of State of Gas

The combustion products may be described using the following equation of state:

$$PV_s = w_p R_s T_s \quad (2)$$

where:

V_s = system volume

w_p = weight of propellant burned

R_s = gas constant for the system

T_s = gas temperature in the chamber

The equation is formally analogous to the familiar Ideal Gas Equation. The difference is in the definition of the system volume term (V_s) which is defined as the chamber volume modified to reflect the presence of unburned propellant and the covolume correction, Equation (3)

$$V_s = V_b - \frac{c_p}{\rho} + \frac{w_p}{\rho} - w_p\eta \qquad (3)$$

where:

V_b = chamber volume

c_p = initial weight of propellant

ρ = solid propellant density

η = propellant covolume.

It should be noted that the mixture of gases making up the propellant combustion products is treated as if it were a single gaseous species having specific properties of molecular weight, heat capacity and covolume. These properties, of course, are determined by the nature and stoichiometry of the combustion products.

Once the appropriate substitutions are made, the Equation of State becomes:

$$P\left[V_b - \frac{c_p}{\rho} + w_p\left(\frac{1}{\rho} - \eta\right)\right] = w_p R_s T_s \qquad (4)$$

(2) Energy Balance Equation

The energy from combustion of the propellant sample is partitioned between the internal energy of the product gases and heat loss to the chamber. The Energy Balance Equation may be written as:

$$E_{cv} = E_p - H_L \quad , \qquad (5)$$

where: E_{cv} = energy of gases in the chamber

E_p = energy from combustion of the propellant, and

H_L = heat loss to walls of the chamber

The equation may be rewritten as:

$$C_V w_p T_s = C_V w_p T_{0p} - H_L \qquad (6)$$

where: C_V = heat capacity at constant volume and

T_{0p} = isochoric flame temperature of propellant.

$$H_L = \frac{C_V V_s}{R_s} (P_{0s} - P_m)$$

P_{0s} = Theoretically computed maximum pressure

P_m = Experimentally measured maximum pressure

The temperature of the combustion gases, T_s, is less than the isochoric adiabatic flame temperature computed for the propellant composition, T_{0p}, due to heat losses to the walls of the chamber. The heat capacity at constant volume, C_V, is an average property between T_s and T_{0p} for the mixture of gases making up the combustion products of the formulation. It is defined per unit weight, rather than per mole.

(3) Rate of Conversion of Solid to Gas.

To obtain the equation for the rate of conversion of the solid propellant to gaseous combustion products, Equations (4) and (6) are differentiated. Differentiation of Equation (4) holding V_b, c_p, ρ, η and R_s constant, yields:

$$\left[V_b - \frac{c_p}{\rho} + w_p \left(\frac{1}{\rho} - \eta \right) \right] \frac{dP}{dt} + P \left(\frac{1}{\rho} - \eta \right) \frac{dw_p}{dt} =$$

$$R_s w_p \frac{dT_s}{dt} + R_s T_s \frac{dw_p}{dt} \qquad (7)$$

The rate of conversion of solid to gas is given by dwp/dt, the rate of formation of propellant combustion products. This is the term we are seeking to evaluate in terms of experimental parameters. To do this, it is necessary to define the rate of change of system temperature

(dT_s/dt). This is done by differenting the Energy Equation. Differentiation of Equation (6) holding C_V and T_{0p} constant and rearranging, yields:

$$\frac{dT_s}{dt} = \frac{(T_{0p} - T_s)}{w_p} \frac{dw_p}{dt} - \frac{\dot{H}_L}{C_V w_p} \tag{8}$$

at this point, the follow_ng relationship is introduced:

$$R_s = C_V (\gamma - 1)$$

where:

γ = ratio of heat capacities

The relationship is strictly true for ideal gases but is commonly used in describing real systems. It allows recasting Equation (8) in the following form:

$$\frac{dT_s}{dt} = \frac{(T_{0p} - T_s)}{w_p} \frac{dw_p}{dt} - \frac{\dot{H}_L (\gamma - 1)}{R_s w_p} \tag{9}$$

Substituting the right hand side of Equation (9) into the differentiated Equation of State, Equation (7); yields:

$$\left[V_b - \frac{c_p}{\rho} + w_p \frac{(1 - \eta)}{\rho}\right] \frac{dP}{dt} = \left[R_s T_s - P \frac{(1 - \eta)}{\rho}\right] \frac{dw_p}{dt} + R_s w_p \left[\frac{(T_{0p} - T_s)}{w_p} \frac{dw_p}{dt} - \frac{\dot{H}_L (\gamma - 1)}{R_s w_p}\right] \tag{10}$$

The equation may now be solved for dw_p/dt, giving the rate of formation of propellant combustion products in terms of experimental data (P, dP/dt) and a series of constants (V_b, c_p, ρ, η, T_{0p}, R_s, $\dot{H}_L$ and γ). The resulting equation is:

$$\frac{dw_p}{dt} = \frac{\left[V_b - \frac{c_p}{\rho} + w_p \left(\frac{1}{\rho} - \eta\right)\right]\frac{dP}{dt} + \dot{H}_L (\gamma-1)}{R_s T_{0p} - P\left(\frac{1}{\rho} - \eta\right)} \tag{11}$$

(4) Linear Burning Rate.

The linear burning rate, r, is the rate of regression of the propellant surface (dx/dt). To compute it one begins with considering the volume element burned through during an infinitesimal time interval. The following equation applies:

$$\frac{dw_p}{dt} = \rho\, S_t \frac{dx}{dt} \tag{12}$$

where:

S_t = the surface area of the propellant at any time t.

$\frac{dx}{dt}$ = rate of regression of the propellant surface, equals r, the linear burning rate.

Equation (12) defines the rate of formation of propellant combustion products in geometric terms. If the propellant is composed of a number of identical grains, the propellant surface area may be computed using a variety of "form function" equations. Equations have been developed for spherical, cylindrical and perforated cylindrical (1, 7, and 19 perforations) grain geometries. The generalized equation is:

$$S_t = f(x) \tag{13}$$

where:

x = the distance burned into the grain.

When x equals zero, the surface area is the initial surface area of the propellant grain. As x increases positively, the surface area of the grain changes characteristically for each grain type. Form functions for all of the grain types mentioned above have been included in Appendix C.

Examining Equation (12), it is evident that the objective of computing the linear burning rate of the propellant from the closed bomb pressure-time data has been attained. The term dw_p/dt is defined by Equation (11), and the surface area, S_t, is defined by the Form Function Equation, Equation (13). This completes the simplified derivation intended for inclusion in the text.

B. Theory Used in The Program.

Both the event described and the equations describing it are considerably more complex than just described. In every experiment an igniter is used to start the propellant burning and in many an ignition aid is used as well. Further, the volume in the bomb not occupied by the propellant at the start of the experiment is occupied by ambient air. It is, therefore, evident that one is not dealing with the single component system described earlier. The Equation of State used in the program includes all components. The Energy Equation is also more complex, since the thermodynamics of the combustion gases are allowed to change and, in addition, allowance is made not only for heat loss from the system but mass loss as well (vented chamber operation). The Mass Burning Rate Equation derived for the system reflects these complexities. See Equation (27), Appendix D. Since the treatment allows for deviations in the ignition of the propellant charge as well as web deviations, computing the surface area at any instant is also slightly more complicated. Finally, the instantaneous Heat Loss Term ($\dot{H}_L$) is evaluated in the program in one of two ways, either as an average value, constant throughout the burn, or as a variable defined by the radiative and convective heat loss elements. The objective of this section is to provide some explanatory comments on several equations used in the program.

(1) Rate of Conversion of Solid to Gas.

For the purpose of discussion the Mass Burning Rate Equation derived in Appendix D has been regrouped and the numerator divided into a series of terms A through E. This is the form in which it appears below.

$$\frac{dw_p}{dt} = \frac{A + B + C + D + E}{P(\eta - \frac{1}{\rho}) + T_{0p}R_s + R_u T_s \left(\frac{1}{\bar{M}_p} - \frac{1}{\bar{M}_s}\right)} \qquad (14)$$

where:

R_u = universal gas constant

M_p = molecular weight of propellant combustion products

M_s = molecular weight of gas in the system

$$A = V_s \frac{dP}{dt}$$

$$B = \dot{H}_L (\gamma-1)$$

$$C = \left[\gamma R_s T_s + P\eta \frac{w_{pl}}{w_s}\right] \frac{dw_n}{dt}$$

where:

w_{pl} = weight of propellant combustion products in the chamber (as opposed to the total weight of propellant burned)

$\frac{dw_n}{dt}$ = gas discharge rate through the nozzle

$$D = w_s T_s \left[\frac{R_u}{(M_p)^2} \frac{dM_p}{dt} + \frac{R_s}{C_V} \frac{dC_V}{dt}\right] - P w_s \frac{d\eta}{dt}$$

$$E = -\left[P(\eta - \frac{1}{\rho}) + T_{0a} R_s + R_u T_s (\frac{1}{M_a} - \frac{1}{M_s})\right] \frac{d w_{al}}{dt}$$

where:

M_a = molecular weight of ignition aid combustion products

w_{al} = weight of ignition aid combustion products in the chamber.

Several of the terms are associated with exercising program options previously described (Table I). The functions of Terms A through E are listed in Table II.

Table II. Functions of Terms A through E in Equation (14).

A	System volume term
B	Heat Loss.
C	Mass Loss.
D	Variable thermochemistry.
E	Contribution of simultaneously burning ignition aid.

The System Volume Term (A) is necessary for all computations. The Heat Loss Term (B) is included as required in the analysis. The term may be evaluated simply (standard option, Table 1) or comprehensively (nonstandard option). This will be discussed more fully in section B(3). In the case of vented chamber operation or in computing burn rates from artificially generated pressure time data, term B can be zero. The Mass Discharge Term, (C) is used in analyzing vented chamber experiments. Term (D), Variable Thermochemistry, is important in analyzing low pressure closed bomb data since the thermochemistry of the combustion products changes significantly with pressure at low pressures. The inclusion of the Ignition Aid Burning Term (E) becomes important when describing situations involving simultaneous burning of propellant and igniter. This is the case more often than not, though the decision on the overlap of ignition aid and propellant burning is made on the basis of experience by the program operator.

In essence, Equation (14) is Equation (11) appropriately modified to reflect the complexities of the experiment. This may be readily demonstrated by imposing the same assumptions on Equation (14) as were used in deriving the simplified Mass Burning Rate Equation (Equation 11). Assuming a single propellant (no igniter or ignition aid), constant thermochemistry, closed bomb operation (no mass loss through a nozzle) and the absence of air from the chamber, the following terms in Equation (14) may be eliminated:

Term C. Under closed bomb conditions $dw_n/dt=0$

Term D. For constant thermochemistry $d\eta/dt=0$

Term E. In the absence of an ignition aid $dw_{a1}/dt=0$

$\left[R_u T_s \left(\frac{1}{M_p} - \frac{1}{M_s}\right)\right]$. For a single component system $(1/M_p - 1/M_s) = 0$

Elimination of the terms above reduces Equation (14) to Equation (11). The methods used in deriving the two equations were the same. The derivation of Equation (14) paralleling the approach used in the text for Equation (11) is given in Appendix D.

(2) Linear Burning Rate

The linear burning rate in the program is computed by Equation (12). Differences arise, however, in the computation of the instantaneous burning surface area S_t. Two of the program options treat ignition deviations in the propellant charge and web deviation in the propellant grains. Both options influence the burning surface area.

If an ignition deviation takes place, parts of the propellant charge begin to burn before others. In this case the simple computation of total burning surface area as a function of distance burned is not appropriate. What is done is to proportion the propellant charge into five parts (two each of 10 percent, two each of 20 percent and one of 40 percent) and to allow the ignition of the charge increments to differ by some arbitrary time input by the operator. The distances burned into the surface of each portion of the charge are carried separately. Under these conditions the burning surface is computed according to the following equation:

$$S_t = \sum_1^5 S_{t_n} \tag{15}$$

where:

S_{t_n} = surface area of the nth propellant charge increment

S_{t_n} = $f(x_n)$

x_n = distance burned into the surface of the nth propellant charge increment.

Of course, for simultaneous ignition of the propellant charge, Equation (15) reduces to Equation (13). It must be emphasized, however, that one has no a priori knowledge of the ignition deviation time of the propellant charge; so this treatment should be viewed with caution.

The web deviation is handled analogously; In this case, however, web deviation values may be obtained from actual measurements.

(3) Heat Loss

(a) Standard Option. Evaluation of the Heat Loss Term ($\dot{H}_L$) is done in either of two ways. In the standard option it is some suitable average value, constant throughout the analysis. The following equation applies:

$$\dot{H}_L = \overline{\dot{H}}_L = \frac{C_V V_s}{R_s} \frac{(P_{0s} - P_m)}{\left(t_{pm} - t_{ig}\right)} \qquad (16)$$

where:

$\overline{\dot{H}}_L$ = average heat loss rate

P_{0s} = theoretically computed maximum pressure (adiabatic conditions, contributions from propellant, igniter, ignition aid and air in system).

t_{pm} = time of maximum pressure

t_{ig} = time of ignition

The total heat loss is the difference between the adiabatically computed internal energy of the system and the internal energy computed from the maximum pressure observed. The total heat loss is converted into the average Heat Loss Rate ($\dot{H}_L$) by dividing by the burning time interval (t_{pm}-t_{ig}).

(b) Nonstandard Option

In the nonstandard option, heat loss is analyzed into its convective and radiative components. It is assumed that during the time that the propellant burns the gas generation results in convective heat transfer to the chamber walls. This is, of course, accompanied by radiative heat losses as well. After the propellant is consumed it is assumed that the convective heat loss becomes insignificant relative to the radiative heat loss. These assumptions allow the following treatment.

(i) Radiative heat loss coefficient. The temperature of the gases in the system is given by:

$$T_s = \frac{P_m V_s}{R_s}$$

The radiative heat loss rate is given by:

$$\dot{H}_{Lr} = \frac{C_V V_s}{R_s} \frac{dP}{dt} \qquad (17)$$

where:

$\dot{H}_{Lr}$ = radiative heat loss rate,

Once a matched array of T_s, $\dot{H}_{Lr}$ data are generated, they may be fitted to the following relationship:

$$h_r A_w = \frac{\dot{H}_{Lr}}{(T_s^4 - T_w^4)} \qquad (18)$$

where:

h_r = radiative heat transfer coefficient

A_w = bomb surface area

T_w = bomb wall temperature.

In carrying out these computations, T_w^4 may be neglected since it is indeed insignificant ($T_s^4 >> T_w^4$) in the radiant heat transfer. The bomb surface area (A_w) is one of the program inputs (alternately a default value of 18.1 in^2 is available in the program) and, therefore, the evaluation of the Radiant Heat Transfer Coefficient (h_r) is accomplished. Throughout the analysis, h_r is a constant.

(ii) Convective Heat Transfer Coefficient. The Convective Heat Transfer Coefficient (h_c) is assumed to be a function of the instantaneous mass flow as in the case of heat transfer in a pipe. The relationship is given as:

$$h_c = F_c \left(\frac{dw_s}{dt}\right)^{0.8} \qquad (19)$$

where:

h_c = convective heat transfer coefficient

F_c = proportionality constant

The value of h_c is computed at every point in the analysis using the instantaneous mass generation rate. The value of the proportionality constant F_c is obtained using an approximation technique in which an approximate value of h_c is calculated from the average mass generation and heat loss rates and this approximate value is refined using the value of h_r and increments of $\Delta P/\Delta t$.

(iii) Heat Loss Rate, nonstandard option. To compute the Heat Loss Rate ($\dot{H}_L$) at any given point in the analysis the following equations are used:

$$\dot{H}_{Lc} = h_c A_w (T_s - T_w) \quad (20)$$

where: $\dot{H}_{Lc}$ = convective heat loss rate

$$\dot{H}_{Lr} = h_r A_w (T_s^4 - T_w^4) \quad (21)$$

$$\dot{H}_L = \dot{H}_{Lc} + \dot{H}_{Lr} \quad (22)$$

The initial value of the Wall Temperature (T_w) is assumed to be 450°K (this may be changed by the operator) and T_w is continuously adjusted throughout the analysis as is the Systems Temperature (T_s). The relationships governing heat conduction to the wall are given in Appendix E.

IV. PROGRAM STRUCTURE AND OPERATION

A. Standard Analysis

The program consists of a main program and a number of subroutines which handle reading in of data, unit conversions, heat loss computations, burning rate calculations, and printing and plotting of the output data. The program structure is outlined in Figure 1. The diagram indicates the relationship of the subroutines in the program. Capsule summaries of the functions of the subroutines are contained in Appendix F.

Program operation is most easily described by following a standard analysis sequence step by step. The options may then be seen as perturbations on the normal mode of analysis. A flow diagram of the program appears in Figure 2. The chart has been arranged to show the operations involved in a standard analysis in sequential form. The options possible, heat loss, mass loss, variable thermochemistry, etc., are shown offset from the main sequence of operations. The optional sections are marked with arterisks.

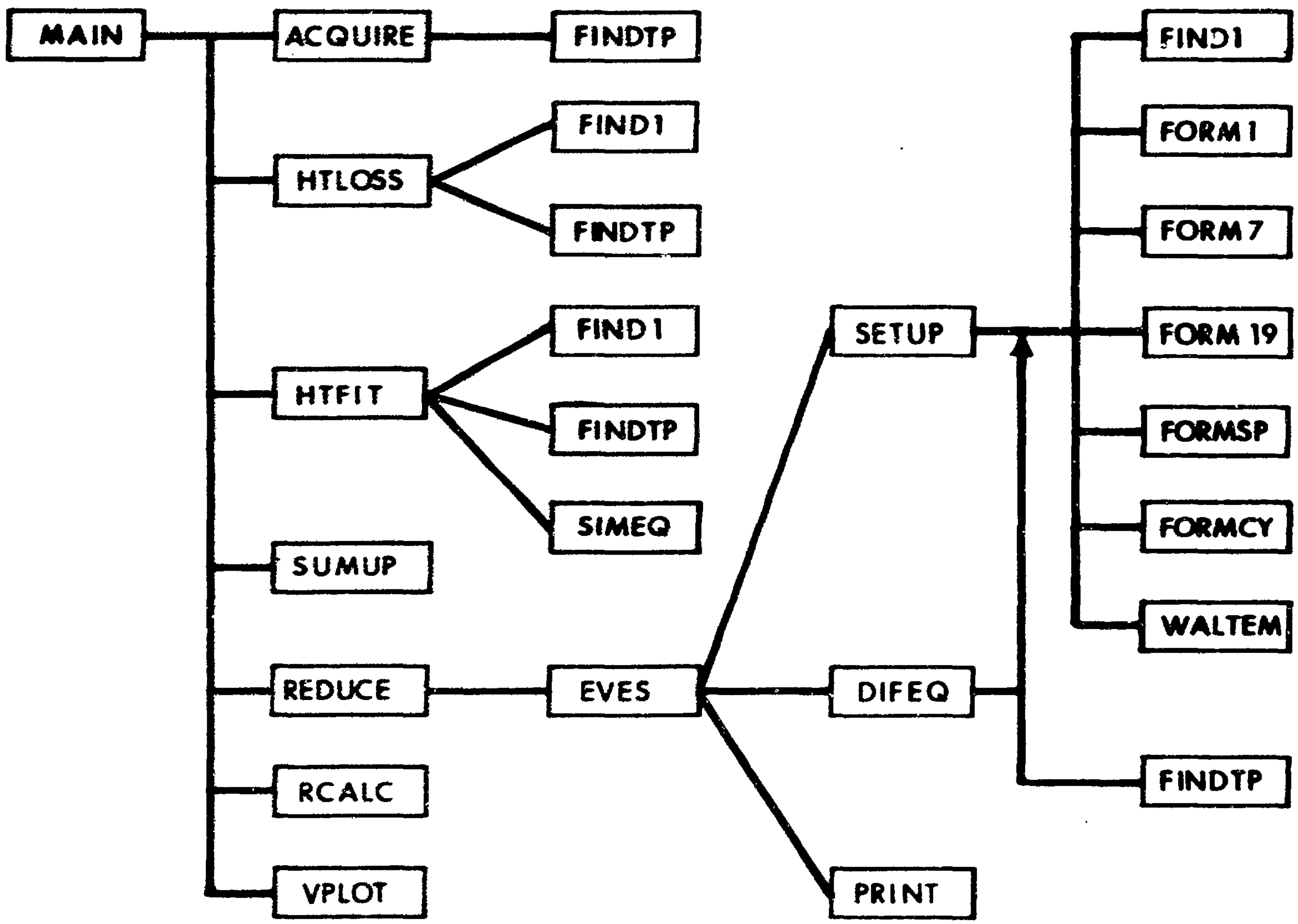


Figure 1. Program Structure (CBRED). Interrelation of Subroutines.

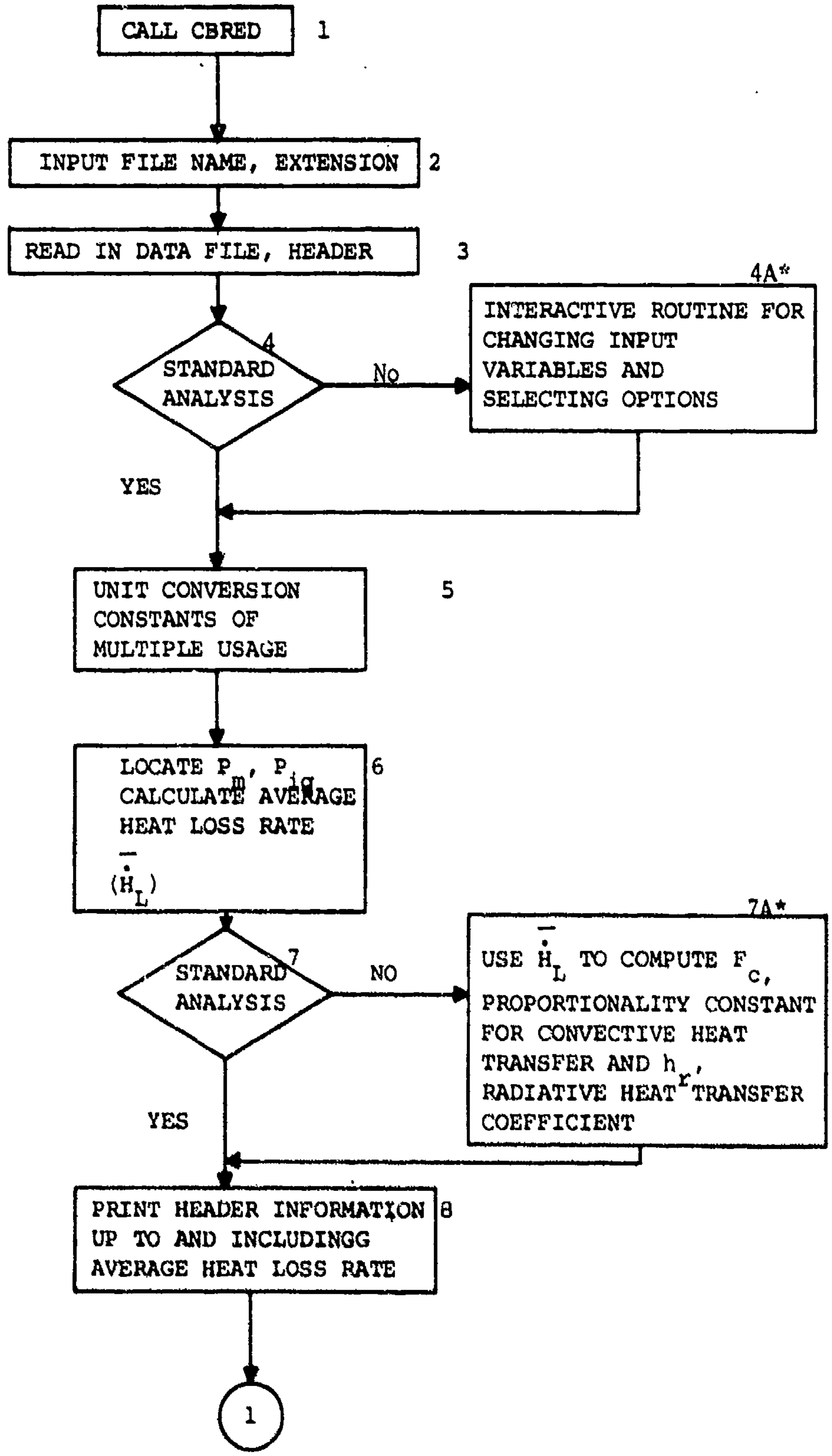


Figure 2-1. Closed Bomb Burn Rate Program (CBRED). Generalized Flow Scheme.

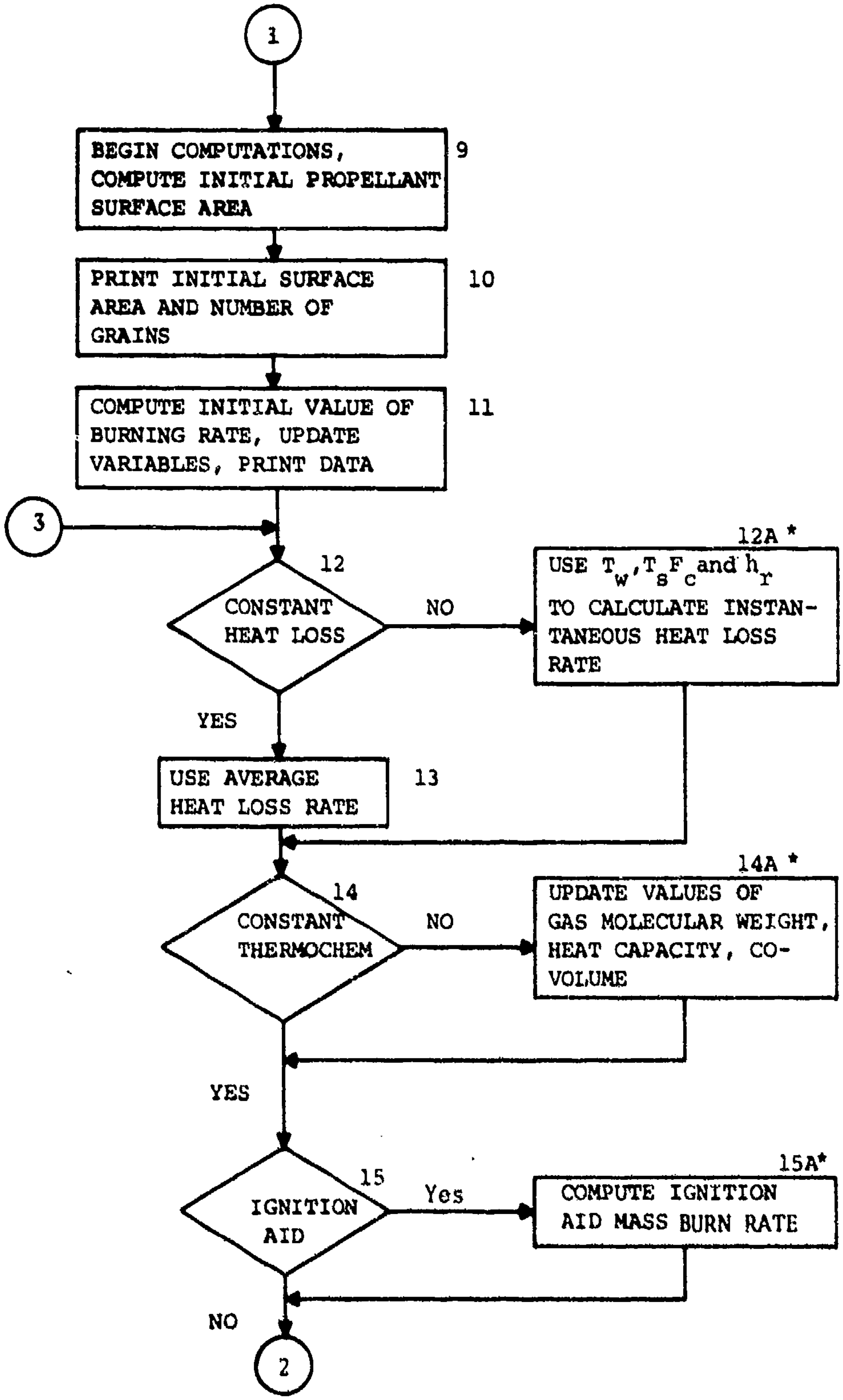


Figure 2-2. Closed Bomb Burn Rate Program (CBRED). Generalized Flow Scheme

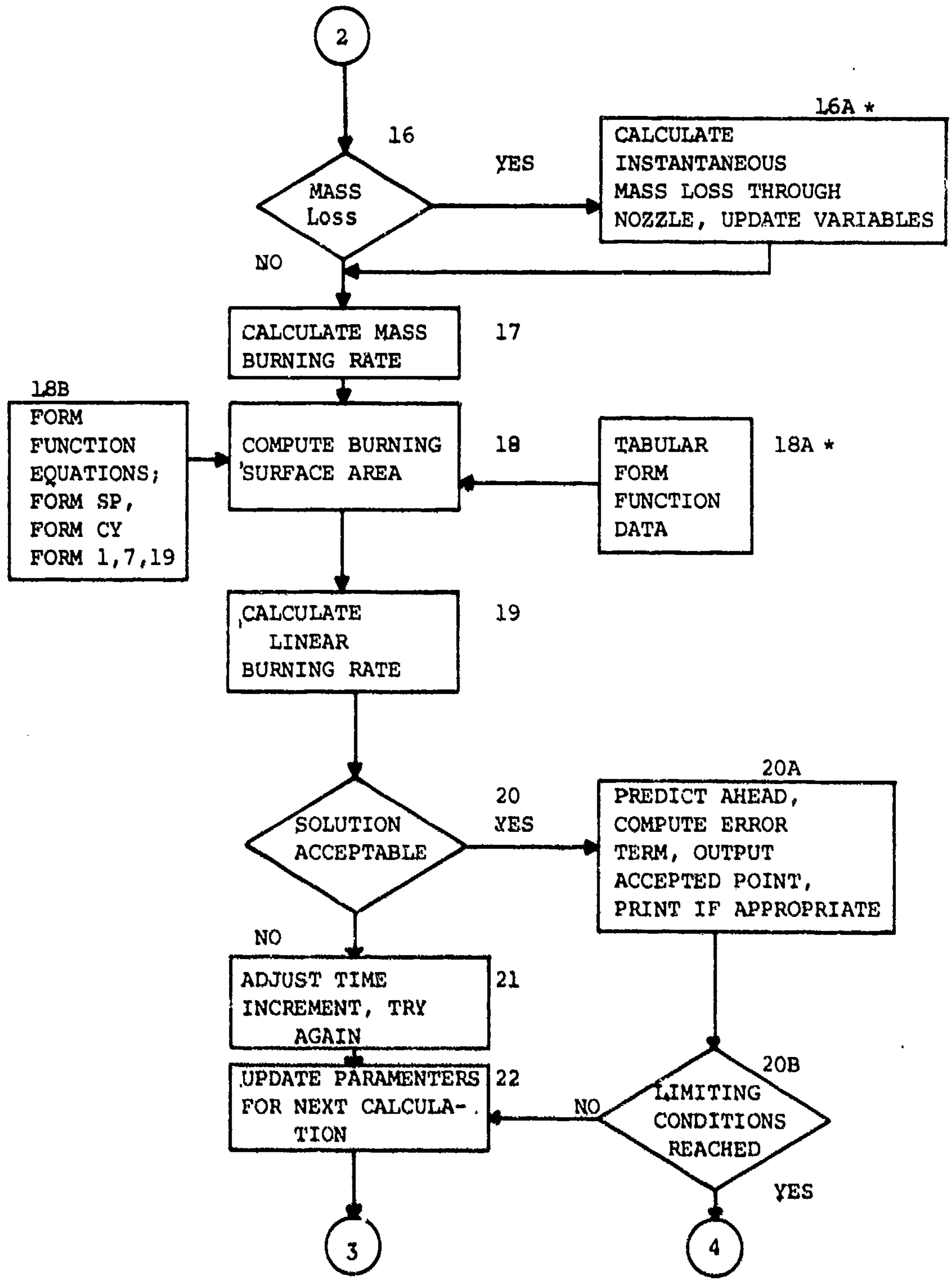


Figure 2-3. Closed Bomb Burn Rate Program (CBRED). Generalized Flow Scheme.

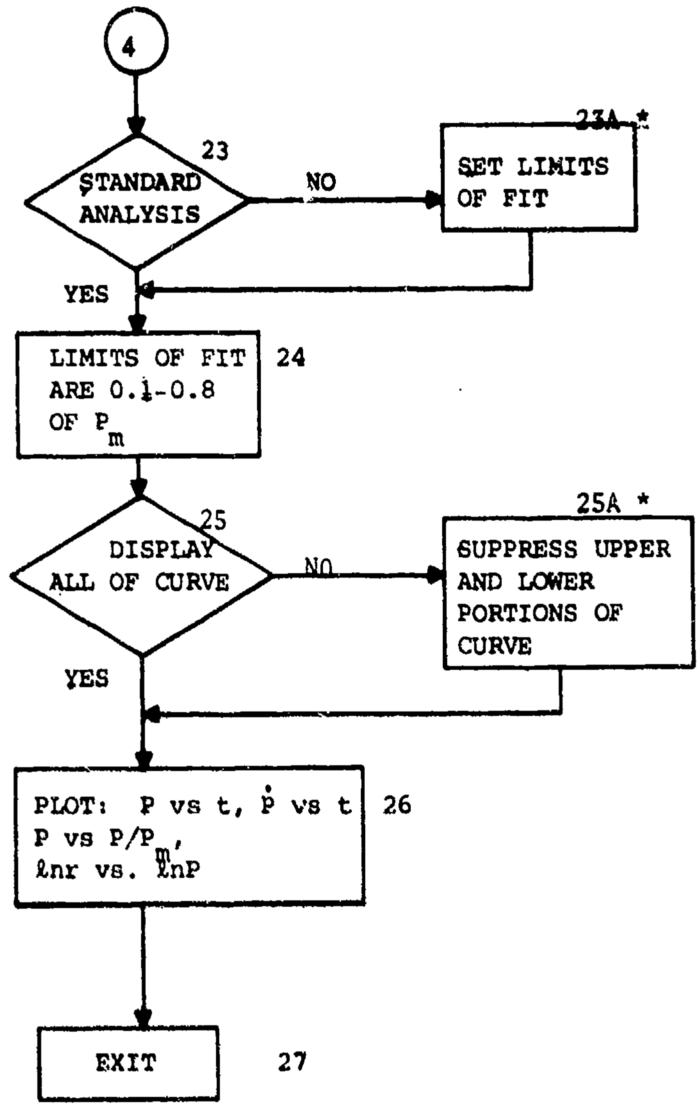


Figure 2-4. Closed Bomb Burn Rate Program (CBRED). Generalized Flow Scheme.

1. Start up (Blocks 1, 2 and 3). Once the program (CBRED) is called, it signs in and requests the file name and extension of the data file to be analyzed. On input of the file name and extension the data file is read in. The input data consists of matched arrays of pressure-time and time derivative of pressure-time data as well as a data set consisting of experimental, thermodynamic and grain geometry data (see Appendix A). The data is stored on magnetic tape and is handled as a single unit. (At the time the experiments run, the operator records in the data file all the parameters required for data reduction. This is done using a separate program, CBDAP. The pressure-time data obtained is differentiated by a second program, SCHECK. The "header" information is carried through to the new data file. Opportunities for updating the "header" information are provided by both programs). These operations take place in the main program and subroutine ACQUIRE.

2. Mode of Analysis (Block 4). The question is posed to the operator whether the analysis to be performed will be in the standard or nonstandard mode. Once the choice for the standard analysis mode has been made, the program goes into execution without further input from the operator. See subroutine ACQUIRE also.

3. Initialization (Block 5). At this point a variety of operations necessary to initialize the problem are performed. The input parameters are converted to a consistent set of units. At present a pound, foot (inch), second, BTU system is employed, but gas temperatures are in degrees Kelvin. A number of constants of multiple usage are also computed. This also takes place in subroutine ACQUIRE. On completion of this task, control reverts to MAIN which then passes operations to subroutine HTLOSS.

4. Heat loss (Block 6). At this point the input data file is searched for the maximum pressure, the maximum time derivative of pressure and selected values of P and dP/dt. The ignition pressure is computed using the igniter weight and thermochemistry and the theoretical (adiabatic) maximum pressure is calculated. This data is used to compute the Average Heat Loss Rate ($\bar{\dot{H}}_L$). Other operations including setting the ignition time for the analysis, setting the starting time interval, computing the initial system temperature and gas generation rate are also performed. These operations are performed in subroutine HTLOSS. Control then passes to MAIN which relinquishes operation to subroutine SUMUP.

5. Run header (Block 8). The function of subroutine SUMUP is to provide the identifying information for the run. Information on the data file designation, propellant parameters, igniter data, bomb data as well as summary information on the pressures and the time derivatives of pressure obtained are printed. The first page and part of the second page of Appendix B are the output from this operation. The only portion of the header not printed at this point relates to the initial

propellant surface area and the number of propellant grains. Subroutine SUMUP passes control back to MAIN which then passes control to subroutine REDUCE.

6. Begin Computation (Blocks 9-11). Subroutine REDUCE controls the differential equation solver, subroutine EVES. It specifies the number of differential equations to be solved, the stopping time and the interval at which data are to be printed out. (See pages 3 and 4 of Appendix B). Control then passes from REDUCE to EVES until the stopping time (or some other limiting condition) is reached.

To initiate computations, subroutine EVES calls subroutine SETUP whose job it is to provide the initial values of the functions and the factors needed to calculate the starting values of the differentials. Values are assigned to the propellant mass generation rate, ignition aid burning rate, mass loss rate, thermodynamic parameters, heat loss, etc. In a standard analysis, the initial heat loss rate is the average heat loss rate computed earlier in subroutine HTLOSS. The initial mass loss rate and igniter burning rate are zero. The initial surface area of the propellant is computed by calling the appropriate form function subroutine. The surface area data and the number of propellant grains are then printed, completing the "header" section of the program output (Block 10). Control passes from SETUP through EVES to DIFEQ where the initial values of the differentials are computed. (The functions evaluated using DIFEQ and EVES are designated as Y(N) and their differentials as DY(N); see the FORTRAN column in the List of Symbols.) In a standard analysis, the initial mass burning rate is set equal to the ignition aid mass burning rate at the point of ignition. The other mass differentials (and their integrals) are, of course, zero.

Using the starting values of the function (Y_0) and its differential ($\dot{Y}_0$) EVES computes an estimated value for the function at the completion of the first time interval ($\bar{Y}_1$). This value is fed back to DIFEQ where it is used to obtain a new value of the differential ($\dot{Y}_1$). The difference between ($\dot{Y}_0$) and ($\dot{Y}_1$) is examined and compared with an error level built into the program. If the value passes, the value of the function (Y_1) and its differential ($\dot{Y}_1$) are accepted, the time interval is incremented (Block 9) and the process is repeated. The initial integration steps are purposely kept small to establish the initial table of differences required by the predictor-corrector technique. Subroutine EVES has the built in capability to adjust the size of the time step used as the analysis progresses so that under conditions where the predictor values are better than required by the difference critereon, the time steps are increased in size, providing a savings of computation time. Time steps are, of course, also automatically reduced by the program as required.

7. Compute Burning Rates (Blocks 12 through 22). The process just described is followed to obtain the required values of linear burning rates throughout the analysis. At each step where a new value of (dw_p/dt) is required, subroutine DIFEQ computes the values based on the updated values of the parameters in the Mass Burning Rate Equation. The value is examined in EVES and accepted or rejected as necessary. Blocks 12 through 22 are involved in the process; Of these 12 through 19 take place in subroutine DIFEQ and the appropriate form function subroutine. In a standard analysis the heat loss rate is constant and the average heat loss rate is used. Since propellant thermodynamic characteristics are constant, no updating of values is done. The same is true for both the ignition aid burning and the mass loss terms. If the solution of the differential equation (as judged in EVES) is acceptable at any point, values for burning rate are accepted along with those of w_p and dw_p/dt. At given intervals during the analysis the data are printed out (EVES calls subroutine PRINT), see pages 50 and 51 of Appendix B. Tests for limiting conditions (web, all burned, pressure = P_m, and time = T_m) are made throughout the analysis and once one of the limiting conditions is reached, EVES returns control to REDUCE which returns control to MAIN.

8. Fitting the burning rate data (Block 25). Once the reduction phase is completed, the burning rate data between 0.1-0.8 of P_m is fitted to an equation of the form $r=AP^n$. This is done in subroutine RCALC.

9. Plotting of data and results. (25,26). The question is posed to the operator whether the lower and upper portion of the burning rate curve are to be suppressed. Generally this is done, since the most meaningful data is between 0.1 & 0.8 of P_m. After this decision, P vs.t; dP/dt vs t; dP/dt vs P/P_m and $\ell n r$ vs. $\ell n P^m$ are prepared and the program exits. The complete output package from the program may be seen in Appendix B.

B. <u>Nonstandard Analysis</u>

If the nonstandard mode of analysis is chosen, an interactive display is activated in subroutine ACQUIRE (Block (4A) which allows temporary modification of the pertinent ballistic information appearing in the data file. In addition to these changes, decisions concerning a variety of options have to be made. A brief discussion of each of the options, follows.

1. Heat loss. (Blocks 7A, 12 and 12A). In the nonstandard mode, the first option concerns the assignment of heat loss. The standard option, (Block 6). was described earlier. The nonstandard option (Block 7A) is a much more sophisticated treatment which assigns values to the convective and radiative components of heat loss based on the decay portion (after P_m) of the firing record itself. The theory was discussed earlier. In the reduction phase of the program

the heat loss rate ($\dot{H}_L$) is computed at each point in subroutine DIFEQ. Both the convective and radiative heat loss rates are functions of the gas and wall temperatures. Subroutine WALTEM is, therefore, invoked to provide current values of wall temperature as are needed in the analysis. This is shown schematically by Block 12A in Figure 2.

2. Propellant Geometry (Blocks 18A & 18B). The purpose of this option is to approximate the effect of real propellant geometry by using a distribution of web values rather than nominal web values. The computations take place in DIFEQ and the appropriate form function subroutine. A web deviation value may be input in the nonstandard mode resulting in the proportioning of the propellant charge into five parts: two each of 10 percent, two each of 20 percent, and one each of 40 percent of the total charge with webs differing from the nominal by plus or minus suitable factors times the web deviation derived from a normal population distribution curve. These five propellants, equivalent in weight to but not having the same initial area or the same overall form function as the total charge considered as a nominal case are treated as separate entities in the burning area portion of the reduction and the instantaneous areas summed for calculation of the linear burning rate. This option eliminates sharp discontinuities of surface area at certain points. (Computer generated pressure-time curves using this approach have resulted in much closer agreement with dP/dt data taken from real propellant geometries.) Only the burning area portion of the analysis is affected.

3. Ignition Deviation. This option permits the simulation of flame spreading effects that may occur in an experimental firing. A population distribution similar to the one above (propellant geometry section) is used. The propellant is assumed to be composed of five samples, each ignited at a different time. (It is the value of the time interval that is input from the keyboard.) The distance burned for each fraction is calculated separately. These values of x are used to compute the area of the burning surface of the charge during the analysis. A linear interpolation method is used to remove gross discontinuities in the burning area between the times of ignition of two adjacent samples and upon burnout of the first sample. Only the burning area portion of the program is affected by this option. Operations take place in subroutine DIFEQ which calls the appropriate form function subroutine as required.

4. Ignition Aid. (Block 15, 15A). This option is useful in describing situations in which not only an igniter but also an ignition aid is present. Since the ignition aid actually has a finite burn time relative to the propellant, the option allows modification of the "ignition pressure" to account for the partial burnout of the aid material at the time that propellant ignition takes place. During the early phase of the firing, therefore, both propellant and ignition aid will be contributing to the mass generation rate, hence to dP/dt. The aid contribution must be evaluated separately. At present this is

accomplished by external input or by analysis of the dP/dt portion of the record just prior to the chosen ignition point (pressure), translating this dP/dt into an equivalent mass burning rate of the aid and fitting it to a power law curve. Evaluation of the instantaneous value of the ignition aid burning rate is performed in subroutine DIFEQ. The function is integrated in EVES. The computation of the mass burning rate (Block 17) is, of course, affected (see Equation 14 term E).

5. Variable thermochemistry. (Blocks 14 and 14A). This option allows the input of the required thermochemical information for the propellant in the form of a table of values versus pressure. The table entry takes place in subroutine ACQUIRE. Values for the rate of change of covolume, heat capacity etc. are computed in subroutine DIFEQ and used in calculating the mass burning rate of the propellant (also in DIFEQ).

6. Vented Chamber Operation. (Blocks 16 and 16A). This option allows analysis of firings made with "leaking" or vented vessels. The effective vent area and the blow-out pressure of the vent are necessary inputs and their presence will automatically result in analysis beyond the time of P_{max} and the computation of the mass-discharge term in the differential equations. Instantaneous temperatures as well as the effects of changing molecular weight are used in determining this term.

7. Burning Surface. (Block 18A). In this option, an arbitrary total burning surface area as a function of some characteristic burning dimension may be input to the program if none of the available form functions appear suitable. The input consists of a table of points, and the instantaneous area is interpolated linearly from the information furnished. For seldom used unique geometries, it avoids the nuisance of recompiling the program to include a special form function generator.

C. Summary

A versatile closed bomb data reduction program has been developed to compute linear burning rate of propellants from the pressure-time histories of their burning process. In Section II, the capability of the program as seen from the user's point of view was discussed, and a comparison of the standard and nonstandard modes of analysis was made. An introduction to the theoretical treatment was made in Section III and the relationship between the equations used in the program and the simplified derived equation was examined. In Section IV, program structure and operation were examined and a flow chart of the program as well as a diagram of the subroutine hierarachy was given. Finally, the impact of each of the options on program execution was discussed. The derivation of the mass burning equations (Appendix D) as well as a program listing (Appendix G) are provided.

ACKNOWLEDGEMENTS

Special acknowledgements go to the following: Dr. I. May, without whose interest and support the work would not have been done; Dr. J. Rocchio whose discussions helped to smooth the rough edges in the text, Mr. F. Lynn, Mr. P. Baer and Mr. T. Trafton for helpful discussions of the programming and equations and Mr. B. Grollman for first sparking our interest in closed bombs.

REFERENCES

1. J. Corner, M. A. PhD, Theory of the Interior Ballistics of Guns, New York, John Wiley and Sons, Inc., 1950.

2. Paul G. Baer and Jerome M. Frankle, "The Simulation of Interior Ballistic Performance of Guns by Digital Computer Program," Ballistic Research Laboratories Report No. 1183, December 1962, AD # 299980.

3. A. C. Haukland and W. M. Burnett, "Sensitivity of Interior Ballistic Performance to Propellant Thermochemical Parameters," Proceedings of the Tri-Service Gun Propellant Symposium, 11-13 October 1972, Picatinny Arsenal, Dover, NJ, Vol 1, Section 7.3.

4. Paul G. Baer, Ingo W. May, and Jerome M. Frankle, "A Comparison of Several Predictive Approaches in Charge Establishment for Large Caliber Artillery Systems," Proceedings of the 11th JANNAF Combustion Meeting, Jet Propulsion Laboratory, Pasadena, CA., September 1974, Vol 1; C.P.I.A. Publication 261, December 1974, The Chemical Propulsion Information Agency, Silver Spring, Md.

5. William H. Tschappat, Lt.-Col, Ord. Dept., Text-Book of Ordnance and Gunnery, 1st Ed., New York, John Wiley and Sons, Inc., 1917, pp. 111-118.

6. Albert A. Bennett, PhD, "Tables of Interior Ballistics," Ordnance Department Pamphlet No. 2039, April 1921.

7. D. W. Reifler and D. J. Lowery, "Linear Burn Rates of Ball Propellants Based on Closed Bomb Firings," Ballistic Research Laboratories Contractor Report No. 172, August 1974. (AD #921704L)

8. Henri Muraour, "Chemie Physique sur la Reaction Entre La Temperature de la Explosion d' une Poudre et sa Vitesse de Combostion," Comp. rend., Vol 187, 1928, pp. 289-294.

9. Ref 1, pp. 42-84 and references therein.

10. Bryce L. Crawford, Jr., Clayton Huggett, and J. J. McBrady, "The Mechanism of Burning of Double Base Propellants," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 854-862.

11. Robert G. Parr and Bryce L. Crawford, Jr., "A Physical Theory of Burning of Double Base Rocket Propellants," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 929-954.

12. O. K. Rice and Robert Ginell, "The Theory of Burning of Double Base Rocket Powders," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 885-917.

REFERENCES (Continued)

13. R. E. Wilfong, S. S. Penner, and F. Daniels, "An Hypothesis for Propellant Burning," J. Phys. and Colloid Chem., Vol 54, 1950, pp. 863-872.

14. R. D. Geckler, "Mechanism of Combustion of Solid Propellants," Selected Combustion Problems, London, Butterworths Scientific Publications, 1954, pp. 289-339.

15. D. B. Spalding, "The Theory of Solid and Liquid Propellants," Combustion and Flame, Vol 4, 1960, pp. 59-76.

16. Method 801.1.1, "Quickness and Force Measurement of Propellant (Closed Bomb Method)," (Revised 21 Oct 75), Military Standard 286B, Department of Defense, Washington, DC 20301.

17. C. M. Dickey, "Determination of Burning Characteristics of Propellant," E. I. duPont de Nemours and Company, Explosives Department, Burnside Laboratory, Memorandum Report No. 31 (File BL-135-101), March 1943.

18. James H. Wiegand, "A Method of Calculation of the Burning Rate of Powders from dP/dt vs. P Records for Closed Chambers," Ballistic Research Laboratories Report No. 546, June 1945.

19. E. Haeuseler and W. Dehl, "State of Development of Testing Procedures for Propellants in the Closed Vessel," Explosivstoffe, Vol 18, 1970, pp. 41-52.

20. H. Krier and S. A. Shimpi, "Predicting Uniform Gun Interior Ballistics: - Part I - An Analysis of Closed-Bomb Testing," University of Illinois Technical Report AAE-74-5, July 1974 (Contract DAAA-21-73-C-0549).

Selected Bibliography of Closed Bomb Burn Rate Reduction Methods

1. Bonner, L.G., "Determination of the Linear Burning Rates of Propellants from Pressure Measurements in the Closed Chamber," OSRD Report No. 4382, Office of Scientific Research and Development, Washington, D. C., 1 November 1944.

2. Celmins, A., "Solid Propellant Burning Rate Measurement in a Closed Bomb," Combustion and Flame, Vol. 23, pp 381-397, 1974.

3. Dickey, C. M., "Determination of Burning Characteristics of Propellant," E. J. duPont de Nemours and Company, Explosives Department, Burnside Laboratory, Memorandum Report No. 31, (File BL-135-101), March 1943.

4. Haeuseler, E. and Dehl, W., "State of Development of Testing Procedures for Propellants in the Closed Vessel," Explosivstoffe, Vol. 18, pp 41-52, 1970.

5. Krier, H. and Shimpi, S. A., "Predicting Uniform Gun Interior Ballistics: Part I - An Analysis of Closed Bomb Testing," University of Illinois Technical Report AAE-74-5, July 1974. (Contract DAAA-21-73-C-0549.)

6. Massey, J. M. Jr., "Measurements of Impetus, Covolume and Burning Rate in Solid Propellants," Naval Weapons Laboratory Report No. 1872, Dahlgren, VA, July 1963.

7. Pallingston, Arnold O. and Weinstein, Murray, "Method of Calculation of Interior Ballistic Properties of Propellants from Closed Bomb Data," Picatinny Arsenal Technical Report No. 2005, Dover, NJ, June 1954.

8. Pike, H. H. M. and Hunt, F. R. W., "Chapter V, Combustion at Constant Volume," from F. R. W. Hunt, ed., Internal Ballistics, New York, Philosophical Library, pp 53-66, 1951.

9. Riefler, D. W., and Lowery, D. J., "Linear Burn Rates of Ball Propellants Based on Closed Bomb Firings," Ballistic Research Laboratory Contractor Report No. 172, Aberdeen Proving Ground, MD, August 1974.

10. Robbins, F. W. and Horst, A. W., "Numerical Simulation of Closed Bomb Performance Based on Blake Code Thermodynamic Data," Indian Head Memorandum Report 76-259, Naval Ordnance Station, Indian Head, MD, December 1976.

11. Wallace, William F., "New Formulas for Rapid Calculation of Linear Burning Rates of Solid Propellants," Picatinny Arsenal Technical Report No. 2488, Dover, NJ, April 1958.

12. Wiegand, James H., "A Method of Calculation of the Burning Rate of Powders from dP/dt vs. P Records for Closed Chambers," Ballistic Research Laboratory Report No. 546, Aberdeen Proving Ground, MD, June 1945.

APPENDIX A

Input Requirements for CBRED

Input Requirements for CBRED*

1. Run ID. Provides input file designation for program.
2. Propellant Data.
   a. Type
   b. Weight (grams)
   c. Density (grams/cc)
   d. Grain Type
   e. Length, OD, ID (inches)
   f. Inner Web, Outer Web (inches)
   g. Theoretical Impetus (ft-lb/lb)
   h. Flame Temperature (°K)
   i. Average Molecular Weight of Products (grams/mole)
   j. Covolume (cubic inch per pound)
   k. Gamma (ratio of specific heat)
3. Igniter Data
   a. Type
   b. Weight (grams)
   c. Impetus (ft-lb/lb)
4. Experiment Data
   a. Bomb Volume (cc)
   b. Bomb Temperature (°K)

* The input information listed is actually what is required by the program being documented. Conversion to metric units is being planned.

5. Data Arrays (digital)

   a. Pressure-Time* (Kpsi, milliseconds)

   b. Time Derivative of Pressure-Time* (mega psi, milliseconds)

*The input information listed is actually what is required by the program being documented. Conversion to metric units is being planned.

APPENDIX B

Sample Output, CBRED*

*Program output is currently not in metric units. Conversion is being planned.

RUN ID:	CB1V75.027
RUN TITLE:	LOVA STUDY RUN SIX
DATE:	31 JULY 1975
OPERATOR:	AAJ/REB

PROPELLANT DATA:

TYPE:	LOVA F704-35-1 FEM 210-5-029; HMX 65% 2MICRON, 10% 10MICRON		
WEIGHT (GMS):	12.50159		
DENSITY (GM/CC):	1.63000		
INITIAL TEMPERATURE (DEG K):	300.50000		
LOT:	LOT 10A		
SOURCE:	THIOKOL WASATCH UTAH		
GRAIN TYPE:	CY		
LENGTH,OD,ID (IN):	0.02170,	0.25000,	0.00000,
INNER WEB,OUTER WEB (IN):	0.02170,	0.02170,	
THEORETICAL IMPETUS (FT-LB/LB):	319502.00000		
FLAME TEMPERATURE:	2280.84351		
AVERAGE MOLECULAR WEIGHT OF PROD:	19.94000		
CO-VOLUME (CU IN/LB):	31.69000		
GAMMA (RATIO OF SP HTS):	1.27100		
REMARKS:	FLAKE, NON-GRAPHITED, NON-PERFORATED		

IGNITER DATA:

TYPE:	DUPONT 700X
WEIGHT (GMS):	0.50850
IMPETUS (FT-LB/LB):	362530.00000

EQUIPMENT DATA

BOMB VOLUME (CC):	80.90000
BOMB TEMP (DEG K):	300.50000
GAUGE TYPE:	PT-3
CALIBRATION FACTOR (PC/PSI):	1.64320

RESULTS:

THEORETICAL MAX PRESS (KPSIA):	24.50900
OBSERVED MAX PRESS (KPSIA):	22.42971
IGNITER PRESSURE (KPSIA):	0.92221

IGNITION TIME INFORMATION:

TIME TO 10% PMAX (MSEC):	14.06122
TIME TO 90% PMAX (MSEC):	25.42654
TIME TO 100% PMAX (MSEC):	33.55000
TIME FROM 10% TO 90% PMAX (MSEC):	11.36532

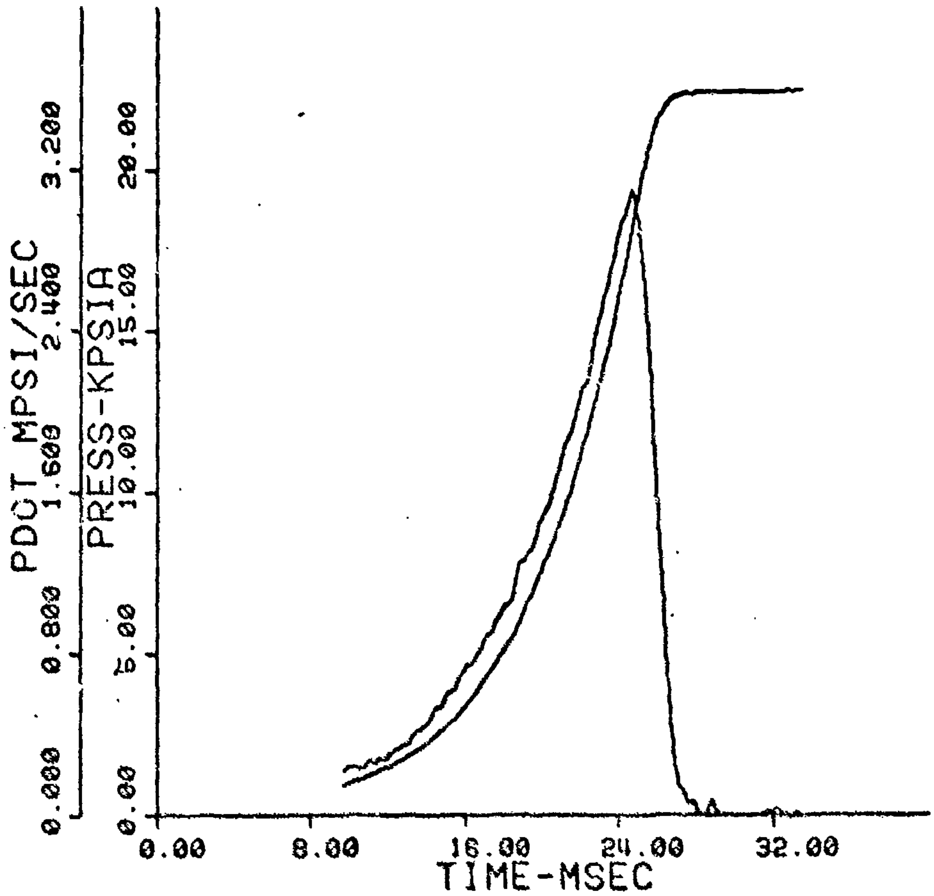
```
QUICKNESS INFORMATION:

PDOT AT .250 PMAX:           1.11212
PDOT AT .375 PMAX:           1.60492
PDOT AT .500 PMAX:           2.09854
PDOT AT .625 PMAX:           2.54956
AVERAGE PDOT:                1.84129

MAXIMUM PDOT (MPSI/SEC):     3.09774     OBSERVED AT P = (KPSIA):     18.20000

HEAT LOSS OPTION:   CONSTANT
HEAT LOSS NUMBER:   1453.51169

INITIAL SURFACE AREA (SQ IN):    50.60287
NUMBER OF GRAINS:                     439
```

CB1V75.027

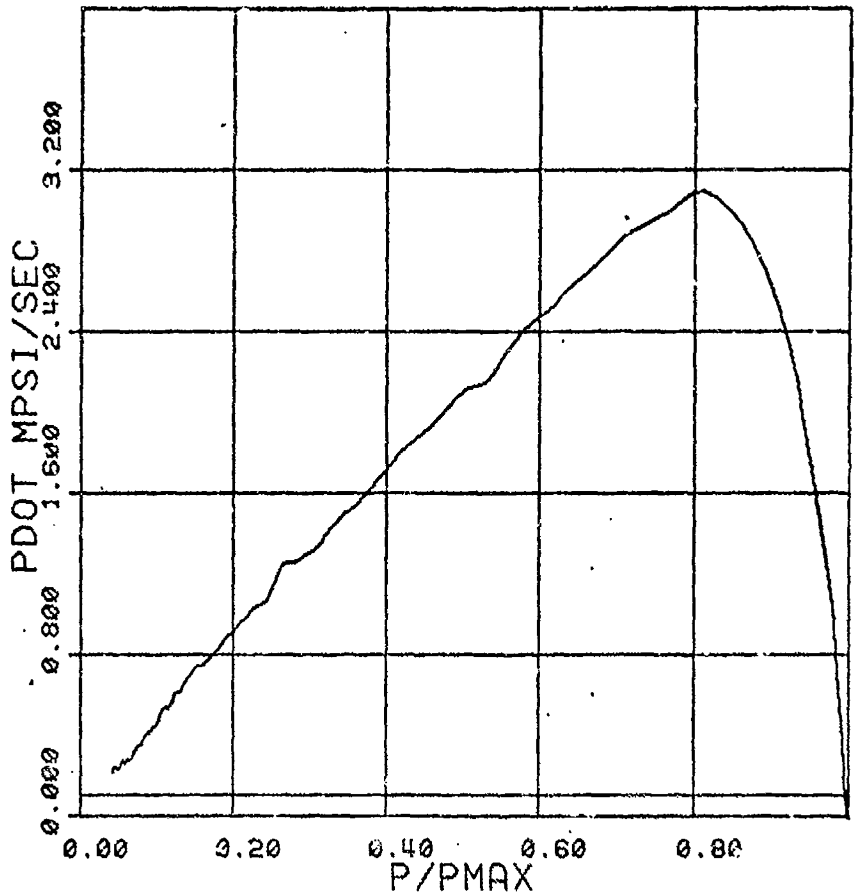
TIME MSEC	PRESS KPSIA	DP/DT MPSI/SEC	RATE IN/SEC	WT FR	SURF FR	WEB BRN INCH	PDOT/PMAX MSEC-1
9.736	0.922	0.216	0.127	0.0000	1.0000	0.0000	0.010
9.986	0.970	0.236	0.136	0.0035	0.9991	0.0001	0.011
10.236	1.030	0.241	0.130	0.0073	0.9981	0.0001	0.011
10.486	1.093	0.233	0.134	0.0109	0.9971	0.0002	0.010
10.736	1.156	0.237	0.137	0.0146	0.9962	0.0003	0.011
10.986	1.215	0.257	0.146	0.0183	0.9952	0.0003	0.011
11.236	1.284	0.262	0.140	0.0224	0.9941	0.0004	0.012
11.486	1.348	0.267	0.150	0.0263	0.9931	0.0005	0.012
11.736	1.417	0.275	0.154	0.0304	0.9920	0.0006	0.012
11.986	1.493	0.278	0.155	0.0346	0.9909	0.0006	0.012
12.236	1.556	0.309	0.168	0.0388	0.9898	0.0007	0.014
12.486	1.637	0.325	0.175	0.0435	0.9885	0.0008	0.014
12.736	1.719	0.342	0.183	0.0482	0.9873	0.0009	0.015
12.986	1.808	0.351	0.187	0.0532	0.9860	0.0010	0.016
13.236	1.895	0.382	0.201	0.0582	0.9846	0.0011	0.017
13.486	1.998	0.413	0.214	0.0638	0.9831	0.0012	0.018
13.736	2.101	0.425	0.219	0.0695	0.9816	0.0013	0.019
13.986	2.211	0.443	0.227	0.0755	0.9800	0.0014	0.020
14.236	2.322	0.472	0.240	0.0816	0.9784	0.0015	0.021
14.486	2.447	0.531	0.266	0.0883	0.9766	0.0017	0.024
14.736	2.534	0.531	0.266	0.0934	0.9747	0.0018	0.024
14.986	2.717	0.579	0.288	0.1026	0.9728	0.0019	0.026
15.236	2.870	0.612	0.303	0.1104	0.9707	0.0021	0.027
15.486	3.023	0.636	0.313	0.1184	0.9686	0.0022	0.028
15.736	3.191	0.685	0.335	0.1269	0.9663	0.0024	0.031
15.986	3.365	0.726	0.353	0.1359	0.9639	0.0026	0.032
16.236	3.551	0.746	0.363	0.1453	0.9613	0.0027	0.033
16.486	3.738	0.769	0.373	0.1548	0.9588	0.0029	0.034
16.736	3.937	0.812	0.392	0.1647	0.9561	0.0031	0.036
16.986	4.143	0.846	0.408	0.1750	0.9533	0.0033	0.038
17.236	4.363	0.898	0.431	0.1858	0.9504	0.0035	0.040
17.486	4.589	0.929	0.446	0.1970	0.9473	0.0037	0.041
17.736	4.830	0.974	0.466	0.2087	0.9442	0.0040	0.043
17.986	5.077	1.024	0.489	0.2209	0.9409	0.0042	0.046
18.236	5.339	1.049	0.501	0.2335	0.9374	0.0045	0.047
18.486	5.605	1.111	0.530	0.2464	0.9339	0.0047	0.050
18.736	5.899	1.237	0.586	0.2605	0.9300	0.0050	0.055
18.986	6.213	1.254	0.595	0.2754	0.9259	0.0053	0.056
19.236	6.529	1.289	0.612	0.2904	0.9218	0.0056	0.057
19.486	6.855	1.322	0.628	0.3055	0.9175	0.0059	0.059
19.736	7.193	1.395	0.663	0.3218	0.9131	0.0062	0.062
19.986	7.551	1.467	0.696	0.3385	0.9084	0.0066	0.065
20.236	7.925	1.520	0.722	0.3559	0.9036	0.0069	0.068
20.486	8.311	1.584	0.753	0.3738	0.8986	0.0073	0.071
20.736	8.717	1.663	0.791	0.3925	0.8933	0.0077	0.074
20.986	9.142	1.750	0.833	0.4121	0.8878	0.0081	0.078
21.236	9.592	1.833	0.874	0.4325	0.8820	0.0085	0.082
21.486	10.059	1.899	0.907	0.4537	0.8760	0.0089	0.085

CB1V75.027

TIME MSEC	PRESS KPSIA	DP/DT MPSI/SEC	RATE IN/SEC	WT FR	SURF FR	WEB BRN INCH	PDOT/PMAX MSEC-1
21.736	10.542	1.975	0.945	0.4755	0.8698	0.0094	0.088
21.986	11.048	2.069	0.992	0.4982	0.8632	0.0099	0.092
22.236	11.577	2.127	1.023	0.5217	0.8565	0.0104	0.095
22.486	12.110	2.190	1.056	0.5456	0.8496	0.0109	0.098
22.736	12.677	2.344	1.133	0.5706	0.8423	0.0115	0.104
22.986	13.270	2.450	1.189	0.5970	0.8346	0.0120	0.109
23.236	13.900	2.530	1.232	0.6241	0.8266	0.0127	0.113
23.486	14.547	2.645	1.293	0.6522	0.8183	0.0133	0.118
23.736	15.221	2.746	1.349	0.6813	0.8096	0.0139	0.122
23.986	15.924	2.859	1.416	0.7114	0.8006	0.0145	0.12[illegible]
24.236	16.653	2.947	1.463	0.7424	0.7912	0.0154	0.131
24.486	17.396	3.022	1.509	0.7739	0.7816	0.0161	0.135
24.736	18.166	3.090	1.557	0.8062	0.7717	0.0169	0.138
24.986	18.934	3.002	1.521	0.8383	0.7618	0.0176	0.134
25.236	19.667	2.828	1.446	0.8687	0.7523	0.0184	0.126
25.486	20.340	2.535	1.310	0.8957	0.7426	0.0191	0.113
25.736	20.920	2.132	1.115	0.9211	0.7359	0.0197	0.095
25.986	21.402	1.660	0.887	0.9409	0.7296	0.0202	0.074
26.236	21.769	1.268	0.683	0.9563	0.7246	0.0206	0.056
26.486	22.028	0.822	0.463	0.9676	0.7218	0.0209	0.037
26.736	22.184	0.474	0.286	0.9747	0.7187	0.0210	0.021
26.986	22.272	0.244	0.169	0.9791	0.7173	0.0212	0.011
27.236	22.313	0.140	0.116	0.9817	0.7165	0.0212	0.006
27.486	22.345	0.093	0.092	0.9838	0.7158	0.0213	0.004
27.736	22.368	0.058	0.074	0.9853	0.7153	0.0213	0.003
27.986	22.378	0.056	0.073	0.9868	0.7149	0.0214	0.002
28.236	22.381	-0.003	0.043	0.9879	0.7145	0.0214	-0.000
28.486	22.381	-0.003	0.043	0.9887	0.7142	0.0214	-0.000
28.736	22.384	0.049	0.070	0.9897	0.7139	0.0214	0.002
28.986	22.403	0.050	0.070	0.9912	0.7134	0.0215	0.002
29.236	22.405	-0.003	0.043	0.9922	0.7131	0.0215	-0.000
29.486	22.405	0.000	0.045	0.9931	0.7128	0.0215	0.000
29.736	22.405	0.000	0.045	0.9933	0.7125	0.0215	0.000
29.986	22.405	0.000	0.045	0.9940	0.7123	0.0216	0.000
30.236	22.405	0.000	0.045	0.9956	0.7120	0.0216	0.000
30.486	22.405	0.000	0.045	0.9965	0.7117	0.0216	0.000
30.736	22.405	0.000	0.045	0.9974	0.7114	0.0216	0.000
30.986	22.405	0.000	0.045	0.9982	0.7112	0.0217	0.000
31.236	22.405	0.000	0.045	0.9991	0.7109	0.0217	0.000
31.486	22.404	0.005	0.047	0.9999	0.7106	0.0217	0.000
31.736	22.410	0.024	0.047	1.0010	0.0000	0.0217	0.001
31.986	22.413	0.014	0.047	1.0020	0.0000	0.0217	0.001
32.236	22.421	0.034	0.047	1.0031	0.0000	0.0218	0.002
32.486	22.425	0.007	0.047	1.0042	0.0000	0.0218	0.000
32.736	22.428	0.004	0.047	1.0051	0.0000	0.0218	0.000
32.986	22.425	-0.006	0.047	1.0059	0.0000	0.0218	-0.000
33.236	22.427	0.013	0.047	1.0068	0.0000	0.0219	0.001

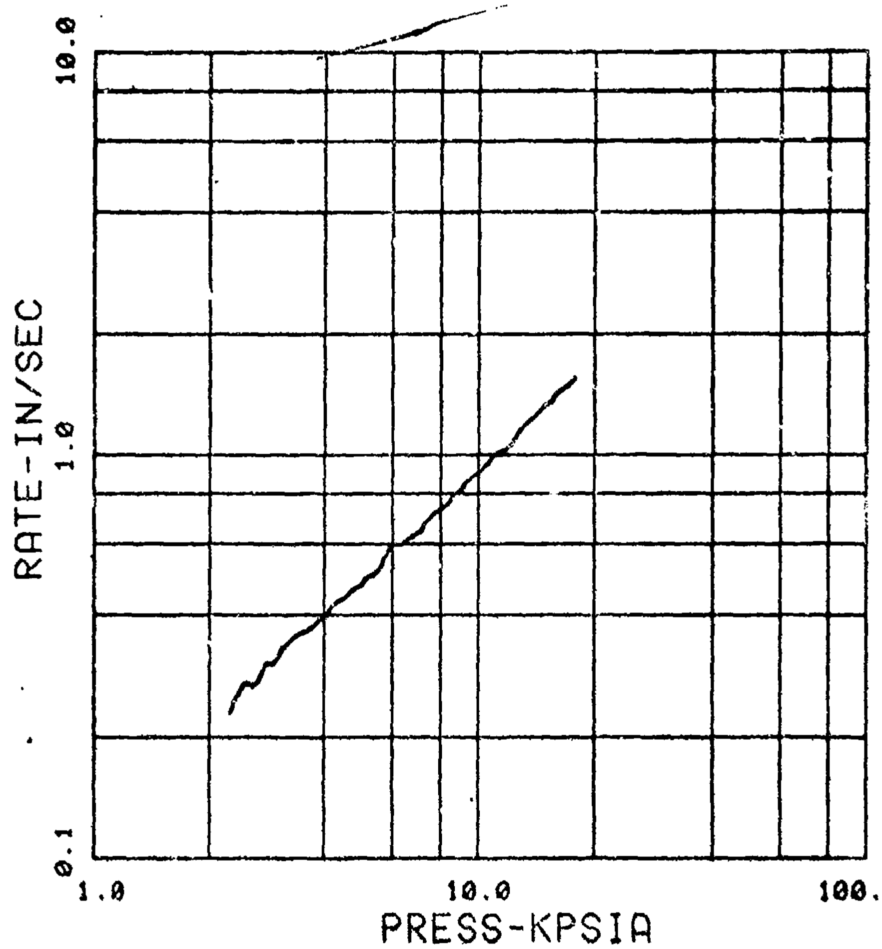


RUN ID: CB1V76.027
RUN TITLE: LOVA STUDY RUN SIX
PROP TYPE: LOVA F79N-S6-1 FEM 210-6-020; HMX 65% 2MICRON, 10% 10MICRON
GRAIN TYPE: 0Y



RUN ID: CB1V76.027
RUN TITLE: LOVA STUDY RUN SIX
PROP TYPE: LOVA F704-35-1 FEM 218-6-029; HMX 65% 2MICRON, 10% 10MICRON
GRAIN TYPE: OY

PDUT	AT	P/PMAX
1.112		5.607
1.606		8.411
2.000		11.215
2.550		14.019



RUN ID: C31V75.027

RUN TITLE: LOVA STUDY RUN SIX

PROP TYPE: LOVA F704-3G-1 FEM 218-5-020; HMX 85% 2MICRON, 10% 10MICRON

GRAIN TYPE: CY

THE CONSTANTS IN THE EQUATION R = R*P**N ARE

A: 0.000233

N: 0.000

FOR P/PMAX 0.100 TO 0.800

COEFFICIENT OF DETERMINATION : 0.9989

PER CENT ROOT MEAN ERROR : 1.6034

APPENDIX C

Form Function Equations
used in CBRED

Equation for FORM SP

Form Function of a Sphere. S, Surface Area, as a function of x, The Distance Burned

$W = D$

where: D = initial diameter of sphere

W = propellant web

x = depth burned at time t.

$S = 0$ for $W \leq 2x$

Otherwise:

$D' = D - 2x$

<u>Surface Area</u>

$$A = 4\pi \left(\frac{D'}{2}\right)^2$$

Equations for FORM CY

Form Function of a Right Circular Cylinder. S, Surface Area as a Function of x, the Distance Burned

$W = D$

where: D = initial grain diameter.

W = propellant web

x = depth burned at time t

$S = 0$ for $L \leq 2x$
(L = initial grain length)

$S = 0$ for $W \leq 2x$

Otherwise:

$D' = D - 2x$
$L' = L - 2x$

<u>End Area</u>:

$$E = \pi/4\,(D')^2$$

<u>Surface Area</u>:

$$S = 2E + \pi L' D'$$

Equations for FORM1

Form Function of a Single Perforated Right Circular Cylinder (Axially Symmetrical). S, Surface Area, as a function of x, the Distance Burned.

$$W = \frac{D - D_p}{2}$$

where:

W = propellant web

D = initial grain diameter

D_p = initial perforation diameter

x = depth burned at time t.

$S = 0$ for $L \leq 2x$

(L= initial grain length)

$S = 0$ for $W \leq 2x$

Otherwise:

$$D' = D - 2x$$
$$L' = L - 2x$$
$$D_{p'} = D_p + 2x$$

End Area:

$$E = \frac{\pi}{4}\left[(D')^2 - (D_{p'})^2\right]$$

Surface Area:

$$S = 2E + \pi L' (D' + D_{p'})$$

Equations for FORM 7

Form Function of a Seven Perforated Right Circular Cylinder (Axially Symmetrical). S, Surface Area, as a Function of x, the distance burned.

I. To splintering:

$$W = \frac{D - 3\,D_p}{4}$$

where:

W = propellant web
D = initial grain diameter
D_p = initial perforation diameter

x = depth burned at time t

$S = 0$ for $L' \leq 2x$
(L' = instantaneous grain length)

$S = S_{max}$ for $W=2x$

$S = < S_{max}$ for $W<2x$

for $0 \leq x$, define

$D' = D-2x$
$L' = L-2x$
(L = initial grain length)
$D_{p'} = D_p+2x$

Then, for $0 \leq 2x \leq W$

End Area

$$E = \frac{\pi}{4} \left[(D')^2 - 7\,(D_{p'})^2 \right]$$

Surface Area:

$$S = 2E + \pi\, L'\, (D' + 7\, D_{p'})$$

Form Function of a Seven Perforated Right Circular Cylinder (Axially Symmetrical). Surface Area, S, as a Function of x, The Distance Burned (continued).

II. After Splintering*

define: $W_w = D_p + W$ and let

$$C = \min\left\{L,\ \frac{D^2 - D_p^2 + 4W_w^2 - 2W_w D\sqrt{3}}{2(D + D_p - W_w\sqrt{3})}\right\}$$

Then for $W < 2x \leq C$, let

$$\Theta = 2\cos^{-1}\left\{\min\left(\frac{W_w}{D_{p'}},\ 1\right)\right\}$$

$$\alpha = \cos^{-1}\left\{\min\left(\frac{1/4\left[(D')^2 - (D_{p'})^2\right] + W_w^2}{W_w D'},\ 1\right)\right\}$$

$$\beta = \cos^{-1}\left\{\max\left(\frac{1/4\left[(D_{p'})^2 - (D')^2\right] + W_w^2}{W_w D_{p'}},\ -1\right)\right\} - \frac{\Theta}{2} - \frac{\pi}{3}$$

E_1 = End area of outer slivers

for $\alpha < \pi/6$

$$E_1 = 3\,D'\,W_w \sin\alpha + 3/2\left[(D')^2(\pi/6 - \alpha) - W_w^2\sqrt{3} - (D_{p'})^2(\beta + 1/2\sin\Theta)\right]$$

$E_1 = 0$ for $\alpha \geq \pi/6$

S_1 = Surface area of outer slivers

for $\alpha < \pi/6$

$$S_1 = 2E_1 + (6\beta Dp' + (\pi - 6\alpha)\,D')\,L'$$

$S_1 = 0$ for $\alpha \geq \pi/6$

* Treatment developed by Mr. Franz Lynn, USABRL.

E_2 = End area of inner slivers
for $\Theta < \pi/3$

$$E_2 = 3/2 \left[w_w^2 \sqrt{3} - 3/2(D_{p'})^2 \left(\sin \Theta + \pi/3 - \Theta\right) \right]$$

$E_2 = 0$ for $\Theta \geq \pi/3$

S_2 = Surface area of inner slivers
for $\Theta < \pi/3$

$$S_2 = 2E_2 + 9D_{p'} (\pi/3 - \Theta) L'$$

$S_2 = 0$ for $\pi/3 \leq \Theta$

S = Total surface area of slivers

$$S = S_1 + S_2$$

E = Total end area
$E = E_1 + E_2$

for $C < 2x$, $E=0$, $S=0$

Equations for FORM 19

Form Function for a Nineteen Perforated Right Circular Cylinder (Axially Symmetrical). S, Surface Area, as a Function of x, The Distance Burned.

I. To Splintering

$$W = \frac{D - 5\,D_p}{6}$$

where:

W = propellant web
D = initial grain diameter
D_p = initial perforation diameter

x = depth burned at time t
$S = 0$ for $L' \leq 2x$
(L' = instantaneous grain length)
$S = S_{max}$ for $W = 2x$
$S < S_{max}$ for $W < 2x$

for $0 \leq x$, define:

$D' = D - 2x$
$L' = L - 2x$
(L=initial grain length)
$D_{p'} = D_p + 2x$

Then, for $0 \leq 2x \leq W$

End Area

$$E = \frac{\pi}{4}\left[(D')^2 - 19\,(D_{p'})^2\right]$$

Surface Area

$$S = 2E + \pi L'\,(D' + 19\,D_{p'})$$

F(Function of a Nineteen Perforated Right Circular Cylinder (Axially Symm trical). Surface Area S, as a function of x, The Distance Burned. (continued).

II. After Slivering*

define: $W_w = D_p + W$ and let

$$C = \min \left\{ L,\ 1/2 \left[D - D_p - W_w \sqrt{\frac{12[(D+D_p)^2 - 16W_w^{\ 2}]}{[D+D_p]^2 - 12W_w^{\ 2}}} \right] \right\}$$

Then, for $w<2x\leq C$, let

$$\Theta = 2 \cos^{-1} \left\{ \min \left(\frac{W_w}{D_{p'}},\ 1 \right) \right\}$$

$$\alpha_1 = \cos^{-1} \left\{ \min \left(\frac{1/8\ [(D')^2 - (D_{p'})^2] + 2\ W_w^{\ 2}}{W_w D'},\ 1 \right) \right\}$$

$$\alpha_2 = \cos^{-1} \left\{ \min \left(\frac{1/4\ [(D')^2] - (D_{p'})^2 - (D_{p'})^2] + 3\ W_w^{\ 2}}{W_w D' \sqrt{3}},\ 1 \right) \right\}$$

$$\beta_1 = \cos^{-1} \left\{ \max \left(\frac{1/8\ [(D_{p'})^2 - (D')^2] + 2\ W_w^{\ 2}}{W_w D_{p'}},\ -1 \right) \right\}$$

$$\beta_2 = \cos^{-1} \left\{ \max \left(\frac{1/4\ [(D_{p'})^2 - (D')^2] + 3\ W_w^{\ 2}}{W_w D_{p'} \sqrt{3}},\ -1 \right) \right\}$$

and:

$$\alpha = \alpha_1 + \alpha_2$$
$$\beta = \beta_1 + \beta_2 - \Theta - 5\pi/6$$

* Treatment developed by Mr. Franz Lynn, USABRL.

E_1 = End area of Outer Slivers
for $\alpha < \pi/6$

$$E_1 = 3\,D'\,W_w(2\sin\alpha_1 + \sqrt{3}\sin\alpha_2) - 6\,W_w^{\,2}\sqrt{3}$$

$$+ 3/2\,[(D')^2\,(\pi/6-\alpha) - (D_{p'})^2\,(\sin\theta + \beta)]$$

$E_1 = 0$ for $\alpha \geq \pi/6$

S_1 = Surface Area of Outer Slivers
for $\alpha < \pi/6$

$$S_1 = 2E_1 + 6\,[\,D'\,(\pi/6-\alpha) + D_{p'}\,\beta] \cdot L'$$

$S_1 = 0$ for $\alpha \geq \pi/6$

E_2 = End area of Inner Slivers
for $\theta < \pi/3$

$$E_2 = 6\,[W_w^{\,2}\sqrt{3} - 3/2\,(D_{p'})^2\,(\sin\theta + \pi/3 - \theta)]$$

$E_2 = 0$ for $\theta \geq \pi/3$

S_2 = Surface Area of Inner Slivers
for $\theta < \pi/3$

$$S_2 = 2E_2 + 36\,D_{p'}(\pi/3 - \theta)L'$$

$S_2 = 0$ for $\theta \geq \pi/3$

S = Total Surface Area of Slivers
$S = S_1 + S_2$

E = Total End Area
$E = E_1 + E_2$

for $C < 2x$, $E = 0$ and $S = 0$

APPENDIX D

Derivation of Mass Burning Rate

Equation for CBRED

Derivation of the Mass Burning Rate Equation for CBRED

The same order of presentation is followed as in the text. The Equation of State is presented first, the Energy Equation, second, followed by the Mass Burning Rate Equation.

(1) Equation of State of Gas

$$PV_s = w_s R_s T_s \tag{23}$$

where:

P = pressure

V_s = system volume

$$= V_b - \frac{(c_a + c_p)}{\rho} + \frac{(w_a + w_p)}{\rho} - w_s \eta$$

V_b = empty bomb volume

c_a = starting weight of ignition aid

c_p = starting weight of propellant

ρ = solid propellant density (assumed same for ignition aid)

w_a = weight of ignition aid burned*

w_p = weight of propellant burned*

w_s = $w_r + w_i + w_{al} + w_{pl}$

w_r = weight of air in chamber

w_i = weight of initiator combustion products in chamber

w_{al} = weight of ignition aid combustion products in chamber*

w_{pl} = weight of propellant combustion products in chamber*

η = covolume

$$R_s = \frac{R_u m_T}{w_s}$$

R_u = universal gas constant

$$m_T = \frac{w_r}{M_r} + \frac{w_i}{M_i} + \frac{w_{al}}{M_a} + \frac{w_{pl}}{M_p}$$

M_r = molecular weight of air (taken as 29.)
M_i = molecular weight of initiator combustion products
M_a = molecular weight of ignition aid combustion products
M_p = molecular weight of propellant combustion products

* Note: For a closed bomb system there is an obvious redundancy between W_p and W_{p1} and W_a and W_{a1}. But for a leaking, or vented vessel, the distinctions are important.

(2) Energy Balance Equation

It is more convenient to describe the energy balance dynamically. The following governing equation applies:

$$\frac{d(C_V w_s T_s)}{dt} = C_V \, [T_{0a} \, \dot{w}_a + T_{0p} \, \dot{w}_p] - \dot{H}_L - C_P \, T_s \, \dot{w}_n \qquad (24)$$

where:

C_V = heat capacity at constant volume (assumed same for ignition aid)

T_{0a} = isochoric adiabatic flame temperature of the ignition aid

T_{0p} = isochoric adiabatic flame temperature of the propellant

$\dot{w}_a = AP^n$ By definition. Ignition aid mass burning rate.

$\dot{w}_p$ = mass burning rate of the propellant.

$\dot{H}_L$ = heat loss rate

C_p = heat capacity at constant pressure

$$\dot{w}_n = g \frac{P_{st} A_t}{C^*}$$

where:

g = gravitational constant

P_{st} = stagnation pressure

A_t = effective throat area (sonic control assumed)

C^* = characteristic discharge velocity

$$= \left[\frac{g R_u T_{st}}{\tau^2 M_s} \right]^{1/2}$$

T_{st} = stagnation temperature

M_s = system molecular weight

τ^2 = a function of the specific heat ratio

$$\tau^2 = \gamma \left(\frac{2}{\gamma + 1} \right)^{\left(\frac{\gamma + 1}{\gamma - 1} \right)}$$

(3) Rate of Conversion of Solid to Gas

Solving the Equation of State (23) for T_s and differentiating yields:

$$\frac{dT_s}{dt} = \frac{1}{R_s w_s} \left[P\dot{V}_s + V_s\dot{P} - \frac{PV_s}{R_s w_s} (w_s\dot{R}_s + R_s\dot{w}_s) \right] \quad (25)$$

where:

$$\dot{V}_s = -w_s \dot{\eta} - \eta\dot{w}_s \frac{(\dot{w}_a + \dot{w}_p)}{\rho}$$

$$\dot{\eta} = \frac{d\eta}{dP} \times \frac{dP}{dt} \quad \text{By definition}$$

$$\dot{R}_s = \frac{R_u}{w_s} \left[\dot{m}_T - \frac{m_T \dot{w}_s}{W_s} \right]$$

$$\dot{m}_T = \frac{\dot{w}_r}{M_r} + \frac{\dot{w}_i}{M_i} + \frac{\dot{w}_{al}}{M_a} + \frac{\dot{w}_p}{M_p} - \frac{w_{pl}\dot{w}_n}{M_p w_s}$$

$$- \frac{W_{pl}\dot{M}_p}{(M_p)^2}$$

$$\dot{w}_r = - \frac{w_r}{W_s} \times \dot{w}_n \quad \text{By definition}$$

$$\dot{w}_i = - \frac{w_i}{W_s} \times \dot{w}_n \quad \text{By definition}$$

$$\dot{w}_{al} = \dot{w}_a - \frac{w_{al}}{w_s} \dot{w}_n \quad \text{By definition}$$

$$\dot{w}_s = \dot{w}_r + \dot{w}_i + \dot{w}_{al} + \dot{w}_p - \frac{w_{pl}}{w_s}\dot{w}_n$$

Note also:

$$\dot{w}_{pl} = \dot{w}_p - \frac{w_{pl}}{w_s}\dot{w}_n \quad \text{By definition}$$

Differentiating the left hand side of Equation (24) as indicated gives:

$$C_V\, w_s\, \dot{T}_s + C_V\, T_s\, \dot{w}_s + w_s\, T_s\, \dot{C}_V = C_V\left(T_{0a}\, \dot{w}_a + T_{0p}\, \dot{w}_p\right) - \dot{H}_L - C_p\, T_s\, \dot{w}_n \qquad (26)$$

where:

$$\dot{C}_V = \frac{d\,(C_V)}{dP} \times \frac{dP}{dt} \qquad \text{by definition}$$

Solving Equation (26) for the rate of change of system temperature with time ($\dot{T}_s$) one may simultaneously solve with Equation (25), which on expansion of terms and appropriate manipulation yields the following equation for mass burning rate:

$$
\frac{dw_p}{dt} = \left\{ \frac{V_s \dot{P}}{R_s} - \frac{P w_s \dot{n}}{R_s} + \frac{\dot{H}_L}{C_V} + \gamma T_s \dot{w}_n + \frac{w_s T_s \dot{C}_V}{C_V} + \frac{P \dot{w}_a}{\rho R_s} T_{0a} \dot{w}_a \right.
$$

$$
\left. - \left[\frac{P\eta}{R_s} - \frac{P V_s m_T R_u}{(R_s w_s)^2} \right] \left[\dot{w}_r + \dot{w}_i + \dot{w}_{a1} - \frac{w_{p1} \dot{w}_n}{w_s} \right] - \frac{P V_s w_s R_u}{(R_s w_s)^2} \left[\frac{\dot{w}_r}{M_r} + \frac{\dot{w}_i}{M_i} + \frac{\dot{w}_{a1}}{M_a} - \frac{w_{p1} \dot{w}_n}{M_p w_s} - \frac{w_{p1} \dot{M}_p}{(M_p)^2} \right] \right\}
$$

$$
\Bigg/ \left[\frac{P\eta}{R_s} - \frac{P V_s m_T R_u}{(R_s w_s)^2} - \frac{P}{\rho R_s} + \frac{P V_s w_s R_u}{(R_s w_s)^2 M_p} + T_{OP} \right] \qquad (27)
$$

APPENDIX E

Equations for Wall Temperature Computations in WALTEM

Heat loss is computed by coupling transient conduction in the bomb wall with the convective and radiative transfer to the wall. In the wall, the governing equation is

$$\frac{\delta T_W}{\delta t} = \frac{\delta^2 T_W}{\delta X^2} \cdot \alpha \tag{23}$$

where T_W = temperature field within the wall

α = thermal diffusivity

X = radial distance into the wall

The initial condition is a uniform temperature (set at 298K). The boundary conditions are:

at $X = 0$: $-K \frac{\delta T}{\delta X} = H_L/A_W$

at $X \to \infty$ $\frac{\delta T}{\delta X} = 0$

An explicit centered difference scheme is used for the calculation. At the boundaries the scheme is as follows:

at $X = 0$:

$$T_o^{n+1} = T_o^{\,n} + \frac{\alpha \Delta t}{(\Delta X)^2} \left[\frac{H_L}{A_W K} \; 2(\Delta X) \; - 2T_1 + 2T_2 \right]^n$$

where $n + 1$ is the new time level

n the old time level

T_1 the first interior point

T_2 the second interior point

at back boundary $X = N\,\Delta X$:

$T_N = T_{N-1}$

N = number of grid points

APPENDIX F

Capsule Summary of Suboutines

Capsule Summary of Subroutines

ACQUIRE	Subroutine to get file data, allow update and start process
HTLOSS	Subroutine to calculate average heat loss value, average heat transfer coefficient
HTFIT	Subroutine to fit the decay portion of the P-t curve to find heat loss coefficients.
SUMUP	Subroutine to print summary sheet of analysis.
REDUCE	Driver for the differential equation solver.
EVES	Subroutine solves N simultaneous first order differential equations by the Adams method.
SETUP	Subroutine sets the initial conditions for the integration and defines the accuracy required in the solution.
DIFEQ	This subroutine evaluates the derivative values at each proposed step in the solution. On each call T1 contains the current time, and Y's are the current integrated values. The results of a call may be rejected and the step size cut in order to maintain accuracy.
PRINT	This subroutine is called to output accepted values during the integration procedure.
FINDTP	A subroutine for table lookup with linear interpolation. A direct access read lookup modification of FIND1.
FIND1	A subroutine for table lookup with linear interpolation. Extrapolates values out of table range, remembers last argument value and begins search from that value.
SIMEQ	A subroutine solving L equations in N unknowns, with N sets of right hand constants.
RCALC	Subroutine to do least squares fit on burn rate data.
VPLOT	Versatech* unit plotting package.

*Registered trademark, does not constitute endorsement by the US Army.

APPENDIX G

Program Listing. CBRED

```
      C     MAIN DRIVER FOR LATEST REDUCTION PROGRAM. 10/14/75
0001        COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
           1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
           2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
           3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
           4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
           5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
           6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
           7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
           8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
           9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
0002        COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
           1 WDEV,TDEV,TUST
0003        COMMON /BLAH/ PLO, PHI, ACO, XNC, RSQ, RMS
0004        COMMON /KEVIN/ TE(35), XT(35)
0005        DATA DUMM/'WOW '/
0006        WRITE (11,197) WOW
0007   197  FORMAT (A4)
0008        REWIND 11
0009        CALL ACQUIRE
0010        CALL HTLOSS
0011        SPACE2(3) = 0.0
0012        IF (IHL.EQ.2) GO TO 1976
0014        CALL HTFIT
0015  1976  CONTINUE
0016        CALL SUMUP
0017        CALL REDUCE
0018        CALL RCALC
0019        TYPE 100
0020   100  FORMAT (///)
0021        CALL VPLOT
0022        STOP
0023        END
```

```
      SUBROUTINE ACQUIRE
C     SUBROUTINE TO GET FILE DATA, ALLOW UPDATE AND START PROCESS
      COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
     1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
     2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
     3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
     4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
     5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
     6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
     7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
     8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
     9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
      COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
     1 WDEV,TDEV,TUST
      COMMON /BLAH/ PLO, PHI, ACO, XNC
      DIMENSION A9(4)
      DATA AY/'Y'/,A9/0.25,.375,.50,.625/,BL/'    '/,
     1 AVG/'AVE '/,P1/' 1P  '/,P7/' 7P  '/,P19/' 19P '/,
     2 SP/'SPH '/,CY/'CY  '/
      DIMENSION LIST (400)
      EQUIVALENCE (LIST(1),RUNID(1))
      EQUIVALENCE (IBUG,LIST(398))
      EQUIVALENCE (ISK1,LIST(399)),(KTOT,LIST(400))
      EQUIVALENCE (ATH,SPACE1(10)),(PBLOW,SPACE1(11)),
     1 (FAID,SPACE1(12)),(TAID,SPACE1(13)),(CAID,SPACE1(15)),
     2 (XMA,SPACE1(14))
      CALL ASSIGN (2,'SY:CBDAT.001',0,'SCR')
      DEFINE FILE 2 (3000,6,U,MZ)
      TYPE 300
  300 FORMAT (5X,'ENTER SMOOTHED TAPE ID'/)
      CALL ASSIGN (3,'FILNAM.EXT',-1,'RDO')
      DEFINE FILE 3(3100,4,U,MY)
      WDEV = 0.0
      TDEV = 0.0
      DO 69 I = 1,100
      J = 4*I
      L = J - 3
   69 READ (3'I) (LIST(K), K = L,J)
      K = 0
      IBUG = 0
      DPMAX = 0.0
      RHOC = SPACE2(1)
      PMAX = 0.0
      FAID = 362000.
      TAID = 3000.
      RU = 1544.*1.0
      XMA = RU*TAID/FAID
      CAID = 0.0
      ATH = 0.0
      PBLOW = 0.0
      KM = KTOT + 100
        DO 68 J = 101,KM
```

```
      READ (3'J) B1, C1
      I = J - 100
      I1 = (I-1)*ISK1 + 1
      TI = I1*STIME*1.0E-03
      K = K + 1
```

```
      IF (B1.LT.PMAX) GO TO 88
      PMAX = B1
      TMAX = TI
      NPMA = K
   88 IF (C1.LT.DPMAX) GO TO 68
      PPM = B1
      DPMAX = C1
   68 WRITE (2'I) TI, B1, C1
      MEM7 = 1
      PDES = 0.99*PMAX
      CALL FINDTP (PDES,TMAX,3,2,1,2,NPMA,MEM7,MZ)
      PDES = 0.1*PMAX
      CALL FINDTP (PDES,T10,3,2,1,2,NPMA,MEM7,MZ)
      PDES = 0.9*PMAX
      CALL FINDTP (PDES,T90,3,2,1,2,NPMA,MEM7,MZ)
      T1090 = T90 - T10
      SUM = 0.0
      DO 62 I = 1,4
      P9(I) = A9(I)*PMAX
      CALL FINDTP (P9(I),DP9(I),3,2,3,2,NPMA,MEM7,MZ)
   62 SUM = SUM + DP9(I)
      DP9(5) = SUM/4.0
      P9(5) = AVG
      ENDFILE 3
      FRAC = 1.0
      IHL = 2
      H = 0.0
      XMI = 60.62
      IF (PCORR.GT.150000.) XMI = 25.
      TYPE 301
  301 FORMAT (5X,'IS THIS TO BE A'/
     1 5X,'STANDARD ANALYSIS, Y OR N?')
      ACCEPT 302, ANSP
  302 FORMAT (A1)
      CALL PLOT (27,12,4)
      SPACE2(2) = 10.1
      PLO = 0.1
      PHI = 0.0
      IF (ANSP.EQ.AY) GO TO 99
      TYPE 303, RHOC
  303 FORMAT (5X,'DENSITY',F12.5)
      ACCEPT 304, TEMP
  304 FORMAT (6E12.0)
      IF (TEMP.NE.0.0) RHOC = TEMP
      TYPE 305, PCORR
  305 FORMAT (5X,'IGNITER IMPETUS',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) PCORR = TEMP
      TYPE 306, WGHTI
  306 FORMAT (5X,'IGNITER WEIGHT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) WGHTI = TEMP
```

```
      IF (PCORR.GT.150000.) XMI = 25.
      TYPE 396, XMI
396   FORMAT (5X,'IGNITER MOL WEIGHT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) XMI = TEMP
```

```
      TYPE 1305, FAID
 1305 FORMAT (5X,'IGNITER AID IMPETUS',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) FAID = TEMP
      TYPE 1306, CAID
 1306 FORMAT (5X,'IGNITER AID WEIGHT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) CAID = TEMP
      CAID = CAID/454.
      TYPE 1396, TAID
 1396 FORMAT (5X,'IGNITER AID TEMPERATURE',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) TAID = TEMP
      XMA = RU*TAID/FAID
      CALL PLOT (27,12,4)
      TYPE 307, FFID
 307  FORMAT (5X,'GRAIN TYPE',2X,A4)
      ACCEPT 308, TEMP
 308  FORMAT (A4)
      IF (TEMP.NE.BL) FFID = TEMP
      TYPE 309, H
 309  FORMAT (5X,'HEAT LOSS NUMBER',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) H = TEMP
      TYPE 310, IHL
 310  FORMAT (5X,'HEAT LOSS OPTION',I4)
      ACCEPT 311, IT
 311  FORMAT (I1)
      IF (IT.NE.0) IHL = IT
      TYPE 991, SPACE2(2)
 991  FORMAT (5X,'BOMB WALL AREA', F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) SPACE2(2) = TEMP
      TYPE 312
 312  FORMAT (5X,'AVERAGE THERMOCHEMISTRY'/
     1 5X,'IS TO BE USED, Y OR N?')
      ACCEPT 302, ANST
      CALL PLOT (27,12,4)
      IF (ANST.EQ.AY) GO TO 98
      TYPE 313
 313  FORMAT (5X,'ENTER NUMBER OF TABLE ENTRIES')
      ACCEPT 311, NPTH
      TYPE 314, NPTH
 314  FORMAT (5X,'ENTER PRESSURE, IMPETUS,COVOLUME'/
     1 5X,'FLAME TEMP AND SPECIFIC HEAT',2X,I1,2X,'ENTRIES')
      DO 44 I = 1,NPTH
  44  ACCEPT 304, PX(I), FX(I), ETX(I), XMWX(I), GAMX(I)
      RU1 = 1544.*1.0
      RU2 = RU1/778.
      XMWX1 = RU1*XMWX(1)/FX(1)
      GAM1 = RU2/(XMWX1*GAMX(1)) + 1.0
      GO TO 97
```

```
98    TYPE 323, F1
323   FORMAT (5X,'PROPELLANT IMPETUS',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) F1 = TEMP
      TYPE 324, ET1
```

```
  324 FORMAT (5X,'PROPELLANT COVOLUME',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) ET1 = TEMP
      TEMP1 = XMWX1
      TEMP2 = GAM1
      TYPE 325, XMWX1
  325 FORMAT (5X,'FLAME TEMP',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) XMWX1 = TEMP
      TYPE 326, GAM1
  326 FORMAT (5X,'SPECIFIC HEAT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) GAM1 = TEMP
      TEMP1 = XMWX1
      TEMP2 = GAM1
      IF (XMWX1.LT.1000.) TEMP1 = F1*XMWX1/(1544.*1.8)
      TEMP3 = XMWX1
      IF (XMWX1.GT.1000.) TEMP3 = 1544.*1.8*XMWX1/F1
      IF (GAM1.GE.1.0) TEMP2 = 1544.*1.8/778./TEMP3/(GAM1 - 1.)
      NPTH = 4
      P2 = 1.0
      DO 447 I = 1,4
      PX(I) = P2
      FX(I) = F1
      ETX(I) = ET1
      XMWX(I) = TEMP1
      GAMX(I) = TEMP2
      P2 = P2 + 1.0
  447 CONTINUE
      RU1 = 1544.*1.8
      RU2 = RU1/778.
      XMWX1 = RU1*TEMP1/FX(1)
      GAM1 = RU2/(XMWX1*TEMP2) + 1.0
   97 IDFF = 0
      IF (FFID.EQ.P1) IDFF = 1
      IF (FFID.EQ.P7) IDFF = 2
      IF (FFID.EQ.P19) IDFF = 3
      IF (FFID.EQ.SP) IDFF = 4
      IF (FFID.EQ.CY) IDFF = 5
      IF (IDFF.NE.0) GO TO 21
      CALL PLOT (27,12,4)
      TYPE 315
  315 FORMAT (5X,'UNKNOWN GRAIN TYPE'/
     1 5X,'INPUT TABLE OF DISTANCE BURNT'/
     2 5X,'VERSUS TOTAL BURN AREA OF CHARGE'/
     3 5X,'FIRST ENTER NUMBER OF POINTS'/
     4 5X,'TWO DIGIT NUMBER - PLEASE')
      ACCEPT 316, NPA
  316 FORMAT (I2)
      TYPE 317, NPA
  317 FORMAT (5X,'INPUT',2X,I2,2X,'ENTRIES OF TABLE'/
     15X,'DIST BURNT - TOTAL BURN AREA')
```

```
      DO 43 I = 1,NPA
   43 ACCEPT 304, WEBX(I), ABX(I)
      GO TO 22
   21 TYPE 318, GL
  318 FORMAT (5X,'GRAIN LENGTH',F12.5)
```

```
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) GL = TEMP
      TYPE 319, OD
 319  FORMAT (5X,'GRAIN OUTER DIAMETER',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) OD = TEMP
      TYPE 320, PD
 320  FORMAT (5X,'PERFORATION DIAMETER',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) PD = TEMP
C     CALL PLOT(27,12,4)
      TYPE 321, WID
 321  FORMAT (5X,'INNER WEB',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) WID = TEMP
      TYPE 322, WOD
 322  FORMAT (5X,'OUTER WEB',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) WOD = TEMP
  22  TYPE 427, FRAC
 427  FORMAT (5X,'IGNITION BRNT FRACT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) FRAC = TEMP
      CALL PLOT(27,12,4)
      TYPE 887, PLO
 887  FORMAT (5X,'LOWER FIT LIMIT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) PLO = TEMP
      TYPE 888, PHI
 888  FORMAT (5X,'UPPER FIT LIMIT',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) PHI = TEMP
      TYPE 531, WDEV
 531  FORMAT (5X,'WEB DEVIATION IS',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) WDEV = TEMP
      TYPE 532, TDEV
 532  FORMAT (5X,'IGNITION DEVIATION IS',F12.5)
      ACCEPT 304, TEMP
      IF (TEMP.NE.0.0) TDEV = TEMP
      SPACE1(10) = 0.0
      TYPE 2468, SPACE1(10)
2468  FORMAT (5X,'VENT AREA FOR VENTED OPERATION',F12.5)
      ACCEPT 2469, TEMP
2469  FORMAT (E12.0)
      IF (TEMP.NE.0.0) SPACE1(10) = TEMP
      TYPE 5832, PBLOW
5832  FORMAT (5X,'BLOW OUT PRESSURE LEVEL',F12.5)
      ACCEPT 2469, TEMP
      IF (TEMP.NE.0.0) PBLOW = TEMP
      TYPE 7354, IBUG
7354  FORMAT (5X,'DIFEQ TRACE CONTROL'/
```

```
     1 5X,'TYPE ''1'' FOR TRACE ON',I3)
      ACCEPT 7355, IBUG
 7355 FORMAT (I1)
      GO TO 92
   99 CONTINUE
```

```
0303          IDFF = 0
0304          IF (FFID.EQ.P1) IDFF = 1
0306          IF (FFID.EQ.P7) IDFF = 2
0308          IF (FFID.EQ.P19) IDFF = 3
0310          IF (FFID.EQ.SP) IDFF = 4
0312          IF (FFID.EQ.CY) IDFF = 5
0314          IF (IDFF.NE.0) GO TO 87
0316          TYPE 86
0317     86   FORMAT (5X,'UNKNOWN GRAIN TYPE IN STANDARD'/
             1 5X,'PROGRAM HAS ABORTED')
0318          STOP
0319     87   CONTINUE
0320          NPTH = 4
0321          TEMP1 = XMWX1
0322          TEMP2 = GAM1
0323          IF (GAM1.GE.1.0) TEMP2 = 1544.*1.8/778./XMWX1/(GAM1 - 1.)
0325          IF (XMWX1.LT.1000.) TEMP1 = F1*XMWX1/(1544.*1.8)
0327          P2 = 1.0
0328          DO 47 I = 1,4
0329          PX(I) = P2
0330          FX(I) = F1
0331          ETX(I) = ET1
0332          XMWX(I) = TEMP1
0333          GAMX(I) = TEMP2
0334          P2 = P2 + 1.0
0335     47   CONTINUE
0336     92   ISK1 = MAX0(ISK1,1)
0337          IF (IDFF.EQ.2.OR.IDFF.EQ.3) GO TO 6138
0339          WMIN = AMIN1 (WID,WOD)
0340          WOD = WMIN
0341          WID = WMIN
0342   6138   CONTINUE
0343          ISK = 10
0344          ISK2 = 5
0345          RHO = RHOC*.0361111
0346          RETURN
0347          END
```

```
0001          SUBROUTINE HTLOSS
        C     SUBROUTINE TO CALCULATE HEAT LOSS NUMBER - 2 OPTIONS
0002          COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
             1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
             2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
             3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
             4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
             5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
             6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
             7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
             8 CON1,CON9,MEM3,MEM7,SFAC,L9,P,DP,TSTOP,I9,
             9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003          EQUIVALENCE (FAID,SPACE1(12)),(TAID,SPACE1(13)),
             1 (XMA,SPACE1(14)),(CAID,SPACE1(15))
0004          MEM2 = 1
0005          CALL FIND1 (PMAX,F,PX,FX,NPTH,MEM2)
0006          CALL FIND1 (PMAX,ETA,PX,ETX,NPTH,MEM2)
0007          CALL FIND1 (PMAX,TZP,PX,XMWX,NPTH,MEM2)
0008          CALL FIND1 (PMAX,CVP,PX,GAMX,NPTH,MEM2)
0009          RU = 1544.*12.*1.8
0010          XMW = RU*TZP/(12.*F)
0011          TZERO = TZP
0012          TA = 298.
0013          TI = 12.*PCORR*XMI/RU
0014          VOL = BVOL/(2.54**3)
0015          CA = 14.7*VOL*29./(298.*RU)
0016          CI = WGHTI/454.
0017          CP = CHGWT/454.
0018          CST = CA + CI
0019          ETX(20) = CA/29. + CI/XMI + CAID*FRAC/XMA
0020          TM = CA*298. + CI*TI + CAID*FRAC*TAID
0021          ETX(19) = CVP*(CST + FRAC*CAID)
0022          TM = TM/(CST + FRAC*CAID)
0023          CTOT = CA + CI + CP + CAID
0024          RA = RU/29.
0025          RI = RU/XMI
0026          RP = RU/XMW
0027          RAID = RU/XMA
0028          PTHEO = (CA*RA*298. + CI*RI*TI + CP*RP*TZERO + CAID*RAID*TAID)
             1  /(VOL - CTOT*ETA)/1000.
0029          TM = TM*PMAX/PTHEO
0030          TL = TI*PMAX/PTHEO
0031          TL1 = TAID*PMAX/PTHEO
0032          PIGN = (CA*TA/29. + CI*TL/XMI + FRAC*CAID*TL1/XMA)*RU/(VOL -
             1 (CST + FRAC*CAID)*ETA - CP/RHO - (1. - FRAC)*CAID/RHO)/1000.
0033          CALL FINDTP (PIGN, TIGN,3,2,1,2,NPMA,MEM2,MZ)
0034          CON9 = VOL - CP/RHO - (1. - FRAC)*CAID/RHO
0035          IF (H.EQ.0.0) GO TO  10
0037          IF (FRAC.EQ.1.0) RETURN
0039     10   DPDT = (PTHEO - PMAX)/(TMAX - TIGN)
0040          H = (VOL - CTOT*ETA)*CVP*DPDT/RU*1000.*CTOT/
             1 (ETX(20) + CP/XMW + (1. - FRAC)*CAID/XMA)
```

```
      IF (IHL.NE.2) GO TO 1492
      IF (FRAC.EQ.1.0) RETURN
      HTL1 = H
      GO TO 1493
 1492 SPACE1(36) = 450.
```

```
            TYPE 372, SPACE1(36)
      372   FORMAT (5X,'AVERAGE BOMB WALL TEMPERATURE',F12.5)
            ACCEPT 373, TEMP
      373   FORMAT (E12.0)
            IF (TEMP.NE.0.0) SPACE1(36) = TEMP
            HB = H*1000./SPACE2(2)/((TZERO*PMAX/PTHEO + TM)/2.
           1 - SPACE1(36))
            WB = ((1. - FRAC)*CAID + CP)/(TMAX - TIGN)*1000.
            WB = WB**0.8
            H = HB/WB
            TYPE 932, HB, H
      932   FORMAT (2E16.6)
            SPACE1(34) = 0.0
     1493   IF (FRAC.EQ.1.0) GO TO 68
            TST = TIGN - 0.50
            TST = AMAX1(TST,0.0)
            SUM = 0.0
            DELT = 0.025
            DO 69 I = 1,20
            CALL FINDTP (TST,DP,3,1,3,2,NPMA,MEM2,MZ)
            SUM = SUM + DP
            TST = TST + DELT
       69   CONTINUE
            DPB = SUM*50.
            PIG = PIGN*1000.
            DYN = FRAC*CAID/TIGN*1000.
            DYNL = DYN
            TSYS = (CON9 - (FRAC*CAID + CST)*ETA)*PIG/ETX(20)/RU
     1490   DYN = DYN**0.8
            HTL = HTL1
            IF (IHL.EQ.2) GO TO 1494
            HTL = H*DYN*SPACE2(2)*(TSYS - 298.)/1000.
     1494   CONTINUE
            DYN = ((CON9 - (FRAC*CAID + CST)*ETA)*DPB + ETX(20)*RU*HTL/
           1 ETX(19))/(ETX(20)*RU*(TAID - TSYS)/(CST + FRAC*CAID) +
           2 RU*TSYS/XMA - PIG/RHO + PIG*ETA)
            IF (ABS (1. - DYN/DYNL) - 0.001) 310,310,311
      311   DYNL = DYN
            GO TO 1490
      310   CONTINUE
            XNIGN = 0.0
            TYPE 1510, XNIGN
     1510   FORMAT (5X,'POWER ON IGNITER FLOW',F12.5)
            ACCEPT 1511, TEMP
     1511   FORMAT (E12.0)
            IF (TEMP.NE.0.0) XNIGN = TEMP
            SPACE1(33) = XNIGN
            PB = PIG**XNIGN
            SPACE1(34) = DYN/PB
            TYPE 1496, SPACE1(34)
     1496   FORMAT (E16.6)
       68   CONTINUE
```

```
      RETURN
      END
```

```
0001          SUBROUTINE HTFIT
      C       SUBROUTINE TO FIT DECAY TO FIND HEAT LOSS COEFFICIENT
0002          COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
             1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
             2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
             3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
             4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
             5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
             6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
             7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
             8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
             9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003          COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
             1 WDEV,TDEV,TUST
0004          COMMON /BLAH/ PLO, PHI, ACO, XMC
0005          DIMENSION A1(500,1),B1(500,1),D1(1,1)
0006       20 MEM2 = 1
0007          MEM3 = 1
0008          NE = NPMA + 50/ISK1
0009          INOT = (KTOT - NE)/500 + 1
0010          CTOT = CST + CP
0011          RU = 12.*1544.*1.8
0012          CALL FIND1 (PMAX, F, PX, FX, NPTH, MEM2)
0013          CALL FIND1 (PMAX, TZP, PX, XMWX, NPTH, MEM2)
0014          CALL FIND1 (PMAX, CVP, PX, GAMX, NPTH, MEM2)
0015          XMW = RU*TZP/(12.*F)
0016          BOT = (ETX(20) + CP/XMW)*RU
0017       44 J = 0
0018          DO 62 I = NE,KTOT,INOT
0019          READ (2'I) TI, P, DP
0020          CALL FIND1 (P, ETA, PX, ETX, NPTH, MEM2)
0021          DETA = (ETX(MEM2+1) - ETX(MEM2))/(PX(MEM2+1) -
             1 PX(MEM2))
0022          P = P*1000.
0023          DP = DP*1000.
0024          DETA = DETA/1000.
0025          T = P*(VOL - CTOT*ETA)/BOT
0026          J = J + 1
0027          A1(J,1) = T**4
0028          B1(J,1) = -DP*(VOL - CTOT*ETA - CTOT*DETA*P)*CVP/RU*1000.
             1 *CTOT/(ETX(20) + CP/XMW)
0029       62 CONTINUE
0030          CALL SIMEQ (A1,B1,D1,J,1,1)
0031          SPACE2(3) = D1(1,1)/SPACE2(2)
0032          SUM = 0.0
0033          DO 777 I7 = 1,J
0034      777 SUM = SUM + B1(J,1)**2
0035          RMS = SQRT(SUM/(J - 1))
0036          WB = (CP/(TMAX - TIGN))*1000.
0037          WB = WB**0.8
0038          TAV = (TZERO**4 + TM**4)/2.
0039          TGOO = (TZERO + TM)/2. - SPACE1(36)
```

```
      HL = H*WB*TGOO - SPACE2(3)*TAV
      SUM1 = 0.0
      SUM2 = 0.0
      DELT7 = (TMAX - TIGN)/1000.
      T7 = TIGN
```

```
 836  CALL FINDTP(T7,DPT,3,1,3,2,3000,MEM2)
      SUM1 = SUM1 + DPT*DELT7
      DPT = AMAX1(DPT,0.00001)
      SUM2 = SUM2 + DELT7*DPT**0.8
      T7 = T7 + DELT7
      IF (T7.LE.TMAX) GO TO 836
      FAC7 = SUM1**0.8/SUM2
      H = HL/WB/TGOO
C     H = H*FAC7
      TYPE 100, D1(1,1), SPACE2(3), RMS, H
 100  FORMAT (4E15.5)
      RETURN
      END
```

```
      SUBROUTINE SUMUP
C     SUBROUTINE TO PRINT SUMMARY SHEET OF ANALYSIS
      COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
     1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
     2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
     3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
     4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
     5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
     6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
     7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
     8 CON1,CON9,MEM3,MEM7,SFAC,L9,P,DP,TSTOP,I9,
     9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
      DIMENSION ABC (5)
      DATA ABC/'CONS','TANT','PROP','ORTI','ONAL'/
      PRINT 100
  100 FORMAT (1H1///)
      PRINT 101, (RUNID(I), I = 1,5)
  101 FORMAT (10X,'RUN ID:'29X,5A4)
      PRINT 102, (RTITLE(I),I = 1,18)
  102 FORMAT (10X,'RUN TITLE:',25X,18A4)
      PRINT 103, (DATE(I), I = 1,3)
  103 FORMAT (10X,'DATE:',30X,3A4)
      PRINT 104, (OPERN(I), I = 1,5)
  104 FORMAT (10X,'OPERATOR:',26X,5A4/)
      PRINT 105
  105 FORMAT (10X,'PROPELLANT DATA:'/)
      PRINT 106, (PROPN(I), I = 1,18)
  106 FORMAT (10X,'TYPE:',30X,18A4)
      PRINT 107, CHGWT
  107 FORMAT (10X,'WEIGHT (GMS):',22X,F12.5)
      PRINT 108, RHOC
  108 FORMAT (10X,'DENSITY (GM/CC):',19X,F12.5)
      PRINT 109, PTEMP
  109 FORMAT (10X,'INITIAL TEMPERATURE (DEG K):',7X,F12.5)
      PRINT 110, (PRLOT(I), I = 1,18)
  110 FORMAT (10X,'LOT:',31X,18A4)
      PRINT 111, (PSORCE(I), I = 1,18)
  111 FORMAT (10X,'SOURCE:',28X,18A4)
      PRINT 112, FFID
  112 FORMAT (10X,'GRAIN TYPE:',24X,A4)
      PRINT 113, GL, OD, PD
  113 FORMAT (10X,'LENGTH,OD,ID (IN):',17X,3(F12.5,','))
      PRINT 114, WID, WOD
  114 FORMAT (10X,'INNER WEB,OUTER WEB (IN):',10X,2(F12.5,','))
      PRINT 115, FX(1)
  115 FORMAT (10X,'THEORETICAL IMPETUS (FT-LB/LB):',4X,F12.5)
      PRINT 116, TZERO
  116 FORMAT (10X,'FLAME TEMPERATURE:',17X,F12.5)
      PRINT 117, XMWX1
  117 FORMAT (10X,'AVERAGE MOLECULAR WEIGHT OF PROD:',2X,F12.5)
      PRINT 118, ETX(1)
  118 FORMAT (10X,'CO-VOLUME (CU IN/LB):',14X,F12.5)
```

```
      PRINT 119, GAM1
119   FORMAT (10X,'GAMMA (RATIO OF SP HTS):'11X,F12.5)
      PRINT 120, (PREM(I), I = 1,18)
120   FORMAT (10X,'REMARKS:',27X,18A4/)
      PRINT 121
```

```
0048    121  FORMAT (10X,'IGNITER DATA:'/)
0049         PRINT 122, (TIGNR(I), I = 1,18)
0050    122  FORMAT (10X,'TYPE:',30X,18A4)
0051         PRINT 123, WGHTI
0052    123  FORMAT (10X,'WEIGHT (GMS):',22X,F12.5)
0053         PRINT 124, PCORR
0054    124  FORMAT (10X,'IMPETUS (FT-LB/LB):',16X,F12.5/)
0055         PRINT 125
0056    125  FORMAT (10X,'EQUIPMENT DATA'/)
0057         PRINT 126, BVOL
0058    126  FORMAT (10X,'BOMB VOLUME (CC):',18X,F12.5)
0059         PRINT 127, BTEMP
0060    127  FORMAT (10X,'BOMB TEMP (DEG K):'17X,F12.5)
0061         PRINT 128, (GAGE(I), I = 1,18)
0062    128  FORMAT (10X,'GAUGE TYPE:',24X,18A4)
0063         PRINT 129,SCAL
0064    129  FORMAT (10X,'CALIBRATION FACTOR (PC/PSI):',7X,F12.5/)
0065         PRINT 130
0066    130  FORMAT (10X,'RESULTS:'/)
0067         PRINT 131, PTHEO
0068    131  FORMAT (10X,'THEORETICAL MAX PRESS (KPSIA):',5X,F12.5)
0069         PRINT 132, PMAX
0070    132  FORMAT (10X,'OBSERVED MAX PRESS (KPSIA):', 8X,F12.5)
0071         PRINT 133, PIGN
0072    133  FORMAT (10X,'IGNITER PRESSURE (KPSIA):',10X,F12.5)
0073         PRINT 134
0074    134  FORMAT (/10X,'IGNITION TIME INFORMATION:' )
0075         PRINT 135, T10
0076    135  FORMAT (10X,'TIME TO 10% PMAX (MSEC):',11X,F12.5)
0077         PRINT 136, T90
0078    136  FORMAT (10X,'TIME TO 90% PMAX (MSEC):',11X,F12.5)
0079         PRINT 137, TMAX
0080    137  FORMAT (10X,'TIME TO 100% PMAX (MSEC):',10X,F12.5)
0081         PRINT 138, T1090
0082    138  FORMAT (10X,'TIME FROM 10% TO 90% PMAX (MSEC):',2X,F12.5)
0083         PRINT 140
0084    140  FORMAT (1H1////10X,        'QUICKNESS INFORMATION:'/)
0085         PRINT 141, DP9(1)
0086    141  FORMAT (10X,'PDOT AT .250 PMAX:',5X,F12.5)
0087         PRINT 142, DP9(2)
0088    142  FORMAT (10X,'PDOT AT .375 PMAX:',5X,F12.5)
0089         PRINT 143, DP9(3)
0090    143  FORMAT (10X,'PDOT AT .500 PMAX:',5X,F12.5)
0091         PRINT  144, DP9(4)
0092    144  FORMAT (10X,'PDOT AT .625 PMAX:',5X,F12.5)
0093         PRINT 145, DP9(5)
0094    145  FORMAT (10X,'AVERAGE PDOT:',10X,F12.5/)
0095         PRINT 139, DPMAX, PPM
0096    139  FORMAT (10X,'MAXIMUM PDOT (MPSI/SEC):',F11.5,5X,'OBSERVED AT',
            1 ' P = (KPSIA):',F12.5/)
0097         GO TO (1,2), IHL
0098      2  PRINT 146, (ABC(I), I = 1,2)
```

```
146  FORMAT (10X,'HEAT LOSS OPTION:',2X,2A4)
     GO TO 3
1    PRINT 147, (ABC (I), I = 3,5)
147  FORMAT (10X,'HEAT LOSS OPTION:',2X,3A4)
3    PRINT 148, H
```

```
  148 FORMAT (10X,'HEAT LOSS NUMBER:',F14.7)
      RETURN
      END
```

```
0001          SUBROUTINE REDUCE
        C     DRIVER FOR DIFFERENTIAL EQUATION SOLVER
0002          COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
             1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
             2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
             3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
             4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
             5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
             6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
             7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
             8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
             9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003          COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
             1 WDEV,TDEV,TWST
0004          DIMENSION TPRNT(2)
0005          TPRNT(1) =- STIME*1.0E-03
0006          TPRNT(2) = 10000.
0007          TSTOP = TMAX
0008          IF (SPACE1(10).NE.0.0) TMAX = 2900*STIME*1.0E-03
0010          IF (SPACE1(10).NE.0.0) H = 0.0
0012          JDO = 5
0013          IF (TDEV.EQ.0.0) JDO = 1
0015          JDO = JDO + 7
0016          CALL EVES (JDO, TPRNT)
0017          ENDFILE 2
0018          ENDFILE 6
0019          RETURN
0020          END
```

```
0001          SUBROUTINE SETUP (T, Y, SIG, N)
0002          COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
             1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
             2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
             3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
             4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
             5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
             6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
             7 ISK,ISK2,MEM2,XM1,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
             8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
             9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
0003          COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
             1 WDEV,TDEV,TUST
0004          COMMON /KEVIN/ TE(35), XT(35)
0005          DIMENSION JD(2)
0006          EQUIVALENCE (JD(1),SPACE1(35)),(CAID,SPACE1(15)),
             1 (CPGM2,SPACE1(16)),(PBLOW,SPACE1(11))
0007          DIMENSION T(2), Y(2), SIG(12,3)
0008          DIMENSION CPRO(5),PRO(5),DDW(5)
0009          DATA PRO/.1,.2,.4,.2,.1/,DDW/-1.17741,-.83255,.0,.83255,1.17741/
0010          MEM2 = 1
0011          MEM3 = 1
0012          CI = WGHTI/454.
0013          CALL FIND1 (PMAX,F,PX,FX,NPTH,MEM2)
0014          CPGM2 = GAM1*(2./(GAM1 + 1.))**((GAM1 + 1.)/(GAM1 - 1.))
0015          ABX(20) = 1.0E+05
0016          MEM7 = 1
0017          JD(1) = 5
0018          JD(2) = 5
0019          IF (TDEV.EQ.0.0) JD(1) = 1
0021          IF (WDEV.EQ.0.0) JD(2) = 1
0023          CON9 = VOL - (CHGWT/454. + CAID)/RHO
0024          IF (IDFF.EQ.0) GO TO 10
0025          I9 = 0
0027          SZERO = 0.0
0028          SUM9 = 0.0
0029          JDO = JD(1)
0030          DO 75 J = 1,JDO
0031          J1 = J + 7
0032          SIG (J1,2) = 0.001
0033          SIG (J1,3) = 1.0E+05
0034          CPART = CP*PRO(J)
0035          IF (JDO.EQ.1) CPART = CP
0037          IDO = JD(2)
0038          DO 76 I = 1,IDO
0039          CPRO(I) = CPART*PRO(I)
0040          IF (IDO.EQ.1) CPRO(I) = CPART
0042          WIDP(I) = WID + DDW(I)*WDEV
0043          WODP(I) = WOD - DDW(I)*WDEV
0044          I9 = 0
0045          GO TO (1,2,3,4,5), IDFF
0046      1     CALL FORM1(0.0, I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
```

```
      GO TO 39
2       CALL FORM7(0.0,I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
3       CALL FORM19(0.0,I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
```

```
 4      CALL FORMSP(0.0.I9.OD.PD.WIDP(I).WODP(I).V0.GL.S.UCR(I))
        GO TO 39
 5      CALL FORMCY(0.0.I9.OD.PD.WIDP(I).WODP(I).V0.GL.S.UCR(I))
39      SFAC(J.I) = CPRO(I)/(RHO*V0)
        SUM9 = SUM9 + SFAC(J.I)
        SZERO = SZERO + SFAC(J.I)*S
        SIG(J1.3) = AMIN1 (SIG(J1.3). UCR(I))
 76     CONTINUE
        TDEL(J) = DDW(J)*TDEV
        IF (J.EQ.1) TDS = TDEL(J)
        TDEL(J) = TDEL(J) - TDS
 75     CONTINUE
 10       CONTINUE
        IF (IDO.EQ.1) GO TO 723
        DO 723 I = 1.4
        K = I + 1
        DO 723 J = K.S
        IF (UCR(J).GE.UCR(I)) GO TO 723
        A1 = UCR(I)
        A2 = WIDP(I)
        A3 = WODP(I)
        DO 724 L = 1.S
        A4 = SFAC(L.I)
        SFAC(L.I) = SFAC(L.J)
        SFAC (L.J) = A4
 724    CONTINUE
        UCR(I) = UCR(J)
        WIDP(I) = WIDP(J)
        WODP(I) = WODP(J)
        UCR(J) = A1
        WIDP(J) = A2
        WODP(J) = A3
723     CONTINUE
        L9 = 0
        T(1) = TIGN
        IF (IDFF.EQ.0) UCR(1) = WEBX(NPA)
        IF (IDFF.EQ.0) UCR(2) = WEBX(NPA)
        IF (IDFF.EQ.0) UCR(3) = WEBX(NPA)
        IF (IDFF.EQ.0) UCR(4) = WEBX(NPA)
        IF (IDFF.EQ.0) UCR(5) = WEBX(NPA)
        IF (IDFF.EQ.0) SZERO = ABX(1)
        NUMB = SUM9
        IF (IDFF.EQ.0) NUMB = 1
        PRINT 100. SZERO. NUMB
100     FORMAT (/10X.'INITIAL SURFACE AREA (SQ IN):'.F12.5/
       1 10X.'NUMBER OF GRAINS:'.16X.I8)
        Y(1) = CST - WGHTI/454.
        Y(2) = WGHTI/454.
        Y(3) = FRAC*CAID
        Y(4) = 0.0
        Y(5) = Y(3)
        Y(6) = 0.0
```

```
Y(7) = PIGN
SIG(1,2) = 0.0001
SIG(2,2) = 0.0001
SIG(3,2) = 0.0001
SIG(4,2) = 0.001
```

```
      SIG(5,2) = 0.0001
      SIG(5,3) = CAID
      SIG(6,2) = 0.001
      SIG(7,3) = PBLOW
      SPACE1(31) = 0.0
      IF (IHL.EQ.2) RETURN
      DN = (WGHTI/454. + FRAC*CAID)/TIGN*1000.
      G = H*DN**0.8
      CALL WALTEM (G,T(1),298.,TM)
      CALL WALTEM (G, T(1),298.,TM)
      SFAZ = TM
      DO 1729 I7 = 1,35
 1729 TE(I7) = XT(I7)
      RETURN
      END
```

```
0001          SUBROUTINE DIFEQ (T, Y, DY, N, TPR)
0002          COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
             1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
             2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
             3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
             4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
             5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
             6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
             7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
             8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
             9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
0003          EQUIVALENCE (IMUD(1),SPACE2(4)),(IBUG,IMUD(2))
0004          DIMENSION IMUD(2)
0005          COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
             1 WDEV,TDEV,TUST
0006          COMMON /KEVIN/ TE(35), XT(35)
0007          DIMENSION T(2), Y(2), DY(2),TPR(2)
0008          DIMENSION ARATJ(5)
0009          DIMENSION JD(2)
0010          EQUIVALENCE (JD(1),SPACE1(35)),(TAID,SPACE1(13)),
             1 (XMA,SPACE1(14)),(CPGM2,SPACE1(16))
0011          CALL FINDTP (T(1),P,3,1,2,2,3000,MEM3, MZ)
0012          CALL FINDTP (T(1),DP,3,1,3,2,3000,MEM3, MZ)
0013          CALL FIND1 (P, ETA, PX, ETX, NPTH, MEM2)
0014          CALL FIND1 (P, F, PX, FX, NPTH, MEM2)
0015          CALL FIND1 (P, TZP, PX, XMWX, NPTH, MEM2)
0016          CALL FIND1 (P, CVP, PX, GAMX, NPTH, MEM2)
0017          RU = 1544.*1.8
0018          TI = PCORR*XMI/RU
0019          XMW = RU*TZP/F
0020          JDO = JD(1)
0021          IDO = JD(2)
0022          DETA = (ETX(MEM2+1) - ETX(MEM2))/(PX(MEM2+1) - PX(MEM2))
0023          DIMP = (FX(MEM2+1) - FX(MEM2))/(PX(MEM2+1) - PX(MEM2))
0024          DCVP = (GAMX(MEM2+1) - GAMX(MEM2))/(PX(MEM2+1) - PX(MEM2))
0025          DTZP = (XMWX(MEM2+1) - XMWX(MEM2))/(PX(MEM2+1) - PX(MEM2))
0026          DXMP = RU*(DTZP/F - TZP*DIMP/(F**2))
0027          P = P*1000.
0028          DP = DP*1000.
0029          XT1 = 10000.
0030          DY1 = DY(5) + DY(6)
0031          DN = AMAX1 (DY1*1000., 0.000001)
0032          DETA = DETA/1000.*DP
0033          DIMP = DIMP/1000.*DP
0034          DCVP = DCVP/1000.*DP
0035          DTZP = DTZP/1000.*DP
0036          DXMP = DXMP/1000.*DP
0037          IF (IDFF.NE.0) GO TO 10
0039          CALL FIND1 (Y(8),AB,WEBX,ABX,NPA,MEM7)
0040          GO TO 40
0041    10    AAB = 0.0
0042          WIP = 0.0
```

```
DELJ = TIGN
TDLJ = 0.0
DELI = ABX(20)
DO 75 J = 1,JDO
J1 = J + 7
```

```
      ARATJ(J) = 1.0
      ARATI = 1.0
      IF (J.EQ.1) GO TO 1978
      IF (TDEL(J).EQ.TDLJ) GO TO 1978
      ARATJ(J) = (T(1) - DELJ)/(TDEL(J) - TDLJ)
      ARATJ(J) = AMIN1 (AMAX1(ARATJ(J),0.0), 1.0)
      ARATI = (T(1) - DELI)/(TDEL(J) - TDLJ)
      ARATI = AMIN1 (AMAX1(ARATI,0.0),1.0)
      ARATI = 1.0 - ARATI
 1978 CONTINUE
      AB = 0.0
      ARATK = 1.0
      UCRI = UCR(1)
      DO 76 I = 1,IDO
      IF (UCR(1).EQ.UCRI) GO TO 486
      ARATK = (Y(J1) - UCRI)/(UCR(I) - UCRI)
      ARATK = AMIN1 (AMAX1 (ARATK, 0.0), 1.0)
      ARATK = 1.0 - ARATK
  486 CONTINUE
      GO TO (1,2,3,4,5), IDFF
 1    CALL FORM1(Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 2    CALL FORM7(Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 3    CALL FORM19 (Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 4    CALL FORMSP (Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
      GO TO 39
 5    CALL FORMCY (Y(J1),I9,OD,PD,WIDP(I),WODP(I),V0,GL,S,UCR(I))
   39 CONTINUE
      AB = AB + SFAC(J,I)*S*ARATK
      UCRI = UCR(I)
   76 CONTINUE
      AAB = AAB + AB*ARATJ(J)*ARATI
      DELJ = TIGN + TDEL(J)
      DELI = ABX(20) + TDEL(J)
      TDLJ = TDEL(J)
   75 CONTINUE
   40 CONTINUE
      WSYS = Y(1) + Y(2) + Y(3) + Y(4)
      VSYS = CON9 + (Y(5) + Y(6))/RHO - WSYS*ETA
      TOTMOL = Y(1)/29. + Y(2)/XMI + Y(3)/XMA + Y(4)/XMW
      RU = 1544.*1.8
      RSYS = RU*TOTMOL/WSYS
      TSYS = P*VSYS/(12.*RSYS*WSYS)
      IF (IBUG.EQ.0) GO TO 7354
      TYPE 2936, TSYS,P,VSYS,RSYS,WSYS
 2936 FORMAT (5E14.5)
 7354 CONTINUE
      CSTAR = SQRT(32.174*RSYS*TSYS/CPGM2)
      DHN = 32.174*P*SPACE1(31)/CSTAR/1000.
      GO TO (20,21), IHL
```

```
20   DO 1739 I7 = 1,35
1739 XT(I7) = TE(I7)
     G = H*DN**0.8
     CALL WALTEM (G,T(2),SFAZ,TSYS)
 97  G = H*DN**0.8
```

```
0109          ARP = G*(TSYS - XT(1))/1000.*SPACE2(2)
0110          ARP = ARP + SPACE2(3)*(TSYS**4 - XT(1)**4)/1000.*
             1 SPACE2(2)
0111          GO TO 22
0112   21     ARP = H
0113   22     CONTINUE
0114          DY(1) = -Y(1)/WSYS*DNN
0115          DY(2) = -Y(2)/WSYS*DNN
0116          DY(5) = SPACE1(34)*P**SPACE1(33)
0117          DY(3) = DY(5) - Y(3)/WSYS*DNN
0118          RWT = DY(1) + DY(2) + DY(3) - Y(4)/WSYS*DNN
0119          RMOL = DY(1)/29. + DY(2)/XMI + DY(3)/XMA - Y(4)/WSYS*DNN/XMW
             1 -Y(4)*DXMP/(XMW**2)
0120          DY(6) = (TSYS*RWT - TAID*DY(5) + WSYS*TSYS*DCVP/CVP
             1 + ARP/CVP + GAM1*TSYS*DNN + P/(12.*RSYS)
             2 *(DY(5)/RHO - WSYS*DETA - ETA*RWT + VSYS*DP/P - VSYS/
             3 WSYS*(RU/RSYS*(RMOL
             4 - TOTMOL*RWT/WSYS))))/(TZP - TSYS + P/(12.*RSYS)*
             5 (ETA - 1./RHO + VSYS/WSYS*(1. + RU/RSYS*(1./XMW - TOTMOL/
             6 WSYS))))
0121          DY1 = DY(5) + DY(6)
0122          DY(4) = DY(6) - Y(4)/WSYS*DNN
0123          DY(7) = DP
0124          GO TO (92,93), IHL
0125    92    IF (ABS(1. - DY1*1000./DN).LE.0.001) GO TO 94
0127          IF (DY1.LE.0.0) GO TO 93
0129          DN = DY1*1000.
0130          GO TO 97
0131    94    IF (ABS(1. - XT(1)/XT1).LE.0.0001) GO TO 93
0133          XT1 = XT(1)
0134          GO TO 20
0135   93     IF (Y(8).EQ.0.0) SZERO = AAB
0137          IF (Y(8).EQ.0.0) ZZERO = Y(6)
0139          SRAT = AAB/SZERO
0140          IF (TDEV.NE.0.0) SRAT = SRAT/10.
0142          Z = (Y(6) - ZZERO)*454./CHGWT
0143          IF (AAB.GT.0.0) GO TO 675
0145          RATE = RL
0146          GO TO 676
0147   675    RATE = DY(6)/(RHO*AAB)
0148   676    CONTINUE
0149          DO 745 I = 1,JDO
0150          J = I + 7
0151          DY(J) = RATE*ARATJ(I)
0152   745    CONTINUE
0153          RL = RATE
0154          RATE = RATE*1000.
0155          FX(20) = TSYS
0156          RETURN
0157          END
```

```
0001        SUBROUTINE PRINT (T, Y, DY, N, TPR)
0002        COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
          1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
          2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
          3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
          4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
          5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
          6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
          7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
          8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
          9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
0003        COMMON /GENE/ WIDP(5),WODP(5),UCR(5),SFAC(5,5),TDEL(5),
          1 WDEV,TDEV,TUST
0004        COMMON /KEVIN/ TE(35), XT(35)
0005        DIMENSION T(2), Y(2), DY(2), TPR(2)
0006        DIMENSION JD(2)
0007        EQUIVALENCE (JD(1),SPACE1(35))
0008        DATA XYZ/101000./
0009        JDO = JD(1)
0010        IF (L9.EQ.0) L6 = 0
0012        IF (L9.EQ.0) L8 = 0
0014        IF (L9.EQ.0) L7 = 0
0016        DO 1729  I7 = 1,35
0017   1729 TE(I7) = XT(I7)
0018        IF (TPR(3).EQ.5.0) SPACE1(34) = 0.0
0020        SFAZ = FX(20)
0021        ISTP = 0
0022        DO 669 I = 1,JDO
0023        J = I + 7
0024        IF (Y(J).LT.UCR(I)) GO TO 669
0026        ISTP = ISTP + 1
0027    669 CONTINUE
0028        IF (ISTP.EQ.JDO) N = 0
0030        IF (L9.EQ.0) GO TO 777
0032        XDO = JDO + 7
0033        IF (TPR(3).LT.0.0.OR.TPR(3).GT.XDO) GO TO 4936
0035        ABX(20) = T(1)
0036   4936 CONTINUE
0037        XDO = XDO + 1.0
0038        IF (TPR(3).EQ.7.0) SPACE1(31) = SPACE1(10)
0040        IF (TPR(3).NE.XDO) RETURN
0042    777 CONTINUE
0043        P = P/1000.
0044        DP = DP/1000.
0045        DIST = 2.*Y(8)
0046        DPRAT = DP/PMAX
0047        IF (MOD(L9,ISK).NE.0) GO TO 676
0049        IF (MOD(L7,40).NE.0) GO TO 677
0051        PRINT 100, (RUNID(I), I = 1,5)
0052    677 L7 = L7 + 1
0053        IF (MOD(L6,30).NE.0) GO TO 832
0055        CALL PLOT (27,12,4)
```

```
832  L6 = L6 + 1
     PRINT 101,    T(1), P, DP, RATE, Z, SRAT, DIST, DPRAT
     TYPE 302, T(1), SFAZ, XT(1)
302  FORMAT (5X, 3E15.6)
676  CONTINUE
```

```
0061          IF (MOD(L9,ISK2).NE.0) GO TO 675
0063          L8 = L8 + 1
0064          WRITE (11,384) T(1), P, DP, RATE
0065    384   FORMAT (4E13.6)
0066    675   CONTINUE
0067          T22 = T(1)
0068          L9 = L9 + 1
0069            IF (T(1).GE.TSTOP) N = 0
0071          IF (N.EQ.0) WRITE (11,384) XYZ,XYZ,XYZ,XYZ
0073          RETURN
0074    100   FORMAT (1H1/5X,5A4/7X,'TIME',6X,'PRESS',6X ,'DP/DT',8X,
          [illegible]TE',6X,'WT FR',4X,'SURF FR',4X,'WEB BR[illegible]',3X,
             2 'PDOT/PMAX'/7X,'MSEC',6X,'KPSIA',4X,'MPSI/SEC',5X,
             3 'IN/SEC',27X,'INCH',6X,'MSEC-1'/)
0075    101   FORMAT (2(4X,F7.3),4X,F8.3,4X,F7.3,3(4X,F7.4),4X,F8.3)
0076          END
```

```
      SUBROUTINE FORM1(DB,I,OD1,PD1,WID,WOD,V0,GL,S,UCRIT)
      DATA PI/3.141593/,PI4/.785399/
      W = DB*2.0
      DDW = (WOD - WID)/4.
      OD = OD1 + DDW
      PD = PD1 - DDW
      PD = AMAX1 (PD, 0.0)
      OD = AMAX1 (OD, 0.0)
      IF (I.NE.0) GO TO 10
      E = PI4*(OD**2 - PD**2)
      E = AMAX1 (E, 0.0)
      V0 = E*GL
      S = 2.*E + GL*PI*(OD + PD)
      I = I + 1
      UCRIT = (OD - PD)/2.
      RETURN
   10 UCRIT = (OD - PD)/2.
      IF (W.GT.UCRIT) GO TO 300
      OOD = OD - W
      OOD = AMAX1 (OOD, 0.0)
      PPD = PD + W
      GGL = GL - W
      E = PI4*(OOD**2 - PPD**2)
      E = AMAX1 (E,0.0)
      S = 2.*E + GGL*PI*(OOD + PPD)
      RETURN
  300 S = 0.0
      RETURN
      END
```

```
      SUBROUTINE FORM7(DB,I,D,PD,WID,WOD,V0,GL,S,CRITU)
      LOGICAL RYPE
      DATA PI,PI3,PI4/3.14159265359,1.047197551197,.7853981633975/
      DATA RT/1.7320508076/
      W = 2.*DB
      IF(I.GT.0) GOTO 10
      I = 1
      E=PI4*(D**2-7.*PD**2)
      V0 = E*GL
      V=V0
      S0=2.*E+PI*(D+7.*PD)*GL
      S=S0
      WW=PD+WID
      E=.5*(D**2-PD**2+4.*WW**2-2.*WW*D*RT)/(D+PD-WW*RT)
      CRITU=AMIN1(.5*(D-PD),AMAX1(2.*WW/RT-PD,E),GL)
      RYPE=D-WID.LT.WW*RT
      Z=0.
      RETURN
   10 E=0.
      WMIN = AMIN1 (WID,WOD)
      RYPE=D-WID.LT.WW*RT
      S=0.
      U=AMAX1(W,0.)
      GRL=GL-U
      IF(U.GT.CRITU) GOTO 300
      PRFD=PD+U
      PRFD2=PRFD**2
      OD=D-U
      OD2=OD**2
      IF(U.GT.WMIN) GOTO 100
      E=PI4*(OD2-7.*PRFD2)
      S=2.*E+PI*(OD+7.*PRFD)*GRL
      GO TO 300
  100 WW=PD+WID
      WW2=WW**2
      THETA=2.*ACOS(AMIN1(WW/PRFD,1.))
      ALPHA=ACOS(AMIN1((.25*(OD2-PRFD2)+WW2)/(WW*OD),1.))
      IF(ALPHA.GE..5*PI3) GOTO 210
      BETA=ACOS(AMAX1((.25*(PRFD2-OD2)+WW2)/(WW*PRFD),-1.))
     1 -.5*THETA - PI3
      IF(RYPE) GOTO 250
      E=3.*OD*WW*SIN(ALPHA)+1.5*(OD2*(.5*PI3-ALPHA)-WW2*RT-PRFD2*(BETA
     1 +.5*SIN(THETA)))
      S=2.*E+(6.*BETA*PRFD+(PI-6.*ALPHA)*OD)*GRL
  210 IF(THETA.GE.PI3) GOTO 300
      E1=1.5*(WW2*RT-1.5*PRFD2*(SIN(THETA)+PI3-THETA))
      E=E+E1
      S=S+2.*E1+9.*PRFD*(PI3-THETA)*GRL
      GOTO 300
  250 E=3.*WW*OD*SIN(ALPHA)+1.5*(OD2*(.5*PI3
     1 -ALPHA) -PRFD2*(SIN(THETA)
     2 +BETA+.5*(PI-THETA)))
```

```
      S=2.*E+6.*(OD*(.5*PI3-ALPHA)+PRFD*(BETA+.5*(PI-THETA)))*GRL
  300 V=E*GRL
      Z=1.-V/V0
      RETURN
      END
```

```
      SUBROUTINE FORM19(DB,I,D,PD,WID,WOD,V0,GL,S,CRITU)
      LOGICAL RYPE
      DATA PI,PI3,PI4/3.14159265359,1.047197551197,.7853981633975/
      DATA RT/1.7320508076/
      W = 2.*DB
      IF(I.GT.0) GOTO 10
      I = 1
      E=PI4*(D**2-19.*PD**2)
      V0=E*GL
      V=V0
      S0=2.*E+PI*(D+19.*PD)*GL
      S=S0
      WW=PD+WID
      E=(D+PD)**2
      WW2=WW**2
      E=.5*(D-PD-WW*SQRT(12.*(E-16.*WW2)/(E-12.*WW2)))
      CRITU=AMIN1(AMAX1(2.*WW/RT-PD,E),GL)
      RYPE=D-WID.LT.WW*SQRT(13.)
      IF(RYPE) GOTO 250
      Z=0.
      RETURN
   10 E=0.
      WMIN=AMIN1(WID,WOD)
      S=0.
      U=AMAX1(W,0.)
      GRL=GL-U
      IF(U.GT.CRITU) GOTO 300
      PRFD=PD+U
      PRFD2=PRFD**2
      OD=D-U
      OD2=OD**2
      IF(U.GT.WMIN) GOTO 100
      E=PI4*(OD2-19.*PRFD2)
      S=2.*E+PI*(OD+19.*PRFD)*GRL
      GOTO 300
  100 WW=PD+WID
      WW2=WW**2
      THETA=2.*ACOS(AMIN1(WW/PRFD,1.))
      ALPHA1=ACOS(AMIN1((.125*(OD2-PRFD2)+2.*WW2)/(WW*OD),1.))
      ALPHA2=ACOS(AMIN1((.25*(OD2-PRFD2)+3.*WW2)/(WW*OD*RT),1.))
      ALPHA=ALPHA1+ALPHA2
      IF(ALPHA.GE..5*PI3) GOTO 210
      BETA1=ACOS(AMAX1((.125*(PRFD2-OD2)+2.*WW2)/(WW*PRFD),-1.))
     1 -.5*THETA-PI3
      BETA2=ACOS(AMAX1((.25*(PRFD2-OD2)+3.*WW2)/(WW*PRFD*RT),-1.))
     1 -.5*(THETA+PI)
      BETA=BETA1+BETA2
      IF(RYPE) GOTO 250
      E=3.*OD*WW*(2.*SIN(ALPHA1)+RT*SIN(ALPHA2))-6.*WW2*RT+1.5*
     1 (OD2*(.5*PI3-ALPHA)-PRFD2*(SIN(THETA)+BETA))
      S=2.*E+6.*(OD*(.5*PI3-ALPHA)+PRFD*BETA)*GRL
  210 IF(THETA.GE.PI3) GOTO 300
```

```
      E1=6.*(WW2*RT-1.5*PRFD2*(SIN(THETA)+PI3-THETA))
      E=E+E1
      S=S+2.*E1+36.*PRFD*(PI3-THETA)*GRL
      GOTO 300
  250 TYPE 251
```

```
251 FORMAT( ' GRAIN GEOMETRY YIELDS NO OUTER SLIVERS.')
    STOP
300 V=E*GRL
    Z=1.-V/V0
    RETURN
    END
```

```
      SUBROUTINE FORMSP (DB,I,OD1,PD1,WID,WOD,V0,GL,S,UCRIT)
      DATA PI4/.785399/,PI/3.141593/
      W = DB*2.0
      DDW = (WOD - WID)/2.
      OD = OD1 + DDW
      OD = AMAX1 (OD, 0.0)
      IF (I.NE.0) GO TO 10
      I = I + 1
      R = OD/2.0
      S = 4.*PI*R**2
      V0 = 4.*PI/3.*R**3
      UCRIT = OD
      RETURN
   10 UCRIT = OD
      IF (W.GT.UCRIT) GO TO 300
      R = (OD - W)/2.
      S = 4.*PI*R**2
      RETURN
  300 S = 0.0
      RET..N
      END
```

```
      SUBROUTINE FORMCY (DB,I,OD1,PD,WID,WOD,V0,GL1,S,UCRIT)
      DATA PI4/.785398/,PI/3.141593/
      W = DB*2.0
      DDW = (WOD - WID)/2.
      OD = OD1 + DDW
      GL = GL1 + DDW
      OD = AMAX1 (OD, 0.0)
      GL = AMAX1 (GL, 0.0)
      IF (I.NE.0 ) GO TO 10
      I = I + 1
      E = PI4*OD**2
      V0 = E*GL
      S = 2.*E + PI*GL*OD
      UCRIT = AMIN1 (OD, GL)
      RETURN
 10   UCRIT = AMIN1 (OD, GL)
      IF (W.GT.UCRIT) GO TO 300
      OOD = OD - W
      GGL = GL - W
      E = PI4*OOD**2
      S = 2.*E + PI*GGL*OOD
      RETURN
 300  S = 0.0
      RETURN
      END
```

```
0001          FUNCTION ACOS (A)
0002          DATA PI2/1.570796/, PI/3.141593/
0003          B = SQRT (1. - A**2)
0004          IF (A.NE.0.0) GO TO 10
0006          ACOS = PI2
0007          RETURN
0008    10    C = B/A
0009          D = ATAN (C)
0010          IF (A.LT.0.0) D = D + PI
0012          ACOS = D
0013          RETURN
0014          END
```

```
0001          SUBROUTINE WALTEM (F,DTINE,DUM1,DUM2)
0002          COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
             1 FSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
             2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
             3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
             4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
             5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
             6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
             7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
             8 CON1,CON9,MEM3,MEM7,SFAZ,L9,P,DP,TSTOP,I9,
             9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW,RATE,RL
0003          COMMON /KEVIN/ TE(35), XT(35)
0004          DIMENSION TMA(2), TTA(2), DELX(35), DT(35)
0005          DATA ISW6/0/,ALFA/.01091/,XK/.0006667/,DELX0/.0009/,FAC/0.3/
0006          TTA(1) = DUM1
0007          TTA(2) = DUM2
0008          TMA(1) = 0.0
0009          TSUM = 0.0
0010          DTIME = DTINE/1000.
0011          TMA(2) = DTIME
0012          IF (ISW6.EQ.0) GO TO 86
0014          IF (DELTCN - DTIME) 90,90,91
0015     91   DELTIM = DTIME
0016          GO TO 92
0017     90   DELTIM = DELTCN
0018     92   TSUM = TSUM + DELTIM
0019          IF (TSUM - DTIME) 93,93,95
0020     95   TSUM = TSUM - DELTIM
0021          DELTIM = DTIME - TSUM
0022          TSUM = TSUM + DELTIM
0023     93   CONTINUE
0024          MEM7 = 1
0025          IF ((TMA(2)-TMA(1)).EQ.0.0) GO TO 1942
0027          CALL FIND1 (TSUM,TG,TMA,TTA,2,MEM7)
0028          GO TO 1943
0029   1942   TG = TTA(1)
0030          GO TO 1943
0031   1943   QDOT = F*(TG - XT(1))
0032          QDOT = QDOT + SPACE2(3)*(TG**4 - XT(1)**4)
0033          TZERO = QDOT/XK*2.*DELX0 + XT(2)
0034          DT(1) = ALFA/(DELX0**2)*(TZERO - 2.*XT(1) + XT(2))
0035          DO 42 I = 2,31
0036          CON17 = CONA/(DELX(I)**2)
0037     42   DT(I) = CON17*(XT(I-1) - CONB*XT(I) + CONC*XT(I+1))
0038          DO 5 I = 1,31
0039      5   XT(I) = XT(I) + DELTIM*DT(I)
0040          XT(32) = XT(30)
0041          IF (TSUM - DTIME) 92,74,74
0042     74   DELTIM = DTIME
0043          RETURN
0044     86   ISW6 = 1
0045          DO 21 I = 1,35
```

```
      XT(I) = 298.
   21 TE(I) = 298.
      TYPE 777, ALFA
  777 FORMAT (5X,'BOMB THERMAL DIFFUSIVITY',F12.5)
      ACCEPT 778, TEMP
```

```
 778  FORMAT (E12.0)
      IF (TEMP.NE.0.0) ALFA = TEMP
      CONA = ALFA/(1. + FAC/2.)
      CONB = (2. + FAC)/(1. + FAC)
      CONC = 1./(1. + FAC)
      J = 1
      DWEB = DELX0
      DELX(J) = DELX0
      DO 22 J = 2,34
      DELX(J) = DWEB
  22  DWEB = DWEB*(1. + FAC)
      DELTCN = 0.35*DELX0**2/ALFA
      RETURN
      END
```

```
0001          SUBROUTINE RCALC
        C     SUBROUTINE TO DO LEAST SQUARES FIT ON BURN RATE DATA
0002          COMMON RUNID(5),RTITLE(10),DATE(3),OPERN(5),PROPN(10),
             1 PSORCE(10),PRLOT(10),PREM(10),TIGNR(10),GAGE(10),
             2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
             3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
             4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
             5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
             6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
             7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
             8 CON1,CON9,MEM3,MEM7,SFAC,L9,P1,DP1,TSTOP,I9,
             9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
0003          DIMENSION T(400),P(400),DP(400),R(400)
0004          COMMON /BLAH/ PLO, PHI, ACO, XNC,RSQ, RMS
0005          REWIND 11
0006          DO 669 I = 1,L8
0007          READ (11,384) T(I),P(I),DP(I),R(I)
0008    384   FORMAT (4E13.6)
0009    669   CONTINUE
0010          PLL = PLO*PMAX
0011          PUL = PHI*PMAX
0012          K = 0
0013          SUM1 = 0.0
0014          SUM2 = 0.0
0015          SUM3 = 0.0
0016          SUM4 = 0.0
0017          SUM5 = 0.0
0018          DO 735 I = 1,L8
0019          IF (P(I).LT.PLL) GO TO 735
0021          IF (P(I).GT.PUL) GO TO 735
0023          K = K + 1
0024          DUM1 = ALOG (P(I)*1000.)
0025          DUM2 = ALOG (AMAX1(R(I),0.001))
0026          SUM1 = SUM1 + DUM1*DUM2
0027          SUM2 = SUM2 + DUM1
0028          SUM3 = SUM3 + DUM2
0029          SUM4 = SUM4 + DUM1**2
0030          SUM5 = SUM5 + DUM2**2
0031    735   CONTINUE
0032          XNC = (SUM1 - SUM2*SUM3/K)/(SUM4 - (SUM2**2)/K)
0033          ACO = EXP (SUM3/K - XNC*SUM2/K)
0034          RSQ = ((SUM1 - SUM2*SUM3/K)**2)/((SUM4 - (SUM2**2)/K)*
             1 (SUM5 - (SUM3**2)/K))
0035          SUM= 0.0
0036          K = 0
0037          DO 733 I = 1,L8
0038          IF (P(I).LT.PLL) GO TO 733
0040          IF (P(I).GT.PUL) GO TO 733
0042          K = K + 1
0043          DUM1 = ACO*(P(I)*1000.)**XNC
0044          DUM1 = (R(I) - DUM1)/AMAX1(R(I),0.001)
0045          SUM = SUM + DUM1**2
```

```
  733 CONTINUE
      RMS = SQRT (SUM/(K - 2))*100.0
      RETURN
      END
```

```
C          VERSATRAN PLOTTER SUBROUTINE FOR CBRED
           SUBROUTINE VPLOT
           COMMON RUNID(5),RTITLE(18),DATE(3),OPERN(5),PROPN(18),
          1 PSORCE(18),PRLOT(18),PREM(18),TIGNR(18),GAGE(18),
          2 SPACE1(36),CHGWT,WID,PTEMP,WGHTI,PCORR,BVOL,BTEMP,
          3 SCAL,CALCON,STIME,FFID,GL,OD,PD,WOD,F1,DUM,XMWX1,ET1,GAM1,
          4 SPACE2(4),ISK1,KTOT,MZ,MY,PMAX,TMAX,NPMA,PPM,DPMAX,IHL,H,
          5 RHOC,RHO,T10,T90,T1090,P9(5),DP9(5),NPTH,PX(20),
          6 FX(20),ETX(20),XMWX(20),GAMX(20),IDFF,NPA,WEBX(20),ABX(20),
          7 ISK,ISK2,MEM2,XMI,RP,TZERO,VOL,CP,CST,TM,PIGN,TIGN,PTHEO,
          8 CON1,CON9,MEM3,MEM7,SFAC,L9,P1,DP1,TSTOP,I9,
          9 L8,CONW,TBW,FRAC,Z,SRAT,XTBW
           DIMENSION T(400),P(400),DP(400),R(400)
           COMMON /BLAH/ PLO, PHI, ACO, XNC, RSQ, RMS
           DIMENSION ABC(17)
           DIMENSION BCD(15)
           DIMENSION A(11)
           DIMENSION T9(2), P11(2)
           DIMENSION X1(9),Y1(13)
           DIMENSION TIT(16)
           DATA TIT/'P/PM','AX  ','PDOT','    ','RUN ','ID: ','RUN ',
          1 'TITL','E:  ','PROP',' TYP','E:  ','GRAI','N TY','PE: ',
          2 'AT  '/, S/9999./
           DATA A/1.0,2.0,4.0,6.0,8.0,10.0,20.0,40.0,60.0,80.0,100.0/
           DATA X1/'TIME','-MSE','C   ','    ',4HP/PM,'AX  ','1.0 ',
          1 '10.0','100.'/,Y1/'PRES','S-KP','SIA ','PDOT',' MPS',
          2 4HI/SE,'C   ','0.1 ','1.0 ','10.0','RATE',4H-IN/,'SEC '/
           DATA ABC/'THE ','CONS','TANT','S IN',' THE',' EQU','ATIO',
          1 'N R ','= A*','P**N',' ARE','A:  ','N:  ','FOR ','P/PM',
          2 'AX  ',' TO'/
           DATA BCD/'COEF','FICI','ENT ','OF D','ETER','MINA',
          1 'TION',' :  ','PER ','CENT',' ROO','T ME','AN E','RROR',' :  '/
           REWIND 11
           DO 683 I = 1,L8
           READ (11,384) T(I),P(I),DP(I),R(I)
      384  FORMAT (4E13.6)
      683  CONTINUE
           ENDFILE 11
           CALL MODE (8,2.0,1.0,-1.)
           CALL MODE (2,0.0,-0.75,0.075)
           CALL MODE (3,6.0,-0.75,3.0)
           CALL MODE (7,5.0,5.0,S)
           TYPE 1976
      1976 FORMAT (5X,'DO YOU WANT TO SUPPRESS THE IGNITION'/
          1 5X,'TIME LAG ON THE PRESSURE AND DP/DT PLOT?'/
          2 5X,'TYPE ''S'' TO SUPPRESS')
           ACCEPT 1977, STS
      1977 FORMAT (A4)
           IF (STS.NE.STR) GO TO 1978
           DATA STR/'S'/
           T9(1) = 10.*IFIX(TIGN/10.)
           DUMA = 0.0
```

```
      GO TO 1979
 1978 T9(1) = 0.0
      DUMA = 5.0
 1979 T9(2) = TMAX
      P11(1) = 0.0
```

```
0040            P11(2) = PMAX
0041            CALL SCAN (T9, P11, -2, 440)
0042            CALL MODE (-8,DUM1,DUM2,DUM3)
0043            DUM2 = AMAX1(DUM2, DUMA)
0044            CALL MODE (8, DUM1, DUM2, S)
0045            DUM4 = DUM2
0046            DUM8 = DUM1
0047            CALL MODE (-9, DUM1,DUM2,DUM3)
0048            DUM2 = AMAX1(DUM2,5.0)
0049            CALL MODE (9,0.0,DUM2,S)
0050            CALL AXES (9.2,X1(1),11.2,Y1(1))
0051            CALL DRAW (T, P, L8, 440)
0052            CALL SCAN (T, DP, -L8, 440)
0053            CALL MODE (8,DUM8,DUM4,S)
0054            CALL MODE (-2,DUM1,DUM2,DUM3)
0055            DUM5 = DUM3 - 0.5
0056            CALL MODE (2,  S,S,DUM5)
0057            CALL MODE (9, 0.0, S, S)
0058            CALL AXES (-4.0,X1(4),13.3,Y1(4))
0059            CALL MODE (2,S,S,DUM3)
0060            CALL DRAW (T, DP, L8, 440)
0061            K = 0
0062            CALL MODE (4,.073,.055,S)
0063            CALL MODE (6,S,.080,S)
0064            CALL MODE (3,S,S,-.2)
0065            CALL NOTE (0.0,3.0,TIT(5),7)
0066            CALL NOTE (1.0,3.0,RUNID(1),20)
0067            CALL NOTE (0.0,2.8,TIT(7),10)
0068            CALL NOTE (1.0,2.8,RTITLE(1),60)
0069            CALL NOTE (0.0,2.6,TIT(10),10)
0070            CALL NOTE (1,0,2.6,PROPN(1),60)
0071            CALL NOTE (0.0,2.4,TIT(13),11)
0072            CALL NOTE (1.0,2.4,FFID,4)
0073            IF (K.EQ.0) GO TO 10
0075            CALL NOTE (0.0,2.2-TIT(3),4)
0076            CALL NOTE (2.0,2.2,TIT(16),2)
0077            CALL NOTE (4.0,2.2,TIT(1),6)
0078            Y = 2.2 - 0.2
0079            DO 61 I = 1,4
0080            CALL NOTE (0.0,Y,DP9(I),1003)
0081            CALL NOTE (4.0,Y,P9(I),1003)
0082      61    Y = Y - 0.2
0083      10    CALL MODE (4,.1,.067,S)
0084            CALL MODE (6,S,.1,S)
0085            CALL MODE (3,S,S,3.0)
0086            CALL DRAW (0.,0.,1,9000)
0087            PMAX = 0.0
0088            DO 65 I = 1,L8
0089      65    PMAX = AMAX1(PMAX,P(I))
0090            DO 69 I =1,L8
0091      69    T(I) = P(I)/PMAX
0092            CALL MODE (8, 0.0, 0.2, 3.0)
```

```
      CALL AXES (6.2,X1(5),13.3,Y1(4))
      CALL DRAW (T, DP, L8, 440)
      CALL FORM (5, 1.0, 5, 1.0)
      K = 1
      CALL MODE (4,.073,.055,S)
```

```
0098          CALL MODE (6,S,.080,S)
0099          CALL MODE (3,S,S,-.2)
0100          CALL NOTE (0.0,3.0,TIT(5),7)
0101          CALL NOTE (1.0,3.0,RUNID(1),20)
0102          CALL NOTE (0.0,2.8,TIT(7),10)
0103          CALL NOTE (1.0,2.8,RTITLE(1),60)
0104          CALL NOTE (0.0,2.6,TIT(10),10)
0105          CALL NOTE (1.0,2.6,PROPN(1),60)
0106          CALL NOTE (0.0,2.4,TIT(13),11)
0107          CALL NOTE (1.0,2.4,FFID,4)
0108          IF (K.EQ.0) GO TO 11
0110          CALL NOTE (0.0,2.2,TIT(3),4)
0111          CALL NOTE (2.0,2.2,TIT(16),2)
0112          CALL NOTE (4.0,2.2,TIT(1),6)
0113          Y = 2.2 - 0.2
0114          DO 81 I = 1,4
0115          CALL NOTE (0.0,Y,DP9(I),1003)
0116          CALL NOTE (4.0,Y,P9(I),1003)
0117     81   Y = Y - 0.2
0118     11   CALL MODE (4,.1,.067,S)
0119          CALL MODE (6,S,.1,S)
0120          CALL MODE (3,S,S,3.0)
0121          CALL DRAW (0.,0.,1,9000)
0122          PFAC = 1.0
0123          IF (PMAX.LE.10.0) PFAC = 10.0
0125          PMIN = 1.0
0126          PMIN = PMIN/PFAC
0127          IGO = 0
0128          PSTO = PMAX
0129          TYPE 529
0130    529   FORMAT (5X,'DO YOU WANT ALL THE RATE CURVE?'/
             1 5X,'ENTER 1 FOR YES, PLEASE')
0131          ACCEPT 530, IGO
0132    530   FORMAT (I1)
0133          IF (IGO.EQ.1) GO TO 533
0135          PMIN = PLO*PMAX
0136          PSTO = PHI*PMAX
0137    533   CONTINUE
0138          RMAX = 10.0
0139          RMIN = 0.1
0140          J97 = 0
0141          DO 68 I = 1,L8
0142          IF (P(I).LT.PMIN) GO TO 68
0144          IF (P(I).GT.PSTO) GO TO 68
0146          J97 = J97 + 1
0147          P(J97) = ALOG10 (AMAX1(P(I),PMIN))
0148          R(J97) = ALOG10 (AMAX1(AMIN1(R(I),10.0), 0.1))
0149     68   CONTINUE
0150          DUM1 = 0.0
0151          IF (PFAC.GT.1.0) DUM1 = -1.0
0153          CALL MODE (8,DUM1, 0.4,   S)
0154          CALL MODE (9, -1.0, 0.4,   S)
```

```
      DO 66 I = 1,10
66    A(I) = 2.5*ALOG10(A(I+1)/A(I))
      CALL FORM (1010,A,1010,A)
      IF (PFAC.EQ.1.0) GO TO 997
      CALL NOTE (-0.1,-0.25,Y1(8),3)
```

```
      CALL NOTE (2.3,-0.25,Y1(9),3)
      CALL NOTE (4.7,-0.25,Y1(10),4)
      GO TO 998
997   CALL NOTE (-.1,-0.25,X1(7),3)
      CALL NOTE (2.3,-0.25, X1(8), 4)
      CALL NOTE (4.7,-0.25, X1(9), 4)
998   CONTINUE
      CALL MODE (4, S, S, 90.0)
      CALL NOTE (-.15,-.10, Y1(8), 3)
      CALL NOTE (-.15,2.40, Y1(9), 3)
      CALL NOTE (-.15,4.8, Y1(10), 4)
      CALL MODE (-4,DUM1,DUM2,DUM3)
      CALL MODE (4, .16,.10,S)
      CALL MODE (-6,DUM4,DUM5,DUM6)
      CALL MODE (6,S,.16,.213)
      CALL NOTE (-.35,1.75,Y1(11),11)
      CALL MODE (4, S, S, 0.0)
      CALL NOTE (1.90,-.51, Y1(1),11)
      CALL MODE (4,DUM1,DUM2,S)
      CALL MODE (6,S,DUM5,DUM6)
      CALL DRAW (P, R, J97, 442)
      K = 0
      CALL MODE (4,.073,.055,S)
      CALL MODE (6,S,.080,S)
      CALL MODE (3,S,S,-.2)
      CALL NOTE (0.0,3.0,TIT(5),7)
      CALL NOTE (1.0,3.0,RUNID(1),20)
      CALL NOTE (0.0,2.8,TIT(7),10)
      CALL NOTE (1.0,2.8,RTITLE(1),68)
      CALL NOTE (0.0,2.6,TIT(10),10)
      CALL NOTE (1.0,2.6,PROPN(1),68)
      CALL NOTE (0.0,2.4,TIT(13),11)
      CALL NOTE (1.0,2.4,FFID,4)
      CALL NOTE (0.0,2.2,ABC(1),44)
      CALL NOTE (0.0,2.0,ABC(12),3)
      CALL NOTE (1.0,2.0,ACO,1006)
      CALL NOTE (0.0,1.8,ABC(13),3)
      CALL NOTE (1.0,1.8,XNC,1003)
      CALL NOTE (0.0,1.6,ABC(14),11)
      CALL NOTE (1.0,1.6,PLO,1003)
      CALL NOTE(1.4,1.6,ABC(17),4)
      CALL NOTE (1.72,1.6,PHI,1003)
      CALL NOTE (0.0,1.4,BCD(1),31)
      CALL NOTE (2.40,1.4,RSQ,1004)
      CALL NOTE (0.0,1.2,BCD(9),27)
      CALL NOTE (2.48,1.2,RMS,1004)
      IF (K.EQ.6) GO TO 12
      CALL NOTE (0.0,2.2,TIT(3),4)
      CALL NOTE (2.0,2.2,TIT(16),2)
      CALL NOTE (4.0,2.2,TIT(1),6)
      Y = 2.2 - 0.2
      DO 91 I = 1,4
```

```
      CALL NOTE (0.0,Y,DP9(I),1003)
      CALL NOTE (4.0,Y,P9(I),1003)
91    Y = Y - 0.2
12    CALL MODE (4,.1,.067,8)
      CALL MODE (F,S,.1,S)
```

```
      CALL MODE (3,S,S,3.8)
      CALL DRAW (0.,0.,1,9000)
      CALL DRAW (0.0, 0.0, 0.0, 9999)
      RETURN
      END
```

```
0001          SUBROUTINE FINDTP (ARG, ANS, NVAR, NARG, NANS, IDEV, NPTS,I,MG)
        C     SUBROUTINE FIND.  TABLE LOOK-UP WITH LINEAR INTERPOLATION.
        C     FINDTP IS A DIRECT ACCESS READ LOOKUP MODIFICATION OF
        C     FIND.  INSTEAD OF AN ARRAY, PASSING THE ARGUMENTS, IT
        C     EXPECTS A FILE WHICH HAS BEEN FILLED WITH NVAR VARIABLES,
        C     TO THE EXTENT OF NPTS RECORDS.  THE INDEPENDENT
        C     VARIABLE MAY OCCUPY ANY OF THE LOCATIONS 1-NVAR AND
        C     NARG GIVES ITS LOCATION.  LIKEWISE FOR THE DEPENDENT
        C     VARIABLE WHOSE LOCATION IS GIVEN BY NANS.  IDEV GIVES
        C     THE DEVICE NUMBER OR FILE NUMBER WHICH WAS DEFINED
        C     IN SETTING UP THE FILE.  ALL OTHER FIND COMMENTS
        C     APPLY TO FINDTP.
        C     NOTE..... LIKE FIND, THE INDEPENDENT VARIABLE MUST
        C     BE MONOTONICALLY INCREASING.....
        C
        C      J. ANDERSON      6-1-65
        C             EXTRAPOLATES FOR VALUES OUT OF TABLE RANGE
        C             REMEMBERS LAST ARG VALUE AND BEGINS SEARCH FROM THAT VALUE
        C             CALLING SEQUENCE IS .....
        C
        C             CALL FINDTP (ARG,ANS,NVAR,NARG,NANS,IDEV,NPTS,I)
        C
        C                    ARG IS THE ARGUMENT
        C                    ANS CONTAINS RESULT ON EXIT
        C                    X IS ONE DIMENSIONAL ARRAY OF INDEP. VARIABLE
        C                    X IS ONE DIMENSIONAL ARRAY OF DEP. VARIABLE
        C                    NPTS IS NUMBER OF TABLE ENTRIES
        C                    MEM SHOULD BE INITIALIZED TO 1 - AFTER FIRST
        C                      CALL THE SUBROUTINE WILL PRESERVE VALUES IN IT
        C   VARIABLE WHOSE LOCATION IS GIVEN BY NANS.  IDEV GIVES
        C     THE DEVICE NUMBER OR FILE NUMBER WHICH WAS DEFINED
        C     IN SETTING UP THE FILE.  ALL OTHER FIND COMMENTS
        C     APPLY TO FINDTP.
        C     NOTE..... LIKE FIND, THE INDEPENDENT VARIABLE MUST
        C     BE MONOTONICALLY INCREASING.....
        C
        C      J. ANDERSON      6-1-65
        C             EXTRAPOLATES FOR VALUES OUT OF TABLE RANGE
        C             REMEMBERS LAST ARG VALUE AND BEGINS SEARCH FROM THAT VALUE
        C             CALLING SEQUENCE IS .....
        C
        C             CALL FINDTP (ARG,ANS,NVAR,NARG,NANS,IDEV,NPTS,I)
        C
        C                    ARG IS THE ARGUMENT
        C                    ANS CONTAINS RESULT ON EXIT
        C                    X IS ONE DIMENSIONAL ARRAY OF INDEP. VARIABLE
        C                    X IS ONE DIMENSIONAL ARRAY OF DEP. VARIABLE
        C                    NPTS IS NUMBER OF TABLE ENTRIES
        C                    MEM SHOULD BE INITIALIZED TO 1 - AFTER FIRST
        C                      CALL THE SUBROUTINE WILL PRESERVE VALUES IN IT
        C
0002          DIMENSION X(10),Y(10)
```

```
    1   READ (IDEV'I) (X(J), J = 1,NVAR)
        IF (X(NARG)-ARG)    4,2,2
      2 I=I-1
        IF (I-1) 3,3,1
      3 I=1
```

```
RT-11 FORTRAN IV        V01-11  SOURCE LISTING          PAGE 002

          GO TO 7
        4 K = I + 1
          READ (IDEV'K) (Y(J), J = 1,NVAR)
          IF (Y(NARG)-ARG) 5,7,7
        5 I=I+1
          IF (I-NPTS)    4,6,6
        6 I=NPTS-1
        7 K = I + 1
          READ (IDEV'I) (X(J), J = 1,NVAR)
          READ (IDEV'K) (Y(J), J = 1,NVAR)
          ANS=X(NANS)+(Y(NANS)-X(NANS))*(ARG-X(NARG))/(Y(NARG)-X(NARG))
          RETURN
          END
```

```
0001          SUBROUTINE FIND1 (ARG,ANS,X,Y,NPTS,I)
        C     SUBROUTINE FIND.  TABLE LOOK-UP WITH LINEAR INTERPOLATION.
        C      J. ANDERSON      6-1-65
        C             EXTRAPOLATES FOR VALUES OUT OF TABLE RANGE
        C             REMEMBERS LAST ARG VALUE AND BEGINS SEARCH FROM THAT VALUE
        C             CALLIN SEQUENCE IS .....
        C
        C                CALL FIND (ARG,ANS,X,Y,NPTS,MEM)
        C
        C                    ARG IS THE ARGUMENT
        C                    ANS CONTAINS RESULT ON EXIT
        C                    X IS ONE DIMENSIONAL ARRAY OF INDEP. VARIABLE
        C                    X IS ONE DIMENSIONAL ARRAY OF DEP. VARIABLE
        C                    NPTS IS NUMBER OF TABLE ENTRIES
        C                    MEM SHOULD BE INITIALIZED TO 1 - AFTER FIRST
        C                      CALL THE SUBROUTINE WILL PRESERVE VALUES IN IT
        C
0002          DIMENSION X(10),Y(10)
0003        1 IF (X(I)-ARG)    4,2,2
0004        2 I=I-1
0005          IF (I-1) 3,3,1
0006        3 I=1
0007          GO TO 7
0008        4 IF (X(I+1)-ARG) 5,7,7
0009        5 I=I+1
0010          IF (I-NPTS)    4,6,6
0011        6 I=NPTS-1
0012        7 ANS=Y(I)+(Y(I+1)-Y(I))*(ARG-X(I))/(X(I+1)-X(I))
0013          RETURN
0014          END
```

```
      SUBROUTINE SIMEQ (A,B,D,L,M,N)
C     SUBROUTINE SOLVING L EQUATIONS IN M UNKNOWNS WITH N SETS OF RIGHT-
C     HAND CONSTANTS. A(L,M) IS THE MATRIX OF COEFFICIENTS AND B(L,N) IS
C     THE MATRIX OF COLUMNS OF ANSWERS. ON RETURN FROM SUBROUTINE, A
C     CONTAINS ORTHOGONALIZED COLUMNS. B CONTAINS THE RESIDUALS, AND
C     D(M,N) CONTAINS THE SOLUTIONS. FOR MORE EQUATIONS THAN UNKNOWNS
C     THE LEAST-SQUARES SOLUTION IS OBTAINED. OTHERWISE THE SOLUTION IS
C     IN TERMS OF THE FIRST L LINEARLY INDEPENDENT VARIABLES. REQUIRES..
C     DIMENSION  A(15,15), B(15,15), D(15,15)
C     CALL SIMEQ (A, B, D, L, M, N)
      DIMENSION A(500,1), B(500,1), C(3,3), D(1,1)
      DO 701 I=1,M
      DO 700 J=1,M
  700 C(I,J) = 0.0
      DO 701 K=1,N
  701 D(I,K) = 0.0
      DO 702 J=2,M
      DO 702 I=1,L
  702 C(J,J-1) = C(J,J-1) +  (A(I,J)*A(I,J))
      DO 712 K=1,M
      DO 709 J=K,M
      DO 703 I1=1,L
  703 C(K,J) = C(K,J) + (A(I1,K)*A(I1,J))
      IF (K-J) 706, 704, 704
  704 IF (K-1) 709, 709, 705
  705 IF (1.E-7*C(K,K-1) - 1.E7*C(K,K)) 709, 712, 712
  706 C(K,J) = C(K,J)/C(K,K)
  707 DO 708 I2=1,L
  708 A(I2,J) = A(I2,J) - (A(I2,K)*C(K,J))
  709 CONTINUE
      DO 711 J2=1,N
      DO 710 I3=1,L
  710 D(K,J2) = D(K,J2) + (A(I3,K)*B(I3,J2)/C(K,K))
      DO 711 I4=1,L
  711 B(I4,J2) = B(I4,J2) - (A(I4,K)*D(K,J2))
  712 CONTINUE
      IF (M - 1) 715, 715, 714
  714 DO 713 I=2,M
      IT = M+1-I
      JT = IT+1
      DO 713 J=1,N
      DO 713 K=JT,M
  713 D(IT,J) = D(IT,J) - (C(IT,K)*D(K,J))
  715 RETURN
      END
```

```
      C     CPEVES.004  22-AUG-75
      C
0001        SUBROUTINE EVES(N,TPRNT)
      C     THIS SUBROUTINE SOLVES N SIMULTANEOUS FIRST ORDER DIFFERENTIAL
      C     EQUATIONS BY THE ADAMS METHOD.
      C     TO USE ...
      C    - WRITE A MAIN PROGRAM TO READ THE INPUT DATA AND PERFORM ANY
      C      DESIRED AALCULATIONS PRIOR TO THE INTEGRATION. AT THE POINT
      C      WHERE THE INTEGRATION IS DESIRED
      C           CALL EVES (N,TPRNT)
      C             WHERE N IS THE NUMBER OF DIFFERENTIAL EQUATIONS
      C                   TPRNT IS A ONE DIMENSIONAL ARRAY FILLED WITH PAIRS
      C                         OF VALUES TO CONTROL PRINTING (DESCRIBED IN
      C                         SUBROUTINE PRINT)
      C      EVES WILL TAKE CONTROL AT THIS POINT AND PERFORM THE INTEGRATION
      C      UNTIL THE USER-PROVIDED SUBROUTINES INDICATE THE UPPER LIMIT HAS
      C      BEEN REACHED, (BY SETTING N=0), THEN CONTROL WILL BE RETURNED
      C      TO THE MAIN PROGRAM
      C
      C   USER SUBROUTINES ...
      C
      C      EVES REQUIRES 3 USER-SUBROUTINES TO PERFORM THE INTEGRATION
      C
      C     -SUBROUTINE SETUP (T,Y,SIG,N)
      C      DIMENSION T(2),Y(N),SIG(N,3)
      C
      C      THIS SUBROUTINE SETS THE INITIAL CONDITIONS FOR THE INTEGRATION
      C      AND DEFINES THE ACCURACY REQUIRED IN THE SOLUTION.
      C          T(1) = STARTING TIME (ASSUMED 0.0 IF NOT SPECIFIED)
      C          T(2) = INITIAL TIME INCREMENT (ASSUMED 1.0E-5 IF UNSPECIFIED)
      C          Y(I) = INITIAL VALUES OF DEPENDENT VARIABLES, I=1,N
      C                   (ASSUMED 0.0 IF UNSPECIFIED)
      C          SIG(I,1) = REQUIRED ACCURACY FOR THE DEPENDENT VARIABLES.
      C                     I=1,N WHERE SIG=1.E-M INDICATES M SIGNIFICANT
      C                     FIGURES. (ASSUMED 1.E-3 IF UNSPECIFIED)
      C          SIG(I,2) = MINIMUM ABSOLUTE ACCURACY DESIRED=SIG(I,2)*SIG(I,1
      C                     ). THIS SUSPENDS THE REQUIRED NO. OF SIGNIFICANT
      C                     FIGURES IF THE ABSOLUTE VALUE OF THE INTEGRAL IS
      C                     LESS THAN THIS VALUE. ITS USE IS TO PREVENT USE
      C                     OF AN INORDINATELY SMALL STEP SIZE AS AN
      C     INSETUP (T,Y,SIG,N)
      C      DIMENSION T(2),Y(N),SIG(N,3)
      C
      C      THIS SUBROUTINE SETS THE INITIAL CONDITIONS FOR THE INTEGRATION
      C      AND DEFINES THE ACCURACY REQUIRED IN THE SOLUTION.
      C          T(1) = STARTING TIME (ASSUMED 0.0 IF NOT SPECIFIED)
      C          T(2) = INITIAL TIME INCREMENT (ASSUMED 1.0E-5 IF UNSPECIFIED)
      C          Y(I) = INITIAL VALUES OF DEPENDENT VARIABLES, I=1,N
      C                   (ASSUMED 0.0 IF UNSPECIFIED)
      C          SIG(I,1) = REQUIRED ACCURACY FOR THE DEPENDENT VARIABLES.
      C                     I=1,N WHERE SIG=1.E-M INDICATES M SIGNIFICANT
      C                     FIGURES. (ASSUMED 1.E-3 IF UNSPECIFIED)
```

```
C          SIG(I,2) = MINIMUM ABSOLUTE ACCURACY DESIRED=SIG(I,2)*SIG(I,1
C                     ). THIS SUSPENDS THE REQUIRED NO. OF SIGNIFICANT
C                     FIGURES IF THE ABSOLUTE VALUE OF THE INTEGRAL IS
C                     LESS THAN THIS VALUE. ITS USE IS TO PREVENT USE
C                     OF AN INORDINATELY SMALL STEP SIZE AS AN INTEGRAL
```

```
C                     LEAVES 0. (ASSUMED 0. IF UNSPECIFIED)
C          SIG(I,3) = THRESHOLD VALUE FOR THE VARIABLE I. EVES WILL HIT
C                     THIS VALUE EXACTLY DURING THE INTEGRATION AND LET
C                     THE USER ROUTINES KNOW THIS VALUE HAS BEEN HIT.
C                     (ASSUMED 1.0E+35 IF UNSPECIFIED)
C
C
C     SUBROUTINE DIFEQ (T,Y,DY,N,TPR)
C      DIMENSION  T(2),Y(N),DY(N),TPR(2)
C
C      THIS SUBROUTINE EVALUATES THE DERIVATIVE VALUES (DY(I)),AT EACH
C      PROPOSED STEP IN THE SOLUTION. ON EACH CALL,T(1) CONTAINS THE
C      CURRENT TIME, AND THE Y(I)S ARE THE CURRENT INTEGRATED VALUES.
C      THE RESULTS OF A CALL MAY BE REJECTED,AND THE STEP SIZE CUT IN
C      ORDER TO MAINTAIN ACCURACY, SO NO PERMANENT SWITCH SETTING SHOULD
C      BE MADE IN THIS ROUTINE, BASED ON PROPOSED VALUES
C
C
C     -SUBROUTINE PRINT (T,Y,DY,N,TPR)
C      DIMENSION  T(2),Y(N),DY(N),TPR(N+4)
C
C      THIS SUBROUTINE IS CALLED TO OUTPUT ACCEPTED VALUES DURING THE
C      INTEGRATION PROCEEDURE. THE FREQUENCY WITH WHICH IT IS CALLED
C      IS DEPENDENT ON THE NUMBER OF INTEGRATION STEPS,THE TPRNT ARRAY
C      SUPPLIED TO EVES BY THE MAIN PROGRAM, AND THE THRESHOLD VALUES
C      FOR VARIABLES SET IN SUBROUTINE SETUP AS FOLLOWS -
C         -THE TPRNT ARRAY CONSISTS OF PAIRS OF VALUES DELTA T AND TLIM
C          SUCH THAT DELTA T IS THE PRINT INTERVAL UNTIL TLIM IS REACHED
C          , WHEREUPON THE NEXT PAIR OF VALUES TAKES CONTROL.
C              IF DELTA T .EQ. 0 EVERY ACCEPTED POINT IS PRINTED
C              IF DELTA T .GT. 0 PRINTING OCCURS ONLY AT INTERVALS OF
C                                DELTA T
C              IF DELTA T .LT. 0 PRINTING OCCURS AT EVERY ACCEPTED
C                                POINT,BUT AMONG THESE POINTS ARE
C                                INTERVALS OF ABS(DELTA T)
C
C         -REGARDLESS OF THE TPRNT CONTROLS,A CALL TO PRINT WILL OCCUR
C          EACH TIME A VARIABLE REACHES IT'S THRESHOLD VALUE.
C
C      THE TPR ARRAY HAS THE FOLLOWING INFORMATION WHEN PRINT IS CALLED
C          TPR(1)  CURRENT DELTA T FROM TPRNT ARRAY
C          TPR(2)  CURRENT TLIM FROM TPRNT ARRAY
C          TPR(3)  0 IF CALLED THRU ACCURACY CONTROLLED STEP SIZE.
C                 +J IF CALLED DUE TO VARIABLE J RISING TO ITS
C                       THRESHOLD VALUE
C                 -J IF CALLED DUE TO VARIABLE J FALLING TO ITS
C                       THRESHOLD VALUE
C                 N+1 IF CALLED AT SPECIFIED PRINT POINT
C          TPR(4)  CURRENT TIME STEP SIZE FOR INTEGRATION
C            (IF THIS VALUE IS CHANGED IN PRINT, THE DIFFERENCE TABLE
C             WILL BE ZEROED AND THE SOLUTION RESTARTED WITH THE ALTERED
C             VALUE AS THE STEP SIZE. THIS IS TO GET AROUND EXTERNALLY
```

```
C           INDUCED DISCONTINUITIES WITHOUT REQUIRING THE INTEGRATION
C           TO DISCOVER THE POINT OF OCCURRENCE BY HALVING ITS STEP.)
C        TPR(5)  ROUGHEST VARIABLE OF CURRENT STEP
C        TPR(6)-TPR(N+5) CURRENT THRESHOLD SETTINGS FOR EACH VARIABLE
C                    (ALLOWING DYNAMIC RESET OF THRESHOLDS)
```

```
C
C
      DIMENSION D1(12,7),T1(2),D2(12,7),T2(2),Y1(12),DY1(12),SIG(12,3),
     1 Y2(12),DY2(12),TPRNT(6),TPR(17)
      DIMENSION T3(2)
      EQUIVALENCE (D1(1),Y1(1)),(D1(13),DY1(1)),(D2(1),Y2(1))
     1 ,(D2(13),DY2(1))
      TBIAS=0.0
      KTERR=0
    1 M=N
    2 DO   4 I=1,M
      DO   3 J=1,7
      D1(I,J)=0.0
    3 D2(I,J)=0.0
      SIG(I,1)=1.0E-03
      SIG(I,3)=1.0E+35
    4 SIG(I,2)=0.0
      IPRNT=1
      T1(1)=0.0
      T1(2)=1.E-5
C
C     INITIAL SETUP COMPLETE. CALL IN THE PROGRAMMERS SETUP.
C
      CALL SETUP(T1,Y1,SIG,M)
      IF (M.LT.0) IPRNT = -M
      M = N
      TPR(1)=TPRNT(IPRNT)
      TPR(2)=TPRNT(IPRNT+1)
      TNEXT=T1(1)+ABS(TPR(1))
      ISWV=1
      TPR(3)=0.
      DO   5 I=1,M
      J=I+5
    5 TPR(J)=SIG(I,3)
    6 CALL DIFEQ(T1,Y1,DY1,M,TPR)
      IF (M) 64, 64, 7
    7 CALL PRINT(T1,Y1,DY1,M,TPR)
      IF (M) 64, 64, 8
    8 T2(1)=T1(1)+T1(2)
      T2(2)=T1(2)
C
C     PREDICT AHEAD BY ADAMS METHOD.
C
      DO   9 I=1,M
    9 Y2(I)=0.34861111*D1(I,6)+0.375*D1(I,5)+0.41666667*D1(I,4)+0.5*
     1 D1(I,3)+T1(2)*DY1(I)+Y1(I)
      T3(1)=T2(1)+TBIAS
      T3(2)=T2(2)
C
C     OBTAIN THE DERIVATIVES AT THE PROPOSED POINT.
C
      CALL DIFEQ(T3,Y2,DY2,M,TPR)
```

```
  701 TZSAVE=-300
      IF (M) 64, 64, 10
   10 EMAX=0.
C
C     DIFFERENCE AND COMPUTE CRITICAL (MAXIMUM) ERROR TERM.
```

```
C
      DO  18 I=1,M
      D2(I,3)=T2(2)*(DY2(I)-DY1(I))
      DO  11 J=3,6
   11 D2(I,J+1)=D2(I,J)-D1(I,J)
C
C     DELETE DIVERGENT DIFFERENCES.
C
      DO  15 J=3,5
      IF (ABS(D2(I,J+1))-ABS(D2(I,J))) 15, 12, 12
   12 IF (ABS(D2(I,J+2))-ABS(D2(I,J+1))) 15, 13, 13
   13 DO  14 K=J,6
   14 D2(I,K+1)=0.
      GO TO  16
   15 CONTINUE
      J=7
   16 XYZ=0.3*D2(I,J)/(SIG(I,1)*AMAX1(ABS(Y2(I)),1.0E-30,SIG(I,2)))
      IF (ABS(XYZ)-EMAX) 18, 17, 17
   17 EMAX=ABS(XYZ)
      JCRAP=I
      TPR(5)=I
   18 CONTINUE
C
C     DETERMINE IF ERROR IS WITHIN BOUNDS.
C
      IF (EMAX-1.0) 30, 30, 19
C
C     ERROR TOO BIG. HALVE THE INTERVAL AND TRY AGAIN.
C
   19 T1(2)=.5*T1(2)
C
C     CHECK FOR DELTA TIME INSIGNIFICANT.
C
      IF (T1(1)/T1(2)-1.0E06) 27, 20, 20
   20 CONTINUE
C
C     DELTA TIME IS INSIGNIFICANT. TRANSLATE THE ORIGIN.
C
      DO  21 IJAZZ=1,M
   21 Y1(IJAZZ)=Y2(IJAZZ)
      TBIAS=TBIAS+T1(1)+2.0*T1(2)
      T2(2)=0.
      T1(1)=0.0
      KTERR=KTERR+1
      IF (KTERR-4) 23, 22, 22
   22 TYPE 67, JCRAP
      RETURN
   23 TYPE 68, KTERR, JCRAP
C
C     RESTART THE SOLUTION.
C
   24 DO  26 IJAZZ=1,M
```

```
      DO 25 JAZZ=2,6
   25 D1(IJAZZ,JAZZ)=0.
      DO 26 JAZZ=2,7
   26 D2(IJAZZ,JAZZ)=0.
      T3(1)=TBIAS+T1(1)
```

```
      T1(2)=1.E-5
      T3(2)=1.E-5
      CALL DIFEQ(T3,Y1,DY1,M,TPR)
      GO TO  8
   27 DO  29 I=1,M
      DO  28 J=1,6
   28 D2(I,J)=D1(I,J)
   29 D2(I,7)=0.0
      GO TO  55
C
C     CALCULATE DELTA T TO HIT THRESHOLD EXACTLY
C
   30 GO TO ( 31, 38),ISWV
   31 IPOLD=ABS(TPR(3))
      TPR(3)=0.
      TRATSV=1.0
      ITER1 = 0
      DO 36 I=1,M
      IF (I .EQ. IPOLD) GO TO 36
      IF (SIGN(1.0,(Y1(I)-TPR(I+5)))*SIGN(1.0,(Y2(I)-TPR(I+5))))
     1  32,32,36
   32 TDY3=0.25*D1(I,6)+0.33333333*D1(I,5)+0.5*D1(I,4)+D1(I,3)
      TDY4=0.1666667*D1(I,6)+D1(I,5)+D1(I,4)
      TDY5=1.5*D1(I,6)+D1(I,5)
      TDY6=D1(I,6)
      YTARG=TPR(I+5)
      ITER=0
      TRAT=0.5
      XINC=0.25
      IF (Y2(I) .LT. Y1(I)) XINC=-XINC
  700 YTEST=Y1(I)+TRAT*T3(2)*DY2(I)+TDY3*TRAT**2/2.0+TDY4*TRAT**3/6.0
     1 +TDY5*TRAT**4/24.0*TDY6*TRAT**5/120.
      IF (YTEST .GT. YTARG) TRAT=TRAT-XINC
      IF (YTEST .LT. YTARG) TRAT=TRAT+XINC
      XINC=XINC/2.
      ITER=ITER+1
      IF (ITER .LT. 30) GO TO 700
      IF (ITER1.EQ.0) TRATSV = TRAT
      TRATSV = AMIN1 (TRATSV, TRAT)
      ITER1 = 1
      TPR(3)=I
      IF (Y2(I) .LT. Y1(I)) TPR(3)=-I
   36 CONTINUE
      IF (ITER1.EQ.0) GO TO 38
   37 T1(2)=TRATSV*T1(2)
      ISWV=2
      GO TO 27
C
C     TEST FOR ERROR TOO SMALL
C
   38 T3(1) = T2(1) + TBIAS
      IF (EMAX -0.0015) 39,39,40
```

```
      C
      C     ERROR TOO SMALL. ACCEPT THIS POINT. BUT DOUBLE THE
      C        INTERVAL FOR THE NEXT POINT.
      C
0134     39 T1(2)=2.0*T2(2)
```

```
0135         GO TO  41
      C
      C      ERROR O.K. BUY THIS POINT AND MAINTAIN CURRENT INTERVAL.
      C
0136      40 T1(2)=T2(2)
0137      41 IF (TPR(3) .NE. 0.0) GO TO 73
0139         IF (TPR(1)) 42, 44, 45
0140      42 T3(1)=T2(1)+TBIAS
0141         T3(2)=T2(2)
      C
      C      OUTPUT THE ACCEPTED POINT.
      C
0142         TPR(4)=T3(2)
0143         IF (ABS((T3(1)-TNEXT)/TNEXT) .LE. 0.00001) TPR(3)=M+1
0145         TZSAVE=TPR(3)
0146         CALL PRINT(T3,Y2,DY2,M,TPR)
0147         ISWV=1
0148         IF (M) 64, 64, 43
      C
      C      TEST FOR PRINTING CONDITIONS.
      C
0149     43  IF (T3(2) .NE. TPR(4)) GO TO 200
0151         IF (ABS((T3(1)-TNEXT)/TNEXT)-0.00001) 47, 51, 51
0152      44 TNEXT=TPR(2)
0153      73 IF (T3(1) - TPR(2)) 46, 45, 46
0154      45 IF (ABS((T3(1)-TNEXT)/TNEXT)-0.00001) 99, 51, 51
0155     99  TPR(3) = M + 1
0156         TZSAVE=TPR(3)
0157     46  T3(2) = T2(2)
0158         T3(2)=T2(2)
0159         TPR(4)=T3(2)
0160         CALL PRINT(T3,Y2,DY2,M,TPR)
0161         ISWV=1
0162         IF (M) 64, 64, 47
0163     47  IF (T3(2) .NE. TPR(4)) GO TO 200
0165         IF (TZSAVE .EQ. TPR(3)) TNEXT=TNEXT+ABS(TPR(1))
0167         IF (T3(1)-TPR(2)+0.1*TPR(1)) 51, 48, 48
0168      48 IPRNT=IPRNT+2
0169         TPR(1)=TPRNT(IPRNT)
0170         TPR(2)=TPRNT(IPRNT+1)
0171         IF (TPR(1)) 49, 50, 49
0172      49 TNEXT=T3(1)+ABS(TPR(1))
0173         GO TO  51
0174      50 TNEXT=TPR(2)
0175      51 IF (T1(2)+T3(1)-TNEXT) 53, 53, 52
0176      52 T1(2)=TNEXT-T3(1)
0177      53 CONTINUE
0178      54 T1(1)=T2(1)
0179      55 W=T1(2)/T2(2)
0180         IF (W-1.0) 56, 65, 56
      C
      C      ADJUST THE DIFFERENCE TABLE FOR INTERVAL CHANGE.
```

```
C
   56 DO  57 I=1,M
      XYZ=W*W
      TMP3=D2(I,3)
      TMP4=D2(I,4)
```

```
0185          TMP5=D2(I,5)
0186          TMP6=D2(I,6)
0187          TMP7=D2(I,7)
0188          TMP3=(0.2*TMP7+0.25*TMP6+0.33333333*TMP5+0.5*TMP4+TMP3)*XYZ
0189          XYZ=XYZ*W
0190          TMP4=(0.83333333*TMP7+0.91666667*TMP6+TMP5+TMP4)*XYZ
0191          XYZ=XYZ*W
0192          TMP5=(1.75*TMP7+1.5*TMP6+TMP5)*XYZ
0193          XYZ=W*XYZ
0194          TMP6=(2.0*TMP7+TMP6)*XYZ
0195          TMP7=TMP7*XYZ*W
0196          Y1(I)=Y2(I)
0197          DY1(I)=DY2(I)
0198          D1(I,3)=0.83333333E-02*TMP7-0.41666667E-01*TMP6+0.16666667*
             1 TMP5-0.5*TMP4+TMP3
0199          D1(I,4)=0.58333333*TMP6-0.25*TMP7-TMP5+0.5*TMP4+TMP3
0200          D1(I,5)=1.25*TMP7-1.5*TMP6+TMP5
0201       57 D1(I,6)=TMP6-2.0*TMP7
        C
        C     DELETE DIVERGENT DIFFERENCES.
        C
0202       58 DO  63 I=1,M
0203          DO  62 J=3,5
0204          IF (ABS(D1(I,J+1))-ABS(D1(I,J))) 62, 59, 59
0205       59 IF (ABS(D1(I,J+2))-ABS(D1(I,J+1))) 62, 60, 60
0206       60 DO  61 K=J,5
0207       61 D1(I,K+1)=0.0
0208          GO TO  63
0209       62 CONTINUE
0210       63 CONTINUE
0211          GO TO   8
0212       64 RETURN
0213       65 T1(1)=T2(1)
0214          T1(2)=T2(2)
0215          DO  66 I=1,M
0216          DO  66 J=1,6
0217       66 D1(I,J)=D2(I,J)
0218          GO TO   8
0219       67 FORMAT (1H1,30X,50HMORE THAN THREE ORIGIN TRANSLATION DUE TO VARIA
            1BLE,I3,/5X,12HRUN ABORTED.)
0220       68 FORMAT (1H0/1H0,30X,22HORIGIN TRANSLATION NO.,I3,26X,15HDUE TO VAR
            1IABLE,I3,/1H0)
        C
        C     CLEAR DIFFERENCE TABLE AT CUSTOMERS REQUEST
        C
0221      200 DO 201 IJAZZ=1,M
0222          DO 202 JAZZ=2,6
0223      202 D1(IJAZZ,JAZZ)=0.0
0224          DO 201 JAZZ=2,7
0225      201 D2(IJAZZ,JAZZ)=0.0
0226          T1(1)=T2(1)
0227          DO 204 I=1,M
```

```
  204 Y1(I)=Y2(I)
      T1(2)=TPR(4)
      CALL DIFEQ (T3,Y1,DY1,M,TPR)
      GO TO 8
      END
```

DISTRIBUTION LIST

No. of Copies	Organization
12	Commander Defense Documentation Center ATTN: DDC-TCA Cameron Station Alexandria, VA 22314
1	Defense Advanced Research Projects Agency ATTN: Mr. C. Lehner 1400 Wilson Boulevard Arlington, VA 22209
1	Institute for Defense Analyses ATTN: R. T. Oliver 400 Army Navy Drive Arlington, VA 22202
1	Commander US Army Materiel Development and Readiness Command ATTN: DRCDMA-ST 5001 Eisenhower Avenue Alexandria, VA 22333
1	Commander US Army Aviation Research and Development Command ATTN: DRSAV-E 12th and Spruce Streets St. Louis, MO 63166
1	Director US Army Air Mobility Research and Development Laboratory Ames Research Center Moffett Field, CA 94035
1	Commander US Army Electronics Command ATTN: DRSEL-RD Fort Monmouth, NJ 07703
2	Commander US Army Missile Research and Development Command ATTN: DRDMI-R DRDMI-RK, R.G. Rhodes Redstone Arsenal, AL 35809
1	Commander US Army Tank Automotive Development Command ATTN: DRDTA-RWL Warren, MI 48090
2	Commander US Army Mobility Equipment Research & Development Cmd ATTN: Tech Docu Cen, Bldg. 315 DRSME-RZT Fort Belvoir, VA 22060
1	Commander US Army Armament Materiel Readiness Command Rock Island, IL 61202
7	Commander US Army Armament Research and Development Command ATTN: SARPA-CO, H.W. Painter SARPA-FR-G Dr. A. Beardell Dr. H. Fair Dr. R. Walker Dr. J. Picard Mr. C. Lenchitz Mr. L. Schulman Dover, NJ 07801
4	Commander US Army Armament Research and Development Command ATTN: SARPA-ADEP-E, D. Katz Mr. S. Einstein Mr. S. Bernstein Dover, NJ 07801

DISTRIBUTION LIST

No. of Copies	Organization
5	Commander US Army Armament Research and Development Command ATTN: SARPA-ADEP-E Mr. F. Fitzsimmons Mr. J. Domen Mr. P. Sergo Mr. C. Allen Mr. J. Rutkowski Mr. E. Wurzell Dover, NJ 07801
1	Commander US Army Rock Island Arsenal Rock Island, IL 61202
1	Commander US Army Watervliet Arsenal ATTN: R. Thierry, SARWV-RD Watervliet, NY 12189
1	Commander US Army Harry Diamond Labs ATTN: DRXDO-TI 2800 Powder Mill Road Adelphi, MD 20783
1	Director US Army TRADOC Systems Analysis Activity ATTN: ATAA-SL (Tech Lib) White Sands Missile Range NM 88002
3	Commander Radford Army Ammunition Plant ATTN: SARPA-IE Mr. J. Horvath Mr. J. Pierce Mr. E. Periman Radford, VA 24141
2	Project Manager M110E2 Weapon Systems ATTN: Mr. S. Smith Rock Island, IL 61202
3	Project Manager Cannon Artillery Weapons Sys ATTN: DRCPM-CAWS DRCPM-CAWS-TM, Mr. H. Nobel DRCPM-CAWS-PA, Mr. R. Schertz US Army Armament Materiel Readiness Command Rock Island, IL 61202
1	HQDA (DAMA, LTC N. Connor) Washington, DC 20310
1	Commander US Army Research Office P. O. Box 12211 Research Triangle Park NC 27709
1	Chief of Naval Research ATTN: James R. Patton, Jr. Code 473 800 N. Quincy Street Arlington, VA 22217
1	Commander US Naval Air Systems Command ATTN: Robert H. Heitkotter Code AIR-330-B Jefferson Plaza, Bldg 1, Rm 478 Washington, DC 20360
1	Commander US Naval Sea Systems Command ATTN: John W. Murrin NAVSEA-0331 National Ctr, Bldg 2, Rm 6E08 Washington, DC 20360
1	Director Navy Strategic Sys Project Ofc ATTN: Roy D. Kinert, SP 2731 Washington, DC 20390

DISTRIBUTION LIST

No. of Copies	Organization
1	Commander US Naval Surface Weapons Ctr ATTN: Code DG-24, Mr. Lisle H. Russell Dahlgren, VA 22448
1	Commander US Naval Surface Weapons Ctr ATTN: Code 240, Sigmund J. Jacobs Silver Spring, MD 20910
1	Commander US Naval Underwater Sys Center Energy Conversion Department ATTN: Code 5B331, Robert S. Lazar Newport, RI 02840
11	Commander US Naval Weapons Center ATTN: Code 6082 Mr. C. Price (10 cys) Mr. H. Bradley (1 cy) China Lake, CA 93555
4	Commander US Naval Weapons Center ATTN: Code 3882, Jack Prentice Code 608, Ronald L. Derr Code 388, Thomas Boggs Code 4505, Charles Thelen China Lake, CA 93555
1	Superintendent US Naval Postgraduate School ATTN: Tech Lib Monterey, CA 93940
2	Superintendent US Naval Postgraduate School Department of Aeronautics ATTN: David W. Netzer Allen F. Fuhs Monterey, CA 93940
3	Commander US Naval Ordnance Station ATTN: Code 5251 Mr. S. Mitchell Mr. F. Robbins Mr. G. Bolling Indian Head, MD 20640
1	AFOSR (Joseph F. Masi, NA) Bolling AFB Washington, DC 20332
1	AFRPL (DYSC, Wilbur C. Andrepont) Edwards AFB, CA 93523
1	AFRPL (DYSC, Daweel George) Edwards AFB, CA 93523
1	AFATL (DLDG, D. Davis) Eglin AFB, FL 32542
1	AFAPL (RJT, Frank Stull) Wright-Patterson AFB, OH 45433
1	Director National Aeronautics and Space Administration ATTN: Code RP, Frank W. Stephenson, Jr. 600 Independence Avenue, SW Room 625 Washington, DC 20546
2	Director National Aeronautics and Space Administration George C. Marshall Space Flight Center ATTN: K. B. Chandler Richard J. Richmond Huntsville, AL 35812

DISTRIBUTION LIST

No. of Copies	Organization
1	Director National Aeronautics and Space Administration Lyndon B. Johnson Space Ctr ATTN: Joseph Thibodaux, EP Houston, TX 77058
1	Director National Aeronautics and Space Administration Lewis Research Center ATTN: Richard J. Priem MS-500-204 21000 Brookpark Road Cleveland, OH 44135
1	AAI Corporation ATTN: Mr. I. Barr P. O. Box 126 Cockeysville, MD 21030
1	Aerojet Solid Propulsion Co ATTN: Arthur L. Karnesky P. O. Box 13400 Sacramento, CA 95813
1	Aeronautical Research Assoc of Princeton, Inc. ATTN: E. S. Fishburne 50 Washington Road Princeton, NJ 08540
1	Aerospace Corporation ATTN: Ellis M. Landsbaum P. O. Box 92957 Los Angeles, CA 90045
1	Atlantic Research Corporation ATTN: Merrill K. King 5390 Cherokee Avenue Alexandria, VA 22314
1	Atlantic Research Corporation ATTN: Kemper E. Eagle 7511 Wellington Road Gainesville, VA 22060
1	AVCO Corporation AVCO Everett Research Lab Div ATTN: D. Stickler 2385 Revere Beach Parkway Everett, MA 02149
1	Calspan Corporation ATTN: Edward B. Fisher P. O. Box 235 Buffalo, NY 14221
1	E. I. duPont de Nemours and Co. ATTN: Mr. L. Werner 1007 Market Street Wilmington, DE 19898
1	ENKI Corporation ATTN: M. I. Madison 9015 Fullbright Avenue Chatsworth, CA 91311
1	Foster Miller Associates, Inc. ATTN: A. J. Erickson 135 Second Avenue Waltham, MA 02154
1	General Applied Science Labs, Incorporated ATTN: John Erdos Merrick and Stewart Avenues Westbury, Long Island, NY 11590
1	General Dynamics Corporation Pomona Division ATTN: Paul L. Boettcher P. O. Box 2507 Pomona, CA 91766

DISTRIBUTION LIST

No. of Copies	Organization
1	General Electric Company Armament Dept. ATTN: M. J. Bulman Lakeside Avenue Burlington, VT 05402
2	Hercules, Inc. Allegany Ballistics Laboratory ATTN: Roy R. Miller John E. Christian P. O. Box 210 Cumberland, MD 21502
3	Hercules, Inc. Bacchus Works ATTN: Merrill W. Beckstead Bruce D. Hopkins Ronald L. Simmons P. O. Box 98 Magna, UT 84044
1	IITRI ATTN: Morton J. Klein 10 W. 35th Street Chicago, IL 60615
1	Lockheed Aircraft Corp. Lockheed Missiles & Space Div. ATTN: J. Linsk P. O. Box 504 Sunnyvale, CA 94088
1	Olin Corporation Badger Army Ammunition Plant ATTN: Jawaharlal Ramnarace Baraboo, WI 53913
2	Olin Corporation New Haven Plant ATTN: Ralph L. Cook David W. Riefler 275 Winchester Avenue New Haven, CT 06504
1	Propulsion Sciences, Inc. ATTN: Vito Agosta P.O. Box 814 Melville, NY 11746
1	Pulsepower Systems, Inc. ATTN: L.C. Elmore 815 American St. San Carlos, CA 94070
2	Rockwell International Corp Rocketdyne Division ATTN: Joseph E. Flanagan, BA 28 Carl L. Oberg, Dept 589-197-SS11 6633 Canoga Ave Canoga Park, CA 91304
1	Rockwell International Corp Rocketdyne Division ATTN: William G. Haymes P.O. Box 548 McGregor, TX 76657
1	Science Applications, Inc. ATTN: Raymond B. Edelman 23146 Cumorah Court Woodland Hills, CA 91364
1	Shock Hydrodynamics, Inc. ATTN: W.H. Anderson 4710-16 Vineland Avenue N. Hollywood, CA 91602
1	Thiokol/Huntsville ATTN: Dick Hessler Redstone Arsenal, AL 35808
1	Thiokol Corporation Huntsville Division ATTN: David A. Flanigan Huntsville, AL 35807

DISTRIBUTION LIST

No. of Copies	Organization
1	Thiokol Corporation Wasatch Division ATTN: John A. Peterson P. O. Box 524 Brigham City, UT 84302
1	TRW, Inc. TRW Systems Group ATTN: A. C. Ellings One Space Park Redondo Beach, CA 90278
1	United Technologies Corporation ATTN: R. H. W. Waesche 400 Main Street East Hartford, CT 06108
1	United Technologies Corporation Chemical Systems Division ATTN: Robert S. Brown 1050 E. Arques Avenue Sunnyvale, CA 94088
1	Universal Propulsion Co. ATTN: H. J. McSpadden P. O. Box 546 Riverside, CA 92502
1	Whittaker Corporation Bermite Division ATTN: L. Bloom 22116 W. Soledad Canyon Road Saugus, CA 90024
1	Battelle Memorial Institute ATTN: Abbott A. Putnam 505 King Avenue Columbus, OH 43201
1	Brigham Young University ATTN: L. Douglas Smoot 673 WIDB Provo, UT 84601
1	California Inst of Technology 204 Karman Laboratory ATTN: Fred E. C. Culick 1201 E. California Street Pasadena, CA 91109
1	California State University School of Engineering ATTN: Frederick H. Reardon 6000 J Street Sacramento, CA 95819
1	Colorado State University ATTN: Charles E. Mitchell Fort Collins, CO 80521
1	Georgia Inst of Technology Georgia Tech Res Inst ATTN: Edward W. Price Atlanta, GA 30332
2	Director Chemical Propulsion Info Agency The Johns Hopkins Univ (APL) ATTN: Mr. T. Christian Johns Hopkins Road Laurel, MD 20810
1	Pennsylvania State University Applied Research Laboratory ATTN: Gerard M. Faeth P. O. Box 30 State College, PA 16801
2	Princeton University Forrestal Campus Library ATTN: Dr. M. Summerfield Dr. L. Caveny P. O. Box 710 Princeton, NJ 08540

DISTRIBUTION LIST

No. of Copies	Organization
1	Purdue University School of Mechanical Engr ATTN: John R. Osborn TSPC Chaffee Hall West Lafayette, IN 47906
1	Purdue University ATTN: James A. Condon Lafayette, IN 47907
1	Seton Hall University Department of Chemistry ATTN: Dr. A. Celiano South Orange, NJ 07079
1	Southwest Research Institute Fire Research Section ATTN: William H. McLain P. O. Drawer 28150 San Antonio, TX 78228
1	University of California, Berkeley Mechanical Engineering Dept ATTN: M. C. Branch Berkeley, CA 94720
1	University of California, San Diego AMES Department ATTN: Forman A. Williams P. O. Box 109 La Jolla, CA 92037
1	University of Delaware ATTN: T. C. Brill Department of Chemistry Newark, DE 19711

No. of Copies	Organization
1	University of Illinois AAE Department ATTN: Herman Krier Transporation Bldg, Rm 105 Urbana, IL 61801
1	University of Massachusetts Dept of Mechanical Engineering ATTN: Karl Jakus Amherst, MA 01002
1	University of Utah Dept of Chemical Engineering ATTN: Alva D. Baer Park Bldg., Room 307 Salt Lake City, UT 84112
1	University of Waterloo Dept of Mechanical Engineering ATTN: Clarke E. Hermance Waterloo, Ontario, Canada

Aberdeen Proving Ground

Marine Corps Ln Ofc
Dir, USAMSAA
Dir, USAMTD
ATTN: Mr. H. Anderson
Mr. W. Rieden
Mr. S. Walton
Cdr, USATECOM
ATTN: DRSTE-FA, Mr. J. Byrne