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THEORETICAL MANUAL AND USERS' GUIDE: LONGITUDINAL-VERTICAL TRAIN ACTION MODEL

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16. Abstract

A mathematical model for simulating the longitudinal-vertical motion of railroad cars in impact situations is described in this document. Development and validation of the model was part of a study concerned with the phenomenon of coupler bypass resulting from impact or squeeze.

The model represents each car as an idealized dynamic system, consisting of springs, masses and dampers and possessing up to 6 degrees of freedom (12 state variables) per car. The degrees of freedom correspond to the longitudinal, vertical and pitching motion of car bodies, lading motion, and truck motion (front and rear separately). The model is capable of representing friction draft gears as well as hydraulic cushioning devices. The model accounts for friction between truck side frame and bolster, possible separation of the truck center plate from the truck bolster and coupler disengagement. A limitation of the model is that, in the absence of more accurate information, the force-deflection relationship of car underframes is represented by linear springs. However, it can be readily modified to represent non-linear force-deflection relationships once those relationships are quantified.

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METRIC CONVERSION FACTORS

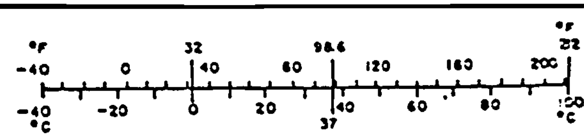
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



METRIC CONVERSION FACTORS

TABLE OF CONTENTS

1. INTRODUCTION

A mathematical model for simulating the (coupled) longitudinal and vertical motion of railroad cars in impact situations is described in this document. The model was developed under contract DOT-OS-40106 for the purpose of studying conditions under which coupler override may occur.

The model is similar to the one developed by Raidt(1)*. A description of Raidt's model was made available to Washington University together with the results of validation studies which included impacts between loaded railroad cars up to 10 mph. Raidt's model was reprogrammed at Washington University and its correlations with experimental data were verified.

The model was then employed to simulate three switchyard accidents, those of East St. Louis [1972], Decatur [1974] and Houston [1974]. The results of this work were presented in a preliminary report(2). Because all switchyard accidents involved impact between loaded hazardous material tank cars and light cars, it became necessary to validate the mathematical model for such impacts. A series of non-destructive tests were conducted at the ramp facility of Miner Enterprises in Chicago early in 1975. On the basis of these tests minor revisions of the mathematical model became necessary. A report, giving detailed account of this work, is available(3). Following revision of the model, close correspondence was established between experimental and analytical results.

At the present, the model provides four options: it can represent car body dynamics only (6 N state variables, N is the number of cars), or it can include longitudinal lading dynamics (8 N state variables), or it can include the longitudinal motion of trucks, without the lading (10 N state variables), or it can add both lading and truck longitudinal degrees of freedom to the car body degrees of freedom (12 N state variables). In addition, friction forces (either viscous or Coulomb friction) can be included in the calculation of truck vertical forces. The model accounts for both vertical and horizontal coupler slacks.

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* Numbers in parentheses indicate references.

A serious limitation of the model is that in the absence of more accurate information, the force-deflection relationship of car underframes is represented by linear springs. It is known, however, that underframes can deform plastically under high buff forces. In the presence of bending moments caused by vertical forces due to dynamic action and eccentricities in the load path caused by vertical coupler misalignment and pitching oscillations, it is established that plastic hinges can form in the underframe of most railroad cars under high buff forces. This can result in plastic buckling. Unfortunately, the subject of plastic buckling and the post-buckling behavior of railroad cars is almost completely unexplored and the mode of buckling cannot be predicted with certainty. Thus the mathematical model does not obviate the need for a great deal of engineering judgement in drawing specific conclusions for any given situation.

The model can be readily modified to accept future information on the actual characteristics of car underframes and couplers when such information becomes available.

The documentation presented herein has been prepared in accordance with "TSC Computer Program Documentation Guidelines", an undated manual issued by the Data Services Division of the Transportation Systems Center. The documentation level is 3, as specified in the manual.

2. PROBLEM DESCRIPTION

2.1 Longitudinal train action model

The car body, lading and trucks are idealized as rigid bodies. The idealized car body dynamic model is shown in Figure 1. Each car has three degrees of freedom: longitudinal X_i, vertical Y_i, and pitching θ_i. Car numbering is from right to left. The right and left trucks are called front and rear trucks respectively.

The lading of each car has one degree of freedom; it can move longitudinally only. The lading model is shown in Figure 2. If lading motion is suppressed, then the lading mass is simply added to the car body mass.

The truck vertical and pitching motions are neglected, however two options are provided for the truck longitudinal motion: the truck may move relative to the car body, or it may be rigidly attached to the car body. The dynamic model for the truck is shown in Figure 3.

2.2 Horizontal coupler force

At both ends of a car body mass, a spring, representing the underframe spring, is connected in series with the draft gear. To account for the hysteresis loop of the draft gear, it is assumed that the draft gear spring rate can drop from a higher spring rate to a lower spring rate, and vice versa, depending on whether the draft gear is unloading or loading. This can be seen in Figure 4, where DK_i is the draft gear spring rate in a loading condition, HL_i is the hysteresis load, DST_i is the draft gear travel.

The combined characteristics of an underframe spring and a draft gear is shown in Figure 5, where UK_i is the underframe spring rate of the i^{th} car. The coupler spring rate can drop from the slope of line O'A' to the slope of line O'B' or B'A', and vice versa, depending on whether the draft gear is unloading or loading.

The coupler spring rates $ES1_i$, $ES2_i$ and $ES3_i$, the loading and unloading spring travels $DS1_i$ and $DS2_i$ can be expressed as

$$ES1_i = DK_i \times UK_i / (DK_i + UK_i) \qquad (1)$$

$$ES2_i = (HL_i/DST_i) \times UK_i \, / \, [(HL_i/DST_i) + UK_i] \qquad (2)$$

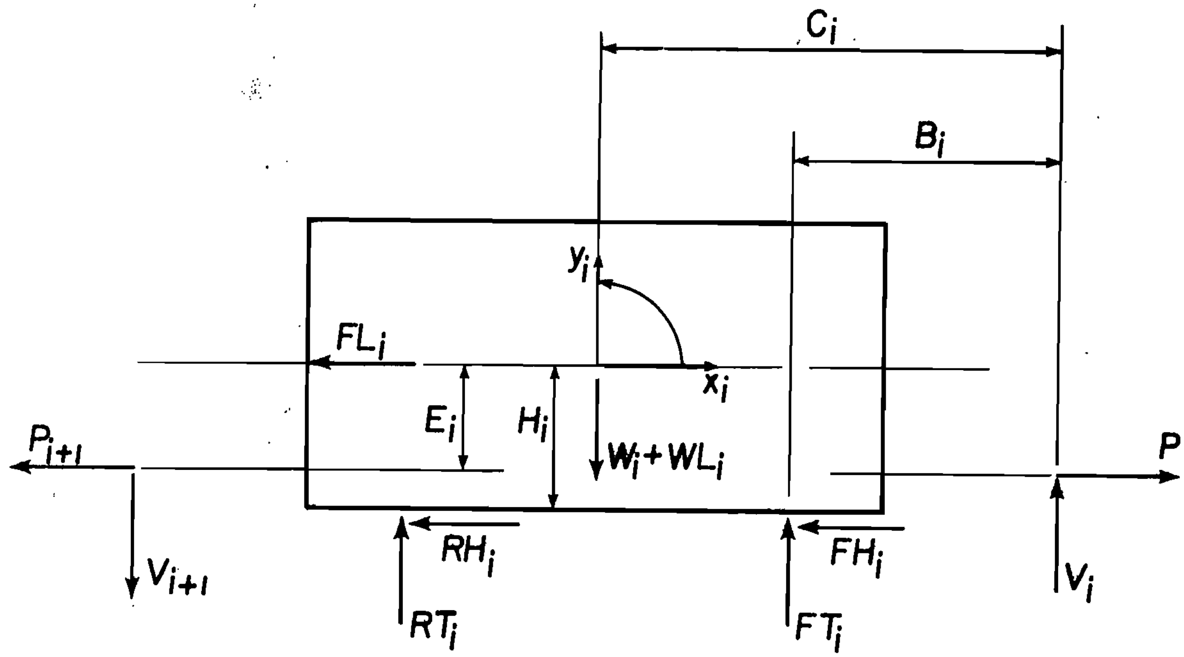

Figure 1 Idealized Car Body

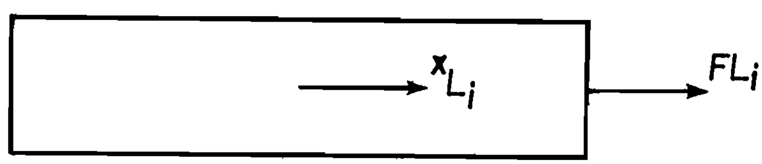

Figure 2 Idealized Lading

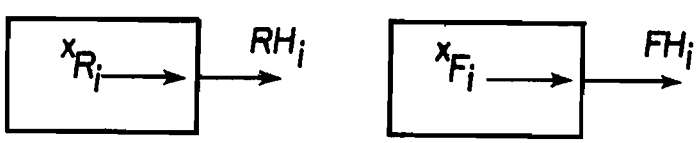

Figure 3 Idealized Trucks

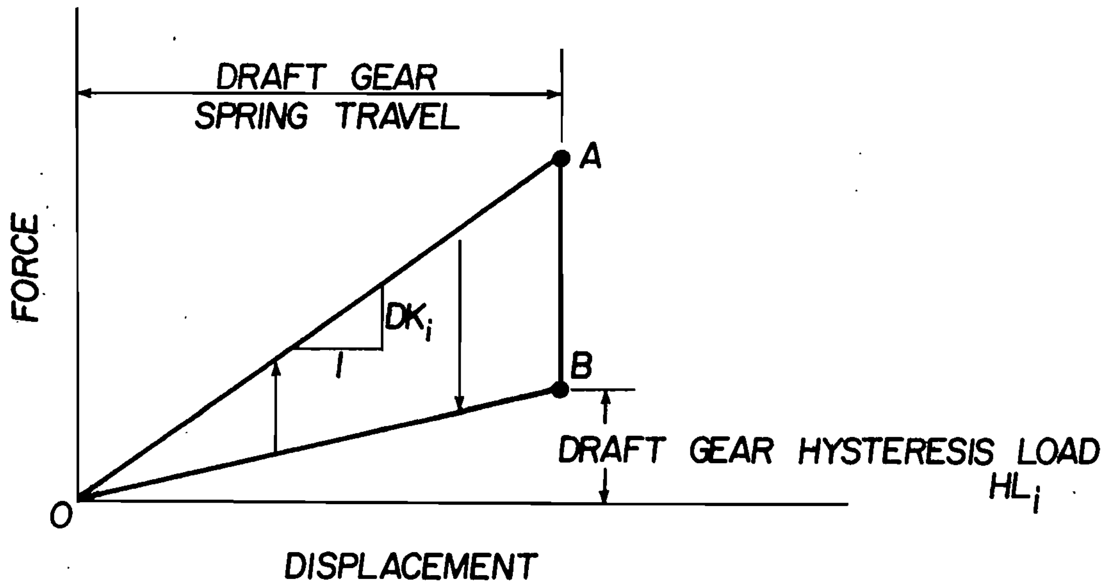

Figure 4 Draft Gear Characteristics

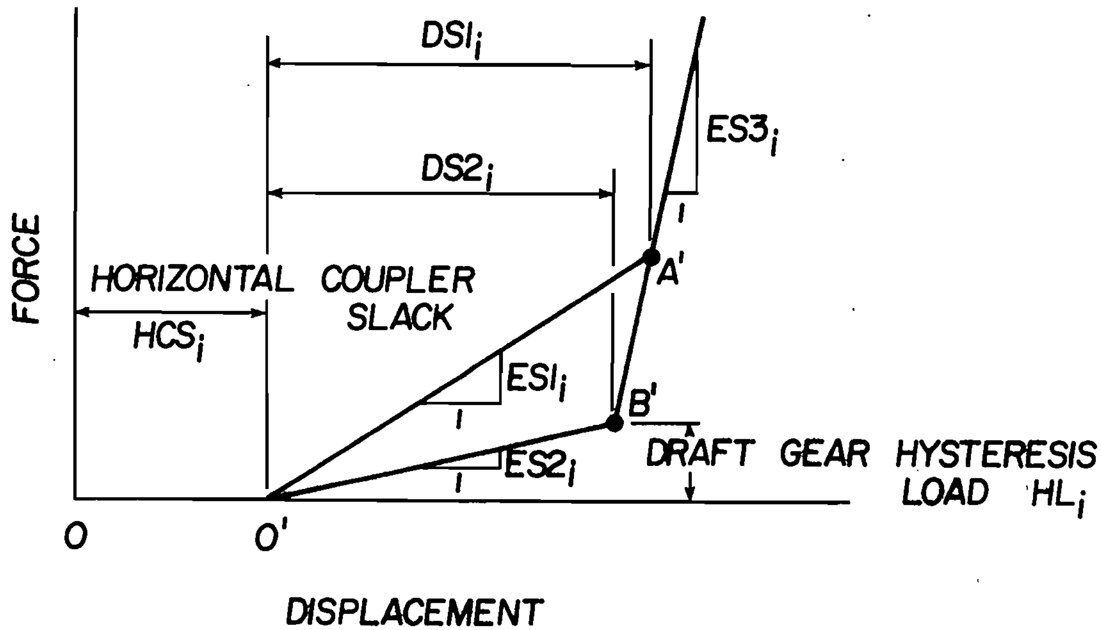

Figure 5 Horizontal Coupler Characteristics

$$ES3_i = UK_i \tag{3}$$

$$DS1_i = DK_i \times DST_i \,/\, ES1_i \tag{4}$$

$$DS2_i = HL_i \,/\, ES2_i \tag{5}$$

The horizontal coupler force is determined by Subroutine HCF.

2.3 Vertical coupler force

In calculating vertical coupler forces, it is assumed that there exists a hypothetical spring rate, representing the elastic properties of the coupler shank, such that the vertical force acting on the coupler is equal to this spring rate multiplied by the coupler vertical displacement. It is assumed also that there is a vertical coupler slack. If the upward displacement of the coupler is smaller than the vertical coupler slack, then the vertical coupler force is zero.

Due to the vertical and pitching motions of two adjacent cars, initally engaged couplers may become disengaged when the offset between the two couplers exceeds the coupler height. The forces which counteract the coupler offset is the friction force acting along the coupler faces, which is proportional to the horizontal coupler force acting through the coupler faces.

The vertical coupler force, the offset between adjacent couplers and whether coupler disengagement occurs are determined by Subroutine CVFS.

2.4 Vertical truck force

In determining the vertical truck forces FT_i, RT_i acting on the i^{th} car, it is assumed that there is a nonlinear spring in the truck-bolster structure. Until the truck spring travel TST_i is exceeded, the truck vertical spring constant TVK_i is used. Once the truck spring has bottomed, the much stiffer bolster spring constant BK_i is used. Coulomb friction or viscous friction can also be included in the calculations.

Due to the fact that the car body is not attached to the truck center plates, the vertical truck forces are always compressive. When the car body lifts off the center plate, there is no vertical truck force acting on the car body.

The vertical truck forces and whether the trucks are separated from the car body are determined by Subroutine TRUCK.

2.5 Lading dynamics

The vertical and pitching motions of the car lading are included in those for the car body itself, in other words, the lading does not have independent degrees of freedom in vertical and pitching motions. However, the lading has an independent longitudinal degree of freedom.

The lading dynamic model is represented by its mass M_{L_i}, the spring between the lading and the car body with a constant rate RLK_i, and the friction coefficient RLF_i.

It is assumed that if the resultant force of the lading inertia force and the spring force acting on the lading by the car body is less than the maximum available friction force between the lading and the body, then the relative motion is zero.

The lading motion and forces are determined by Subroutine HFORCE. If the lading longitudinal degree of freedom is not wanted, then the lading mass can be simply added to the car body mass.

2.6 Horizontal truck force

Either both trucks may move together with the car body, or each truck may have one degree of freedom representing its longitudinal motion. In the former case, the horizontal truck force acting on the car body is simply equal to the truck inertia force; in the latter case, it is assumed that there exists a linear spring represented by the rate THK_i and a friction coefficient THF_i between the truck and the car body.

The horizontal truck force is determined by Subroutine HFORCE. Due to the fact that the vertical truck forces are, in general different, the front and rear horizontal truck forces are calculated by calling Subroutine HFORCE separately.

3. METHOD OF SOLUTION

3.1 Mathematical equations

The equations of motion for the longitudinal train action models as shown in Figures 1, 2 and 3 are:

Car:

$$M_i \ddot{X}_i = P_i - P_{i+1} - FL_i - FH_i - RH_i \quad (6)$$

$$(M_i + M_{L_i}) \ddot{Y}_i = V_i - V_{i+1} - W_i - WL_i + FT_i + RT_i \quad (7)$$

$$\begin{aligned} I_{b_i} \ddot{\theta}_i = {} & P_i (E_i - C_i \theta_i) - P_{i+1} (E_i + C_i \theta_i) \\ & + V_i (C_i + E_i \theta_i) + V_{i+1} (C_i - E_i \theta_i) \\ & + FT_i (B_i + H_i \theta_i) - RT_i (B_i - H_i \theta_i) \\ & - FH_i (H_i - B_i \theta_i) - RH_i (H_i + B_i \theta_i) \end{aligned} \quad (8)$$

Lading:

$$M_{L_i} \ddot{X}_{L_i} = FL_i \quad (9)$$

Trucks:

$$M_{T_i} \ddot{X}_{F_i} = FH_i \quad (10)$$

$$M_{T_i} \ddot{X}_{R_i} = RH_i \quad (11)$$

In the program, the equations of motion are expressed in forms of state variables.

3.2 Functional flow chart

Subroutine RKGSM which applies a fourth order Runge-Kutta numerical method, is used to solve the differential equations (6) to (11).

Using the given initial state values, Subroutines HCF, CVFS, TRUCK, HFORCE are called to determine horizontal coupler forces, vertical coupler forces, vertical truck forces, lading and horizontal truck forces. Then Subroutine RKGSM is called to calculate the new state variables.

After new state variables were obtained, Subroutines HCF, CVFS, TRUCK, HFORCE are again called to calculate new forces and Subroutine RKGSM is called to find new state variables until the final state variables are obtained. The functional flow chart is shown in Figure 6.

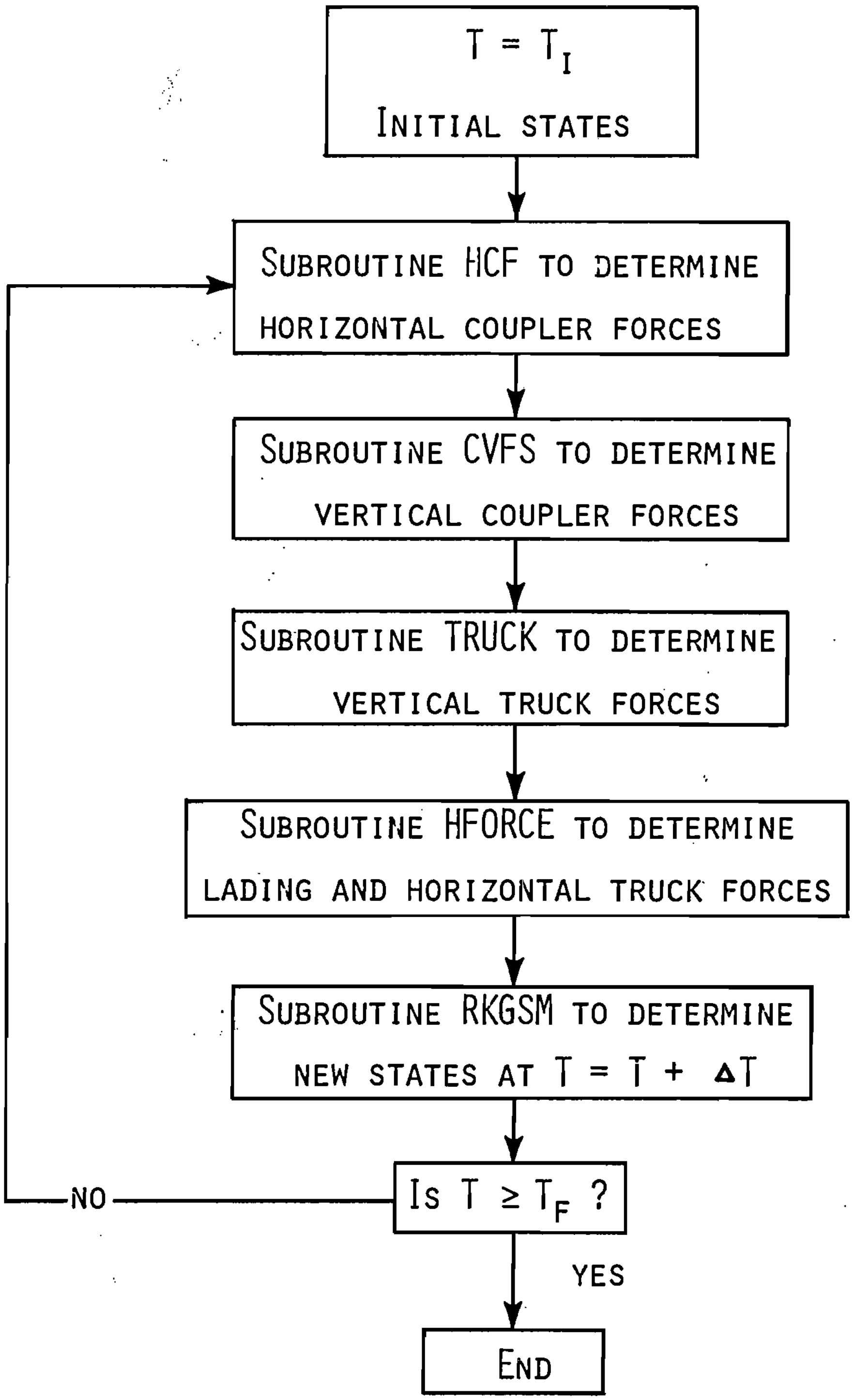

Figure 6 Functional Flow Chart

4. PROGRAM DESCRIPTION

4.1 Operating environment

This program has been developed on an IBM Model 360/65 running under OS-MFT Release 21.8 and HASP 3.1. It uses standard IBM FORTRAN Library I/O routines and the ABS Function. No tapes and disks other than the SPOOL disks by HASP are used. The memory requirements depend on the parameter NSIZE (see the following section).

4.2 Program specifications

The program structure is shown in Figure 7. The figure can be used to overlay the program. The MAIN program sets the maximum size of the arrays, NSIZE. If not enough words are available in the array A used to dynamically allocate all other arrays whose size is dependent on the input parameters, only two statements need to be changed, and only the MAIN program needs to be recompiled.

```
DIMENSION A(nnnn)
NSIZE  =  nnnn
```

where nnnn is replaced by a number representing the number of words (or doublewords in the double precision version) needed for the variable arrays.

nnnn must be at least (110+20*IJK)*NC+2, where NC is the number of cars and IJK is a parameter indicating which degree of freedom option is being investigated.

The I/O device assignments are:

Unit 5	card reader
Unit 6	printer
Unit 7	punch

To change any of these, see ICRD, IPRT, IPUN in Subroutine MAINO.

4.3 Subprograms

Subroutine MAINO is called by MAIN to set up arrays. Subroutine MAIN1 is called by MAINO. It calls Subroutine READEM to read in the input

For better understanding of the subprogram, the user may refer to the IBM scientific subroutine package and reference (4).

4.4 Source listing

The source listing of the entire program are provided in Appendix A.

4.5 Detailed flow charts

The flow charts of MAIN, MAIN0, MAIN1, FCT, OUTP, HCF, TRUCK, CVFS and HFORCE are provided in Appendix B.

data, it calls Subroutines RITEM1, RITEM2 to print out the input data, it sets initial conditions and calls Subroutine RKGSM to solve the system equations, and it calls the plotting subroutine if supplied by the user.

Subroutines FCT and OUTP are called by RKGSM. FCT is used to calculate the derivates of the system state variables, and OUTP is used to print out the solutions. OUTP stores the data to be plotted if a plotting subroutine is supplied by users in Subroutine MAIN1.

Subroutines HCF, TRUCK, CVFS and HFORCE are called by FCT, their functions are shown in Figure 6.

Subroutine RKGSM is a modified program of RKGS in IBM System/360 Scientific Subroutine Package (360A-CM-03X), Version III. It employs a fourth-order Runge-Kutta method for the solution of initial-value problems.

The main parameters used in RKGS and RKGSM are described in the following:

PRMT(1)	Lower bound of the interval (input)
PRMT(2)	Upper bound of the interval (input)
PRMT(3)	Initial increment of the independent variable (input)
PRMT(4)	Upper error bound (input)
PRMT(5)	Not input parameter. Subroutine RKGS (or RKGSM) initializes PRMT(5) = 0. If the user wants to terminate the subroutine at any output point, he has to change PRMT(5) to non-zero by means of Subroutine OUTP.
Y	Input vector of initial values (destroyed). Later on Y is the resulting vector of dependent variables computed at intermediate points T.
DERY	Input vector of error weights (destroyed). The sum of its components must be equal to 1. Later on DERY is the vector of derivatives which belong to Y at a point T.
NDIM	An input value, which specifies the number of the state variables of the system.
IHLF	An output value, which specifies the number of bisections of the initial increment
AUX	An auxiliary storage array with 8 rows and NDIM columns

For better understanding of the subprogram, the user may refer to the IBM scientific subroutine package and reference (4).

4.4 Source listing

The source listing of the entire program are provided in Appendix A.

4.5 Detailed flow charts

The flow charts of MAIN, MAIN0, MAIN1, FCT, OUTP, HCF, TRUCK, CVFS and HFORCE are provided in Appendix B.

5. PROGRAM USE

5.1 Input

The first input card is for NC, IM, IC, IJK, IT, IPLOT with a format (6I5), where

NC	Number of total cars
IM	Number of the first impacted car
IC	IC = 0, couplers not engaged at the impacted end
	IC ≠ 0, couplers engaged at the impacted end
IJK	IJK = 1, car body degrees of freedom only
	IJK = 2, lading degrees of freedom added
	IJK = 3, horizontal truck degrees of freedom added
	IJK = 4, both lading and horizontal truck degrees of freedom added
IT	IT = 1, Coulomb friction in truck vertical force
	IT = 2, viscous friction in truck vertical force
IPLOT	IPLOT = 0, no plotting subprogram supplied by the user
	IPLOT ≠ 0, a plotting subprogram is supplied by the user

The second input card is for SPEED, (PRMT(I), I = 1, 4), ST1, ST2 with a format (8F10.0), where

SPEED	Impacting speed in miles per hour
PRMT	Defined in Section 4.3
ST1	Time step to print output
ST2	Time step to plot output

Then car parameters W, WL, WT, C, B, H, E, RMI, UK, DK, HL, DST, HCS, TVK, BK, TST, TF, CVK, CVF, VCS, RLK, RLF, THK, THF are read with a format (8F10.0). The definition of these parameters is given in Chapter 7. If IJK = 1, RLK, RLF, THK, THF are omitted, if IJK = 2, THK, THF are omitted, if IJK = 3, RLK, RLF are omitted.

5.2 Output

The first set of output data contains NC, NDIM, ICRD, IPRT, IPUN with a format (I4, I6/3I2).

The second set of output data contains NEEDED, NSIZE with a format (2I6).

The third set of output data contains NC, IM, SPEED with a format (2I3, F7.2).

The fourth set of output data contains IC with a format (I3).

The fifth set of output data contains IJK, IT, IPLOT with a format (3I3).

The sixth set of output data contains (PRMT(I), I = 1,4) with a format (4F7.3).

The seventh set of output data contains ST1, ST2 with a format (2F7.3).

Then car number (I, I = 1, NC) with a format (10I10) and the car input parameters W, WL, WT, C, B, H, E, RM1, UK, DK, HL, DST, HCS, TVK, BK, TST, TF, CVK, CVF, VCS, RLK, RLF, THK, THF with a format (10F10.3) are printed. Same as for the input data, the printing of RLK, RLF, THK, THF depends on the value of IJK.

Next the car number (I, I = 1, NC) with a format (10I10) and the calculated car parameters YO, ES1, ES2, DS1, DS2 with a format (10F10.3) are printed.

The solutions are printed in the following sequences:

First, T, IHLF with a format (F10.4, I2), then all state variables with a format (6F12.5). The car body state variables printed first:

$$\begin{array}{cccccc} X(1), & \dot{X}(1), & Y(1), & \dot{Y}(1), & \theta(1), & \dot{\theta}(1) \\ X(2), & \dot{X}(2), & Y(2), & \dot{Y}(2), & \theta(2), & \dot{\theta}(2) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ X(NC), & \dot{X}(NC), & Y(NC), & \dot{Y}(NC), & \theta(NC), & \dot{\theta}(NC) \end{array}$$

If IJK = 2, the car body state variables are followed by the lading state variables:

$$X_L(1),\ \dot{X}_L(1),\ X_L(2),\ \dot{X}_L(2),\ X_L(3),\ \dot{X}_L(3),$$

$$X_L(4),\ \dot{X}_L(4),\ \ldots\ \ \ldots$$

If IJK = 3, the car body state variables are followed by the front and rear truck state variables:

$X_F(1)$, $\dot{X}_F(1)$, $X_R(1)$, $\dot{X}_R(1)$, $X_F(2)$, $\dot{X}_F(2)$,

$X_R(2)$, $\dot{X}_R(2)$, $X_F(3)$, $\dot{X}_F(3)$, ...

If IJK = 4, the car body state variables are followed by the lading and truck state variables:

$$
\begin{array}{llllll}
X_L(1), & \dot{X}_L(1), & X_F(1), & \dot{X}_F(1), & X_R(1), & \dot{X}_R(1) \\
X_L(2), & \dot{X}_L(2), & X_F(2), & \dot{X}_F(2), & X_R(2), & \dot{X}_R(2) \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
X_L(NC), & \dot{X}_L(NC), & X_F(NC), & \dot{X}_F(NC), & X_R(NC), & \dot{X}_R(NC)
\end{array}
$$

The sequence of the state variables in subroutine MAIN1, where their initial values are set is the same as those described above.

Following the state variables, I, P(I+1), X1(I), X2(I), XC(I), V(I+1), FL(I), FH(I), RH(I) are printed with the format (I2, 8F12.5) for I = 1,NC.

Then I, FT(I), RT(I), FD(I), RD(I), SP(I), IFT(I), IRT(I), ICD(I) are printed with the format (I2, 5F12.5, 3I2) for I = 1, NC.

5.3 Editing and diagnostics

IHLF is an output value, which specifies the number of bisections of the initial increment (PRMT (3)). If IHLF becomes greater than 10, Subroutine RKGSM returns with error message IHLF = 11 into Subroutine MAIN1. Error message IHLF = 12 or IHLF = 13 appears in case PRMT(3) = 0 or in case SIGN (PRMT(3)). NE.SIGN (PRMT(2) - PRMT(1)) respectively.

5.4 Sample problem

To illustrate the application of the program, the following example is presented. Five loaded tank cars, moving with a constant speed of 12 mph, strike a standing box car. The couplers at the impacted end are assumed not engaged after the impact (IC = 0). The lading degrees of freedom are considered (IJK = 2). The Coulomb friction force is assumed to be zero in calculating the truck vertical forces (IT = 1).

The program was run for PRMT(1) = 0.0, PRMT(2) = .040, PRMT(3) = .002. It actually used 64 K bytes (with NSIZE = 1000), and took 2.82 seconds when compiled using the IBM FORTRAN IV H (OPT = 2) Compiler. The input data deck is shown in Figure 8, and the output data are shown in Figure 9. Some computer plotted results with PRMT(1) = 0.0, PRMT(2) = 0.800, PRMT(3) = .002, ST2 = .008 are shown in Figure 10.

```
      6       6       0       2       1       0
   12.0     0.0     .04     .C02    0.1     .CC4     .CC8
   85.5     85.5    85.5    85.5    85.5    29.C
   132.9    132.9   132.9   132.9   132.9   0.
   10.      10.     10.     1C.     1C.     7.5
   440.     440.    440.    440.    44C.    255.
   354.     354.    354.    354.    354.    171.
   50.      50.     50.     50.     5C.     5C.
   40.      40.     40.     4C.     4C.     4C.
   31000.   31000.  31COC.  310CO.  31CCC.  1370.
   800.     800.    800.    800.    8C0.    15CC.
   86.4     86.4    86.4    86.4    86.4    86.4
   40.      40.     40.     4C.     4C.     4C.
   2.5      2.5     2.5     2.5     2.5     2.5
   0.       0.      0.      0.      0.      0.
   90.      90.     90.     9C.     9C.     6C.
   1500.    1500.   1500.   1500.   15CC.   15CC.
   2.5      2.5     2.5     2.5     2.5     2.5
   0.0      0.0     0.0     0.0     C.C     0.C
   75.0     75.0    75.0    75.0    75.C    5C.C
   0.2      0.2     0.2     0.2     0.2     0.2
   1.2      1.2     1.2     1.2     1.2     1.2
  250.0    250.0   250.0   250.0   250.C    0.0
  0.01     0.01    0.01    0.01    C.C1     0.C
```

Figure 8 Input data deck for the sample problem

```
NC=   6, NDIM=    48
CARD READER IS UNIT  5, PRINTER IS UNIT  6, PUNCH IS UNIT  7
   902 WORDS NEEDED,  1000 WORDS AVAILABLE.

         TOTAL NUMBER OF CARS =   6   THE IMPACTED CAR NUMBER =   6   THE IMPACTING SPEED =   12.00MPH

         IC=  0  IMPACTED ENDS NOT COUPLED

         IJK =   2            IT =   1            IPLOT =   0

         INITIAL TIME =  0.0       FINAL TIME =   0.040     TIME STEP =   0.002     ACCURACY CONTROL PARAMETER =   0.100

         PRINT STEP =   0.004     PLOTTING STEP =   0.008
```

CAR NUMBER	1	2	3	4	5	6
CAR WEIGHT	85.500	85.500	85.500	85.500	85.500	29.000
LADING WEIGHT	132.900	132.900	132.900	132.900	132.900	0.0
EACH TRUCK WEIGHT	10.000	10.000	10.000	10.000	10.000	7.500
HALF DIST. C.P.F.	440.000	440.000	440.000	440.000	440.000	255.000
HALF DIST. T.C.	354.000	354.000	354.000	354.000	354.000	171.000
HEIGHT C.G. TO PLATE	50.000	50.000	50.000	50.000	50.000	50.000
HEIGHT COUPLER TO C.G.	40.000	40.000	40.000	40.000	40.000	40.000
MASS MOMENT OF INERTIA	31000.000	31000.000	31000.000	31000.000	31000.000	1370.000
UNDERFRAME SP. CONST	800.000	800.000	800.000	800.000	800.000	1500.000
DRAFT GEAR SP. CONST	86.400	86.400	86.400	86.400	86.400	86.400
DRAFT GEAR HYST. LOAD	40.000	40.000	40.000	40.000	40.000	40.000
DRAFT GEAR SP. TRAVEL	2.500	2.500	2.500	2.500	2.500	2.500
HORIZONTAL COUPLER SLACK	0.0	0.0	0.0	0.0	0.0	0.0
TRUCK VERTICAL SP. CONST	90.000	90.000	90.000	90.000	90.000	60.000
BOLSTER SP. CONST	1500.000	1500.000	1500.000	1500.000	1500.000	1500.000
TRUCK SP. TRAVEL	2.500	2.500	2.500	2.500	2.500	2.500
TRUCK VERTICAL FRICTION	0.0	0.0	0.0	0.0	0.0	0.0
COUPLER VERT. SP. CONST	75.000	75.000	75.000	75.000	75.000	50.000
COUPLER VERT. FRIC. COEFF	0.200	0.200	0.200	0.200	0.200	0.200
VERTICAL COUPLER SLACK	1.200	1.200	1.200	1.200	1.200	1.200
LADING SP. CONST	250.000	250.000	250.000	250.000	250.000	0.0
LADING FRICTION COEFF	0.010	0.010	0.010	0.010	0.010	0.0

CAR NUMBER	1	2	3	4	5	6
CAR INITIAL VERT. DISP.	-1.213	-1.213	-1.213	-1.213	-1.213	-0.242

COMBINED LOADING SP. CONST	77.978	77.978	77.978	77.978	77.978	81.694
COMBINED UNLOAD. SP. CONST	15.686	15.686	15.686	15.686	15.686	15.831
LOADING SPRING TRAVEL	2.770	2.770	2.770	2.770	2.770	2.644
UNLOADING SPRING TRAVEL	2.550	2.550	2.550	2.550	2.550	2.527

Figure 9   Output for the sample problem

```
T =     0.0          IHLF =   0
          CAR
                                  0.0      -211.19989      0.0          0.0          0.0          0.0
                                  0.0      -211.19989      0.0          0.0          0.0          0.0
                                  0.0      -211.19989      0.0          0.0          0.0          0.0
                                  0.0      -211.19989      0.0          0.0          0.0          0.0
                                  0.0      -211.19989      0.0          0.0          0.0          0.0
                                  0.0         0.0          0.0          0.0          0.0          0.0
          LADING
                                  0.0      -211.19989      0.0      -211.19989       0.0      -211.19989
                                  0.0      -211.19989      0.0      -211.19989       0.0         0.0
     I      P(I+1)      X1(I)      X2(I)      XC(I)      V(I+1)      FL(I)      FH(I)      RH(I)
     1       0.0         0.0        0.0        0.0        0.0         0.0        0.0        0.0
     2       0.0         0.0        0.0        0.0        0.0         0.0        0.0        0.0
     3       0.0         0.0        0.0        0.0        0.0         0.0        0.0        0.0
     4       0.0         0.0        0.0        0.0        0.0         0.0        0.0        0.0
     5       0.0         0.0        0.0        0.0        0.0         0.0        0.0        0.0
     6       0.0         0.0        0.0        0.0        0.0         0.0        0.0        0.0
     I      FT(I)       RT(I)      F.C.D.     R.C.D.      SP(I)      IFT(I)     IRT(I)     ICC(I)
     1    109.19998   109.19998     0.0        0.0        0.0          0          0          0
     2    109.19998   109.19998     0.0        0.0        0.0          0          0          0
     3    109.19998   109.19998     0.0        0.0        0.0          0          0          0
     4    109.19998   109.19998     0.0        0.0        0.0          0          0          0
     5    109.19998   109.19998     0.0        0.0       -0.97167      0          0          0
     6     14.50000    14.50000     0.0        0.0        0.0          0          0          0
T =     0.0040       IHLF =   0
          CAR
                              -0.84480   -211.19989    -0.00000     -0.00000      0.0          0.0
                              -0.84480   -211.19989    -0.00000     -0.00000      0.0          0.0
                              -0.84480   -211.19989    -0.00000     -0.00000     -0.00000     -0.00000
                              -0.84480   -211.19789    -0.00000     -0.00000      0.00000      0.00000
                              -0.84450   -210.96817    -0.00000     -0.00000      0.00000      0.00007
                              -0.00074     -0.58143    -0.00000     -0.00000     -0.00000     -0.00110
          LADING
                              -0.84480   -211.19989    -0.84480   -211.19989     -0.84480   -211.19989
                              -0.84480   -211.20111    -0.84477   -211.18623     -0.00074     -0.58143
     I      P(I+1)      X1(I)      X2(I)      XC(I)      V(I+1)      FL(I)      FH(I)      RH(I)
     1       0.0         0.0        0.0        0.0        0.0         0.0        0.0        0.0
     2       0.00000     0.00000    0.00000    0.00000    0.0         0.0        0.0        0.0
     3      -0.00000    -0.00000   -0.00000   -0.00000    0.0         0.00001    0.00000    0.00000
     4      -0.01173    -0.00015   -0.00015   -0.00030    0.0         1.32898    0.15737    0.15737
     5     -33.66084    -0.43167   -0.41203   -0.84370    0.0         1.39740    3.25067    3.25067
     6       0.0         0.0        0.0        0.0        0.0         0.0       -6.74171   -6.74171
     I      FT(I)       RT(I)      F.C.D.     R.C.D.      SP(I)      IFT(I)     IRT(I)     ICC(I)
     1    109.19998   109.19998   -0.00000   -0.00000     0.0          0          0          0
     2    109.19998   109.19998   -0.00000   -0.00000     0.0          0          0          0
```

Figure 9 Output for the sample problem (continued)

```
 3      109.19998   109.19998   -0.00000   -0.00000    0.0          0          0          0
 4      109.19998   109.19998    0.00000   -0.00000    0.0          0          0          0
 5      109.19705   109.20280    0.00003   -0.00003   -0.97167      0          0          0
 6       14.51401    14.48598   -0.00023    0.00023    0.0          0          0          0

T =     0.0080     IHLF =   0
         CAR
                          -1.68959  -211.19989   -0.00000   -0.00000    0.0        0.0
                          -1.68959  -211.19989   -0.00000   -0.00000   -0.00000    0.00000
                          -1.68959  -211.19788   -0.00000   -0.00000   -0.00000   -0.00000
                          -1.68960  -211.19823   -0.00000   -0.00000   -0.00000   -0.00000
                          -1.68710  -210.25148   -0.00000   -0.00000    0.00000    0.00027
                          -0.00611    -2.32708   -0.00000   -0.00000   -0.00001   -0.00435
         LADING
                          -1.68959  -211.19989   -1.68959  -211.19989   -1.68959  -211.20111
                          -1.68959  -211.20105   -1.68948  -211.16753   -0.00611    -2.32708

 I        P(I+1)       X1(I)       X2(I)       XC(I)      V(I+1)       FL(I)       FH(I)       RH(I)
 1        0.00000     0.00000     0.00000     0.00000     0.0         0.00000     0.00000     0.00000
 2        0.00000     0.00000     0.00000     0.00000     0.0         0.00000     0.00000     0.00000
 3        0.00026     0.00000     0.00000     0.00001     0.0         1.32900     0.15549     0.15549
 4       -0.09854    -0.00126    -0.00126    -0.00253     0.0         1.32638    -0.18987    -0.18987
 5      -67.04620    -0.85981    -0.82070    -1.68050     0.0         1.92362     6.35075     6.35075
 6        0.0         0.0         0.0         0.0         0.0         0.0       -12.42769   -12.42769

 I        FT(I)        RT(I)      F.C.D.      R.C.D.      SP(I)      IFT(I)      IRT(I)      ICD(I)
 1      109.19998   109.19998   -0.00000   -0.00000    0.0          0          0          0
 2      109.19998   109.19998   -0.00000   -0.00000    0.0          0          0          0
 3      109.19998   109.19998   -0.00000   -0.00000    0.0          0          0          0
 4      109.19998   109.19989   -0.00000    0.00000    0.0          0          0          0
 5      109.17706   109.22281    0.00025   -0.00025   -0.97167      0          0          0
 6       14.61707    14.38292   -0.00195    0.00195    0.0          0          0          0

T =     0.0120     IHLF =   0
         CAR
                          -2.53439  -211.19989   -0.00000   -0.00000   -0.00000    0.00000
                          -2.53439  -211.19789   -0.00000   -0.00000   -0.00000   -0.00000
                          -2.53440  -211.19888   -0.00000   -0.00000   -0.00000   -0.00000
                          -2.53440  -211.19514   -0.00000   -0.00000   -0.00000    0.00000
                          -2.52589  -209.06584   -0.00000   -0.00000    0.00000    0.00060
                          -0.02080    -5.23660   -0.00000   -0.00000   -0.00004   -0.00965
         LADING
                          -2.53439  -211.19989   -2.53439  -211.20111   -2.53439  -211.20105
                          -2.53438  -211.20103   -2.53409  -211.13774   -0.02080    -5.23660

 I        P(I+1)       X1(I)       X2(I)       XC(I)      V(I+1)       FL(I)       FH(I)       RH(I)
 1        0.00000     0.00000     0.00000     0.00000     0.0         0.00000     0.00000     0.00000
 2        0.00030     0.00000     0.00000     0.00001     0.0         1.32900     0.15548     0.15548
 3        0.00001     0.00000     0.00000     0.00000     0.0         1.32638    -0.20020    -0.20020
 4       -0.33550    -0.00430    -0.00430    -0.00860     0.0         1.32518    -0.16647    -0.16647
 5      -99.87866    -1.28085    -1.22259    -2.50344     0.0         3.37988     9.29142     9.29142
 6        0.0         0.0         0.0         0.0         0.0         0.0       -18.00606   -18.00606
```

Figure 9   Output for the sample problem (continued)

I	FT(I)	RT(I)	F.C.D.	R.C.D.	SP(I)	IFT(I)	IRT(I)	ICC(I)
1	109.19998	109.19998	-0.00000	-0.00000	0.0	0	0	0
2	109.19998	109.19998	-0.00000	-0.00000	0.0	0	0	0
3	109.19998	109.19989	-0.00000	0.00000	0.0	0	0	0
4	109.19998	109.19989	-0.00000	0.00000	0.0	0	0	0
5	109.12332	109.27654	0.00085	-0.00085	-0.97167	0	0	0
6	14.89629	14.10369	-0.00661	0.00661	0.0	0	0	0

T = 0.0160 IHLF = 0

CAR

-3.37918	-211.19788	-0.00000	-0.00000	-0.00000	-0.00000
-3.37919	-211.19890	-0.00000	-0.00000	-0.00000	-0.00000
-3.37920	-211.19873	-0.00000	-0.00000	-0.00000	-0.00000
-3.37917	-211.18701	-0.00000	-0.00000	0.00000	0.00000
-3.35904	-207.44104	-0.00000	-0.00000	0.00001	0.00105
-0.04942	-9.28608	-0.00000	-0.00000	-0.00009	-0.01672

LADING

-3.37918	-211.20111	-3.37918	-211.20105	-3.37918	-211.20103
-3.37918	-211.20102	-3.37854	-211.08348	-0.04942	-9.28608

I	P(I+1)	X1(I)	X2(I)	XC(I)	V(I+1)	FL(I)	FH(I)	RH(I)
1	0.00034	0.00000	0.00000	0.00001	0.0	1.32900	0.15547	0.15547
2	0.00005	0.00000	0.00000	0.00001	0.0	1.32614	-0.20018	-0.20018
3	-0.00105	-0.00001	-0.00001	-0.00003	0.0	1.32375	-0.19997	-0.19997
4	-0.79362	-0.01018	-0.01018	-0.02036	0.0	1.32948	-0.12220	-0.12220
5	-131.88853	-1.69135	-1.61441	-3.30577	0.0	6.20347	11.99915	11.99915
6	0.0	0.0	0.0	0.0	0.0	0.0	-23.43620	-23.43620

I	FT(I)	RT(I)	F.C.D.	R.C.D.	SP(I)	IFT(I)	IRT(I)	ICC(I)
1	109.19998	109.19998	-0.00000	-0.00000	0.0	0	0	0
2	109.19998	109.19989	-0.00000	0.00000	0.0	0	0	0
3	109.20006	109.19980	-0.00000	0.00000	0.0	0	0	0
4	109.19980	109.20006	0.00000	-0.00000	0.0	0	0	0
5	109.01999	109.37996	0.00200	-0.00200	-0.97167	0	0	0
6	15.43037	13.56962	-0.01551	0.01551	0.0	0	0	0

T = 0.0200 IHLF = 0

CAR

-4.22399	-211.19890	-0.00000	-0.00000	-0.00000	-0.00000
-4.22400	-211.19875	-0.00000	-0.00000	-0.00000	-0.00000
-4.22400	-211.19852	-0.00000	-0.00000	-0.00000	-0.00000
-4.22393	-211.18613	-0.00000	-0.00000	0.00000	0.00001
-4.18489	-205.41774	-0.00000	-0.00000	0.00001	0.00161
-0.09647	-14.44227	-0.00000	-0.00000	-0.00017	-0.02522

LADING

-4.22398	-211.20105	-4.22397	-211.20105	-4.22397	-211.20105
-4.22395	-211.18953	-4.22270	-210.98651	-0.09647	-14.44227

I	P(I+1)	X1(I)	X2(I)	XC(I)	V(I+1)	FL(I)	FH(I)	RH(I)
1	0.00034	0.00000	0.00000	0.00001	0.0	1.32638	-0.20037	-0.20037
2	0.00005	0.00000	0.00000	0.00001	0.0	1.32352	-0.20004	-0.20004
3	-0.00306	-0.00004	-0.00004	-0.00008	0.0	1.32113	-0.19932	-0.19932
4	-1.53911	-0.01974	-0.01974	-0.03948	0.0	1.33401	0.35063	0.35063

Figure 9 Output for the sample problem (continued)

```
5     -162.81834    -2.08800    -1.99302    -4.08102     0.0        10.78134    14.40727    14.40727
6        0.0         0.0         0.0         C.0         0.0         0.0       -28.67462   -28.67462

I      FT(I)        RT(I)      F.C.D.      R.C.D.       SP(I)      IFT(I)      IRT(I)      ICC(I)
1     109.19998    109.19989   -0.CCC00     0.0C000     0.C         0           0           0
2     109.20006    109.19980   -0.CCC00     0.CCC00     0.0         0           0           0
3     109.20015    109.19972   -0.CCC00     0.0CCCC     0.0         0           0           0
4     109.19911    109.20074    0.CCC01    -0.C0C01     0.0         0           0           0
5     108.85193    109.54793    0.00387    -0.C0387    -0.97167     0           0           0
6      16.28548     12.71451   -0.02976     0.02976     0.0         0           0           0

T =     0.0240      IHLF =    0
         CAR
                            -5.06879   -211.19876   -0.00000    -C.C0000    -0.CC000    -0.00000
                            -5.06880   -211.19859   -0.00000    -0.CC000    -0.0C000    -0.CCC00
                            -5.06880   -211.19824   -C.CCCC0    -0.C0000    -0.0C000    -0.00000
                            -5.06865   -211.17413   -0.00000    -0.C0000     0.C0000     0.00002
                            -5.00192   -203.04640   -C.00000    -C.CC000     0.00002     0.00228
                            -0.16629    -2C.66307   -0.CCCCC    -0.C0000    -0.00029    -0.03474
         LADING
                            -5.06877   -211.20103   -5.06877   -211.20107   -5.06876   -211.20110
                            -5.06868   -211.17799   -5.06634   -210.82451   -0.16629    -20.66307

I      P(I+1)       X1(I)       X2(I)       XC(I)       V(I+1)      FL(I)       FH(I)       RH(I)
1       0.00007     0.00000     0.C0C00     0.CCC01     0.C         1.32375    -0.20010    -0.20010
2       0.00003     0.00000     0.C0C00     0.C0000     0.0         1.32089    -0.19982    -0.19982
3      -0.00611    -0.C0008    -0.0CCC8    -0.CCC16     0.0         1.31922    -0.19894    -0.19894
4      -2.63072    -0.03374    -C.C3374    -0.06747     0.0         1.33639     0.12995     0.12995
5    -192.42665    -2.46770    -2.35544    -4.82314     0.0        17.43393    16.45686    16.45686
6       0.0         0.0         0.C         0.0         0.0         0.0       -33.68057   -33.68057

I      FT(I)        RT(I)      F.C.D.      R.C.D.       SP(I)      IFT(I)      IRT(I)      ICC(I)
1     109.20006    109.19980   -0.C0C00     0.CC000     0.0         0           0           0
2     109.20015    109.19972   -0.CCC00     C.0C000     0.0         0           0           0
3     109.20015    109.19972   -0.CCCC0     0.00CCC     0.0         0           0           0
4     109.19774    109.20212    0.CCC02    -0.CCC02     0.0         0           0           0
5     108.60535    109.79453    0.C0661    -0.C0661    -0.97167     0           0           0
6      17.51202     11.48796   -0.C5C20     0.05020     0.0         0           0           0

T =     0.0280      IHLF =    0
         CAR
                            -5.91359   -211.19859   -0.C00C0    -0.C0000    -0.00000    -0.00000
                            -5.91360   -211.19836   -0.CCCC0    -0.CC000    -0.00000    -0.0CCC0
                            -5.91360   -211.19789   -C.C00C0    -0.CC000    -C.0C000    -0.00000
                            -5.91329   -211.14476   -0.00CC0    -0.C0001     0.C0000     0.00003
                            -5.80887   -200.30417   -0.00CC0    -0.C0001     0.00003     0.00306
                            -0.26304    -28.13876   -0.CCCC0    -0.CC000    -0.00045    -0.04533
         LADING
                            -5.91356   -211.20105   -5.91356   -211.20113   -5.91356   -211.20117
                            -5.91336   -211.16237   -5.90916   -210.57187   -0.26304    -28.13876

I      P(I+1)       X1(I)       X2(I)       XC(I)       V(I+1)      FL(I)       FH(I)       RH(I)
1       0.00005     0.00000     0.CC000     0.C0001     0.0         1.32113    -0.19985    -0.19985
```

Figure 9   Output for the sample problem (continued)

```
 2        0.00002     0.00000     C.CCCCO     0.COCCO     0.0          1.31875    -0.19962    -0.19962
 3       -0.01250    -0.00016    -C.CCC16    -0.CCC32     0.0          1.31732    -C.19814    -0.19814
 4       -4.11661    -0.05279    -0.C5279    -0.10558     0.0          1.34569     0.27073     0.27073
 5     -274.72827    -2.84341    -2.68315    -5.52656     0.0         26.40228    24.43307    24.43307
 6        0.0         0.0         C.C         0.0         0.0          0.0       -52.41927   -52.41927

 I       FT(I)       RT(I)      F.C.D.      R.C.D.      SP(I)      IFT(I)      IRT(I)      ICC(I)
 1     109.20015   109.19972   -0.CCC00     0.CCCCO     U.0          0           0           0
 2     109.20015   109.19972   -0.CCCCO     0.CCCCO     0.0          0           0           0
 3     109.20023   109.19963   -0.CCC00     0.CCC00     0.0          0           0           0
 4     109.19482   109.20503    0.CCC06    -0.CCC06     0.0          0           0           0
 5     108.26776   110.13210    0.C1036    -C.01036    -0.97167      0           0           0
 6      19.14203     9.85796   -C.C7737     0.07737     0.0          0           0           0

T =    0.0320      IHLF =   0
         CAR
                            -6.75839  -211.19836    -0.CCCCO    -0.CC000    -0.00000    -0.00CC0
                            -6.75840  -211.19814    -0.CCC00    -0.C0000    -C.00000    -0.0CCC0
                            -6.75840  -211.19739    -0.CC000    -0.CC001    -0.CC000    -0.00000
                            -6.75776  -211.08997    -0.00000    -0.00001     0.00000     0.00005
                            -6.59968  -194.29333    -0.CCCCO    -0.CC001     0.00004     0.00474
                            -0.40218   -43.60039    -0.CC0C0    -C.C0000    -0.00067    -0.06916
         LADING
                            -6.75835  -211.20110    -6.75835  -211.20120    -6.75835  -211.20126
                            -6.75797  -211.14651    -6.75C74  -210.19633    -0.40218   -43.60039

 I      P(I+1)       X1(I)       X2(I)       XC(I)      V(I+1)       FL(I)       FH(I)       RH(I)
 1        0.00005     0.00000     0.00C00     0.C0C01     C.0          1.31899    -0.19965    -0.19965
 2        0.00002     0.C0000     0.CCCCO     0.00CC0     0.0          1.31684    -0.19944    -0.19944
 3       -0.02535    -0.C0033    -C.CC033    -0.C0065     0.0          1.31565    -0.19672    -0.19672
 4       -6.23245    -0.07993    -0.07993    -0.15985     0.0          1.38026     0.47290     0.47290
 5     -609.79761    -3.26225    -2.90653    -6.16878     C.C         39.09520    55.11351    55.11351
 6        0.0         0.0         0.0         0.0         0.0          0.0      -113.35117  -113.35117

 I       FT(I)       RT(I)      F.C.D.      R.C.D.      SP(I)      IFT(I)      IRT(I)      ICC(I)
 1     109.20015   109.19972   -0.CCC00     0.CC000     C.0          0           0           0
 2     109.20023   109.19963   -0.CCC00     0.C0CCC     0.0          0           0           0
 3     109.20032   109.19963   -0.CCC00     0.CCC00     0.0          0           0           0
 4     109.18976   109.21010    0.C0011    -0.00011     0.0          0           0           0
 5     107.78514   110.61481    0.01572    -0.01572    -0.97167      0           0           0
 6      21.40994     7.59006   -0.11517     0.11517     0.0          0           0           0

T =    0.0360      IHLF =   0
         CAR
                            -7.60319  -211.19814    -0.0C0CC    -0.C0001    -0.00000    -0.000C0
                            -7.60320  -211.19785    -0.CCCCO    -0.CC001    -0.CC000    -0.0CCC0
                            -7.60320  -211.19655    -0.000C0    -0.0C001    -0.00000    -0.00C00
                            -7.60195  -210.99655    -0.000C0    -C.CC001     0.00000     0.00008
                            -7.35769  -184.C9033    -0.CCCCC    -0.00001     0.00007     0.00757
                            -0.62526   -69.75024    -0.C00C0    -0.C0000    -0.00103    -0.11C73
         LADING
                            -7.60315  -211.20117    -7.60314  -211.20131    -7.60314  -211.20137
                            -7.60252  -211.12997    -7.59047  -209.63208    -0.62526   -69.75024
```

Figure 9   Output for the sample problem (continued)

I	P(I+1)	X1(I)	X2(I)	XC(I)	V(I+1)	FL(I)	FH(I)	RH(I)
1	0.00005	0.00000	0.00000	0.00001	0.0	1.31708	-0.19947	-0.19947
2	-0.00007	-0.00000	-0.00000	-0.00000	0.0	1.31517	-0.19928	-0.19928
3	-0.04956	-0.00064	-0.00064	-0.00127	0.0	1.31493	-0.19429	-0.19429
4	-9.62967	-0.12349	-0.12349	-0.24698	0.0	1.47110	0.79177	0.79177
5	-881.00684	-3.60126	-3.08734	-6.68860	0.0	59.52481	78.09888	78.09888
6	0.0	0.0	0.0	0.0	0.0	0.0	-157.56844	-157.56844

I	FT(I)	RT(I)	F.C.D.	R.C.D.	SP(I)	IFT(I)	IRT(I)	ICC(I)
1	109.20023	109.19963	-0.00000	0.00000	0.0	0	0	0
2	109.20032	109.19954	-0.00000	0.00000	0.0	0	0	0
3	109.20032	109.19954	-0.00000	0.00000	0.0	0	0	0
4	109.18135	109.21852	0.00021	-0.00021	0.0	0	0	0
5	107.01172	111.38814	0.02431	-0.02431	-0.97167	0	0	0
6	25.03777	3.96223	-0.17563	0.17563	0.0	0	0	0

T = 0.0400 IHLF = 0

CAR

-8.44799	-211.19785	-0.00000	-0.00001	-0.00000	-0.00000
-8.44800	-211.19757	-0.00000	-0.00001	-0.00000	-0.00000
-8.44799	-211.19527	-0.00000	-0.00001	-0.00000	0.00000
-8.44565	-210.84280	-0.00000	-0.00001	0.00000	0.00013
-8.06861	-171.01306	-0.00000	-0.00001	0.00011	0.01123
-0.97017	-103.91341	0.00000	0.00796	-0.00157	-0.16361

LADING

-8.44794	-211.20128	-8.44794	-211.20143	-8.44794	-211.20149
-8.44700	-211.11180	-8.42739	-208.76842	-0.97017	-103.91341

I	P(I+1)	X1(I)	X2(I)	XC(I)	V(I+1)	FL(I)	FH(I)	RH(I)
1	0.00004	0.00000	0.00000	0.00000	0.0	1.31541	-0.19932	-0.19932
2	-0.00037	-0.00000	-0.00000	-0.00001	0.0	1.31374	-0.19911	-0.19911
3	-0.09282	-0.00119	-0.00119	-0.00238	0.0	1.31541	-0.19014	-0.19014
4	-14.86424	-0.19062	-0.19062	-0.38124	0.0	1.66660	1.27538	1.27538
5	-1059.80566	-3.82476	-3.20654	-7.03130	0.0	91.02444	90.94728	90.94728
6	0.0	0.0	0.0	0.0	0.0	0.0	-185.24095	-185.24095

I	FT(I)	RT(I)	F.C.D.	R.C.D.	SP(I)	IFT(I)	IRT(I)	ICC(I)
1	109.20032	109.19954	-0.00000	0.00000	0.0	0	0	0
2	109.20032	109.19954	-0.00000	0.00000	0.0	0	0	0
3	109.20032	109.19954	-0.00000	0.00000	0.0	0	0	0
4	109.16805	109.23181	0.00035	-0.00035	0.0	0	0	0
5	105.82056	112.57930	0.03755	-0.03755	-0.97167	0	0	0
6	30.63298	0.0	-0.26888	0.26888	0.0	0	0	0

Figure 9 Output for the sample problem (continued)

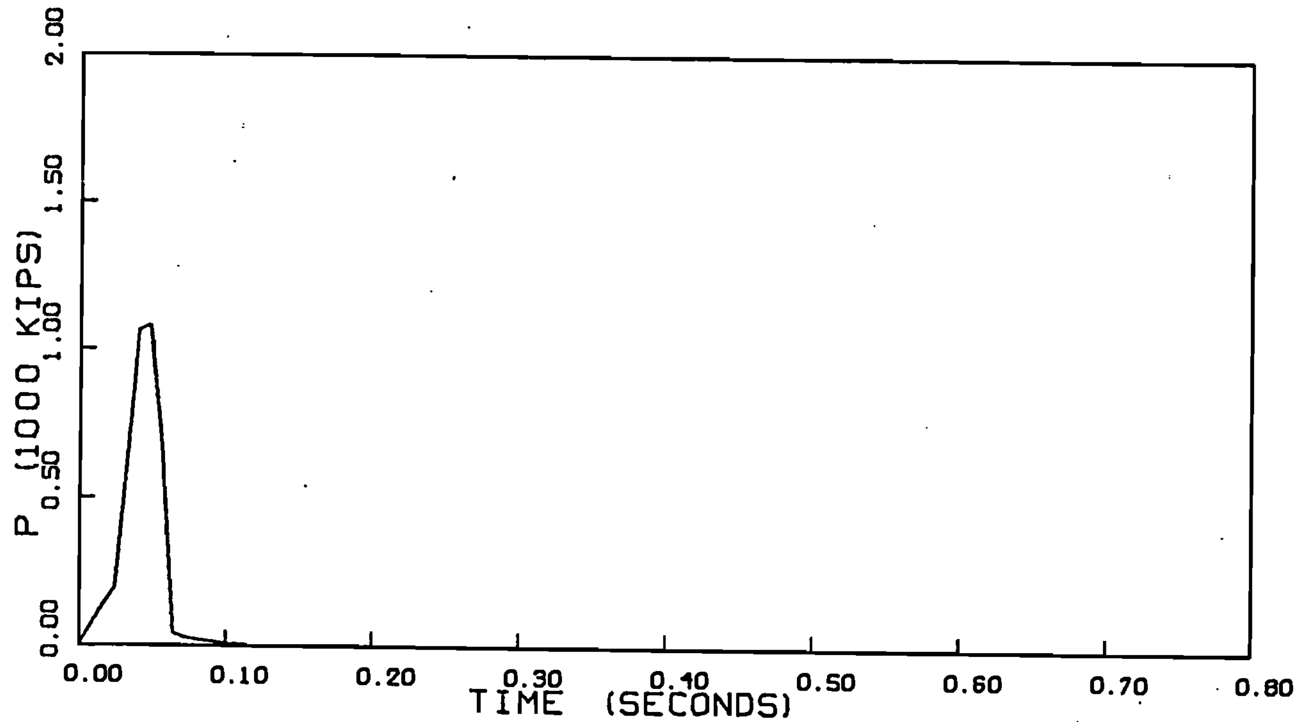

Figure 10a Horizontal coupler force at the impact end of the box car

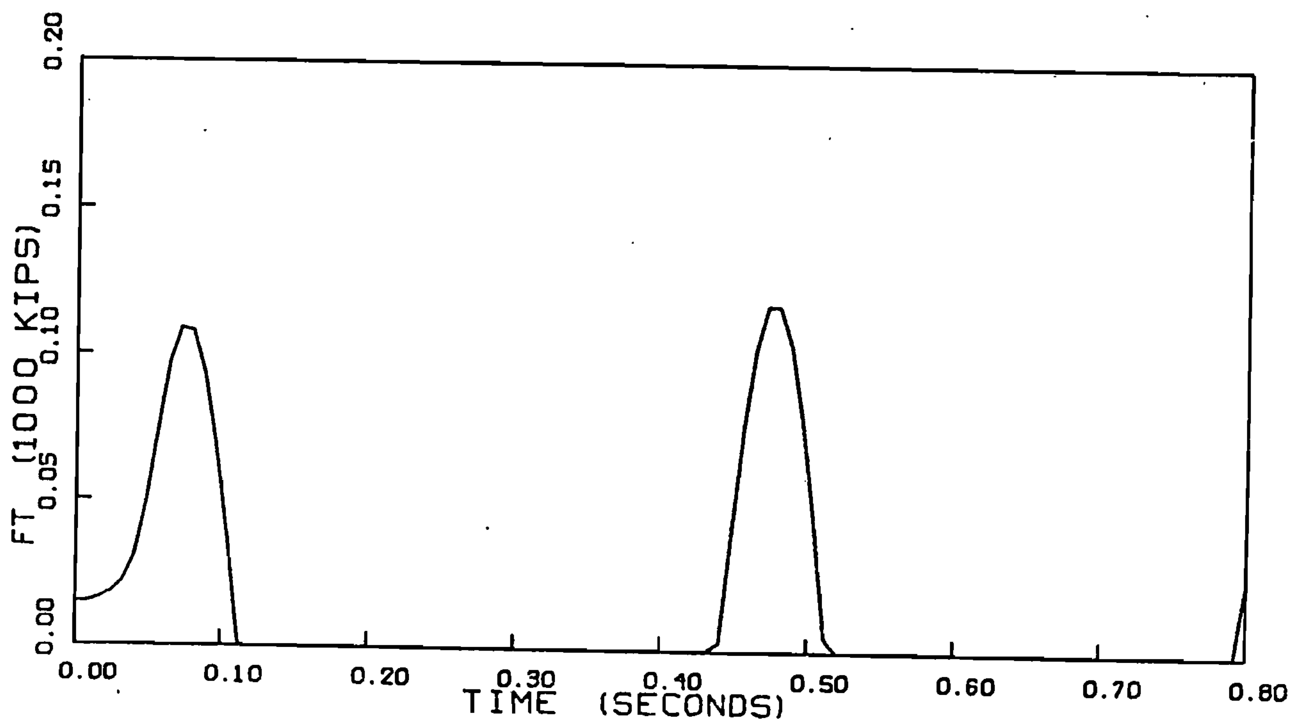

Figure 10b Vertical truck force at the impact end of the box car

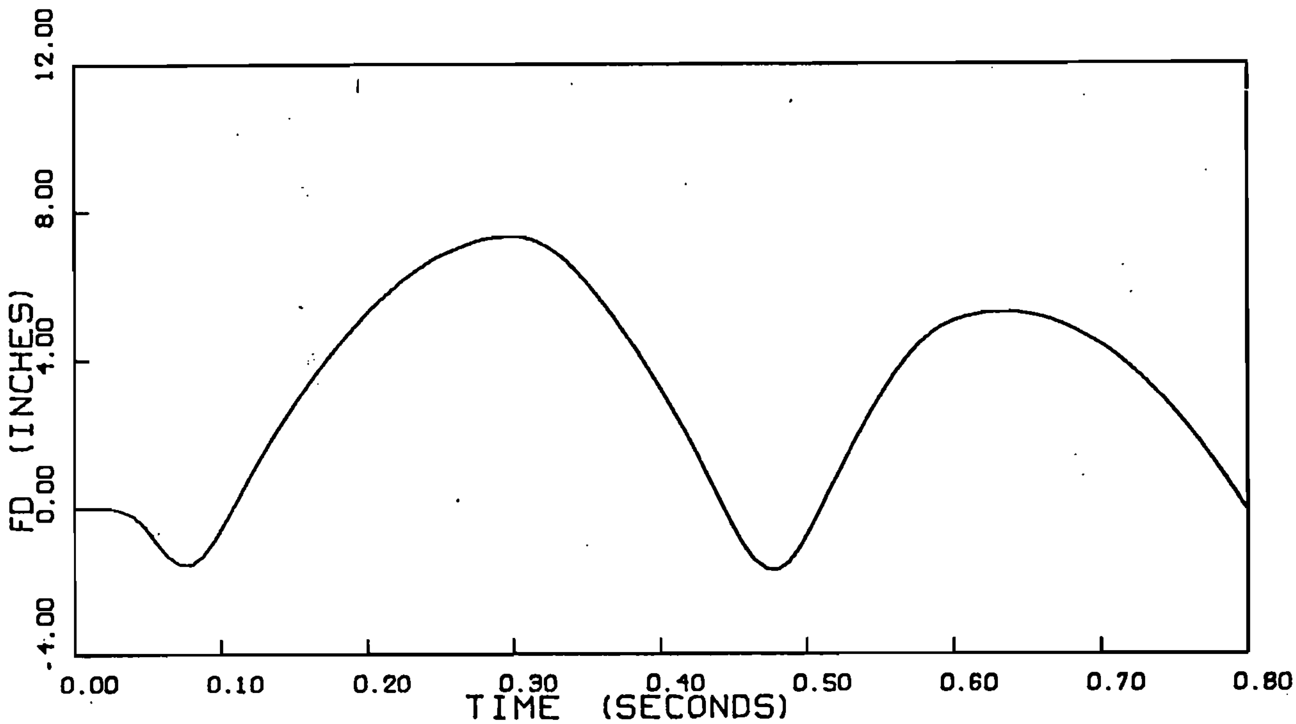

Figure 10c Car body center plate displacement at the impact end of the box car

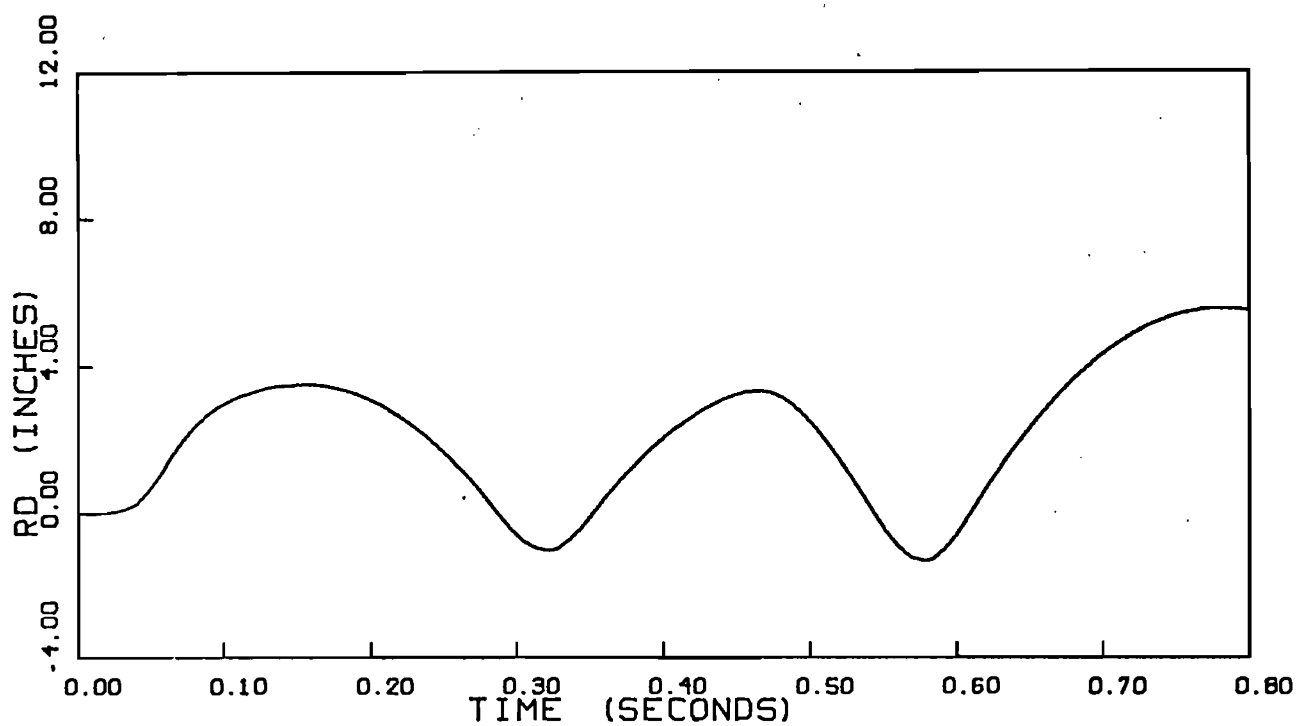

Figure 10d Car body center plate displacement at the free end of the box car

6. ACKNOWLEDGEMENTS

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Finally, the writer is indebted to Dr. Barna A. Szabo, principal investigator of the contract, for his kindness and understanding. His reviewing of the manuscript is deeply appreciated.

7. NOTATIONS AND SYMBOLS

A: Name of the major array

B: Half length between truck centers, inches

BK: Bolster spring constant, Kips per inch

C: Half length between coupler faces, inches

CH: Coupler height, inches

CVF: Coupler vertical friction coefficient

CVK: Coupler vertical spring constant, Kips per inch

DDX: Symbol for d^2x/dt^2

DDXT: Horizontal acceleration of car body center plate

DK: Draft gear spring constant, Kips per inch

DS1: Draft gear loading spring travel, inches

DS2: Draft gear unloading spring travel, inches

DST: Draft gear spring travel, inches

DTH: Symbol for $d\theta/dt$

DX: Symbol for dx/dt

DXF: Symbol for dX_F/dt

DKL: Symbol for dX_L/dt

DXR: Symbol for dX_R/dt

DXT: Horizontal velocity of car body center plate

DY: Symbol for dy/dt

E: C.G. height above coupler, inches

ES1: Equivalent draft gear and underframe loading spring constant, Kips per inch

ES2: Equivalent draft gear and underframe unloading spring constant, Kips per inch

ES3: Same as UK, underframe spring constant, Kips per inch

FD: Front car body centerplate displacement, inches

FH: Front truck horizontal force, Kips

FL: Lading force, Kips

FT: Front truck vertical force, Kips

H:	C.G. height above center plate, inches
HCS:	Horizontal coupler slack, inches
HL:	Draft gear hysteresis load, Kips
I:	Car number i
I_b:	Mass moment of inertia, Kips-inch-sec^2
IC:	IC = 0, impacted end not coupled
	IC $\neq$ 0, impacted end, coupled
ICD:	ICD = 0, no coupler disengagement
	ICD = 1, coupler disengagement occurs
ICRD:	Card reader unit
IDP:	Parameter indicates the sequence of the data to be plotted
IFT:	IFT = 0, no front truck separation from car body
	IFT = 1, front truck separated from car body
IJK:	IJK = 1, car body degrees of freedom only
	IJK = 2, lading degrees of freedom is added
	IJK = 3, horizontal truck degrees of freedom are added
	IJK = 4, lading and horizontal truck degrees of freedom are added
IM:	The first impacted car number
IPLOT:	IPLOT = 0, no plotting subprogram supplied by the user
	IPLOT $\neq$ 0, plotting subprogram supplied by the user
IPRT:	Printer unit
IRT:	IRT = 0, no rear truck separation from car body
	IRT = 1, rear truck separated from car body
IPUN:	Card punch unit
IT:	IT = 1, Coulomb friction in vertical truck force
	IT = 2, viscous friction in vertical truck force
K1,K2,K3:	Dimensions of variables
M:	Car body mass, = W/g
M_L:	Lading mass, = W_L/g
M_T:	Truck mass, = W_T/g
NC:	Number of cars

NDIM: Number of state variables

NEEDED: Needed words

NSIZE: Size of array A

P: Horizontal coupler force, Kips

PL: Bolster pin length, inches

RD: Rear car body centerplate displacement, inches

RH: Rear truck horizontal force, Kips

RLF: Friction coefficient between lading and car body

RLK: Lading spring constant, Kips per inch

RMI: Symbol for I_b

RT: Rear truck vertical force, Kips

SP: Coupler offset, inches

SPEED: Impacting speed, miles per hour or inch per second

SPO: Coupler offset at previous time step, inches

ST1: Time increment to print out results, ≥ 2 PRMT(3)

ST2: Time increment to plot results, ≥ 2 PRMT(3)

T: Time

TF: Truck vertical friction force or friction coefficient

T_f: Final time

TH: Symbol for θ

T_i: Initial time

THF: Truck horizontal friction coefficient

THK: Truck horizontal spring constant, Kips per inch

TST: Truck spring travel, inches

TVK: Truck vertical spring constant, Kips per inch

T1: Time at which solutions are printed out

T2: Time at which solutions are plotted

UK: Underframe spring constant, Kips per inch

V: Vertical coupler force, Kips

VCS: Vertical coupler slack, inches

W: Car body weight, Kips

WA: Lading or truck mass

WL: Lading weight, Kips

WT:	Each truck weight, Kips
X:	Symbol for x
XC:	Relative horizontal displacement between the adjacent cars, inches
XCO:	Relative horizontal displacement between the adjacent cars at previous time step, inches
XF:	Symbol for x_F
XL:	Symbol for x_L
XR:	Symbol for x_R
XT:	Horizontal displacement of car body center plate
X1:	Coupler spring displacement for front car, inches
X2:	Coupler spring displacement for rear car, inches
x:	Car body horizontal displacement, inches
x_F:	Front truck horizontal displacement, inches
x_L:	Lading horizontal displacement, inches
x_R:	Rear truck horizontal displacement, inches
Y:	State variables, or symbol for y
Y0:	Initial truck spring displacement, inches
YY:	Symbol for y
y:	Car body vertical displacement, inches
θ:	Car body pitching displacement

8. REFERENCES

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9. APPENDICES

9.1 Appendix A - Source Listing

DISCLAIMER

This program is furnished by Washington University, School of Engineering and Applied Science, in partial fulfillment of the terms of Contract No. DOT-OS-40106. The contractor and program developers make no warranties, expressed or implied, concerning the accuracy, completeness, reliability, usability or suitability of the computer program and its associated data and documentation, except that these parties do attest that the program does meet the contract requirements.

9.1 Appendix A - Source Listing

```
C       MAIN PROGRAM TO SET MAXIMUM SIZE
        DIMENSION A(400)
        NSIZE=400
        CALL MAINO(A,NSIZE)
        STOP 0
        END

        SUBROUTINE MAINO(A,NSIZE)
C       SUBPROGRAM TO SET UP ARRAYS
        DIMENSION A(NSIZE)
        COMMON/IO/ICRD,IPRT,IPUN
        COMMON/SIZES/K1,K2,K3
        COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
        COMMON/ISTART/ I1,I2,I3,I4,I5,I6,I7,I8,I9,I10,I11,I12,I13,I14,I15,
       1 I16,I17,I18,I19,I20,I21,I22,I23,I24,I25,I26,I27,I28,I29,I3C,I31,
       2 I32,I33,I34,I35,I36,I37,I38,I39,I40,I41,I42,I43,I44,I45,I46,I47,
       3 I48,I49,I50,I51,I52,I53,I54,I55,I56,I57,I58,I59,I60,I61,I62,I63,
       4 I64,I65,I66,I67,I68,I69,I70,I71,I72,I73
        DIMENSION I(73)
        EQUIVALENCE (I(1),I1)
        ICRD=5
        IPRT=6
        IPUN=7
        READ(ICRD,101,ENC=199)NC,IM,IC,IJK,IT,IPLOT
  101   FORMAT(6I5)
        K1=NC
        K2=K1+1
        NDIM=NC*(IJK*2+4)
        K3=NDIM
        WRITE(IPRT,60)NC,NCIM,ICRD,IPRT,IPUN
   60   FORMAT('1NC=',I4,', NDIM=',I6/'0CARD READER IS UNIT ',
       1 I2,', PRINTER IS UNIT ',I2,', PUNCH IS UNIT ',I2)
        I1=1
        I2=I1+8*K3
        I3=I2+K3
        I4=I3+K3
        I5=I4+K2
        I6=I5+K2
        DO 10 J=7,73
   10   I(J)=I(J-1)+K1
        NEEDED=I73+K1-1
        IF(NEEDED .GT. NSIZE) GO TO 100
        WRITE(IPRT,61)NEEDED,NSIZE
   61   FORMAT('0',I6,' WORCS NEEDED,',I6,' WORDS AVAILABLE.')
        CALL MAIN1(A(I1),A(I2),A(I3),A(I4),A(I5),A(I6),A(I7),A(I8),A(I9),
       1 A(I10),A(I11),A(I12),A(I13),A(I14),A(I15),A(I16),A(I17),A(I18),
       2 A(I19),A(I20),A(I21),A(I22),A(I23),A(I24),A(I25),A(I26),A(I27),
       3 A(I28),A(I29),A(I30),A(I31),A(I32),A(I33),A(I34),A(I35),A(I36),
       4 A(I37),A(I38),A(I39),A(I40),A(I41),A(I42),A(I43),A(I44),A(I45),
       5 A(I46),A(I47),A(I48),A(I49),A(I50),A(I51),A(I52),A(I53),A(I54),
       6 A(I55),A(I56),A(I57),A(I58),A(I59),A(I60),A(I61),A(I62),A(I63),
       7 A(I64),A(I65),A(I66),A(I67),A(I68),A(I69),A(I7C),A(I71),A(I72),
```

```
      8 A(I73))
        RETURN
    100 WRITE(IPRT,66)NEEDED,NSIZE
     66 FORMAT('0****** ',I6,' WORDS NEEDED, ONLY ',I6,' AVAILABLE.')
        STOP 99
    199 STOP 199
        END

        SUBROUTINE MAIN1(AUX,Y,DERY,          P,V,
      1 B,BK,C,CVF,CVK,DS1,DS2,E,ES1,ES2,ES3,FD,FH,FL,FT,H,HCS,ICD,IFT,
      2 IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,TF,THF,THK,TST,TVK,VCS,W,WL,WT,
      3 XC,XCO,X1,X2,YO,YY,
      4 DK,DST,HL,UK,
      5 DDX,DDXT,DTH,DX,DXT,DXF,DXL,DXR,DY,TH,X,XT,XF,XL,XR,
      6 S1,ST,                YF,YR,                        FE,FF)
        COMMON/SIZES/K1,K2,K3
        COMMON/IO/ICRD,IPRT,IPUN
        COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
        COMMON PRMT(10),ST1,ST2, T1,T2,IDP
        DIMENSION AUX(8,K3),Y(K3),DERY(K3)
        DIMENSION P(K2),V(K2)
        DIMENSION B(K1),BK(K1),C(K1),CVF(K1),CVK(K1),DS1(K1),DS2(K1)
        DIMENSION E(K1),ES1(K1),ES2(K1),ES3(K1),FD(K1),FH(K1),FL(K1)
        DIMENSION FT(K1),H(K1),HCS(K1),ICD(K1),IFT(K1),IRT(K1),RH(K1)
        DIMENSION RD(K1),RT(K1)
        DIMENSION RLF(K1),RLK(K1),RMI(K1),SP(K1),SPO(K1),TF(K1),THF(K1)
        DIMENSION THK(K1),TST(K1),TVK(K1),VCS(K1),W(K1),WL(K1),WT(K1)
        DIMENSION XC(K1),XCO(K1),X1(K1),X2(K1),YO(K1),YY(K1)
        DIMENSION DK(K1),DST(K1),HL(K1),UK(K1)
        DIMENSION DDX(K1),DDXT(K1),DTH(K1),DX(K1),DXT(K1)
        DIMENSION DXF(K1),DXL(K1),DXR(K1),DY(K1),TH(K1),X(K1)
        DIMENSION XT(K1),XF(K1),XL(K1),XR(K1)
        DIMENSION S1(K1),ST(K1)
        DIMENSION YF(K1),YR(K1)
        DIMENSION FE(K1),FF(K1)
    103 FORMAT(//12X,'TOTAL NUMBER OF CARS = ',I3,'   THE IMPACTED CAR NUM
       *BER = ',I3,'   THE IMPACTING SPEED = ',F7.2,'MPH')
    104 FORMAT(//12X,'IC=',I3,'   IMPACTED ENDS NOT COUPLED')
    105 FORMAT(//12X,'IC=',I3,'   IMPACTED ENDS COUPLED')
    106 FORMAT(//12X,'IJK = ',I3,10X,'IT = ',I3,10X,'IPLOT = ',I3)
    107 FORMAT(//12X,'INITIAL TIME =',F7.3,5X,'FINAL TIME = ',F7.3,5X,
       * 'TIME STEP = ',F7.3,5X,'ACCURACY CONTROL PARAMETER = ',F7.3)
    108 FORMAT(//12X,'PRINT STEP = ',F7.3,5X,'PLOTTING STEP = ',F7.3////)
    109 FORMAT(//2X,'CAR NUMBER',12X,10I10/)
    139 FORMAT(1H1)
        CALL READEM(SPEED,PRMT,ST1,ST2,B,BK,C,CVF,CVK,DK,DST,E,H,HCS,HL,
      1 RLF,RLK,RMI,TF,THF,THK,TST,TVK,UK,VCS,W,WL,WT)
      3 WRITE(IPRT,103)NC,IM,SPEED
        IF(IC .GE. 1) GO TO 5
      4 WRITE(IPRT,104)IC
        GO TO 6
      5 WRITE(IPRT,105)IC
```

```
    6 WRITE(IPRT,106)IJK,IT,IPLOT
      WRITE(IPRT,107)(PRMT(I),I=1,4)
      WRITE(IPRT,108)ST1,ST2
      N2=0
    7 N1=N2+1
      N2=N2+10
      IF(N2 .GT. NC) N2=NC
      N3=N2-N1+1
    9 WRITE(IPRT,109)(I,I=N1,N2)
      CALL RITEM1(N3,W(N1),WL(N1),WT(N1),C(N1),B(N1),H(N1),E(N1),RMI(N1)
     1,UK(N1),DK(N1),HL(N1),DST(N1),HCS(N1),TVK(N1),BK(N1),TST(N1),
     2 TF(N1),CVK(N1),CVF(N1),VCS(N1),RLK(N1),RLF(N1),THK(N1),THF(N1))
      IF(N2 .LT. NC) GO TC 7
   15 DO 16 I=1,NC
      YO(I)=-.5*(W(I)+WL(I))/TVK(I)
      ES1(I)=DK(I)*UK(I)/(DK(I)+UK(I))
      HLK=HL(I)/CST(I)
      ES2(I)=HLK*UK(I)/(HLK+UK(I))
      ES3(I)=UK(I)
      DS1(I)=DK(I)*DST(I)/ES1(I)
   16 DS2(I)=HL(I)/ES2(I)
      N2=0
   17 N1=N2+1
      N2=N2+10
      IF(N2 .GT. NC) N2=NC
      N3=N2-N1+1
   19 WRITE(IPRT,109)(I,I=N1,N2)
      CALL RITEM2(N3,YO(N1),ES1(N1),ES2(N1),DS1(N1),DS2(N1))
      IF(N2 .LT. NC) GO TC 17
   27 RNDIM=NDIM
      DO 28 I=1,NDIM
      DERY(I)=1./RNDIM
   28 Y(I)=0.
      DO 29 I=1,NC
      ICD(I)=0
      IFT(I)=0
      IRT(I)=0
      XCO(I)=0.
   29 CONTINUE
      NC1=NC-1
      DO 30 I=1,NC1
   30 SPO(I)=YO(I)-YO(I+1)
      XC(NC)=0.
      SPO(NC)=0.
      SP(NC)=0.
      X1(NC)=0.
      X2(NC)=0.
      P(1)=0.
      P(NC+1)=0.
      V(1)=0.
      V(NC+1)=0.
C
C   INITIAL VELOCITY
```

```
      SPEED=-SPEED*17.6
      NIM=IM-1
      DO 31 I=1,NIM
      J=(I-1)*6+2
   31 Y(J)=SPEED
      GO TO (38,32,34,36),IJK
   32 DO 33 I=1,NIM
      J=NC*6+(I-1)*2+2
   33 Y(J)=SPEED
      GO TO 38
   34 DO 35 I=1,NIM
      J=NC*6+(I-1)*4+2
      Y(J)=SPEED
   35 Y(J+2)=Y(J)
      GO TO 38
   36 DO 37 I=1,NIM
      J=NC*6+(I-1)*6+2
      Y(J)=SPEED
      Y(J+2)=Y(J)
   37 Y(J+4)=Y(J)
   38 WRITE(IPRT,139)
      IDP=1
      T1=PRMT(1)
      T2=PRMT(1)
      CALL RKGSM(IHLF,AUX,Y,DERY,P,V,B,BK,C,CVF,CVK,DS1,DS2,E,ES1,ES2,
     1 ES3,FD,FH,FL,FT,H,HCS,ICD,IFT,IRT,RC,RH,RLF,RLK,RMI,RT,SP,SPC,
     2 TF,THF,THK,TST,TVK,VCS,W,WL,WT,XC,XCO,X1,X2,YO,DDX,DDXT,
     3 DTH,DX,DXT,DXF,DXL,DXR,DY,TH,X,XT,XF,XL,XR,YY,FE,FF,S1,ST,
     4 YF,YR)
      IF(IPLOT .EQ. 0) STOP
C
C   CALL PLOTTING SUBROUTINE
   39 CONTINUE
   40 STOP
      END

      SUBROUTINE READEM(SPEED,PRMT,ST1,ST2,B,BK,C,CVF,CVK,DK,DST,E,H,
     1 HCS,HL,RLF,RLK,RMI,TF,THF,THK,TST,TVK,UK,VCS,W,WL,WT)
      COMMON/IO/ICRD,IPRT,IPUN
      COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
      DIMENSION PRMT(4)
      DIMENSION B(NC),BK(NC),C(NC),CVF(NC),CVK(NC),DK(NC),DST(NC),E(NC)
      DIMENSION H(NC),HCS(NC),HL(NC),RLF(NC),RLK(NC),RMI(NC),TF(NC)
      DIMENSION THF(NC),THK(NC),TST(NC),TVK(NC),UK(NC),VCS(NC),W(NC)
      DIMENSION WL(NC),WT(NC)
  102 FORMAT(8F10.0)
      READ(ICRD,102)SPEED,PRMT,ST1,ST2
      READ(ICRD,102)W
      READ(ICRD,102)WL
      READ(ICRD,102)WT
      READ(ICRD,102)C
      READ(ICRD,102)B
```

```
      READ(ICRD,102)H
      READ(ICRC,102)E
      READ(ICRD,102)RMI
      READ(ICRD,102)UK
      READ(ICRD,102)CK
      READ(ICRC,102)HL
      READ(ICRD,102)CST
      READ(ICRD,102)HCS
      READ(ICRD,102)TVK
      READ(ICRC,102)PK
      READ(ICRD,102)TST
      READ(ICRD,102)TF
      READ(ICRD,102)CVK
      READ(ICRD,102)CVF
      READ(ICRD,102)VCS
      GO TO (3,1,2,1),IJK
    1 READ(ICRD,102)RLK
      READ(ICRC,102)RLF
      IF(IJK .LE. 3) RETURN
    2 READ(ICRC,102)THK
      READ(ICRD,102)THF
    3 RETURN
      END

      SUBRCUTINE RITEM1(N3,W,WL,WT,C,B,H,E,RMI,UK,DK,HL,DST,HCS,TVK,BK,
     1 TST,TF,CVK,CVF,VCS,RLK,RLF,THK,THF)
      COMMON/IO/ICRD,IPRT,IPUN
      COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
      COMMON/SIZES/K1,K2,K3
      DIMENSION W(N3),WL(N3),WT(N3),C(N3),B(N3),H(N3),E(N3),RMI(N3)
      DIMENSION UK(N3),DK(N3),HL(N3),DST(N3),HCS(N3),TVK(N3),BK(N3)
      DIMENSION TST(N3),TF(N3),CVK(N3),CVF(N3),VCS(N3),RLK(N3),RLF(N3)
      DIMENSION THK(N3),THF(N3)
  110 FORMAT(2X,'CAR WEIGHT',16X,10F10.3)
  111 FORMAT(2X,'LACING WEIGHT',13X,10F10.3)
  112 FORMAT(2X,'EACH TRUCK WEIGHT',9X,1CF10.3)
  113 FORMAT(2X,'HALF CIST. C.P.F.',9X,1CF10.3)
  114 FORMAT(2X,'HALF CIST. T.C.',11X,10F1C.3)
  115 FORMAT(2X,'HEIGHT C.G. TO PLATE',6X,1CF10.3)
  116 FORMAT(2X,'HEIGHT COUPLER TO C.G.',4X,10F1C.3)
  117 FORMAT(2X,'MASS MOMENT OF INERTIA',4X,10F1C.3)
  118 FORMAT(2X,'UNCERFRAME SP. CONST',6X,10F10.3)
  119 FORMAT(2X,'CRAFT GEAR SP. CONST',6X,1CF10.3)
  120 FORMAT(2X,'CRAFT GEAR HYST. LOAD',5X,1CF10.3)
  121 FORMAT(2X,'CRAFT GEAR SP. TRAVEL',5X,1CF1C.3)
  122 FORMAT(2X,'HORIZONTAL COUPLER SLACK',2X,10F10.3)
  123 FORMAT(2X,'TRUCK VERTICAL SP. CONST',2X,1CF10.3)
  124 FORMAT(2X,'BCLSTER SP. CONST',9X,10F10.3)
  125 FORMAT(2X,'TRUCK SP. TRAVEL',10X,1CF10.3)
  126 FORMAT(2X,'TRUCK VERTICAL FRICTION',3X,10F1C.3)
  127 FORMAT(2X,'CCUPLER VERT. SP. CONST',3X,1CF1C.3)
  128 FORMAT(2X,'CCUPLER VERT. FRIC. COEFF',1X,1CF10.3)
```

```
129 FORMAT(2X,'VERTICAL COUPLER SLACK',4X,10F10.3)
130 FORMAT(2X,'LACING SP. CONST',10X,10F10.3)
131 FORMAT(2X,'LACING FRICTION COEFF',5X,10F10.3)
132 FORMAT(2X,'TRUCK HORI. SP. CONST',5X,10F10.3)
133 FORMAT(2X,'TRUCK HORI. FRIC. COEFF',3X,10F10.3)
    WRITE(IPRT,110)W
    WRITE(IPRT,111)WL
    WRITE(IPRT,112)WT
    WRITE(IPRT,113)C
    WRITE(IPRT,114)B
    WRITE(IPRT,115)H
    WRITE(IPRT,116)E
    WRITE(IPRT,117)RMI
    WRITE(IPRT,118)UK
    WRITE(IPRT,119)CK
    WRITE(IPRT,120)HL
    WRITE(IPRT,121)CST
    WRITE(IPRT,122)HCS
    WRITE(IPRT,123)TVK
    WRITE(IPRT,124)BK
    WRITE(IPRT,125)TST
    WRITE(IPRT,126)TF
    WRITE(IPRT,127)CVK
    WRITE(IPRT,128)CVF
    WRITE(IPRT,129)VCS
    GO TO (12,10,11,10),IJK
 10 WRITE(IPRT,130)RLK
    WRITE(IPRT,131)RLF
    IF(IJK .LE. 3) RETURN
 11 WRITE(IPRT,132)THK
    WRITE(IPRT,133)THF
 12 RETURN
    END

    SUBROUTINE RITEM2(N3,YO,ES1,ES2,DS1,DS2)
    COMMON/IO/ICRD,IPRT,IPUN
    COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
    COMMON/SIZES/K1,K2,K3
    DIMENSION YO(N3),ES1(N3),ES2(N3),DS1(N3),DS2(N3)
134 FORMAT(2X,'CAR INITIAL VERT. DISP.',3X,10F10.3)
135 FORMAT(2X,'COMBINED LOADING SP. CONST',10F10.3)
136 FORMAT(2X,'COMBINED UNLOAD. SP. CONST',10F10.3)
137 FORMAT(2X,'LOADING SPRING TRAVEL',5X,10F10.3)
138 FORMAT(2X,'UNLOADING SPRING TRAVEL',3X,10F10.3)
    WRITE(IPRT,134)YO
    WRITE(IPRT,135)ES1
    WRITE(IPRT,136)ES2
    WRITE(IPRT,137)DS1
    WRITE(IPRT,138)DS2
    RETURN
    END
```

```
      SUBROUTINE RKGSM(IHLF,AUX,Y,DERY,P,V,BB,BK,CC,CVF,CVK,DS1,DS2,E,
     1 ES1,ES2,ES3,FC,FH,FL,FT,HH,HCS,ICC,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,
     2 SP,SPO,TF,THF,THK,TST,TVK,VCS,W,WL,WT,XC,XCC,X1,X2,YO,DDX,DDXT,
     3 DTH,DX,DXT,DXF,DXL,DXR,DY,TH,XX,XT,XF,XL,XR,YY,FE,FF,
     4 S1,ST,YF,YR)
      COMMON/SIZES/K1,K2,K3
      COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
      COMMON/IO/ICRD,IPRT,IPUN
      COMMON PRMT(10),ST1,ST2, T1,T2,IOP
      DIMENSION AUX(8,K3),Y(K3),DERY(K3)
      DIMENSION P(K2),V(K2)
      DIMENSION BB(K1),BK(K1),CC(K1),CVF(K1),CVK(K1),DS1(K1),DS2(K1)
      DIMENSION E(K1),ES1(K1),ES2(K1),ES3(K1),FD(K1),FH(K1),FL(K1)
      DIMENSION FT(K1),HH(K1),HCS(K1),ICD(K1),IFT(K1),IRT(K1),RD(K1)
      DIMENSION RH(K1),RLF(K1),RLK(K1),RMI(K1),RT(K1),SP(K1),SPO(K1)
      DIMENSION TF(K1),THF(K1),THK(K1),TST(K1),TVK(K1),VCS(K1),W(K1)
      DIMENSION WL(K1),WT(K1),XC(K1),XCO(K1),X1(K1),X2(K1),YO(K1)
      DIMENSION DDX(K1),DDXT(K1),DTH(K1),DX(K1),DXT(K1)
      DIMENSION DXF(K1),DXL(K1),DXR(K1),DY(K1),TH(K1),XX(K1),XT(K1)
      DIMENSION XF(K1),XL(K1),XR(K1),YY(K1),FE(K1),FF(K1),S1(K1)
      DIMENSION ST(K1),YF(K1),YR(K1)
      DIMENSION A(4),B(4),C(4)
      DO 1 I=1,NDIM
    1 AUX(8,I)=.06666667*DERY(I)
      X=PRMT(1)
      XEND=PRMT(2)
      H=PRMT(3)
      PRMT(5)=0.
      CALLFCT(X,Y,DERY,P,V,BB,BK,CC,CVF,CVK,DS1,DS2,E,ES1,ES2,ES3,FC,FH,
     1 FL,FT,HH,HCS,ICC,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,TF,THF,THK,
     2 TST,TVK,VCS,W,WL,WT,XC,XCO,X1,X2,YC,DDX,DDXT,DTH,DX,DXT,
     3 DXF,DXL,DXR,DY,TH,XX,XT,XF,XL,XR,YY,FE,FF,S1,ST,YF,YR)
      IF(H*(XEND-X))38,37,2
    2 A(1)=.5
      A(2)=.2928932
      A(3)=1.707107
      A(4)=.1666667
      B(1)=2.
      B(2)=1.
      B(3)=1.
      B(4)=2.
      C(1)=.5
      C(2)=.2928932
      C(3)=1.707107
      C(4)=.5
      DO 3 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=0.
    3 AUX(6,I)=0.
      IREC=0
      H=H+H
```

```
      IHLF=-1
      ISTEP=0
      IEND=0
    4 IF((X+H-XEND)*H)7,6,5
    5 H=XEND-X
    6 IEND=1
    7 IF(X    .GE.   T1) CALL OUTP(IREC,X   ,P,V,Y,DERY,BB,BK,CC,CVF,CVK,
     * DS1,DS2,E,ES1,ES2,
     1 ES3,FD,FH,FL,FT,FF,FCS,ICD,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,
     2 TF,THF,THK,TST,TVK,W,WL,WT,XC,XCO,X1,X2,YO)
      IF(PRMT(5) .NE. 0.0) RETURN
    8 ITEST=0
    9 ISTEP=ISTEP+1
      J=1
   10 AJ=A(J)
      BJ=B(J)
      CJ=C(J)
      DO 11 I=1,NDIM
      R1=H*DERY(I)
      R2=AJ*(R1-BJ*AUX(6,I))
      Y(I)=Y(I)+R2
      R2=R2+R2+R2
   11 AUX(6,I)=AUX(6,I)+R2-CJ*R1
      IF(J .GE. 4) GO TO 15
   12 J=J+1
      IF(J .NE. 3) X=X+0.5*H
   14 CALLFCT(X,Y,DERY,P,V,BB,BK,CC,CVF,CVK,DS1,DS2,E,ES1,ES2,ES3,FD,FH,
     1 FL,FT,HH,HCS,ICC,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,TF,THF,THK,
     2 TST,TVK,VCS,W,WL,WT,XC,XCO,X1,X2,YO,DDX,DDXT,DTH,DX,DXT,
     3 DXF,DXL,DXR,DY,TH,XX,XT,XF,XL,XR,YY,FE,FF,S1,ST,YF,YR)
      GO TO 10
   15 IF(ITEST .GT. 0) GO TO 20
   16 DO 17 I=1,NDIM
   17 AUX(4,I)=Y(I)
      ITEST=1
      ISTEP=ISTEP+ISTEP-2
   18 IHLF=IHLF+1
      X=X-H
      H=.5*H
      DO 19 I=1,NDIM
      Y(I)=AUX(1,I)
      DERY(I)=AUX(2,I)
   19 AUX(6,I)=AUX(3,I)
      GO TO 9
   20 IMOD=ISTEP/2
      IF(ISTEP .EQ. 2*IMOD) GO TO 23
   21 CALLFCT(X,Y,DERY,P,V,BB,BK,CC,CVF,CVK,DS1,DS2,E,ES1,ES2,ES3,FD,FH,
     1 FL,FT,HH,HCS,ICC,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,TF,THF,THK,
     2 TST,TVK,VCS,W,WL,WT,XC,XCO,X1,X2,YO,DDX,DDXT,DTH,DX,DXT,
     3 DXF,DXL,DXR,DY,TH,XX,XT,XF,XL,XR,YY,FE,FF,S1,ST,YF,YR)
      DO 22 I=1,NDIM
      AUX(5,I)=Y(I)
   22 AUX(7,I)=DERY(I)
```

```
      GO TO 9
   23 DELT=0.
      DO 24 I=1,NDIM
   24 DELT=DELT+AUX(8,I)*ABS(AUX(4,I)-Y(I))
      IF(DELT .LE. PRMT(4)) GO TO 28
   25 IF(IHLF .GE. 10) GO TO 36
   26 DO 27 I=1,NDIM
   27 AUX(4,I)=AUX(5,I)
      ISTEP=ISTEP+ISTEP-4
      X=X-H
      IEND=0
      GO TO 18
   28 CALLFCT(X,Y,DERY,P,V,BB,BK,CC,CVF,CVK,DS1,DS2,E,ES1,ES2,ES3,FD,FH,
     1 FL,FT,HH,HCS,ICC,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,TF,THF,THK,
     2 TST,TVK,VCS,W,WL,WT,XC,XCO,X1,X2,YC,DDX,DDXT,DTH,DX,DXT,
     3 DXF,DXL,DXR,DY,TH,XX,XT,XF,XL,XR,YY,FE,FF,S1,ST,YF,YR)
      DO 29 I=1,NDIM
      AUX(1,I)=Y(I)
      AUX(2,I)=DERY(I)
      AUX(3,I)=AUX(6,I)
      Y(I)=AUX(5,I)
   29 DERY(I)=AUX(7,I)
      IF(X-H .GE.  T1) CALL OUTP(IHLF,X-H,P,V,Y,DERY,BB,BK,CC,CVF,CVK,
     * DS1,DS2,E,ES1,ES2,
     1 ES3,FD,FH,FL,FT,FF,FCS,ICC,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,
     2 TF,THF,THK,TST,TVK,W,WL,WT,XC,XCO,X1,X2,YO)
      IF(PRMT(5) .NE. 0.0) RETURN
   30 DO 31 I=1,NDIM
      Y(I)=AUX(1,I)
   31 DERY(I)=AUX(2,I)
      IREC=IHLF
      IF(IEND .GT. 0) GO TO 39
   32 IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      IF(IHLF .LT. 0) GO TO 4
   33 IMOD=ISTEP/2
      IF(ISTEP .NE. 2*IMOD) GO TO 4
   34 IF(DELT .GT. 0.02*PRMT(4)) GO TO 4
   35 IHLF=IHLF-1
      ISTEP=ISTEP/2
      H=H+H
      GO TO 4
   36 IHLF=11
      CALLFCT(X,Y,DERY,P,V,BB,BK,CC,CVF,CVK,DS1,DS2,E,ES1,ES2,ES3,FD,FH,
     1 FL,FT,HH,HCS,ICC,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,TF,THF,THK,
     2 TST,TVK,VCS,W,WL,WT,XC,XCO,X1,X2,YO,DDX,DDXT,DTH,DX,DXT,
     3 DXF,DXL,DXR,DY,TH,XX,XT,XF,XL,XR,YY,FE,FF,S1,ST,YF,YR)
      GO TO 39
   37 IHLF=12
      GO TO 39
   38 IHLF=13
   39 IF(X    .GE.  T1) CALL OUTP(IHLF,X  ,P,V,Y,DERY,BB,BK,CC,CVF,CVK,
```

```
     * DS1,DS2,E,ES1,ES2,
     1 ES3,FD,FH,FL,FT,HH,HCS,ICD,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,
     2 TF,THF,THK,TST,TVK,W,WL,WT,XC,XCO,X1,X2,YO)
  40 RETURN
     END

      SUBROUTINE FCT(T,Y,DERY,P,V,B,BK,C,CVF,CVK,DS1,DS2,E,ES1,ES2,ES3,
     1 FD,FH,FL,FT,H,HCS,ICD,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,TF,THF,
     2 THK,TST,TVK,VCS,W,WL,WT,XC,XCO,X1,X2,YO,DDX,DDXT,DTH,DX,DXT,
     3 DXF,DXL,DXR,DY,TH,X,XT,XF,XL,XR,YY,FE,FF,S1,ST,YF,YR)
      COMMON/SIZES/K1,K2,K3
      COMMON/IO/ICRD,IPRT,IPUN
      COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
      COMMON PRMT(10),ST1,ST2, T1,T2,IDP
      DIMENSION Y(K3),DERY(K3)
      DIMENSION P(K2),V(K2)
      DIMENSION B(K1),BK(K1),C(K1),CVF(K1),CVK(K1),DS1(K1),DS2(K1)
      DIMENSION E(K1),ES1(K1),ES2(K1),ES3(K1),FD(K1),FH(K1),FL(K1)
      DIMENSION FT(K1),H(K1),HCS(K1),ICD(K1),IFT(K1),IRT(K1),RD(K1)
      DIMENSION RH(K1),RLF(K1),RLK(K1),RMI(K1),RT(K1),SP(K1),SPO(K1)
      DIMENSION TF(K1),THF(K1),THK(K1),TST(K1),TVK(K1),VCS(K1),W(K1)
      DIMENSION WL(K1),WT(K1),XC(K1),XCO(K1),X1(K1),X2(K1),YO(K1)
      DIMENSION DDX(K1),DDXT(K1),DTH(K1),DX(K1),DXT(K1)
      DIMENSION DXF(K1),DXL(K1),DXR(K1),DY(K1),TH(K1),X(K1),XT(K1)
      DIMENSION XF(K1),XL(K1),XR(K1),YY(K1)
      DIMENSION FE(K1),FF(K1)
      DIMENSION S1(K1),ST(K1)
      DIMENSION YF(K1),YR(K1)
      DO 3 I=1,NC
      I1=(I-1)*6+1
      X(I)=Y(I1)
      DX(I)=Y(I1+1)
      IF(T .GT. PRMT(1)+0.0001) GO TO 2
    1 DERY(I1+1)=0.
      DERY(I1+5)=0.
    2 DDX(I)=DERY(I1+1)
      YY(I)=Y(I1+2)
      DY(I)=Y(I1+3)
      TH(I)=Y(I1+4)
      DTH(I)=Y(I1+5)
    3 CONTINUE
      CALL HCF(P,DS1,DS2,E,ES1,ES2,ES3,HCS,TH,X,XC,XCO,X1,X2,S1,ST)
      CALL TRUCK(B,BK,DTH,DY,FD,FT,IFT,IRT,RD,RT,TF,TH,TST,TVK,YY,YC)
      CALL CVFS(P,V,C,CVF,CVK,ICD,SP,SPO,TH,VCS,YY,YF,YR,YO)
      GO TO (13,4,6,6),IJK
C
C    CALCULATE LADING FORCES
    4 DO 5 I=1,NC
      J=NC*6+(I-1)*2+1
      XL(I)=Y(J)
      DXL(I)=Y(J+1)
      FH(I)=WT(I)/386.4*DDX(I)
```

```
      RH(I)=FH(I)
    5 CONTINUE
      CALL HFORCE(CDX,DX,CXL,FL,RLF,WL,RLK,WL,X,XL,FE,FF)
      GO TO 15
    6 DO 7 I=1,NC
      I1=(I-1)*6+1
      XT(I)=X(I)+H(I)*TH(I)
      DXT(I)=DX(I)+H(I)*CTH(I)
      DDXT(I)=DCX(I)+H(I)*DERY(I1+5)
    7 CONTINUE
      IF(IJK .GE. 4) GO TO 10
C
C   CALCULATE TRUCK HORIZONTAL FORCES
    8 DO 9 I=1,NC
      J=NC*6+(I-1)*4+1
      XF(I)=Y(J)
      DXF(I)=Y(J+1)
      XR(I)=Y(J+2)
      DXR(I)=Y(J+3)
      FL(I)=0.
    9 CONTINUE
      GO TO 12
C
C   CALCULATE LADING AND TRUCK HORIZONTAL FORCES
   10 DO 11 I=1,NC
      J=NC*6+(I-1)*6+1
      XL(I)=Y(J)
      DXL(I)=Y(J+1)
      XF(I)=Y(J+2)
      DXF(I)=Y(J+3)
      XR(I)=Y(J+4)
   11 DXR(I)=Y(J+5)
      CALL HFORCE(DDX,DX,DXL,FL,RLF,WL,RLK,WL,X,XL,FE,FF)
   12 CALL HFORCE(DDXT,DXT,DXF,FH,THF,FT,THK,WT,XT,XF,FE,FF)
      CALL HFORCE(DDXT,DXT,DXR,RH,THF,RT,THK,WT,XT,XR,FE,FF)
      GO TO 15
C
C   NO LADINGS AND NO TRUCK HORIZONTAL DEGREES OF FREEDOM
   13 DO 14 I=1,NC
      FL(I)=0.
      FH(I)=WT(I)/386.4*DDX(I)
   14 RH(I)=FH(I)
   15 DO 24 I=1,NC
      I1=(I-1)*6+1
      I2=I1+1
      I3=I1+2
      I4=I1+3
      I5=I1+4
      I6=I1+5
      DERY(I1)=Y(I2)
      DERY(I2)=(P(I)-P(I+1)-FL(I)-FH(I)-RH(I))/W(I)*386.4
      DERY(I3)=Y(I4)
      DERY(I4)=(V(I)-V(I+1)-W(I)-WL(I)+FT(I)+RT(I))/(W(I)+WL(I))*386.4
```

```
      DERY(I5)=Y(I6)
      DERY(I6)=(P(I)*(E(I)-C(I)*Y(I5))-P(I+1)*(E(I)+C(I)*Y(I5))
     *+V(I)*(C(I)+E(I)*Y(I5))+V(I+1)*(C(I)-E(I)*Y(I5))
     *+FT(I)*(B(I)+H(I)*Y(I5))-RT(I)*(B(I)-H(I)*Y(I5))
     *-FH(I)*(H(I)-B(I)*Y(I5))-RH(I)*(H(I)+B(I)*Y(I5)))/RMI(I)
      GO TO (24,16,19,20),IJK
   16 J1=NC*6+(I-1)*2+1
      J2=J1+1
      IF(WL(I) .NE. 0.0) GO TO 18
   17 DERY(J1)=DERY(I1)
      DERY(J2)=DERY(I2)
      GO TO 24
   18 DERY(J1)=Y(J2)
      DERY(J2)=FL(I)/WL(I)*386.4
      GO TO 24
   19 J1=NC*6+(I-1)*4+1
      J2=J1+1
      J3=J1+2
      J4=J1+3
      DERY(J1)=Y(J2)
      DERY(J2)=FH(I)/WT(I)*386.4
      DERY(J3)=Y(J4)
      DERY(J4)=RH(I)/WT(I)*386.4
      GO TO 24
   20 J1=NC*6+(I-1)*6+1
      J2=J1+1
      J3=J1+2
      J4=J1+3
      J5=J1+4
      J6=J1+5
      IF(WL(I) .NE. 0.0) GO TO 22
   21 DERY(J1)=DERY(I1)
      DERY(J2)=DERY(I2)
      GO TO 23
   22 DERY(J1)=Y(J2)
      DERY(J2)=FL(I)/WL(I)*386.4
   23 DERY(J3)=Y(J4)
      DERY(J4)=FH(I)/WT(I)*386.4
      DERY(J5)=Y(J6)
      DERY(J6)=RH(I)/WT(I)*386.4
   24 CONTINUE
      DO 25 I=1,NCIM
      IF(ABS(DERY(I)) .LT. 1.0E-20) DERY(I)=0.0
   25 CONTINUE
      RETURN
      END

      SUBROUTINE OUTP(IHLF,T,P,V,Y,DERY,B,BK,C,CVF,CVK,DS1,DS2,E,ES1,ES2
     1,ES3,FD,FH,FL,FT,F,FCS,ICC,IFT,IRT,RD,RH,RLF,RLK,RMI,RT,SP,SPO,TF,
     2 THF,THK,TST,TVK,W,WL,WT,XC,XCC,X1,X2,YO)
      COMMON/SIZES/K1,K2,K3
      COMMON/IO/ICRD,IPRT,IPUN
```

```
      COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
      COMMON PRMT(10),ST1,ST2,T1,T2,IDP
      DIMENSION P(K2),V(K2)
      DIMENSION Y(K3),CERY(K3)
      DIMENSION B(K1),BK(K1),C(K1),CVF(K1),CVK(K1),DS1(K1),DS2(K1),E(K1)
      DIMENSION ES1(K1),ES2(K1),ES3(K1),FC(K1),FH(K1),FL(K1),FT(K1)
      DIMENSION H(K1),HCS(K1),ICD(K1),IFT(K1),IRT(K1),RD(K1),RH(K1)
      DIMENSION RLF(K1),RLK(K1),RMI(K1),RT(K1),SP(K1),SPC(K1),TF(K1)
      DIMENSION THF(K1),THK(K1),TST(K1),TVK(K1),W(K1),WL(K1),WT(K1)
      DIMENSION XC(K1),XCO(K1),X1(K1),X2(K1),YO(K1)
  101 FORMAT(/2X,'T = ',F10.4,5X,' IHLF = ',I2)
  102 FORMAT(12X,'CAR')
  103 FORMAT(26X,6F12.5)
  104 FORMAT(12X,'LACING')
  105 FORMAT(12X,'TRUCK')
  106 FORMAT(12X,'LACING & TRUCK')
  107 FORMAT(/8X,'I',6X,'P(I+1)',7X,'X1(I)',7X,'X2(I)',7X,'XC(I)',6X,
     *'V(I+1)',7X,'FL(I)',7X,'FH(I)',7X,'RH(I)')
  108 FORMAT(7X,I2,3X,8F12.5)
  109 FORMAT(/8X,'I',7X,'FT(I)',7X,'RT(I)',6X,'F.C.D.',6X,'R.C.D.',7X,
     *'SP(I)',6X,' IFT(I)',6X,' IRT(I)',6X,'ICD(I)')
  110 FORMAT(7X,I2,3X,5F12.5,5X,I2,10X,I2,10X,I2)
      IF(T .LT. T1) RETURN
    1 WRITE(IPRT,101)T,IHLF
      N1=1
      N2=NC*6
      WRITE(IPRT,102)
      WRITE(IPRT,103)(Y(I),I=N1,N2)
      GO TO (6,2,3,4),IJK
    2 N1=NC*6+1
      N2=NC*8
      WRITE(IPRT,104)
      GO TO 5
    3 N1=NC*6+1
      N2=NC*10
      WRITE(IPRT,105)
      GO TO 5
    4 N1=NC*6+1
      N2=NC*12
      WRITE(IPRT,106)
    5 WRITE(IPRT,103)(Y(I),I=N1,N2)
    6 WRITE(IPRT,107)
      DO 7 I=1,NC
    7 WRITE(IPRT,108)I,P(I+1),X1(I),X2(I),XC(I),V(I+1),FL(I),FH(I),RH(I)
      WRITE(IPRT,109)
      DO 8 I=1,NC
    8 WRITE(IPRT,110)I,FT(I),RT(I),FC(I),RD(I),SP(I),IFT(I),IRT(I),
     1 ICD(I)
      DO 9 I=1,NC
      XCO(I)=XC(I)
    9 SPO(I)=SP(I)
      T1=T+ST1-.0001
      IF(IPLOT .EQ. 0) RETURN
```

```
   10 IF(T .LT. T2) RETURN
C
C  DATA TO BE PLOTTED
   11 CONTINUE
      T2=T+ST2-.0001
      IDP=IDP+1
   12 RETURN
      END

      SUBROUTINE HCF(P,DS1,DS2,E,ES1,ES2,ES3,HCS,TH,X,XC,XCO,X1,X2,S1,T1
     1)
      COMMON/SIZES/K1,K2,K3
      COMMON/IO/ICRD,IPRT,IPUN
      COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
      DIMENSION P(K2)
      DIMENSION DS1(K1),DS2(K1),E(K1),ES1(K1),ES2(K1),ES3(K1),HCS(K1)
      DIMENSION TH(K1),X(K1),XC(K1),XCO(K1),X1(K1),X2(K1)
      DIMENSION S1(K1),ST(K1)
      NC1=NC-1
      DO 1 I=1,NC1
    1 XC(I)=X(I)-X(I+1)+E(I)*TH(I)-E(I+1)*TH(I+1)
      DO 45 I=1,NC1
      IF(I .NE. IM-1) GO TO 5
    2 IF(XC(I) .LT. 0.0) GO TO 5
    3 IF(IC .GT. 0) GO TO 5
    4 P(I+1)=0.
      X1(I)=0.
      X2(I)=0.
      GO TO 45
    5 HCS2=HCS(I)+HCS(I+1)
      IF(XCO(I) .LT. 0.0) GO TO 11
    6 IF(XC(I) .GE. 0.0) GO TO 8
    7 IJ=-1
      GO TO 16
    8 IF(XC(I) .GE. XCO(I)) GO TO 10
    9 IJ=1
      GO TO 37
   10 IJ=1
      GO TO 16
   11 IF(XC(I) .LT. 0.0) GO TO 13
   12 IJ=1
      GO TO 16
   13 IF(XC(I) .GT. XCO(I)) GO TO 15
   14 IJ=-1
      GO TO 16
   15 IJ=-1
      GO TO 37
C
C  LOADING
   16 IF(IJ .LT. 0) XC(I)=-XC(I)
   18 IF(XC(I) .GT. HCS2) GO TO 20
   19 P(I+1)=0.
```

```
      XS1=0.
      XS2=0.
      GO TO 42
   20 S1(I)=ES1(I)
      S1(I+1)=ES1(I+1)
      ST(I)=DS1(I)
      ST(I+1)=DS1(I+1)
   21 XC(I)=XC(I)-DCS2
      D1=S1(I)*ST(I)
      D2=S1(I+1)*ST(I+1)
      IF(C1 .GT. C2) GO TO 27
   22 E1=C1/S1(I+1)
      E2=ST(I)+(D2-C1)/ES3(I)
      D3=ST(I)+E1
      D4=E2+ST(I+1)
      IF(XC(I) .GE. C3) GO TO 24
   23 IK=1
      GO TO 32
   24 IF(XC(I) .GT. C4) GO TO 26
   25 IK=2
      GO TO 32
   26 IK=4
      GO TO 32
   27 E1=D2/S1(I)
      E2=ST(I+1)+(D1-C2)/ES3(I+1)
      D3=ST(I+1)+E1
      D4=E2+ST(I)
      IF(XC(I) .GE. C3) GO TO 29
   28 IK=1
      GO TO 32
   29 IF(XC(I) .GT. C4) GO TO 31
   30 IK=3
      GO TO 32
   31 IK=4
   32 GO TO (33,34,35,36),IK
   33 P(I+1)=XC(I)*S1(I)/(S1(I)+S1(I+1))*S1(I+1)
      XS1=P(I+1)/S1(I)
      XS2=P(I+1)/S1(I+1)
      GO TO 41
   34 P(I+1)=(XC(I)-ST(I)+C1/ES3(I))*ES3(I)/(S1(I+1)+ES3(I))*S1(I+1)
      XS1=(P(I+1)-C1)/ES3(I)+ST(I)
      XS2=P(I+1)/S1(I+1)
      GO TO 41
   35 P(I+1)=(XC(I)-ST(I+1)+D2/ES3(I+1))*ES3(I+1)/(S1(I)+ES3(I+1))*S1(I)
      XS1=P(I+1)/S1(I)
      XS2=(P(I+1)-C2)/ES3(I+1)+ST(I+1)
      GO TO 41
   36 P(I+1)=(XC(I)-ST(I)-ST(I+1)+D1/ES3(I)+C2/ES3(I+1))*ES3(I)
     * /(ES3(I)+ES3(I+1))*ES3(I+1)
      XS1=(P(I+1)-C1)/ES3(I)+ST(I)
      XS2=(P(I+1)-C2)/ES3(I+1)+ST(I+1)
      GO TO 41
C
```

```
C   UNLOADING
    37 IF(IJ .LT. 0) XC(I)=-XC(I)
    39 IF(XC(I) .LE. HCS2) GO TO 19
    40 S1(I)=ES2(I)
       S1(I+1)=ES2(I+1)
       ST(I)=DS2(I)
       ST(I+1)=DS2(I+1)
       GO TO 21
    41 XC(I)=XC(I)+HCS2
    42 IF(IJ .GE. 0) GO TO 44
    43 XC(I)=-XC(I)
       XS1=-XS1
       XS2=-XS2
       P(I+1)=-P(I+1)
    44 X1(I)=XS1
       X2(I)=XS2
    45 CONTINUE
       RETURN
       END

       SUBROUTINE TRUCK(B,BK,DTH,DY,FD,FT,IFT,IRT,RD,RT,TF,TH,TST,TVK,Y,
      1 YO)
       COMMON/SIZES/K1,K2,K3
       COMMON/IO/ICRD,IPRT,IPUN
       COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
       DIMENSION B(K1),BK(K1),DTH(K1),DY(K1),FD(K1),FT(K1),IFT(K1)
       DIMENSION IRT(K1),RD(K1),RT(K1),TF(K1),TH(K1),TST(K1),TVK(K1)
       DIMENSION Y(K1),YO(K1)
       PL=10.0
       DO 25 I=1,NC
       TSS=TST(I)
       CFF=TF(I)
       DO 25 J=1,2
       GO TO (1,2),J
     1 FAC=1.0
       GO TO 3
     2 FAC=-1.0
     3 A1=Y(I)+FAC*B(I)*TH(I)
       IF(A1 + YO(I) .LT. 0.0) GO TO 9
C
C   LIFT OFF
     4 GO TO (5,7),J
     5 FT(I)=0.
       IF(A1+YO(I) .LT. PL) GO TO 22
C
C   FRONT TRUCK IS SEPARATED FROM CAR BODY
     6 IFT(I)=1
       GO TO 22
     7 RT(I)=0.
       IF(A1+YO(I) .LT. PL) GO TO 22
C
C   REAR TRUCK IS SEPARATED FROM CAR BODY
```

```
    8 IRT(I)=1
      GO TO 22
C
C   NO LIFT OFF
    9 A2=-(A1+YO(I))
      DA=CY(I)+FAC*B(I)*CTH(I)
      GO TO (10,14),IT
C
C   COULOMB FRICTION FORCE
   10 IF(DA)11,12,13
   11 FF=CFF
      GO TO 15
   12 FF=0.
      GO TO 15
   13 FF=-CFF
      GO TO 15
C
C   VISCOUS FRICTION FORCE
   14 FF=-CFF*DA
   15 IF(A2 .GT. TSS) GO TO 19
C
C   TRUCK SPRING NOT BOTTOMED
   16 GO TO (17,18),J
   17 FT(I)=TVK(I)*A2+FF
      GO TO 22
   18 RT(I)=TVK(I)*A2+FF
      GO TO 22
C
C   TRUCK SPRING BOTTOMED
   19 GO TO (20,21),J
   20 FT(I)=TVK(I)*TSS+BK(I)*(A2-TSS)+FF
      GO TO 22
   21 RT(I)=TVK(I)*TSS+BK(I)*(A2-TSS)+FF
   22 GO TO (23,24),J
   23 FD(I)=A1
      GO TO 25
   24 RD(I)=A1
   25 CONTINUE
      RETURN
      END

      SUBROUTINE CVFS(P,V,C,CVF,CVK,ICD,SP,SPO,TH,VCS,Y,YF,YR,YO)
      COMMON/SIZES/K1,K2,K3
      COMMON/IO/ICRD,IPRT,IPUN
      COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
      DIMENSION P(K2),V(K2)
      DIMENSION C(K1),CVF(K1),CVK(K1),ICD(K1),SP(K1),SPO(K1),TH(K1)
      DIMENSION VCS(K1),Y(K1)
      DIMENSION YF(K1),YR(K1),YO(K1)
      CH=11.0
      DO 1 I=1,NC
      YF(I)=Y(I)+C(I)*TH(I)+YO(I)
```

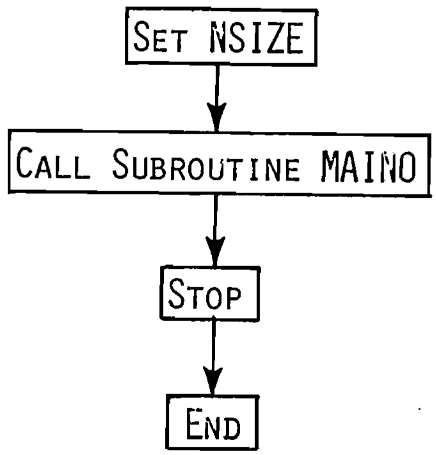
```
    1 YR(I)=Y(I)-C(I)*TH(I)+YO(I)
      NC1=NC-1
      DO 9 I=1,NC1
      VF=CVF(I)*ABS(P(I+1))
      SP(I)=YR(I)-YF(I+1)-SPO(I)
      ASP=ABS(SP(I))
      IF(SP(I) .GE. 0.0) GO TO 3
    2 FAC=-1.0
      SLACK=VCS(I)
      GO TO 4
    3 FAC=1.0
      SLACK=VCS(I+1)
    4 IF(ASP .GT. SLACK) GO TO 6
C
C   NO VERTICAL COUPLER FORCE
    5 V(I+1)=0.
      SP(I)=SPO(I)
      GO TO 9
C
C   COMPARE ELASTIC AND FRICTION FORCES
    6 CD=ASP-SLACK
      VE=CD/(1./CVK(I)+1./CVK(I+1))
      IF(VE .GT. VF) GO TO 8
C
C   SLIPPAGE REMAINS THE SAME
    7 V(I+1)=FAC*VE
      SP(I)=SPO(I)
      GO TO 9
C
C   CALCULATE NEW SLIPPAGE
    8 CE=CD*VF/VE
      V(I+1)=FAC*VF
      SP(I)=FAC*(CD-CE)+SPO(I)
    9 CONTINUE
      DO 11 I=1,NC1
      IF(ABS(SP(I)) .GT. CH) ICD(I)=1
   11 CONTINUE
      RETURN
      END

      SUBROUTINE HFORCE(CCX,CX,DXA,F,FC,FNOR,SK,WA,X,XA,FE,FF)
      COMMON/SIZES/K1,K2,K3
      COMMON/IO/ICRC,IPRT,IPUN
      COMMON/SCALAR/NC,IT,IM,IJK,IC,IPLOT,NDIM
      DIMENSION CCX(K1),CX(K1),DXA(K1),F(K1),FC(K1),FNOR(K1),SK(K1)
      DIMENSION WA(K1),X(K1),XA(K1)
      DIMENSION FE(K1),FF(K1)
      DO 12 I=1,NC
      IF(WA(I) .GT. 0.0) GO TO 2
C
C   NO HORIZONTAL FORCE
    1 F(I)=0.
```

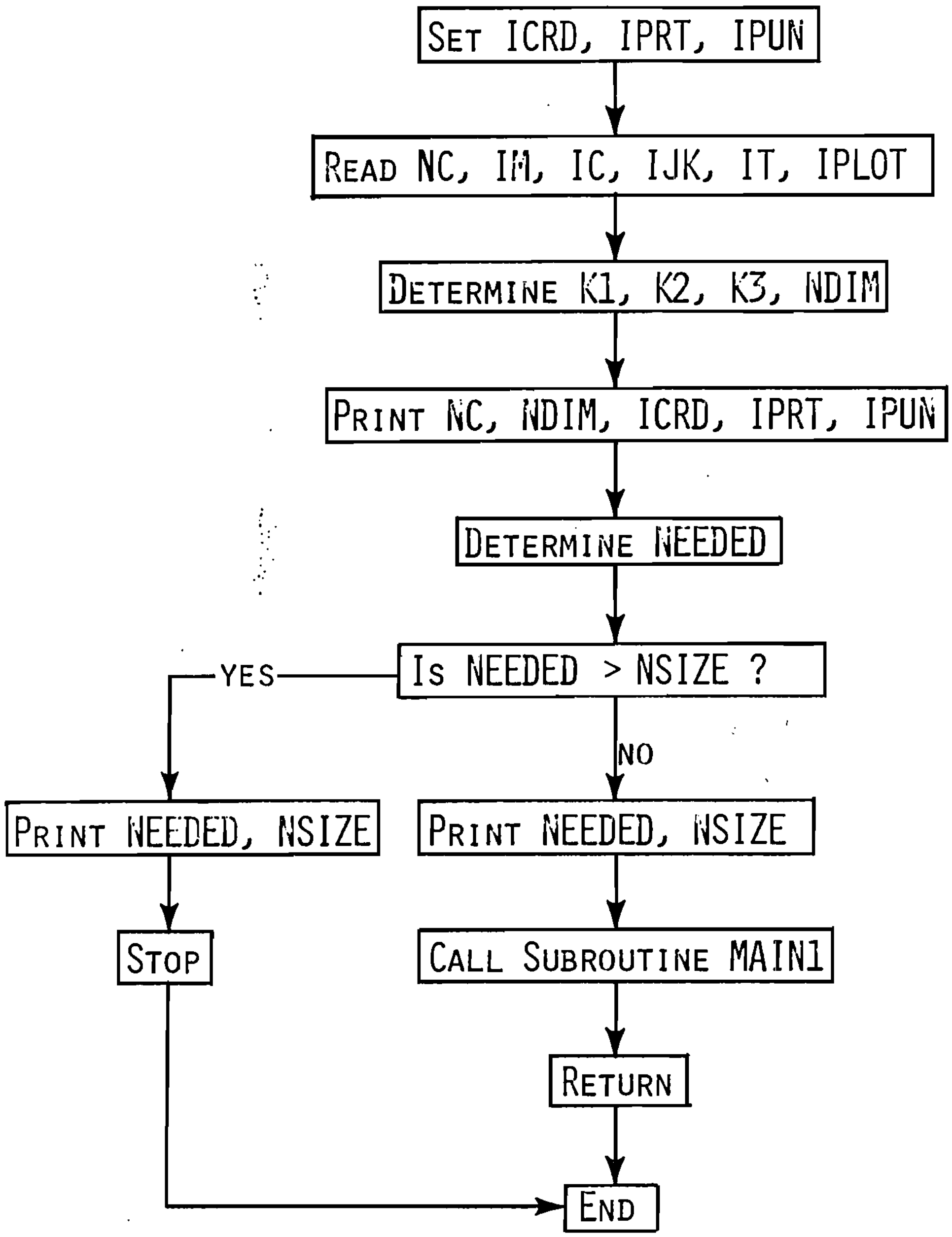
```
      GO TO 12
C
C   CALCULATE HORIZONTAL FORCE
    2 FFM=FC(I)*FNOR(I)
      FE(I)=SK(I)*(X(I)-XA(I))
      DV=ABS(DXA(I)-DX(I))
      IF(DV .GE. 0.0001) GO TO 8
    3 FI=-WA(I)/386.4*DDX(I)
      FA=FE(I)+FI
      IF(FFM .LT. ABS(FA)) GO TO 5
C
C   NO RELATIVE MOTION
    4 FF(I)=-FA
      GO TO 11
C
C   WITH RELATIVE MOTION
    5 IF(FA .GT. 0.0) GO TO 7
    6 FF(I)=FFM
      GO TO 11
    7 FF(I)=-FFM
      GO TO 11
    8 IF(DXA(I) .GE. DX(I)) GO TO 10
    9 FF(I)=FFM
      GO TO 11
   10 FF(I)=-FFM
   11 F(I)=FE(I)+FF(I)
   12 CONTINUE
      RETURN
      END
```

9.2 Appendix B - Detailed Flow Charts

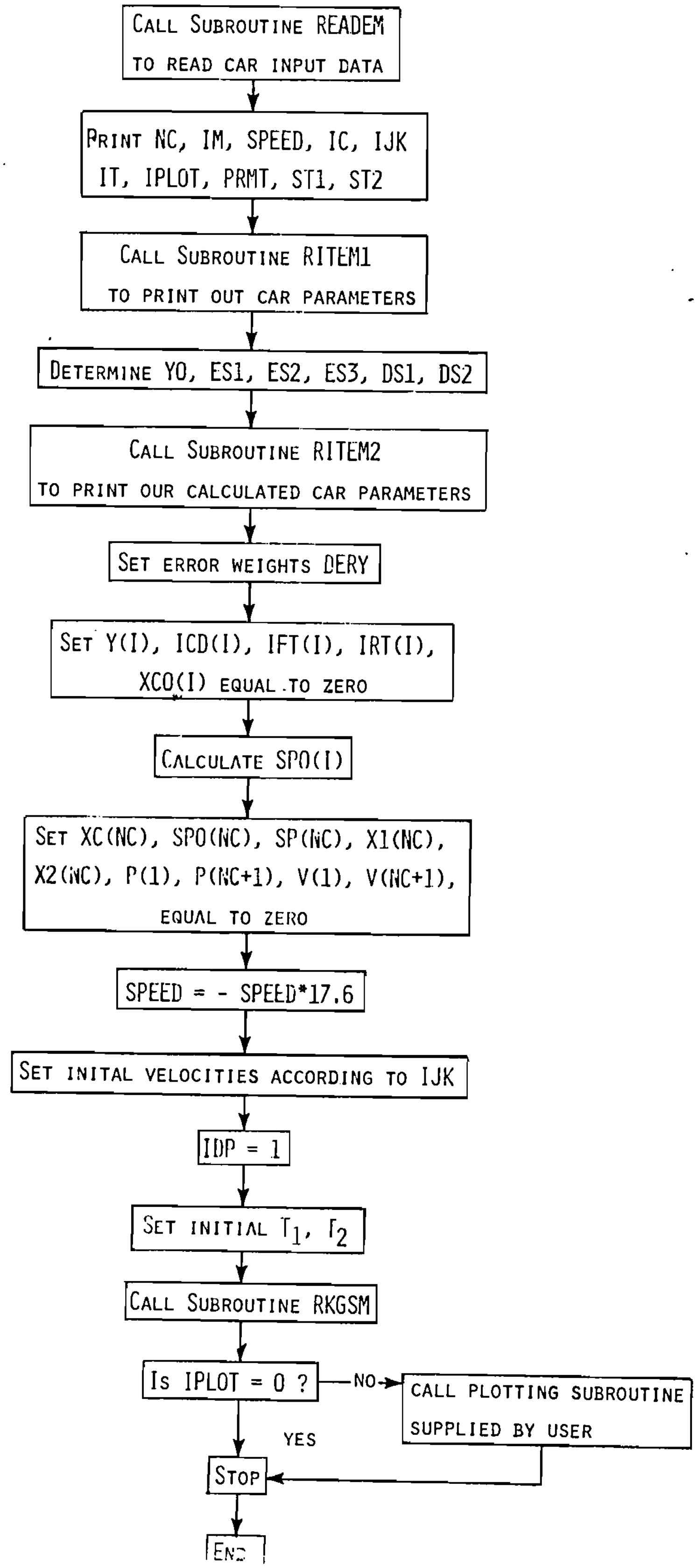
MAIN PROGRAM FLOW CHART



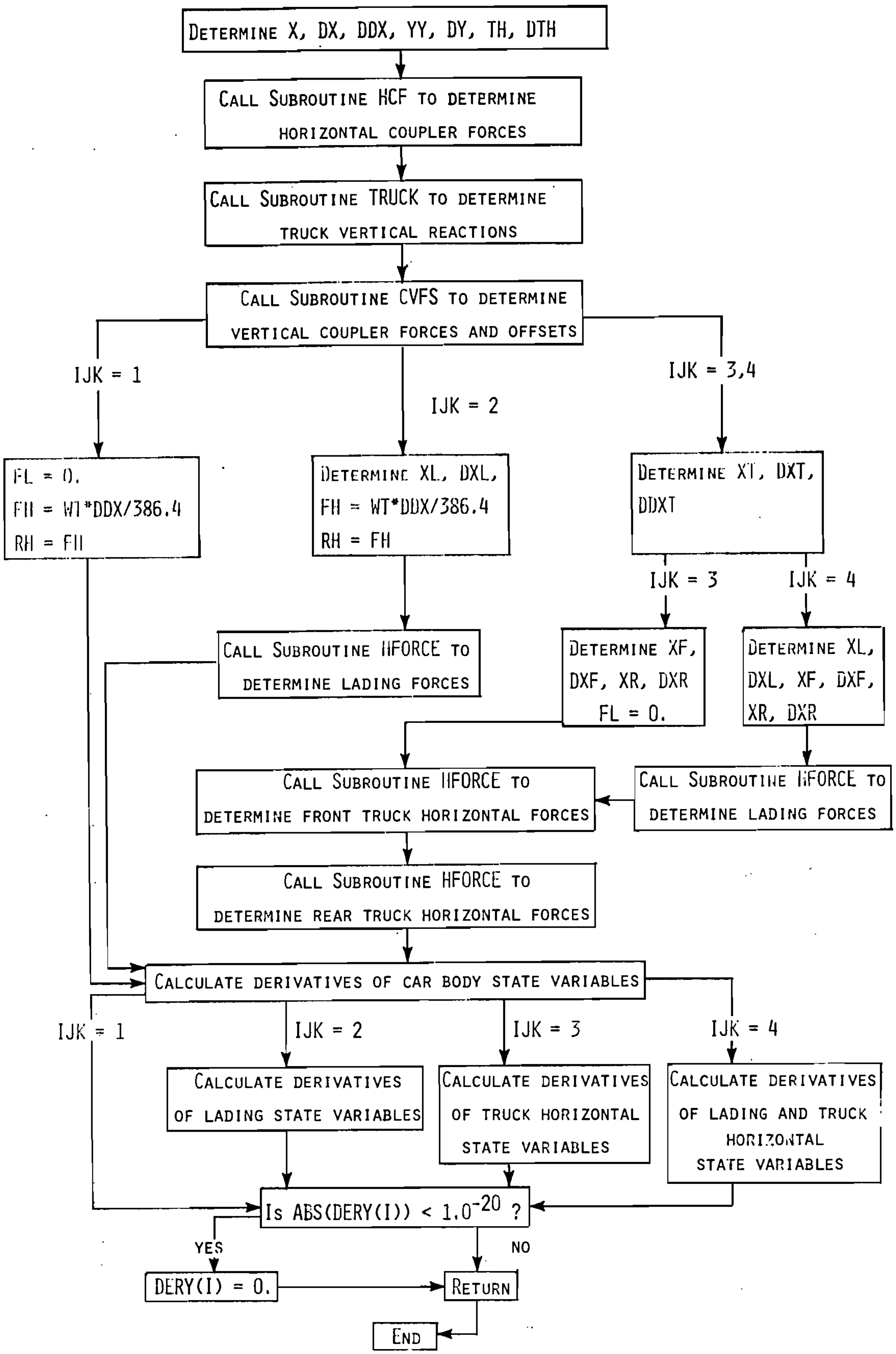
Subroutine MAIN0 flow chart (MAIN0 is called by the main program)



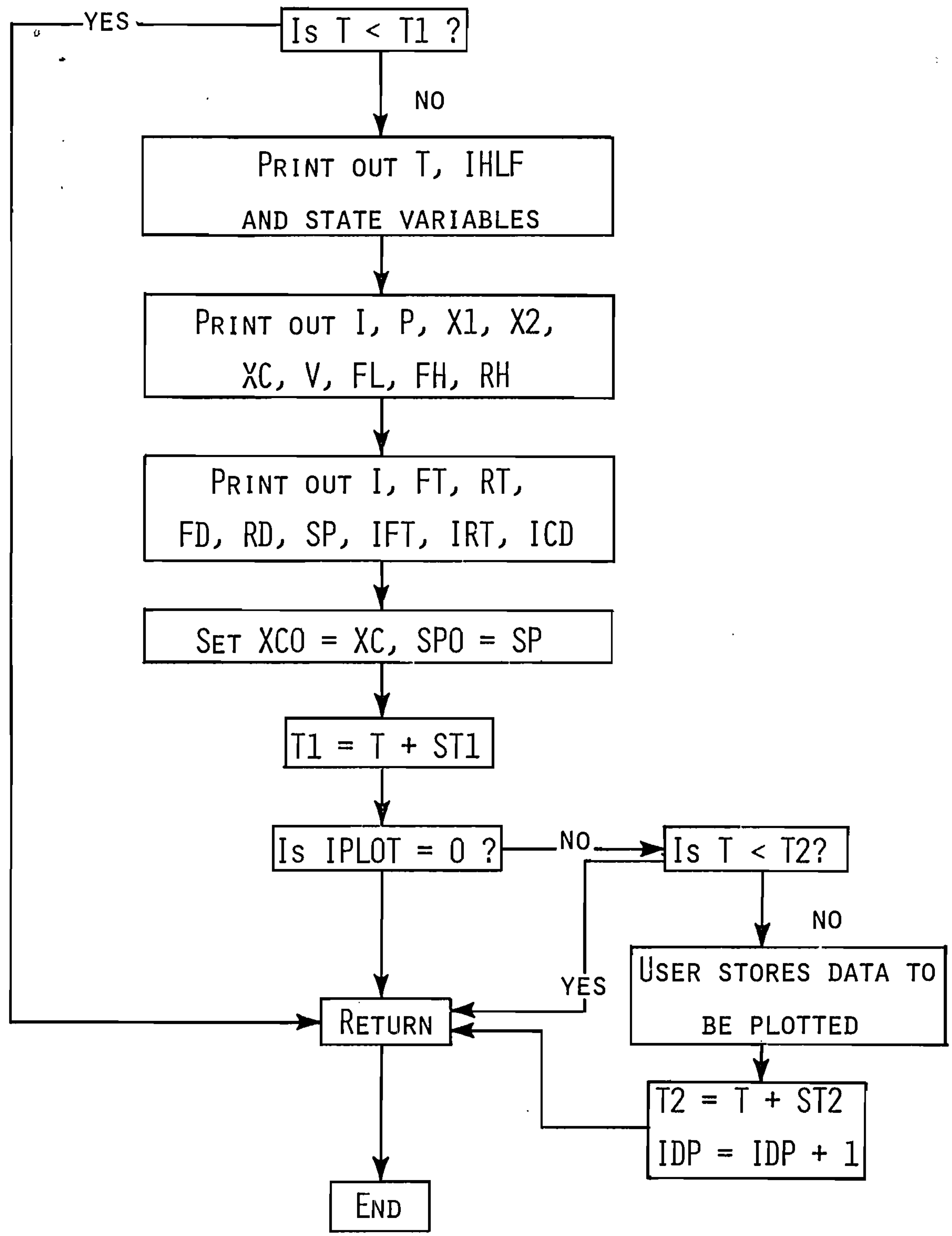
SUBROUTINE MAIN1 FLOW CHART (MAIN1 IS CALLED BY MAIN0)



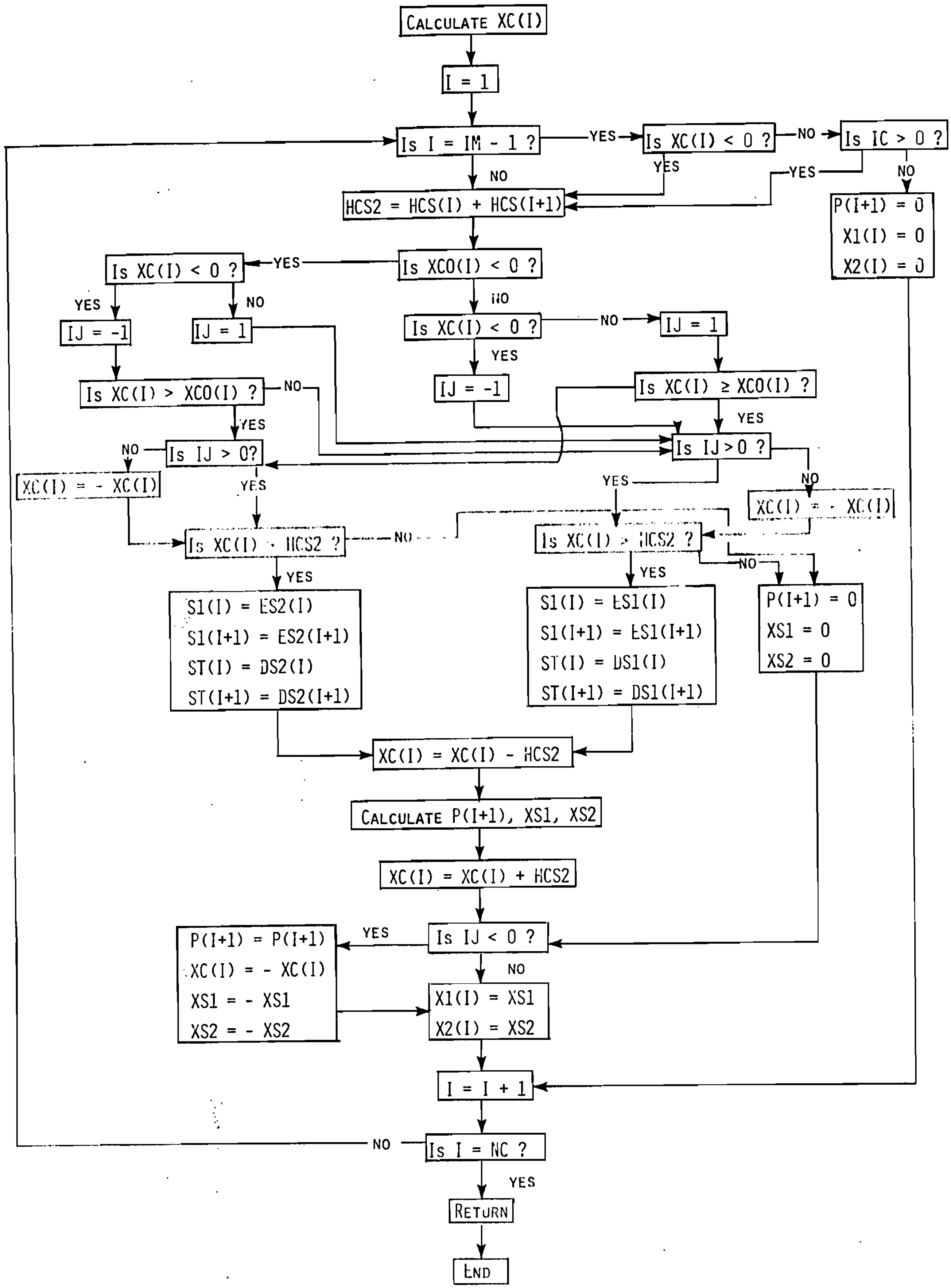
SUBROUTINE FCT FLOW CHART (FCT IS CALLED BY RKGSM)



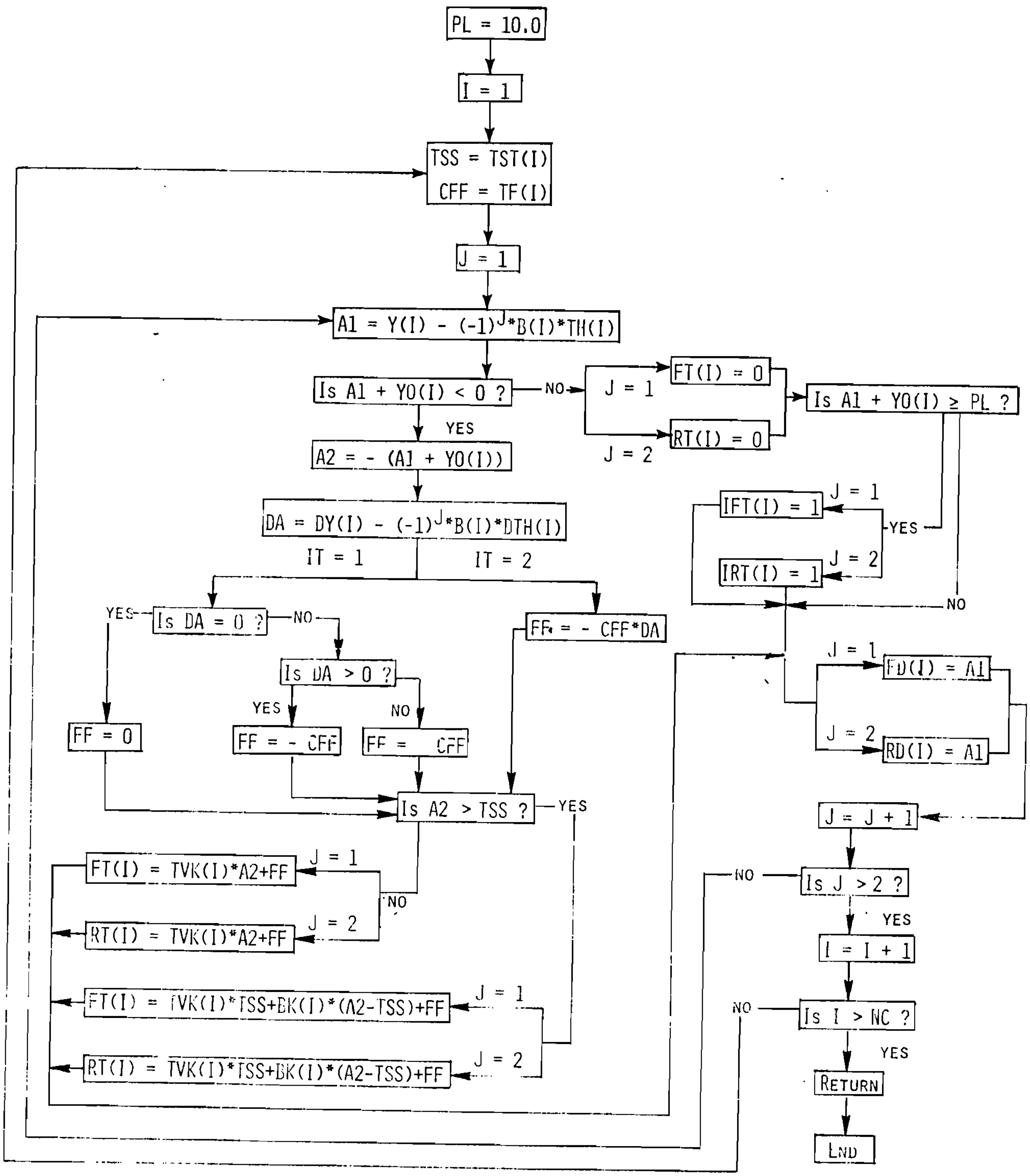
Subroutine OUTP flow chart (OUTP is called by RKGSM)



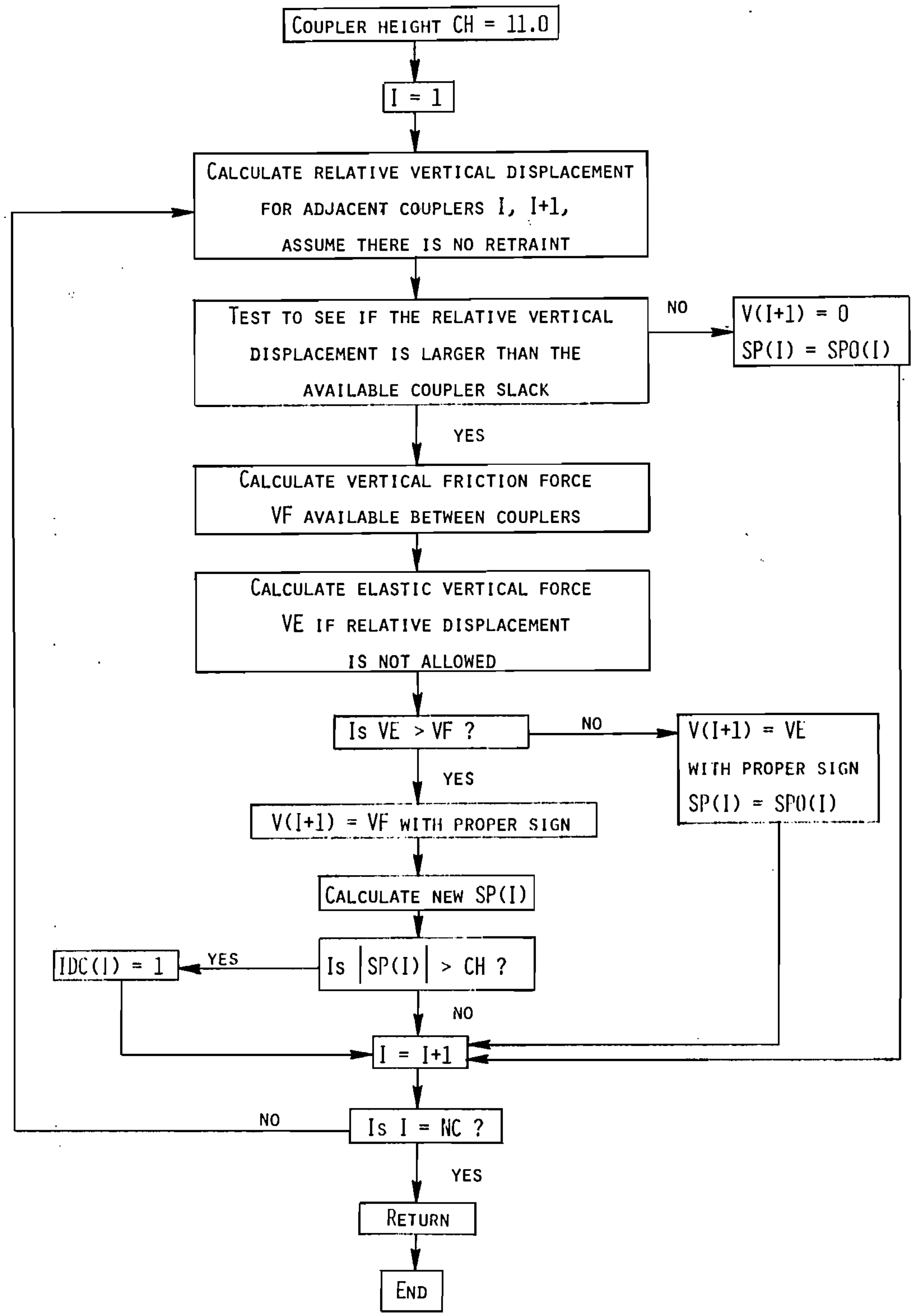
Subroutine HCF flow chart (HCF is called by FCT)



SUBROUTINE TRUCK FLOW CHART (TRUCK IS CALLED BY FCT)



<u>Subroutine CVFS flow chart</u> (CVFS is called by FCT)



Subroutine HFORCE flow chart (HFORCE is called by FCT)