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Unclas
G3/85 27874

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

A P P E N D I C E S

C1 & C3

PRELIMINARY DESIGN DATA PACKAGE

PREPARED FOR:

JET PROPULSION LABORATORIES

CONTRACT NUMBER 955189

PREPARED BY:

SOUTH COAST TECHNOLOGY, INC.

JULY 25, 1979

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C1.1 HYBRID2

1. Program Description

HYBRID2 computes the fuel and energy consumption of a hybrid vehicle with a bi-modal control strategy over specified component driving cycles. Fuel and energy consumption are computed separately for the two modes of operation. The program also computes yearly average fuel and energy consumption using a composite driving cycle which varies as a function of daily travel.

The modelling techniques used include the following:

Heat engine - represented by a map of bsfc as a function of bmep and rpm, together with a curve of maximum torque versus rpm. The displacement of the engine for which this data is supplied is used as input; the program has provisions for scaling the data to other displacements.

Electric motor/controls - electrical input represented as a constant load plus shaft power divided by a fixed efficiency, in both driving and braking modes. Maximum (driving) and minimum (braking) torque as functions of rpm are also required.

Battery - modelled by a fractional depletion technique using the power averaged over a specified time interval rather than instantaneous power.

Engine accessory load - represented by a curve of torque required vs. system output (torque converter input) rpm. Included in these is the transmission front pump, in addition to belt-driven accessories.

Torque converter - represented by curves of speed and torque ratios (output/input) as functions of an output speed-torque parameter equal to output speed/output torque. An input speed-torque factor, $(\text{input speed})^2/$ (input torque), at stall must also be specified.

Gearbox - represented by a set of gear ratios with different efficiencies for each ratio. Spin loss coefficients (exclusive of the front pump) may also be specified.

Differential - same treatment as gearbox.

Vehicle road load - represented by a combination of an aerodynamic load (proportional to speed squared) and tire rolling resistance. The rolling resistance coefficients can include a constant term and one which is linear with vehicle speed.

The program structure is modular, with the control strategy and shift strategies being contained in separate subroutines. A breakdown of the program routines and their functions is as follows:

1. HYBRID2 (Main Program)
   - Input of case data
   - Output
   - Numerical integration
   - Computation of yearly average fuel and energy consumption from individual driving cycle results.
2. VEHIC
   - Computation of road loads, power flow through the vehicle system up to the torque converter output.

- Computation of derivatives of all variables of integration.

3. HYREAD
   - Input of fixed, detailed component data.
4. GRSHFT
   - Controls transmission gear ratio in accord with a pre-set shift strategy.
5. PMOVR
   - Controls heat engine/motor power split in accord with a pre-set control strategy.
6. TQCON
   - Computes torque converter input speed and torque given output conditions, or output torque and input speed given input torque and output speed.
7. FILTER
   - Filters battery output power to provide a smoothed battery output power curve.
8. INT1, INT2
   - One and two dimensional interpolation routines, respectively.

PARAMETERS		UNITS	DESCRIPTION
EQUATION	PROGRAM		
	NRPM	—	Number of RPM's (engine)
	NMEP	—	Number of BMEP's and BSFC's
	FUELSG	g/cc	Fuel specific gravity
	DISPL	cc	Displacement
	SKALE	—	Scale factor for engine
	RPM(20)	rpm	RPM (engine)
	TQMAX(20)	ntm	Maximum torque (engine)
	BMEP(20)	bar	Brake mean effective pressure
	BSFC(20,20)	gm/kw·hr	Brake specific fuel consumption
	NOP	—	Number of engine powers
	RPMBST	rpm	Best operating speed (engine)
	PBEST	KW	Best operating power (engine)
	PEOP(20)	KW	Engine power
	RPMEOP(20)	rpm	Optimum engine speed at specified power
	NSPMO	—	Number RPM's (motor)
	EMUM	—	Motor efficiency
	EMUG	—	Generator efficiency
	TMSKL	—	Scale factor for motor
	PINNLD	KW	No load input power (motor)
	RPMIDL	rpm	Idle speed (motor)
	RPMOPM	rpm	Best operating speed (motor)
	SPMO(20)	rpm	RPM (motor)
	TMOMAX(20)	ntm	Maximum torque (motor)
	TMOMIN(20)	ntm	Minimum torque (motor)
	JCVT	—	=1→ continuously variable transmission (CVT)
	EMUCVT	—	Efficiency (CVT)
	RATUP	—	Speed up ratio (CVT)
	RATDN	—	Slowdown ratio (CVT)
	NTSP	—	Number of TSP's, TQR's and SPR's
	CTCZRO	rpm²/ntm	NI**2/TI (STALL)
	TSP(20)	rpm/√ntm	NO/√TO (MODE 1)
	TSP2(20)		NO/√TO (MODE 2)
	TQR(20)	—	TO/TI
	SPR(20)	—	NO/NI
	NGEAR	—	Number of gears
	NTH	—	Number of THSET's UPSHIFTs and DNSHIFTs
	UPSEL	rpm	Shift up for electric operation
	DNSEL	rpm	Shift down for electric operation
	NLOCK(5)	—	Lockup (Gear box)
	TRATIO(5)	—	Ratio (gear box)

PARAMETERS: EQUATION	PARAMETERS: PROGRAM	UNITS	DESCRIPTION
	CT2(5)	ntm/rpm	Spin loss coefficient (gear box)
	EMUT(5)	—	Torque efficiency (gear box)
	THSET(5)	KW	Set of powers defining shift function
	UPSHFT(5)	rpm	Upshift RPM
	DNSHFT(5)	rpm	Downshift RPM
	NDDSCH	—	Number discharge depths (battery)
	NDENS	—	Number of specific powers (battery)
	WE	KG	Battery Mass
	EBMAX	wh/KG	Energy density (battery)
	EMURG	—	Average regeneration efficiency (battery)
	EMURG2	—	Maximum regeneration efficiency (battery)
	CHGEFF	—	Recharge efficiency (battery)
	DDISCH(20)	—	Discharge depth (battery)
	CYCLES(20)	—	Cycle life (battery)
	PDENS(20)	KW	Specific power (battery)
	EDENS(20)	MJ	Specific energy (battery)
	DRATIO	—	Differential ratio
	CD1	ntm	Spin loss coefficient (differential)
	CD2	ntm/rpm	Spin loss coefficient (differential)
	EMUD	—	Torque efficiency (differential)
	RTIRE	m	Rolling radius (tire)
	CTIRE1	—	Rolling resistance coefficient (tire)
	CTIRE2	1/(km/hr)	Rolling resistance coefficient (tire)
	NAX	—	Number speeds and torques (accessory load)
	RPMAX(20)	rpm	Speed (accessory load)
	TAX(20)	nt·m	Torque (accessory load)
	VMASS	KG	Vehicle mass
	DLI	kg·m²	Driveline inertia
	CDA	m²	Drag coefficient * area
	NCYCLE	—	Number of driving cycles
	NTC(3)	—	TIMC, SPEDC matrix size
	NPRTC(3)	—	Output print flag for driving cycle
	NUNITS	—	Miles/hr to km/hr conversion flag
	DTC(3)	SEC	Time interval for driving cycles
	TFC(3)	SEC	Final time for driving cycles
	TIMC(3,200)	SEC	Time (driving cycle)
	SPEDC(3,200)	KM/HR	Speed (driving cycle)
	NCOMP	—	DSUP, DNC, GAMMA matrix size } TRAVEL DISTRIBUTION DATA
	DSTAV	—	Average usage } TRAVEL DISTRIBUTION DATA

PARAMETERS		UNITS	DESCRIPTION
EQUATION	PROGRAM		
	DSUP(30)	KM	Maximum distance-driving cycle } TRAVEL
	DNC(30)	—	Fraction of total distance } DISTRIBUTION
	GAMMA(30,3)	—	Driving cycle weights } DATA
	NCASE	—	Number of cases
	TEOMIN	nt·m	Minimum engine torque (MODE 1)
	TEOMN2	nt·m	Minimum engine torque (Mode 2)
	DBMAX	—	Battery discharge limit
	PEOMIN	KW	Heat engine minimum power
	VMAX	km/hr	Transition speed
	DTFLTR	—	low-pass filter sub-interval length

VARIABLES: EQUATION	VARIABLES: PROGRAM	UNITS	DESCRIPTION
	A(3)	m/sec^2	Vehicle acceleration vector
	ABPI	J	Absolute value battery power
	BDBAR(30)	KW	Battery energy consumption - composite cycle
	BLIFE	Km	Battery life (expected)
	BPI	J	Battery power
	DBAR(30)	Km	Interpolated values of driving cycle distance
	DDAV	Km	Average distance on driving cycle
	DELT	SEC	Time interval size
	DEPL(3)	1/Km	Battery depletion on each cycle
	DIST(3)	m	Distance on each cycle
	DLOW	Km	Minimum distance on driving cycle
	DT	SEC	Time increment
	EB	MJ	System output energy - Mode 1
	EB2	MJ	System output energy - Mode 2
	EBMAX	wh/KG	Energy density (battery)
	ECAV	MJ/Km	Yearly average energy consumption
	ECBAR(30)	MJ/Km	Composite cycles energy consumption - Mode
	ECBAR2(30)	MJ/Km	Composite cycles energy consumption - Mode
	ECHE(3)	MJ/Km	Cycle heat engine energy consumption
	ECMAV(30)	MJ/Km	Composite cycles mode averaged energy consumption
	ECONS(3)	MJ/Km	Cycle energy consumption - Mode 1
	ECONS2(3)	MJ/Km	Cycle energy consumption - Mode 2
	ECSYS(3)	MJ/Km	Cycle system energy consumption
	EHEAV	MJ/Km	Yearly avg. heat engine energy consumption
	EHEBAR(30)	MJ/Km	Composite cycles heat engine energy consumption
	EK(80)	—	YDCT [illegible] vector
	EKIN	MJ	Kinetic energy
	ERG(2800)	MJ	Battery specific energy
	ESYSAV	MJ/Km	Yearly average system energy consumption
	ESYSBR(30)	MJ/Km	Composite cycles system energy consumption
	FCAV	g/Km	Yearly average fuel consumption
	FCBAR(30)	g/Km	Composite cycles fuel consumption - Mode 1
	FCBAR2(30)	g/Km	Composite cycles fuel consumption - Mode 2
	FCMAV(30)	g/Km	Composite cycles mode averaged fuel consumption
	FCONS	g/Km	Cycle fuel consumption, Mode 1
	FCONS2	g/Km	Cycle fuel consumption, Mode 2
	FEAV	Km/L	Yearly averaged fuel economy
	HEEF	—	Heat engine energy fraction
	IBP(20)	—	Storage for cycle battery power distribution

VARIABLES		UNITS	DESCRIPTION
EQUATION	PROGRAM		
	INT1	—	Interpolation subroutine (1 d[illegible])
	INT2	—	In[illegible] subroutine (2 dimensional)
	ITIBP	—	Total number of cycle time interations
	K	—	Print skip control counter
	NPRNT	—	Number of skips between successive prints
	NTIME	—	Number of TIME's and SPEED's
	PBRK	KW	Braking power
	PED	KW	Engine output power
	PED2	KW	[illegible] output power 2
	PEDP	KW	Set of powers for optimum power curve
	PGO	KW	Regenerative output power
	PMO	KW	Motor output power
	PMO2	KW	Motor output power 2
	PMOT(2800)	W	Storage for cycle specific battery power.
	PRW	KW	Rear wheel power
	PSO	KW	Hybrid system output power
	PSO2	KW	Hybrid [illegible] output power 2
	RANGE(30)	KM	Range for new battery discharge limit
	RFRAC(30)	—	Composite cycles fraction of total driving distance
	RPMTC1	rpm	Torque converter RPM - Mode 1
	RPMTC2	rpm	Torque converter RPM - Mode 2
	SPEED(200)	KM/HR	Dr[illegible] speed
	SPENG(25)	MJ	Composite cycle specific energy - Mode 1
	SPPWR(25)	KW	Composite cycles specific power - Mode 1
	T	SEC	[illegible]e in simulation
	TIME(200)	SEC	Driving cycle time
	TTMP	SEC	Time holder
	V(6)	km/hr	Vehicle speed vector
	VAVG(3)	m/sec	Average velocity
	VBAR(25)	m/sec	Composite cycles average speed
	VMASS2	kg	Effective [illegible]
	VMPS	m/sec	Vehicle speed
	VRECIP	sec/m	Reciprocal of avg velocity for composite cycl
	VTMP	m/sec	Velocity hold
	VTMPL	m/sec	Velocity hold
	WPAV	KW/km	Yearly average wallplug output

VARIABLES		UNITS	DESCRIPTION
EQUATION	PROGRAM		
	Y(1)	MJ	Aerodynamic + rolling resistance energy loss
	Y(2)	MJ	Drive train energy output - Mode 1
	Y(3)	MJ	Drive train energy output - Mode 2
	Y(4)	MJ	Braking output energy
	Y(5)	MJ	System output energy - Mode 1
	Y(6)	MJ	System output energy - Mode 2
	Y(7)	MJ	Engine output energy - Mode 1
	Y(8)	MJ	Engine output energy - Mode 2
	Y(9)	MJ	Motor shaft output energy - Mode 1
	Y(10)	MJ	Motor shaft output energy - Mode 2
	Y(11)	m/sec	Velocity
	Y(12)	Km	Distance
	Y(13)	MJ	Generator output energy
	Y(14)	sec	Heat engine on time - Mode 1
	Y(15)	sec	Heat engine on time - Mode 2
	Y(16)	g	Fuel output energy - Mode 1
	Y(17)	g	Fuel output energy - Mode 2
	Y(18)	MJ	System Output energy - Mode 1
	Y(19)	MJ	System Output energy - Mode 2
	YDOT(20)	—	Runga - Kutta integration variables
	YTMP(20)	—	Runga - Kutta integration variables
	NOT	—	Number of entries in vector DMOT after Power function smoothed
	JGEAR	—	Gear Mode 1 Current [illegible]
	JGEAR2	—	Gear Mode 2 Current [illegible]
	NTM	—	Number of entries in vector PMOT
	TF	sec	Final time in simulation of cycle

VARIABLES EQUATION	VARIABLES PROGRAM	UNITS	DESCRIPTION
	BRMEP	bar	[illegible] mean effective pressure
	BRMEP2	bar	Brake mean effective pressure 2
	FA	nt	Aerodynamic drag force
	FAC	nt	Acceleration force on vehicle
	FC	g/hr	Engine fuel rate - Mode 1
	FC2	g/hr	Engine fuel rate - Mode 2
	FG	nt	Road grade force
	FNET	nt	Net vehicle force
	FR	nt	Rolling resistance force
	PA	KW	Aerodynamic drag power
	PD	KW	Differential output power
	PLTC	KW	Power load on torque converter - Mode 1
	PLTC2	KW	Power load on torque converter - Mode 2
	PR	KW	Rolling resistance power
	PRW	KW	Rear wheel power
	PT	KW	Transmission output power
	RPMDO	rpm	Differential output rpm
	RPMEO	rpm	Engine output rpm
	RPMEO2	rpm	[illegible] output rpm 2
	RPMSO	rpm	Hybrid system output rpm
	RPMSO2	rpm	Hybrid system output rpm 2
	RPMTO	rpm	Transmission output [illegible]
	SFC	g/KWH	[illegible] fuel [illegible]
	TDO	nt·m	Differential output torque
	TEO	nt·m	[illegible] output torque
	TEO2	nt·m	Engine output torque 2
	TLFD	nt·m	Diff [illegible]
	TLFT	nt·m	Transmission torque loss
	TLFT2	nt·m	Transmission torque loss 2
	TSO	nt·m	Hybrid [illegible] output [illegible]
	TSO2	nt·m	Hybrid system output [illegible]
	TTO	nt·m	Transmission output torque
	ILC	—	Gear lockup flag Mode 1
	ILC2	—	Gear lockup flag Mode 2

VARIABLES		UNITS	DESCRIPTION
EQUATION	PROGRAM		
	CC	KW/(rad/sec)	(rad/sec)/(1000 rpm)
	PCOM	KW	
	PHEMAX	KW	Maximum heat engine power
	PHEMIN	KW	Minimum heat engine power
	PMMAX	KW	Maximum motor power
	PNOM	KW	Nominal power
	RPMTC	rpm	Torque converter rpm
	RPMTCN	rpm	Torque converter input rpm
	RPMTCO	rpm	Torque converter output rpm
	TACC	nt·m	Accessory output torque
	TGO	nt·m	Generator output torque
	THEMAX	nt·m	Maximum heat engine torque
	TMMAX	nt·m	Maximum motor torque
	TMMIN	nt·m	Minimum motor torque
	TMO	nt·m	Motor output torque
	TMO2	nt·m	Motor output torque 2
	TTCIN	nt·m	Torque converter input torque
	TTCN1	nt·m	Torque converter input torque - Mode 1
	TTCN2	nt·m	Torque converter input torque - Mode 2
	TTCO	nt·m	Torque converter output torque
	JBRK	--	Braking (not) required flag

VARIABLES		UNITS	DESCRIPTION
EQUATION	PROGRAM		
	SPRAT	—	speed ratio
	TQRAT	—	[illegible]
	TSPAR	[illegible]	torque speed ratio
	TSPAR2	[illegible]	[illegible] 2

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

PROGRAM: HYBRID2
ROUTINE: MAIN PROGRAM
NAME:
DATE:
PAGE OF

FORTRAN STATEMENT
0 ZERO, 0 ALPHA O — 1 = ONE, I = ALPHA I — 2 = TWO, Z = ALPHA Z

```
          RUN DATA
     NCASE

          CASE DATA
     TEOMIN    TEOMN2    DAMAX     PEOMIN    VMAX
     DTFLTR
```


FORM NO. GRC 109 REV. 1

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

PROGRAM: HYBRID2

ROUTINE: [illegible]

NAME:

DATE:

FORTRAN STATEMENT — 0 ZERO / O ALPHA O; 1 = ONE / I = ALPHA I; 2 = TWO / Z = ALPHA Z

STATEMENT NO.	7–10	11–20	21–30	31–40	41–50	51–60	61–70
		ENGINE DATA					
	NRPM	NMEP	FUELOG	DISPL	SKALE		
RPM(1)		TQMAX(1)	...	RPM(NRPM)	TQMAX(NRPM)	BMEP(1)	...
BMEP(NMEP)		BSFC(1,1)	...	BSFC(NRPM,NMEP)			
	NOP	RPMBST	PBEST				
[illegible](1)		RPMEQR(1)	...	[illegible](NOP)	RPMEQR(NOP)		
		MOTOR/GENERATOR DATA					
	NSPMO	EMUM	EMUG	TMSKL	PINNLD	RPMIDL	RPMOPM
SPMO(1)		TMOMAX(1)	TMOMIN(1)	...	SPMO(NSPMO)	TMOMAX(NSPMO)	TMOMIN(NSPMO)
	JCVT						
		CONTINUOUSLY VARIABLE TRANSMISSION DATA					
EMUCVT		RATIUP	RATIDN				
		TORQUE CONVERTER DATA					
	NTSP						
CTCZRD		TSR(1)	TQR(1)	SPR(1)	...	TSR(NTSP)	TQR(NTSP)
SPR(NTSP)							

FORM NO. [illegible]

FORTRAN CODING FORM

GENERAL RESEARCH CORPORATION

PROGRAM: HYBRID2

ROUTINE: HYREAD

NAME:

DATE:

PAGE 2 OF 3

FORTRAN STATEMENT

0 ZERO / 0 ALPHA O — 1 = ONE / I = ALPHA I — 2 = TWO / Z = ALPHA Z

SERIAL NUMBER

```
          TRANSMISSION DATA
     NGEAR       NTH      UPSEL      DNSEL
     NLOCK(1) T[illegible](1)  [illegible](1)  [illegible](1)  [illegible](1)  . . .  NLOCK(NGEAR)
     RATIO(NGEAR)  CT1(NGEAR)  CT2(NGEAR)  EMUT(NGEAR)
     THSFT(1)  UPSHFT(1)  DNSHFT(1)  . . .  THSFT(NTH)  UPSHFT(NTH)  DNSHFT(NTH)

          BATTERY DATA
     NDDSCH      NDENS        WB      EBMAX      EMURG     EMURG2     CHGEFF
     DDISCH(1)  CYCLES(1)  . . .  DDISCH(NDDSCH)  CYCLES(NDDSCH)
     PDENS(1)   EDENS(1)   . . .  PDENS(NDENS)   EDENS(NDENS)
          DIFFERENTIAL AND TIRE DATA
     DRATIO      CD1       CD2       EMUD      CTIRE     CTIRE1     CTIRE2
          ACCESSORY DATA
     NAX
     RPMAX(1)   TAX(1)   . . .   RPMAX(NAX)   TAX(NAX)
          VEHICLE DATA
     VMASS       DLI       CDA
          DRIVING CYCLE DATA
     NCYCLE
     NTC(1)  NPRTC(1)  NUNITS  DTC(1)  TTC(1)  . . .  NTC(NCYCLE)
     NPRTC(NCYCLE)  NUNITS  DTC(NCYCLE)  TTC(NCYCLE)
     TIMC(1,1)  SPEED(1,1)  . . .  TIMC(N[illegible]  SPEED(N[illegible]
```

FORM NO. GRC 103 REV. 1

GRC
GENERAL RESE CH CORPORATION

FORT RAN CODING FORM

PROGRAM HYREDR [illegible]

ROUTINE HYREND

NAME

DATE

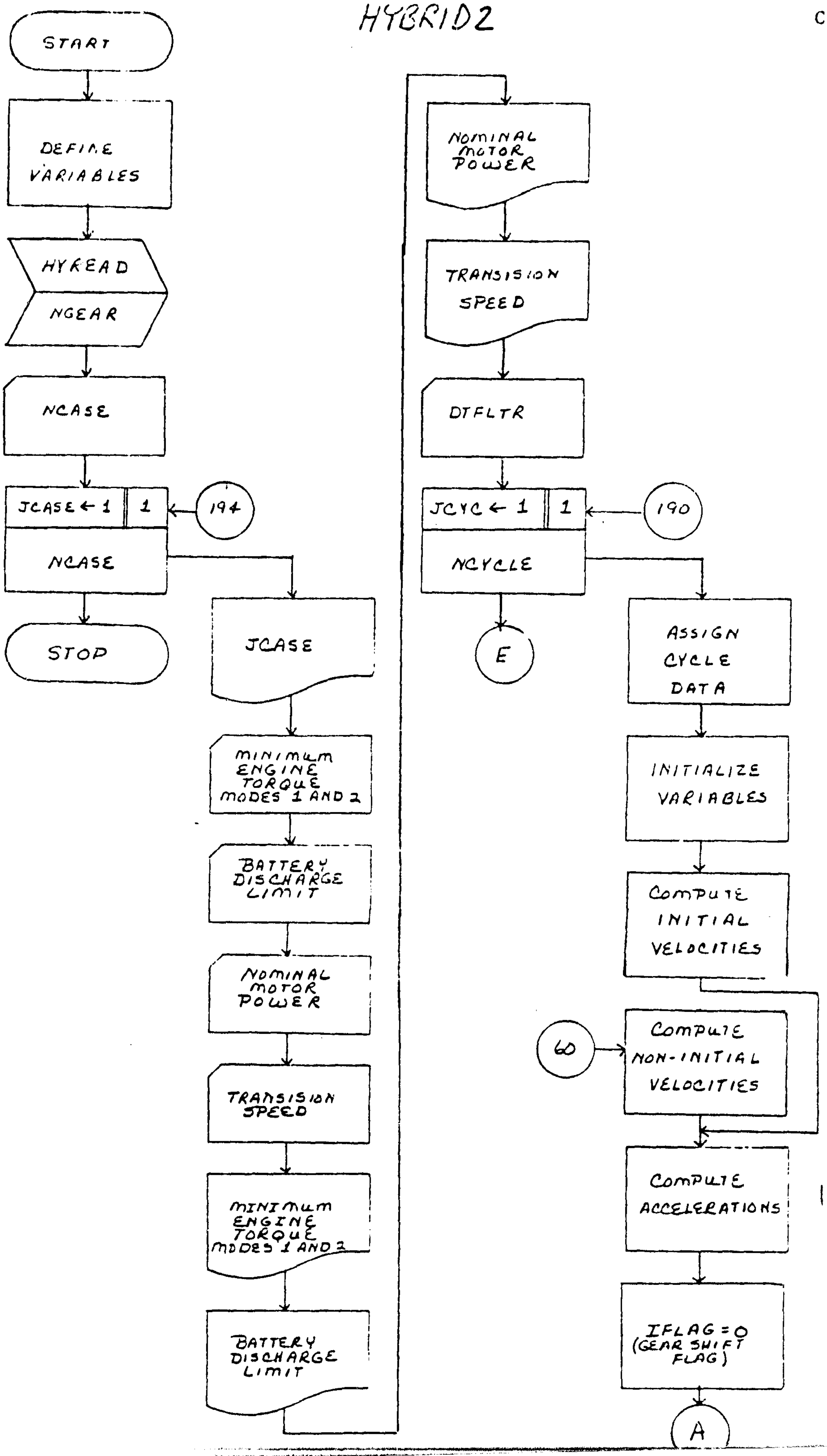
PAGE 3 OF 3

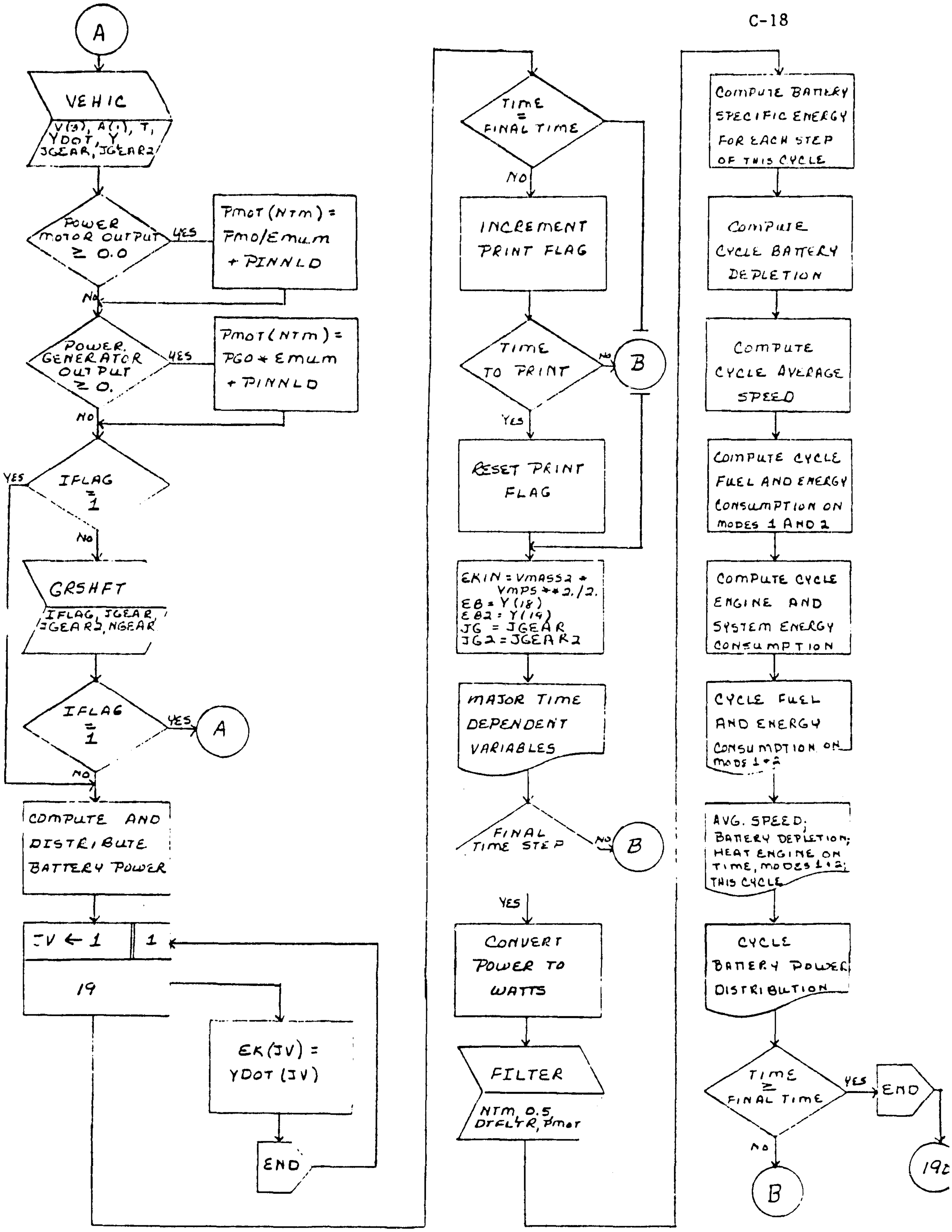
FORTRAN STATEMENT

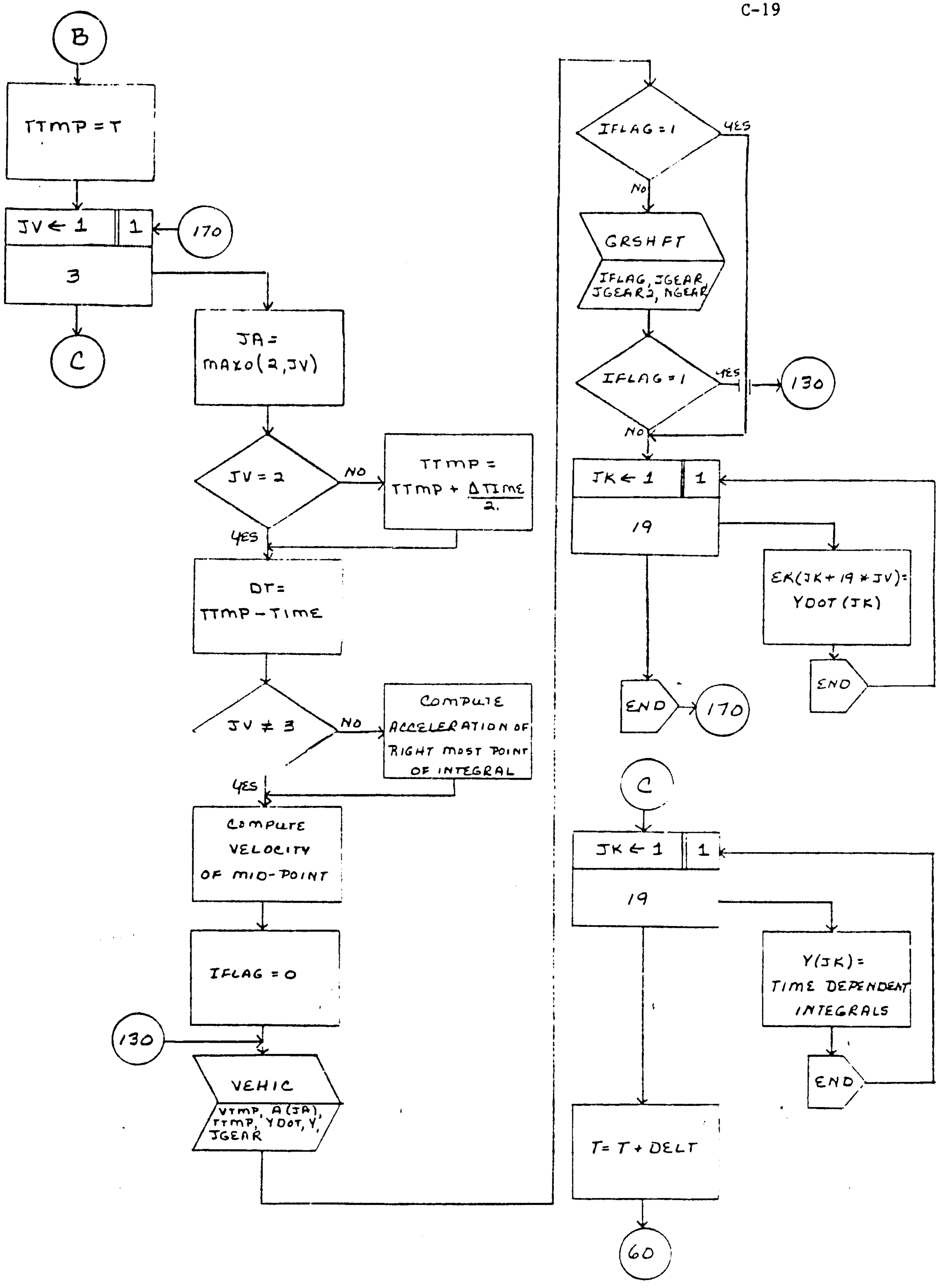
0 ZERO 0 ALPHA O   1 = ONE I = ALPHA I   2 = TWO Z = ALPHA Z

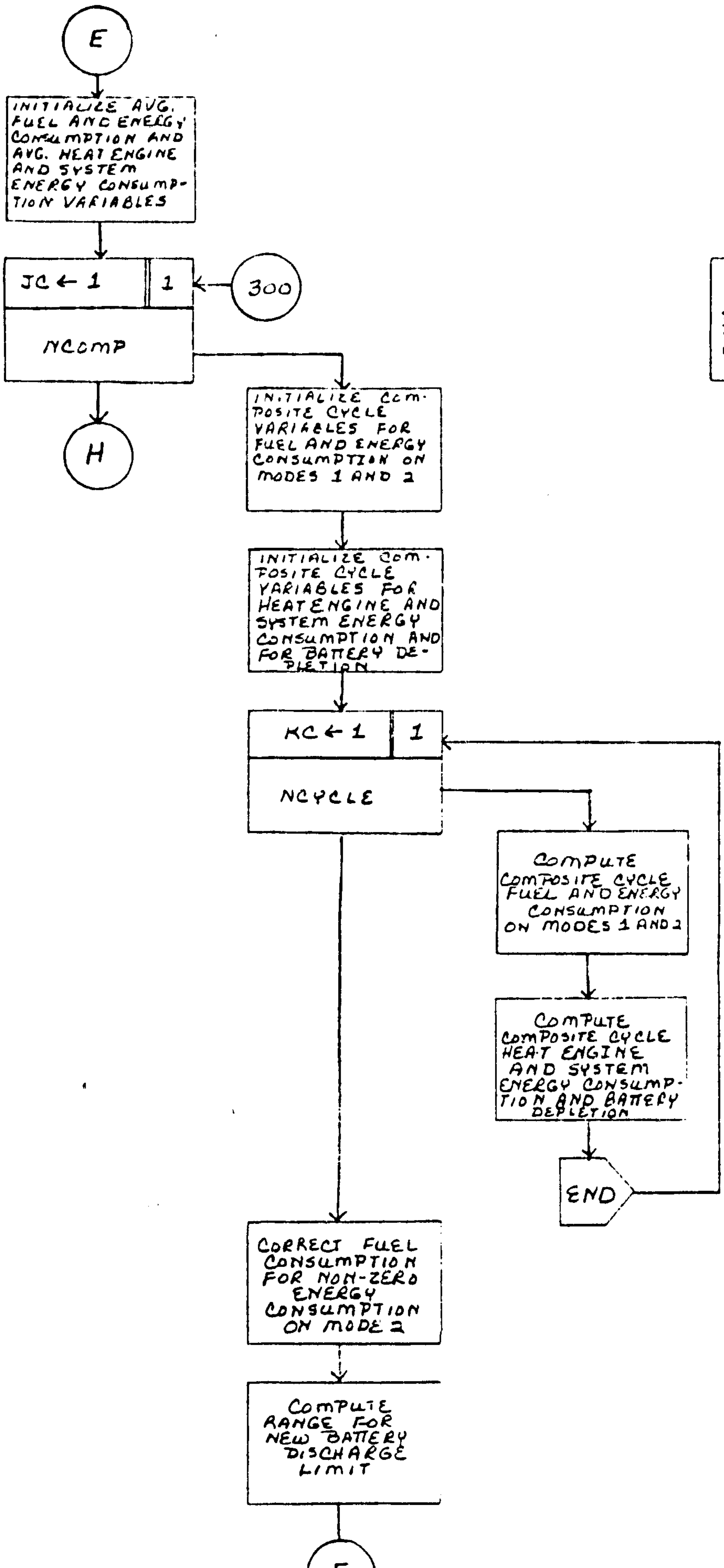
```
      [illegible]
     NCOMM   DSTAY      DWARM
DS[illegible](1)   DNC(1) GAMMA(1,1) . . .  DSWP[illegible]   DNC(NCDMF GAMMA(NCOARN[illegible]
```

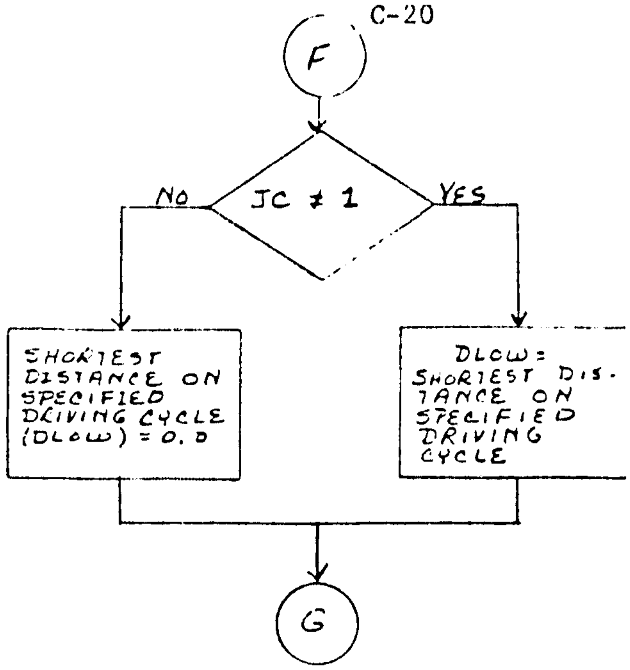
HYBRID2

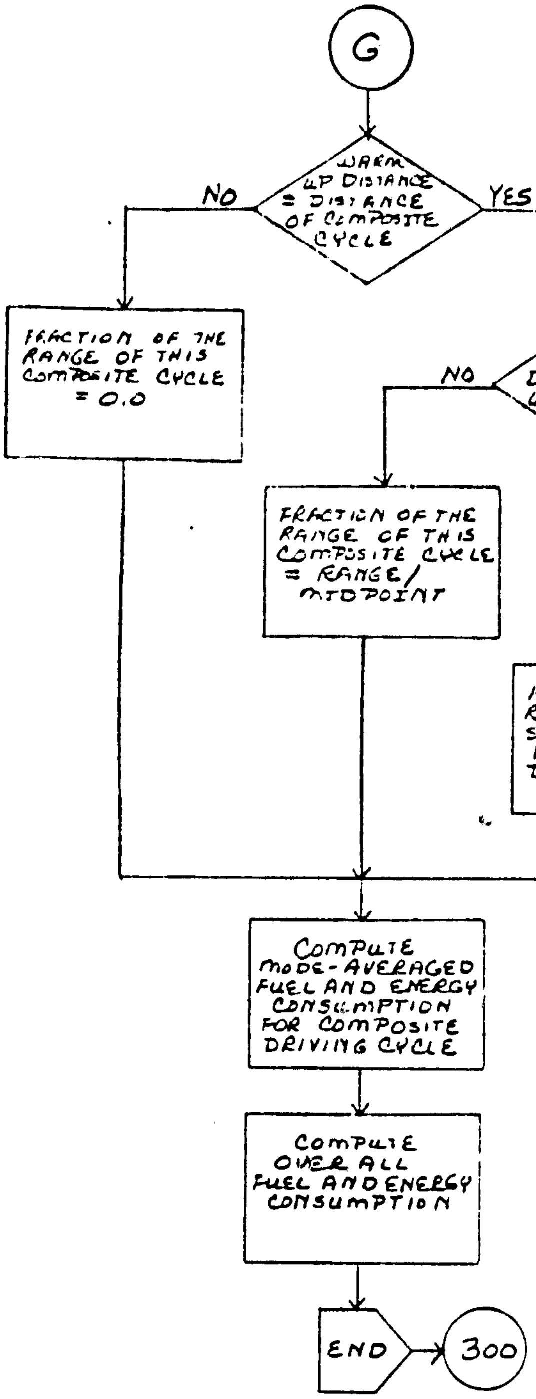

START
DEFINE VARIABLES
HYREAD
NGEAR
NCASE
JCASE ← 1
1
194
NCASE
STOP
JCASE
MINIMUM ENGINE TORQUE MODES 1 AND 2
BATTERY DISCHARGE LIMIT
NOMINAL MOTOR POWER
TRANSISION SPEED
MINIMUM ENGINE TORQUE MODES 1 AND 2
BATTERY DISCHARGE LIMIT
NOMINAL MOTOR POWER
TRANSISION SPEED
DTFLTR
JCYC ← 1
1
190
NCYCLE
E
ASSIGN CYCLE DATA
INITIALIZE VARIABLES
COMPUTE INITIAL VELOCITIES
60
COMPUTE NON-INITIAL VELOCITIES
COMPUTE ACCELERATIONS
IFLAG = 0 (GEAR SHIFT FLAG)
A

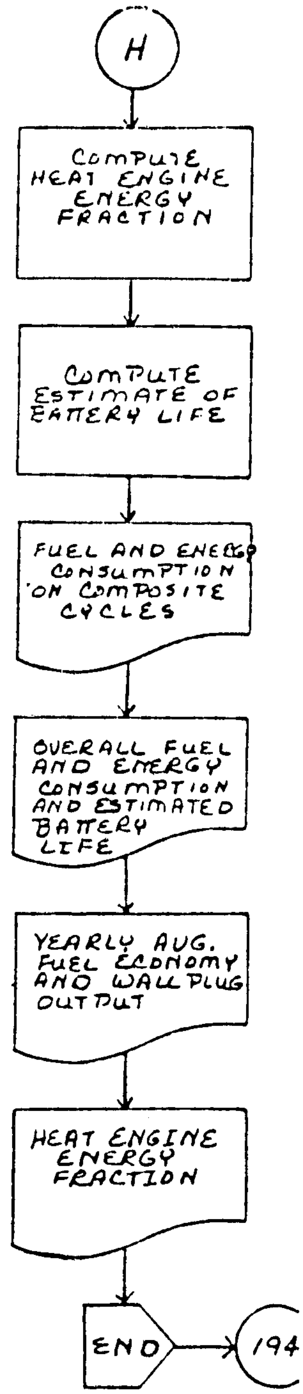

A
VEHIC
Y(3), A(1), T, YDOT, Y, JGEAR, JGEAR2
POWER MOTOR OUTPUT ≥ 0.0
YES
PMOT(NTM) = PMO/EMUM + PINNLD
NO
POWER GENERATOR OUTPUT ≥ 0.
YES
PMOT(NTM) = PGO * EMUM + PINNLD
NO
IFLAG = 1
YES
NO
GRSHFT
IFLAG, JGEAR, JGEAR2, NGEAR
IFLAG = 1
YES
A
NO
COMPUTE AND DISTRIBUTE BATTERY POWER
JV ← 1
1
19
EK(JV) = YDOT(JV)
END
TIME = FINAL TIME
NO
INCREMENT PRINT FLAG
TIME TO PRINT
NO
B
YES
RESET PRINT FLAG
EKIN = VMASS2 * VMPS ** 2./2.
EB = Y(18)
EB2 = Y(19)
JG = JGEAR
JG2 = JGEAR2
MAJOR TIME DEPENDENT VARIABLES
FINAL TIME STEP
NO
B
YES
CONVERT POWER TO WATTS
FILTER
NTM, 0.5 DTFLTR, PMOT
COMPUTE BATTERY SPECIFIC ENERGY FOR EACH STEP OF THIS CYCLE
COMPUTE CYCLE BATTERY DEPLETION
COMPUTE CYCLE AVERAGE SPEED
COMPUTE CYCLE FUEL AND ENERGY CONSUMPTION ON MODES 1 AND 2
COMPUTE CYCLE ENGINE AND SYSTEM ENERGY CONSUMPTION
CYCLE FUEL AND ENERGY CONSUMPTION ON MODS 1+2
AVG. SPEED; BATTERY DEPLETION; HEAT ENGINE ON TIME, MODES 1+2; THIS CYCLE
CYCLE BATTERY POWER DISTRIBUTION
TIME ≥ FINAL TIME
YES
END
NO
B

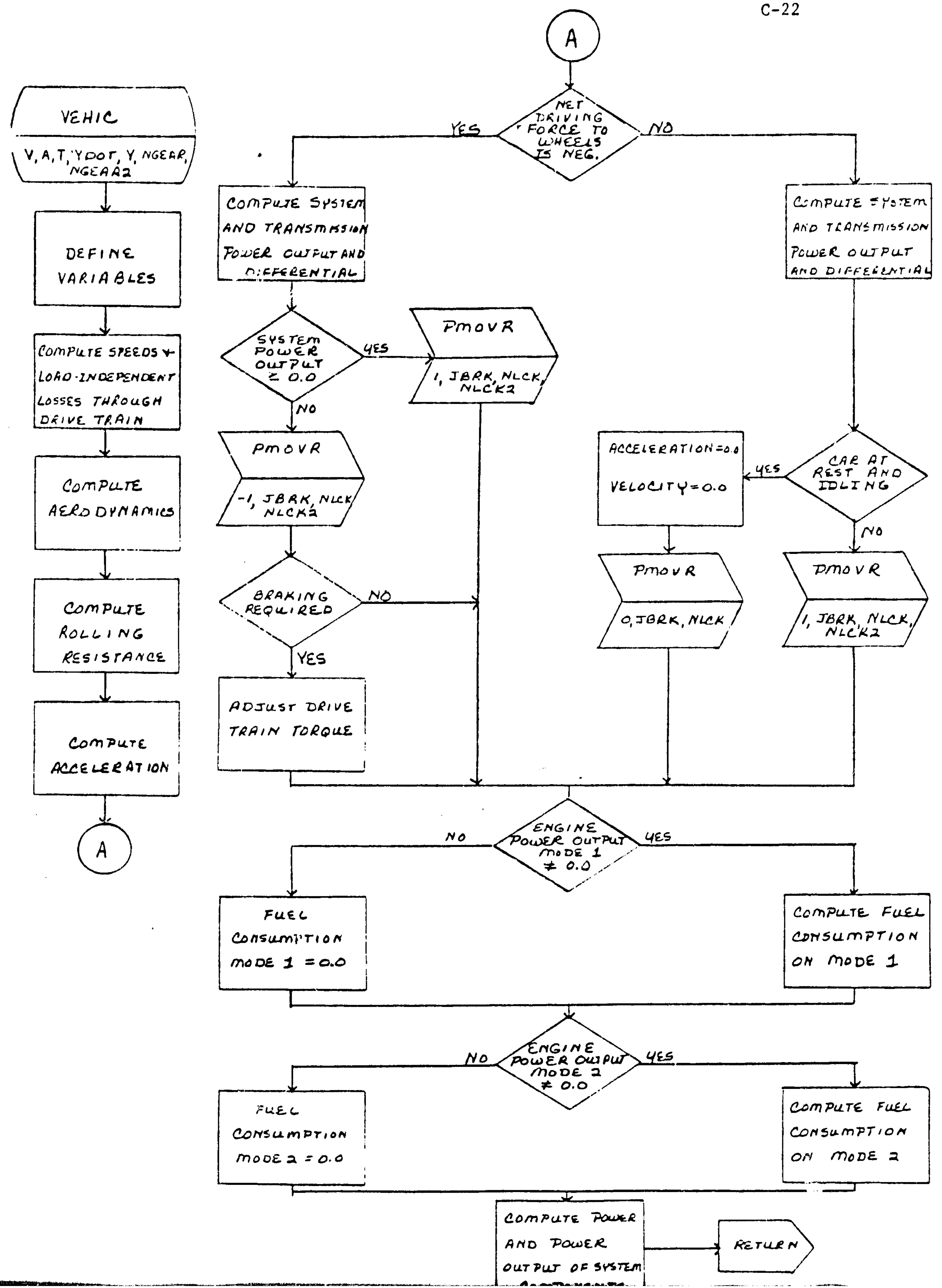

B
TTMP = T
JV ← 1
1
3
170
C
JA =
MAX0(2,JV)
JV = 2
NO
YES
TTMP =
TTMP + ΔTIME / 2.
DT =
TTMP − TIME
JV ≠ 3
NO
YES
COMPUTE
ACCELERATION OF
RIGHT MOST POINT
OF INTEGRAL
COMPUTE
VELOCITY
OF MID-POINT
IFLAG = 0
130
VEHIC
VTMP, A(JA), TTMP, YDOT, Y, JGEAR
IFLAG = 1
YES
NO
GRSHFT
IFLAG, JGEAR, JGEAR2, NGEAR
IFLAG = 1
YES
130
NO
JK ← 1
1
19
EK(JK + 19 * JV) =
YDOT(JK)
END
END
170
C
JK ← 1
1
19
Y(JK) =
TIME DEPENDENT
INTEGRALS
END
T = T + DELT
60

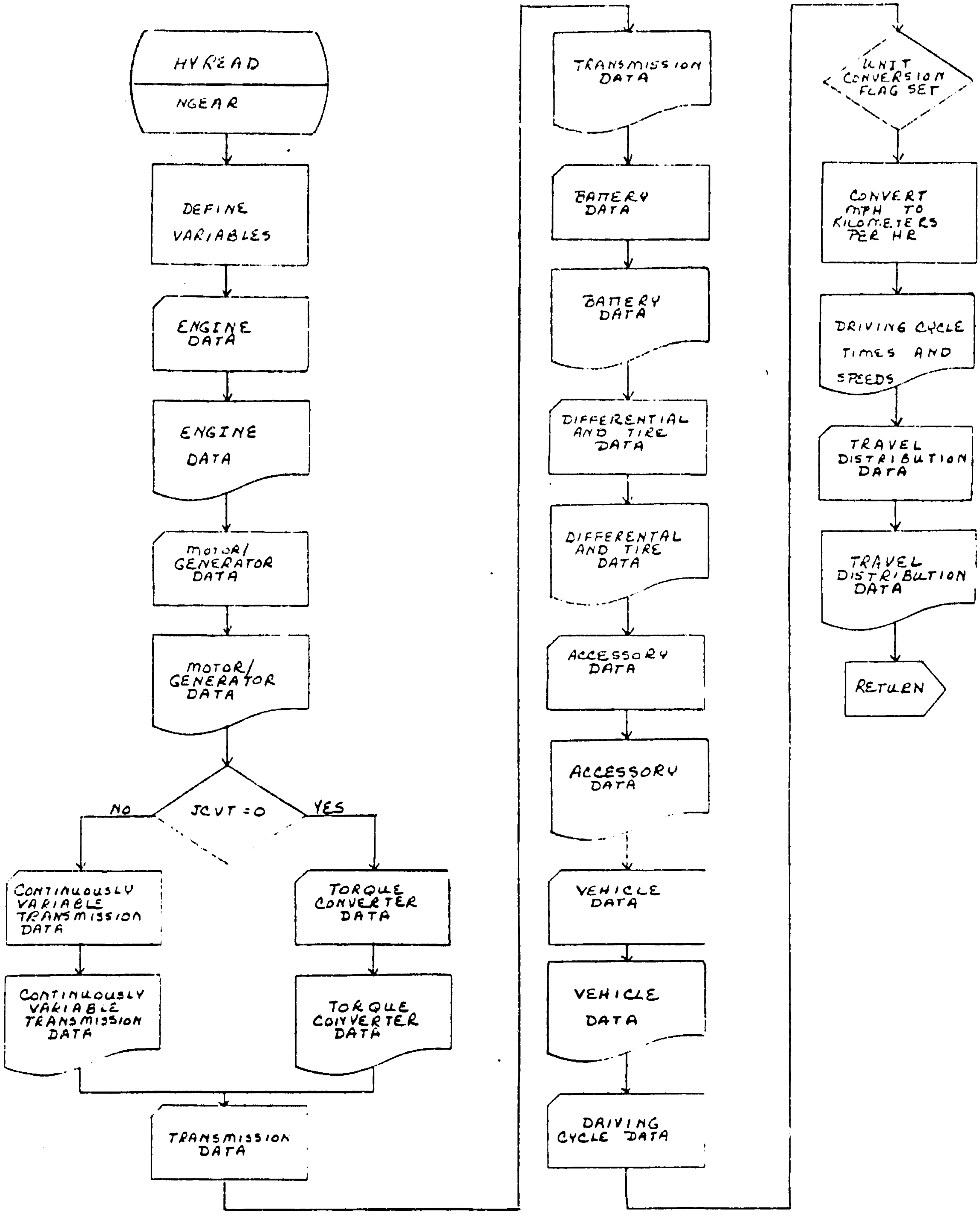

E
INITIALIZE AVG. FUEL AND ENERGY CONSUMPTION AND AVG. HEAT ENGINE AND SYSTEM ENERGY CONSUMPTION VARIABLES
JC ← 1
1
300
NCOMP
H
INITIALIZE COMPOSITE CYCLE VARIABLES FOR FUEL AND ENERGY CONSUMPTION ON MODES 1 AND 2
INITIALIZE COMPOSITE CYCLE VARIABLES FOR HEAT ENGINE AND SYSTEM ENERGY CONSUMPTION AND FOR BATTERY DEPLETION
KC ← 1
1
NCYCLE
COMPUTE COMPOSITE CYCLE FUEL AND ENERGY CONSUMPTION ON MODES 1 AND 2
COMPUTE COMPOSITE CYCLE HEAT ENGINE AND SYSTEM ENERGY CONSUMPTION AND BATTERY DEPLETION
END
CORRECT FUEL CONSUMPTION FOR NON-ZERO ENERGY CONSUMPTION ON MODE 2
COMPUTE RANGE FOR NEW BATTERY DISCHARGE LIMIT
F

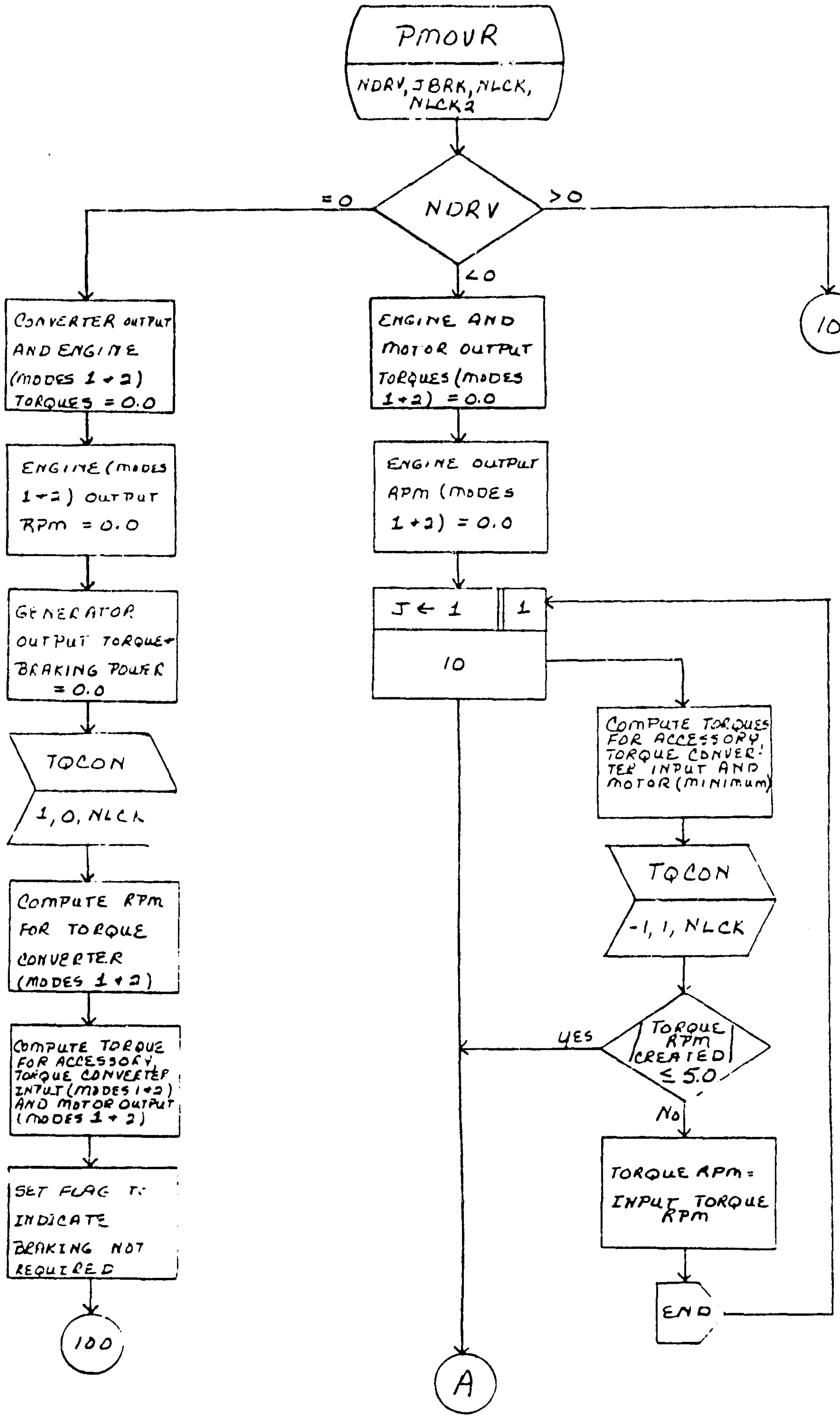

F
JC ≠ 1
NO
YES
SHORTEST DISTANCE ON SPECIFIED DRIVING CYCLE (DLOW) = 0.0
DLOW = SHORTEST DISTANCE ON SPECIFIED DRIVING CYCLE
G

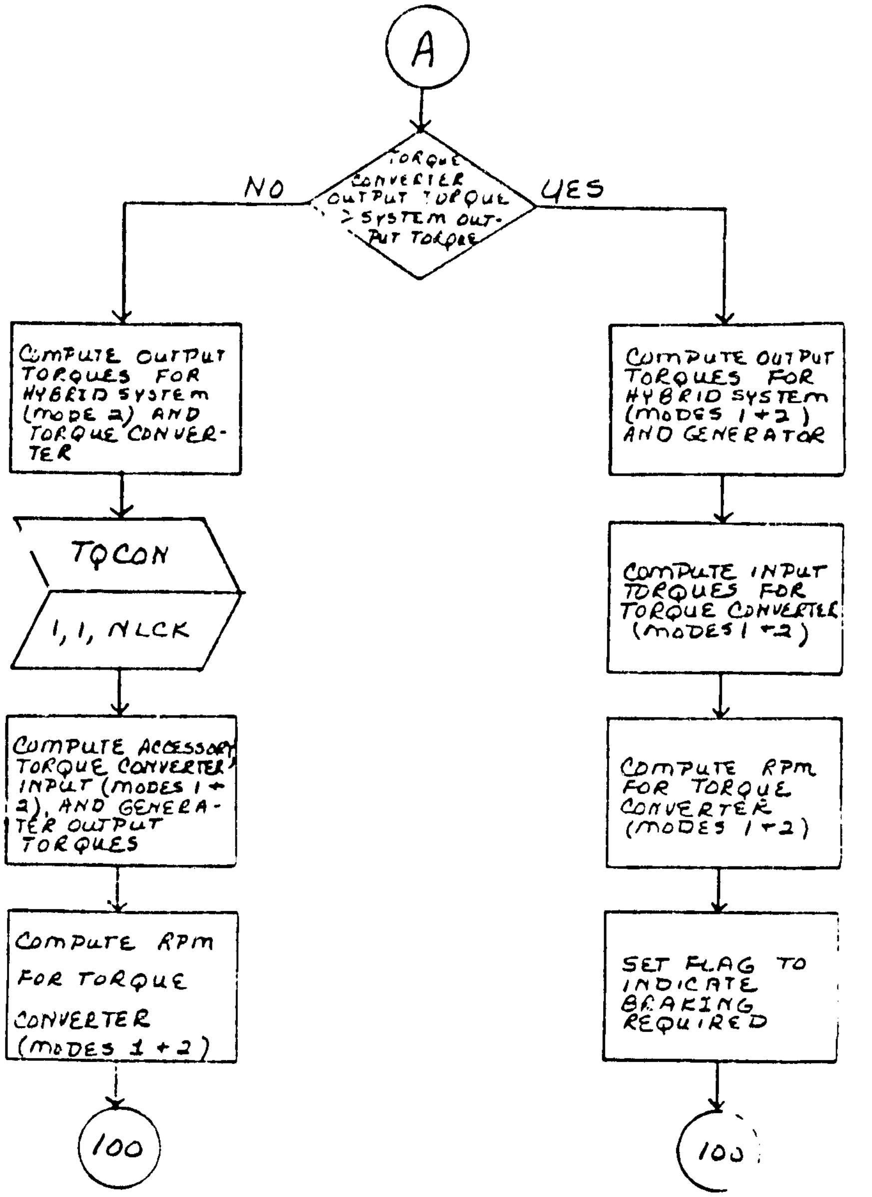

G
WARM UP DISTANCE = DISTANCE OF COMPOSITE CYCLE
NO
YES
FRACTION OF THE RANGE OF THIS COMPOSITE CYCLE = 0.0
RANGE > SHORTEST DISTANCE − WARM UP DISTANCE
NO
YES
FRACTION OF THE RANGE OF THIS COMPOSITE CYCLE = RANGE/ MIDPOINT
RANGE > DISTANCE OF COMPOSITE CYCLE − WARM UP DISTANCE
YES
NO
FRACTION OF RANGE OF COMPOSITE CYCLE = 1. − WARM UP DISTANCE / MIDPOINT
FRACTION OF RANGE OF COMPOSITE CYCLE = (RANGE/MIDPOINT) + (1. − (RANGE − LOW DISTANCE + WARMUP DISTANCE)²
COMPUTE MODE-AVERAGED FUEL AND ENERGY CONSUMPTION FOR COMPOSITE DRIVING CYCLE
COMPUTE OVERALL FUEL AND ENERGY CONSUMPTION
END
300

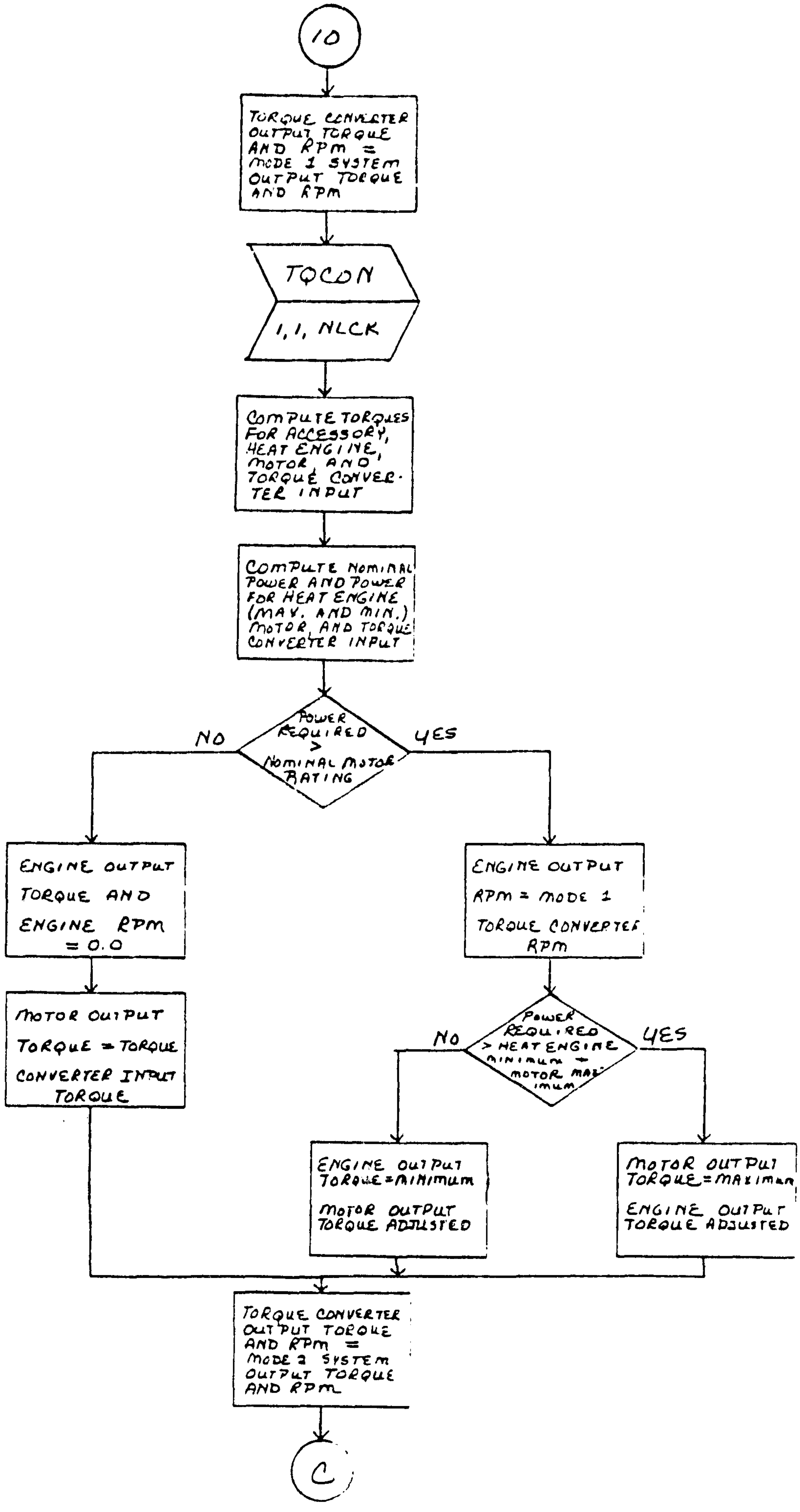

H
COMPUTE HEAT ENGINE ENERGY FRACTION
COMPUTE ESTIMATE OF BATTERY LIFE
FUEL AND ENERGY CONSUMPTION ON COMPOSITE CYCLES
OVERALL FUEL AND ENERGY CONSUMPTION AND ESTIMATED BATTERY LIFE
YEARLY AVG. FUEL ECONOMY AND WALL PLUG OUTPUT
HEAT ENGINE ENERGY FRACTION
END
194

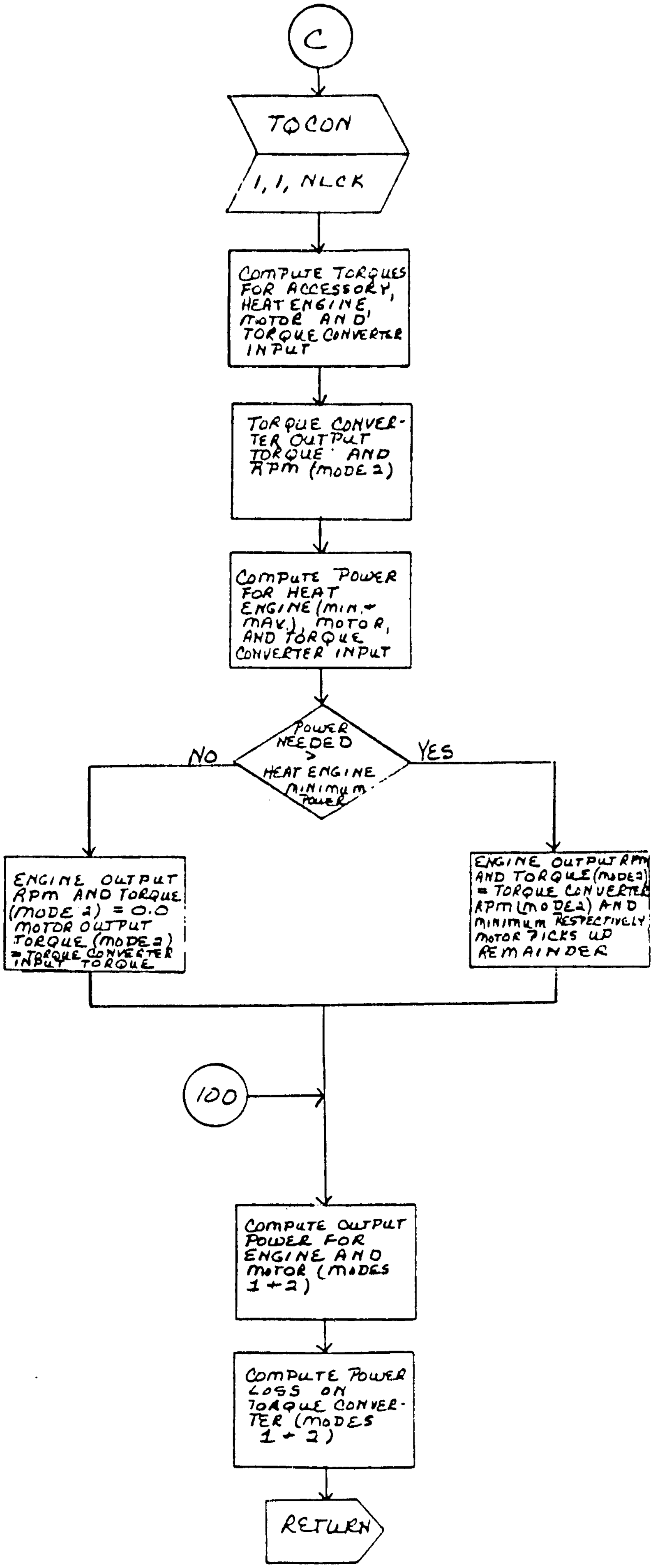

VEHIC
V, A, T, YDOT, Y, NGEAR, NGEAR2
DEFINE VARIABLES
COMPUTE SPEEDS + LOAD-INDEPENDENT LOSSES THROUGH DRIVE TRAIN
COMPUTE AERODYNAMICS
COMPUTE ROLLING RESISTANCE
COMPUTE ACCELERATION
A
A
NET DRIVING FORCE TO WHEELS IS NEG.
YES
NO
COMPUTE SYSTEM AND TRANSMISSION POWER OUTPUT AND DIFFERENTIAL
COMPUTE SYSTEM AND TRANSMISSION POWER OUTPUT AND DIFFERENTIAL
SYSTEM POWER OUTPUT ≥ 0.0
YES
NO
PMOVR
1, JBRK, NLCK, NLCK2
PMOVR
-1, JBRK, NLCK, NLCK2
BRAKING REQUIRED
NO
YES
ADJUST DRIVE TRAIN TORQUE
CAR AT REST AND IDLING
YES
NO
ACCELERATION=0.0
VELOCITY=0.0
PMOVR
0, JBRK, NLCK
PMOVR
1, JBRK, NLCK, NLCK2
ENGINE POWER OUTPUT MODE 1 ≠ 0.0
NO
YES
FUEL CONSUMPTION MODE 1 = 0.0
COMPUTE FUEL CONSUMPTION ON MODE 1
ENGINE POWER OUTPUT MODE 2 ≠ 0.0
NO
YES
FUEL CONSUMPTION MODE 2 = 0.0
COMPUTE FUEL CONSUMPTION ON MODE 2
COMPUTE POWER AND POWER OUTPUT OF SYSTEM
RETURN

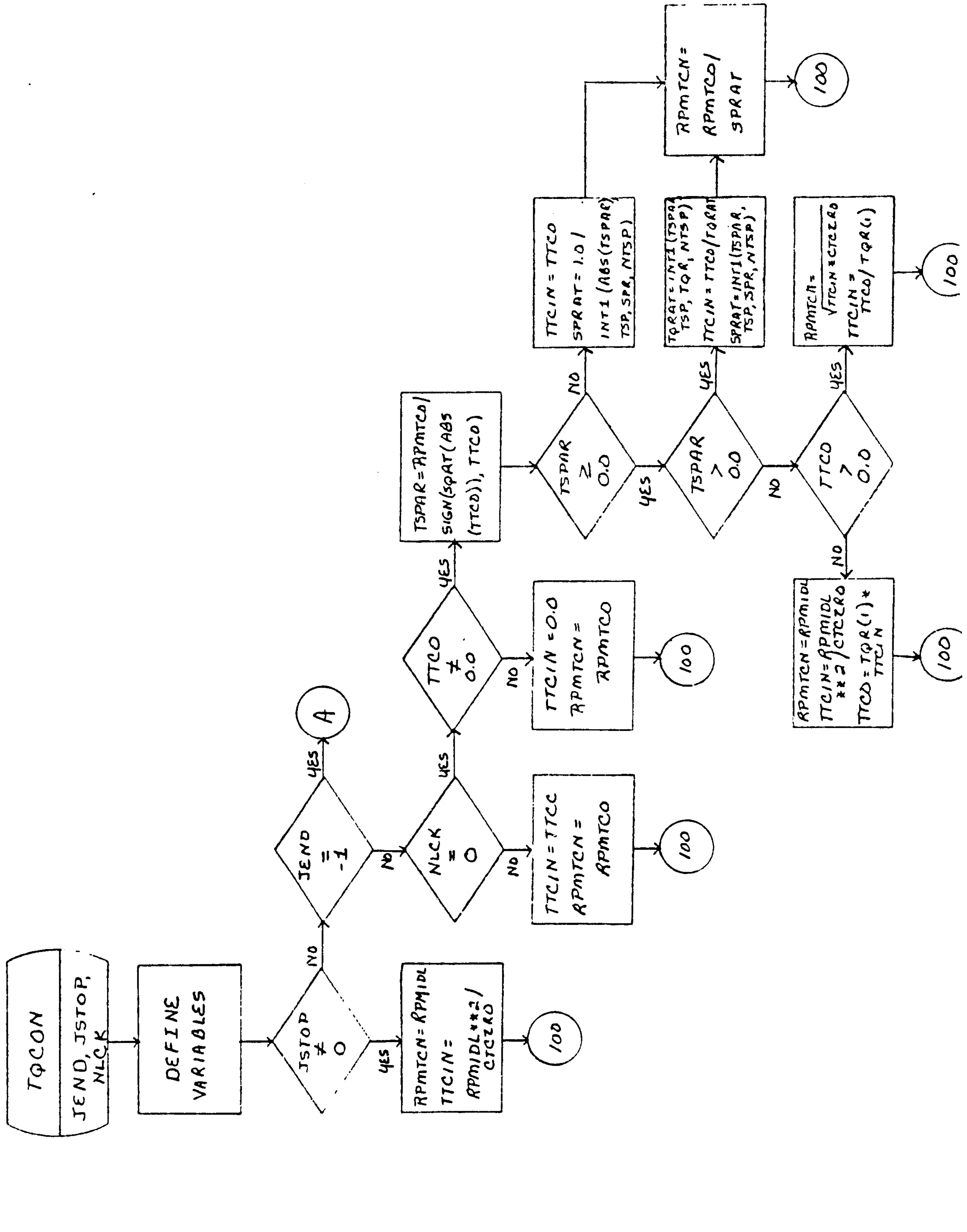

HYREAD
NGEAR
DEFINE VARIABLES
ENGINE DATA
ENGINE DATA
MOTOR/ GENERATOR DATA
MOTOR/ GENERATOR DATA
JCVT = 0
NO
YES
CONTINUOUSLY VARIABLE TRANSMISSION DATA
CONTINUOUSLY VARIABLE TRANSMISSION DATA
TORQUE CONVERTER DATA
TORQUE CONVERTER DATA
TRANSMISSION DATA
TRANSMISSION DATA
BATTERY DATA
BATTERY DATA
DIFFERENTIAL AND TIRE DATA
DIFFERENTAL AND TIRE DATA
ACCESSORY DATA
ACCESSORY DATA
VEHICLE DATA
VEHICLE DATA
DRIVING CYCLE DATA
UNIT CONVERSION FLAG SET
CONVERT MPH TO KILOMETERS PER HR
DRIVING CYCLE TIMES AND SPEEDS
TRAVEL DISTRIBUTION DATA
TRAVEL DISTRIBUTION DATA
RETURN

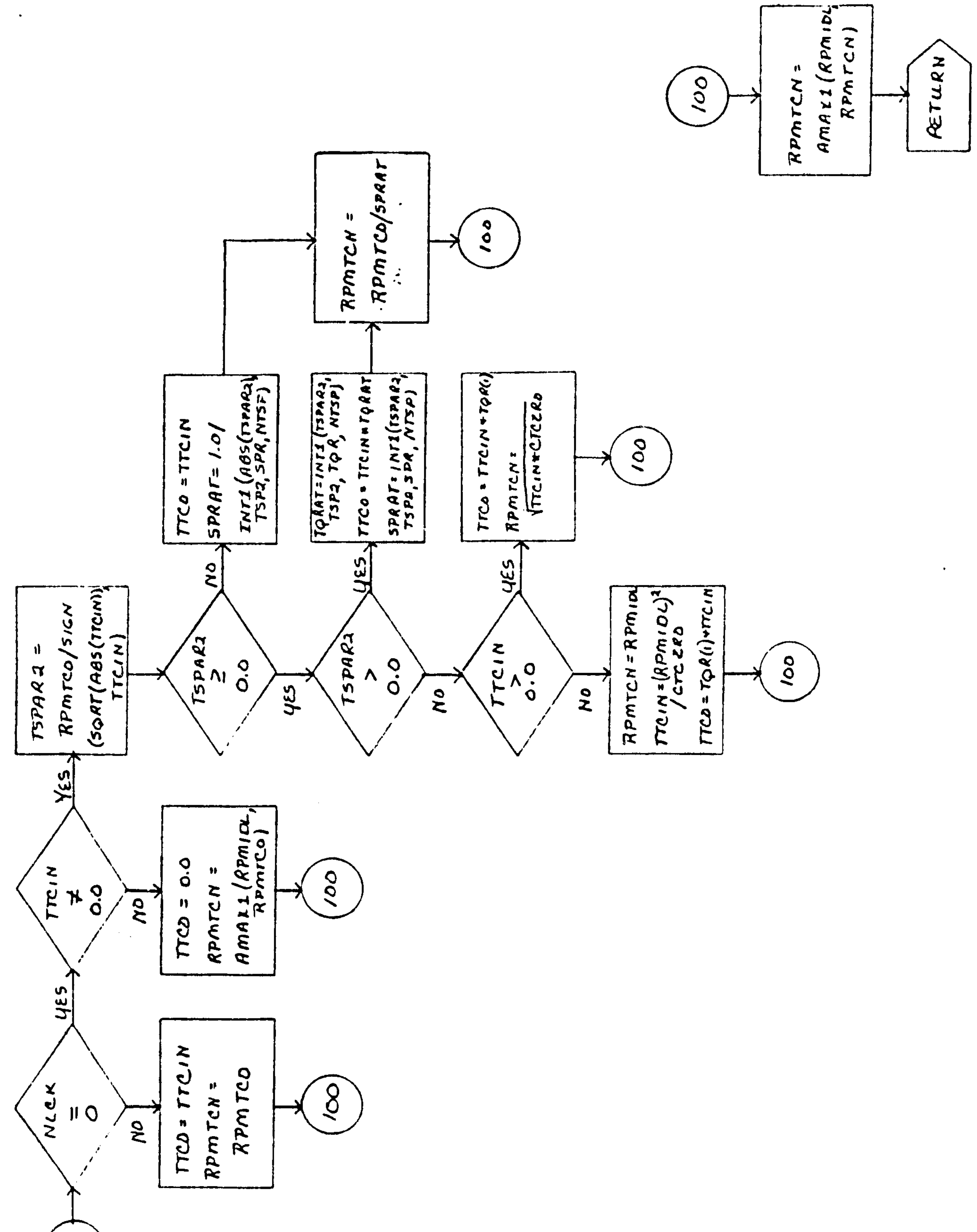

PMOVR
NDRV, JBRK, NLCK, NLCK2
NDRV
=0
>0
<0
10
CONVERTER OUTPUT AND ENGINE (MODES 1 + 2) TORQUES = 0.0
ENGINE (MODES 1 + 2) OUTPUT RPM = 0.0
GENERATOR OUTPUT TORQUE + BRAKING POWER = 0.0
TQCON
1, 0, NLCK
COMPUTE RPM FOR TORQUE CONVERTER (MODES 1 + 2)
COMPUTE TORQUE FOR ACCESSORY, TORQUE CONVERTER INPUT (MODES 1 + 2) AND MOTOR OUTPUT (MODES 1 + 2)
SET FLAG TO INDICATE BRAKING NOT REQUIRED
100
ENGINE AND MOTOR OUTPUT TORQUES (MODES 1 + 2) = 0.0
ENGINE OUTPUT RPM (MODES 1 + 2) = 0.0
J ← 1
1
10
COMPUTE TORQUES FOR ACCESSORY, TORQUE CONVERTER INPUT AND MOTOR (MINIMUM)
TQCON
-1, 1, NLCK
|TORQUE RPM CREATED| ≤ 5.0
YES
NO
TORQUE RPM = INPUT TORQUE RPM
END
A

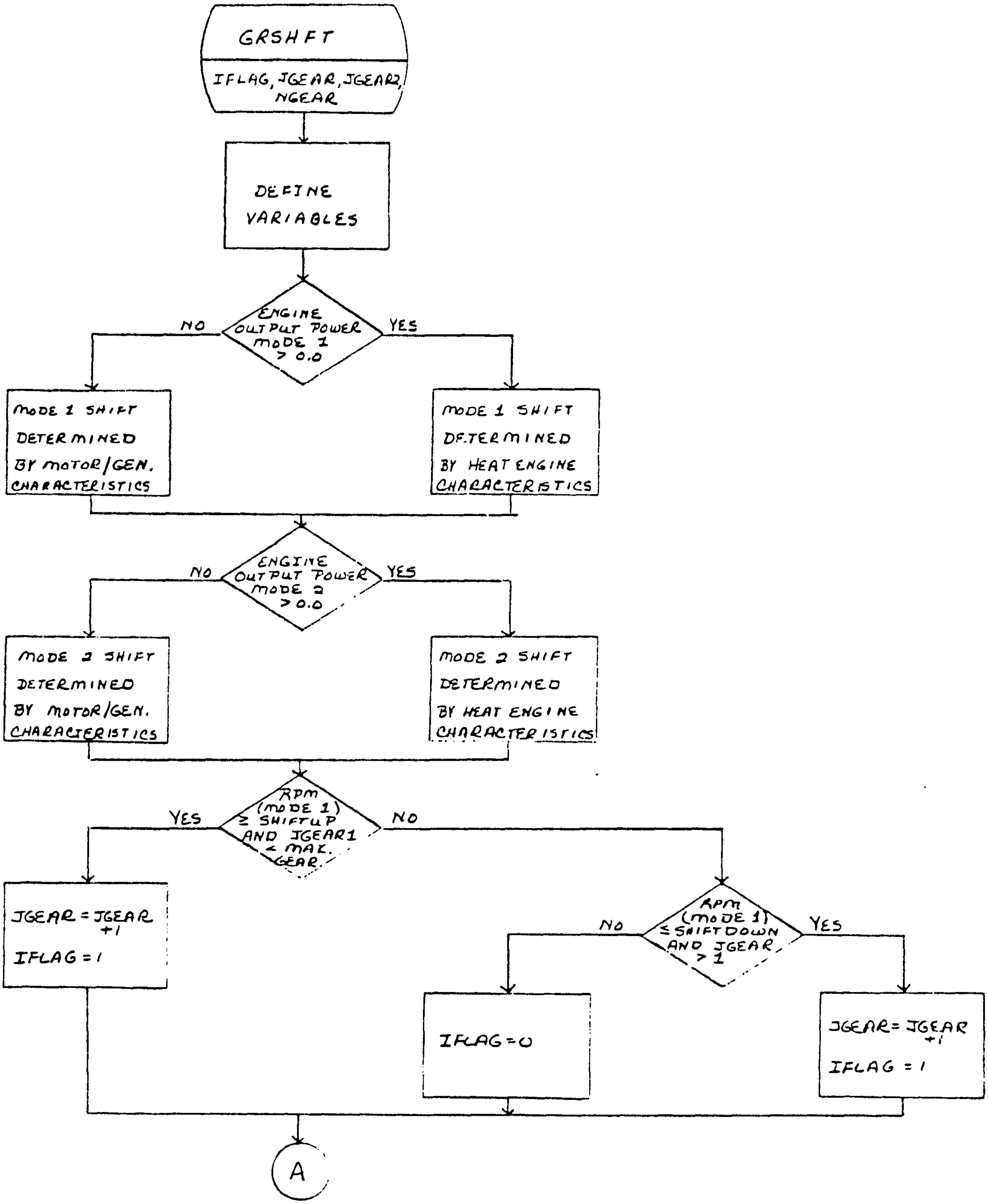

A
TORQUE CONVERTER OUTPUT TORQUE > SYSTEM OUTPUT TORQUE
NO
YES
COMPUTE OUTPUT TORQUES FOR HYBRID SYSTEM (MODE 2) AND TORQUE CONVERTER
TQCON
1, 1, NLCK
COMPUTE ACCESSORY TORQUE CONVERTER INPUT (MODES 1 + 2), AND GENERATER OUTPUT TORQUES
COMPUTE RPM FOR TORQUE CONVERTER (MODES 1 + 2)
100
COMPUTE OUTPUT TORQUES FOR HYBRID SYSTEM (MODES 1 + 2) AND GENERATOR
COMPUTE INPUT TORQUES FOR TORQUE CONVERTER (MODES 1 + 2)
COMPUTE RPM FOR TORQUE CONVERTER (MODES 1 + 2)
SET FLAG TO INDICATE BRAKING REQUIRED
100

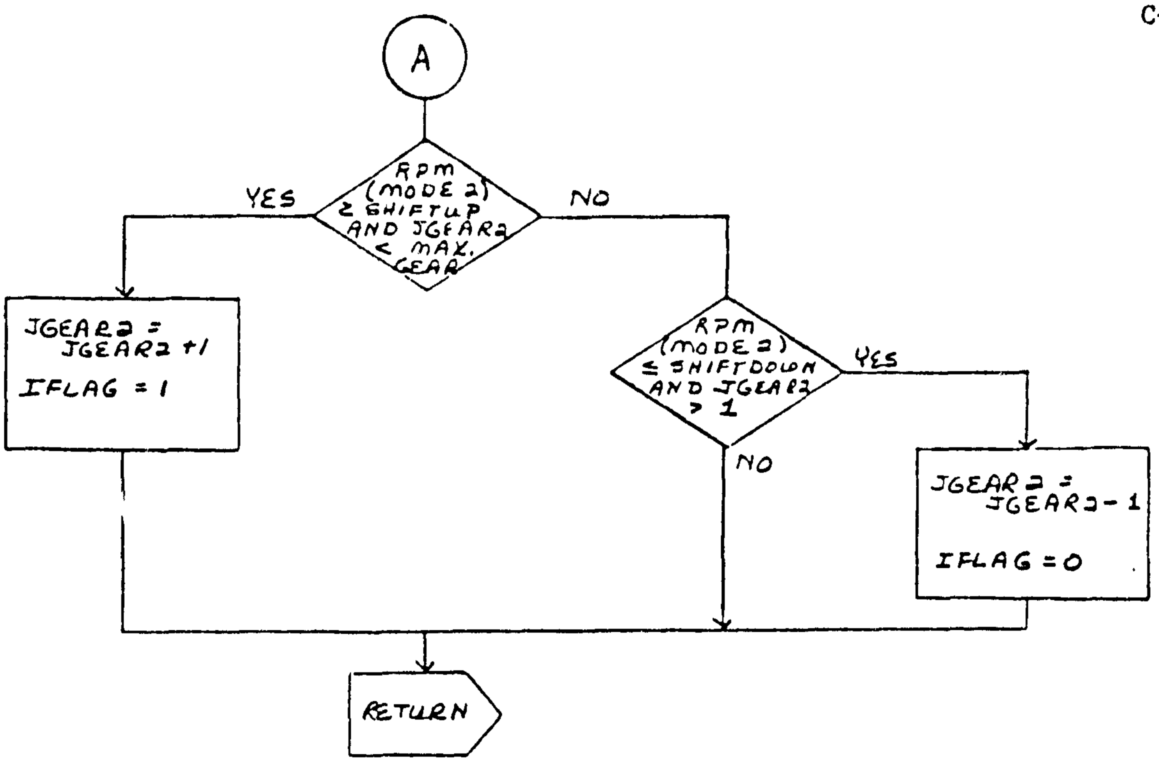

10
TORQUE CONVERTER OUTPUT TORQUE AND RPM = MODE 1 SYSTEM OUTPUT TORQUE AND RPM
TQCON
1, 1, NLCK
COMPUTE TORQUES FOR ACCESSORY, HEAT ENGINE, MOTOR AND TORQUE CONVERTER INPUT
COMPUTE NOMINAL POWER AND POWER FOR HEAT ENGINE (MAX. AND MIN.) MOTOR, AND TORQUE CONVERTER INPUT
POWER REQUIRED > NOMINAL MOTOR RATING
NO
YES
ENGINE OUTPUT TORQUE AND ENGINE RPM = 0.0
MOTOR OUTPUT TORQUE = TORQUE CONVERTER INPUT TORQUE
ENGINE OUTPUT RPM = MODE 1 TORQUE CONVERTER RPM
POWER REQUIRED > HEAT ENGINE MINIMUM + MOTOR MAXIMUM
NO
YES
ENGINE OUTPUT TORQUE = MINIMUM
MOTOR OUTPUT TORQUE ADJUSTED
MOTOR OUTPUT TORQUE = MAXIMUM
ENGINE OUTPUT TORQUE ADJUSTED
TORQUE CONVERTER OUTPUT TORQUE AND RPM = MODE 2 SYSTEM OUTPUT TORQUE AND RPM
C

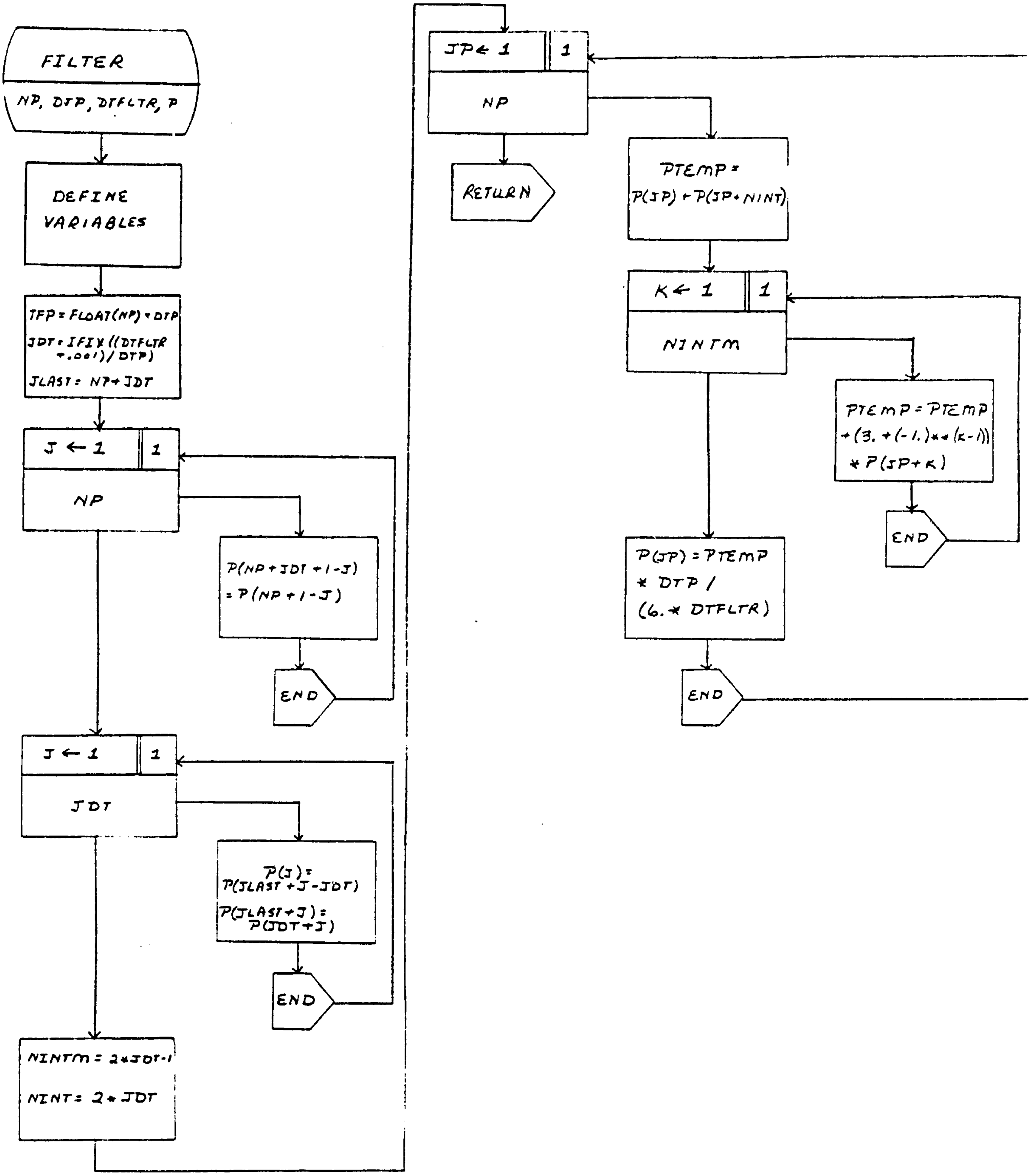

C
TQCON
1, 1, NLCK
COMPUTE TORQUES FOR ACCESSORY, HEAT ENGINE, MOTOR AND TORQUE CONVERTER INPUT
TORQUE CONVERTER OUTPUT TORQUE AND RPM (MODE 2)
COMPUTE POWER FOR HEAT ENGINE (MIN. + MAX.), MOTOR, AND TORQUE CONVERTER INPUT
POWER NEEDED > HEAT ENGINE MINIMUM POWER
NO
YES
ENGINE OUTPUT RPM AND TORQUE (MODE 2) = 0.0 MOTOR OUTPUT TORQUE (MODE 2) = TORQUE CONVERTER INPUT TORQUE
ENGINE OUTPUT RPM AND TORQUE (MODE 2) = TORQUE CONVERTER RPM (MODE 2) AND MINIMUM RESPECTIVELY; MOTOR PICKS UP REMAINDER
100
COMPUTE OUTPUT POWER FOR ENGINE AND MOTOR (MODES 1 + 2)
COMPUTE POWER LOSS ON TORQUE CONVERTER (MODES 1 + 2)
RETURN

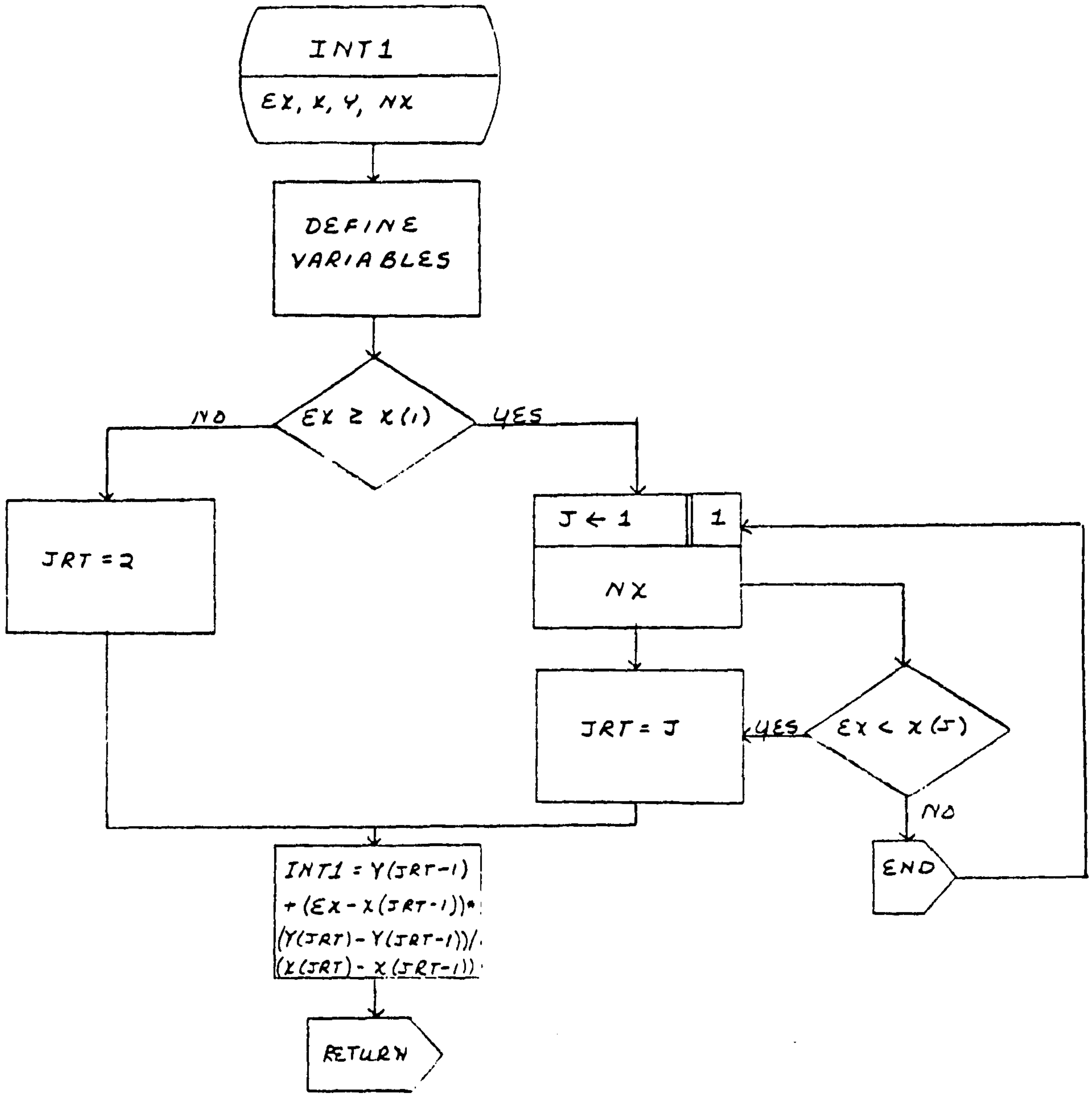

TQCON
JEND, JSTOP, NLCK
DEFINE VARIABLES
JSTOP ≠ 0
YES
NO
RPMTCN = RPMIDL
TTCIN = RPMIDL**2/CTCZRO
100
JEND = -1
YES
A
NO
NLCK = 0
YES
NO
TTCIN = TTCC
RPMTCN = RPMTCO
100
TTCO ≠ 0.0
YES
NO
TTCIN = 0.0
RPMTCN = RPMTCO
100
TSPAR = RPMTCO/SIGN(SQRT(ABS(TTCO)), TTCO)
TSPAR ≥ 0.0
NO
TTCIN = TTCO
SPRAT = 1.01
INT1 (ABS(TSPAR), TSP, SPR, NTSP)
YES
TSPAR > 0.0
YES
TQRAT = INT1(TSPAR, TSP, TQR, NTSP)
TTCIN = TTCO/TQRAT
SPRAT = INT1(TSPAR, TSP, SPR, NTSP)
RPMTCN = RPMTCO/SPRAT
100
NO
TTCO > 0.0
YES
RPMTCN = √(TTCIN * CTCZRO)
TTCIN = TTCO/TQR(1)
100
NO
RPMTCN = RPMIDL
TTCIN = RPMIDL**2/CTCZRO
TTCO = TQR(1) * TTCIN
100

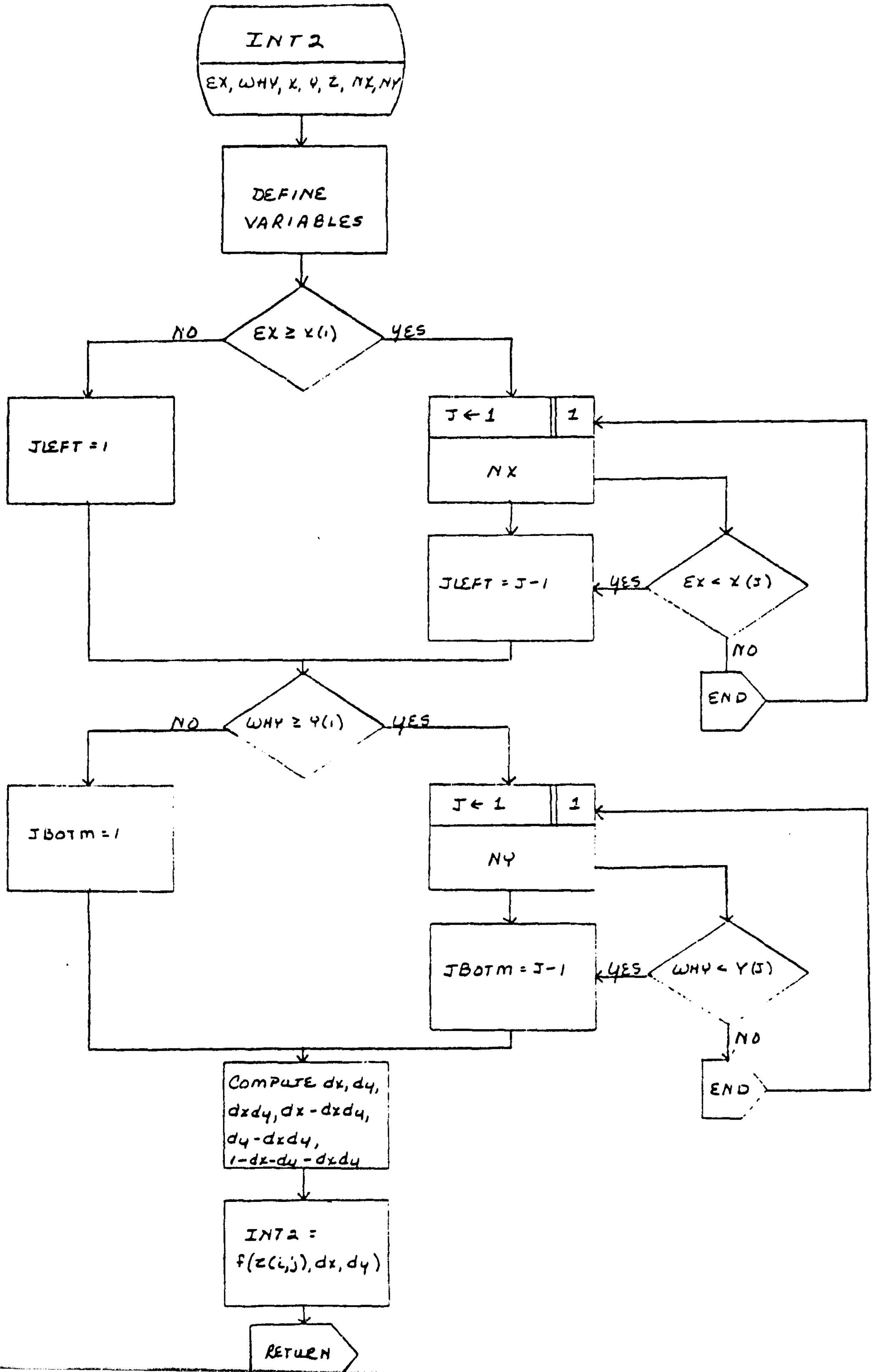

A
NLCK = 0
NO
YES
TTCO = TTCIN
RPMTCN = RPMTCO
100
TTCIN ≠ 0.0
NO
YES
TTCO = 0.0
RPMTCN = AMAX1(RPMIDL, RPMTCO)
100
TSPAR2 = RPMTCO/SIGN(SQRT(ABS(TTCIN)), TTCIN)
TSPAR2 ≥ 0.0
NO
YES
TTCO = TTCIN
SPRAT = 1.0/INT1(ABS(TSPAR2), TSP2, SPR, NTSP)
RPMTCN = RPMTCO/SPRAT
100
TSPAR2 > 0.0
YES
NO
TQRAT = INT1(TSPAR2, TSP2, TQR, NTSP)
TTCO = TTCIN*TQRAT
SPRAT = INT1(TSPAR2, TSP2, SPR, NTSP)
TTCIN > 0.0
YES
NO
TTCO = TTCIN*TQR(1)
RPMTCN = √(TTCIN*CTCZRO)
100
RPMTCN = RPMIDL
TTCIN = (RPMIDL)^2/CTCZRO
TTCO = TQR(1)*TTCIN
100
100
RPMTCN = AMAX1(RPMIDL, RPMTCN)
RETURN


GRSHFT
IFLAG, JGEAR, JGEAR2, NGEAR
DEFINE VARIABLES
ENGINE OUTPUT POWER MODE 1 > 0.0
NO
YES
MODE 1 SHIFT DETERMINED BY MOTOR/GEN. CHARACTERISTICS
MODE 1 SHIFT DETERMINED BY HEAT ENGINE CHARACTERISTICS
ENGINE OUTPUT POWER MODE 2 > 0.0
NO
YES
MODE 2 SHIFT DETERMINED BY MOTOR/GEN. CHARACTERISTICS
MODE 2 SHIFT DETERMINED BY HEAT ENGINE CHARACTERISTICS
RPM (MODE 1) ≥ SHIFTUP AND JGEAR1 < MAX. GEAR
YES
NO
JGEAR = JGEAR +1
IFLAG = 1
RPM (MODE 1) ≤ SHIFTDOWN AND JGEAR > 1
NO
YES
IFLAG = 0
JGEAR = JGEAR +1
IFLAG = 1
A


A
RPM (MODE 2) ≥ SHIFTUP AND JGEAR2 < MAX. GEAR
YES
NO
JGEAR2 = JGEAR2 +1
IFLAG = 1
RPM (MODE 2) ≤ SHIFTDOWN AND JGEAR2 > 1
YES
NO
JGEAR2 = JGEAR2 - 1
IFLAG = 0
RETURN


FILTER
NP, DTP, DTFLTR, P
DEFINE VARIABLES
TFP = FLOAT(NP) * DTP
JDT = IFIX((DTFLTR +.001)/DTP)
JLAST = NP+JDT
J ← 1
1
NP
P(NP+JDT+1-J) = P(NP+1-J)
END
J ← 1
1
JDT
P(J) = P(JLAST+J-JDT)
P(JLAST+J) = P(JDT+J)
END
NINTM = 2*JDT-1
NINT = 2*JDT
JP ← 1
1
NP
RETURN
PTEMP = P(JP) + P(JP+NINT)
K ← 1
1
NINTM
PTEMP = PTEMP +(3.+(-1.)**(K-1)) *P(JP+K)
END
P(JP) = PTEMP * DTP / (6.* DTFLTR)
END


INT1
EX, X, Y, NX
DEFINE VARIABLES
EX ≥ X(1)
NO
YES
JRT = 2
J ← 1
1
NX
JRT = J
YES
EX < X(J)
NO
END
INT1 = Y(JRT-1) + (EX - X(JRT-1))* (Y(JRT) - Y(JRT-1))/ (X(JRT) - X(JRT-1))
RETURN


INT2
EX, WHY, X, Y, Z, NX, NY
DEFINE VARIABLES
EX ≥ X(1)
NO
YES
JLEFT = 1
J ← 1
1
NX
JLEFT = J-1
YES
EX < X(J)
NO
END
WHY ≥ Y(1)
NO
YES
JBOTM = 1
J ← 1
1
NY
JBOTM = J-1
YES
WHY < Y(J)
NO
END
COMPUTE dx, dy, dxdy, dx-dxdy, dy-dxdy, 1-dx-dy-dxdy
INT2 = f(z(i,j), dx, dy)
RETURN

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

PROGRAM: HYBRID2

NAME:

ROUTINE: MAIN PROGRAM

DATE:

PAGE 1 OF 1

FORTRAN STATEMENT

0 : ZERO, 0 : ALPHA O — 1 = ONE, I = ALPHA I — 2 = TWO, Z = ALPHA Z

TYPE	STATEMENT NO.	CONT	FORTRAN STATEMENT	SERIAL NUMBER
			CASE DATA:	
		T	EOMØ TEODEL RPMØ TEOMN2 DBMAX PEOMIN VMAX	
	D	T	FLTR	

FORM NO. GRC 109 REV. 1

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

PROGRAM: HYBRID2

ROUTINE: HYREAD

NAME:

DATE:

PAGE 1 OF 3

FORTRAN STATEMENT

0 = ZERO, O = ALPHA O; 1 = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z

	ENGINE DATA							
NRPM	NMEP	FUELSG	DISPL	SKALE				
IBMEP								
*	IF(IBMEP.NE.Ø)							
BMEP(1)	. . .	BMEP(NMEP)						
NMEPO(1)	RPM(1)	TQMAX(1)						
BMEPO(1,1)	BSFCO(1,1)	. . .	BMEPO(1,NMEPO(1))	BSFCO(1,NMEPO(1))				
			. . .					
NMEPO(NRPM)	RPM(NRPM)	TQMAX(NRPM)						
BMEPO(NRPM,1)	BSFCO(NRPM,1)	. . .	BMEPO(NRPM,NMEPO(NRPM))		BSFCO(NRPM,NMEPO(NRPM))			
*	IF(IBMEP.EQ.Ø)							
RPM(1)	TQMAX(1)	. . .	RPM(NRPM)	TQMAX(NRPM)	BMEP(1)	. . .		
BMEP(NMEP)	BSFC(1,1)	. . .	BSFC(NRPM,NMEP)					
NOP	RPMBST	PBEST						
PEOP(1)	RPMEOP(1)	. . .	PEOP(NOP)	RPMEOP(NOP)				
	MOTOR/GENERATOR							
NSPMO	EMUM	EMUMM	TMSKL	PINNLD	RPMIDL	RPMOPM		
PBREAK								
SPMO(1)	TMOMAX(1)	TMOMIN(1)	. . .	SPMO(NSPMO)	TMOMAX(NSPMO)	TMOMIN(NSPMO)		

SERIAL NUMBER

FORM NO. GRC 109 REV. 1

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

PROGRAM: HYBRID2
ROUTINE: HYREAD
NAME:
DATE:
PAGE 2 OF 3

```
          CONTINUOUSLY VARIABLE TRANSMISSION DATA
    EMUCVT     RATUP     RATDN

          TORQUE CONVERTOR DATA
      NTSP
    CTCZRD     TSP(1)     TQR(1)     SPR(1)  . . .  TSP(NTSP)  TQR(NTSP)
SPR(NTSP)

          TRANSMISSION DATA
     NGEAR       NTH       UPSEL       DNSEL
 NLOCK(1)  TRATIO(1)     CT1(1)      CT2(1)     EMUT(1)  . . .  NLOCK(NGEAR)
TRATIO(NGEAR)CT1(NGEAR)CT2(NGEAR)EMUT(NGEAR)

          BATTERY DATA
    NDDSCH     NDENS        WB       EBMAX       EMURG      EMURG2     CHGEFF
DDISCH(1)  CYCLES(1)  . . .  DDISCH(NDDSCH)CYCLES(NDDSCH)
 PDENS(1)   EDENS(1)  . . .  PDENS(NDENS)EDENS(NDENS)

          DIFFERENTIAL AND TIRE DATA
    DRATIO       CD1       CD2        EMUD       RTIRE      CTIRE1     CTIRE2
```

FORM NO. GRC 53 R...

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

PROGRAM HYBRID2

ROUTINE HYREAD

NAME

DATE

PAGE 3 OF 3

FORTRAN STATEMENT

0 = ZERO, Ø = ALPHA O; 1 = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z

SERIAL NUMBER

```
          ACCESSORY DATA
      NAX
RPMAX(1)  TAX(1)  . . .  RPMAX(NAX)  TAX(NAX)

          VEHICLE DATA
     VMASS  DLI  CDA

          DRIVING CYCLE DATA
    NCYCLE
    NTC(1)  NPRTC(1)  NUNITS  DTC(1)  TFC(1)
TIME(1,1)  SPEDC(1,1)  . . .  TIME(1,NTC(1))  SPEDC(1,NTC(1))
                                 . . .
NTC(NCYCLE)  NPRTC(NCYCLE)  NUNITS  DTC(NCYCLE)  TFC(NCYCLE)
TIME(NCYCLE,1)  SPEDC(NCYCLE,1)  . . .  TIME(NCYCLE,NTC(NCYCLE))  SPEDC(NCYCLE,NTC(NCYCLE))
     NCOMP  DSTAV  DWARM
  DSUP(1)  DNC(1)  (GAMMA(1,1)  . . .  GAMMA(1,NCYCLE))  . . .  DSUP(NCOMP)
DNC(NCOMP)  (GAMMA(NCOMP,1)  . . .  GAMMA(NCOMP,NCYCLE))
```

FORM NO. GRC 109 REV. 1

GOLETA FORTRAN 1.3 * SEMI-AUTO EFL * (01-10-73)

```
                   PROGRAM HYBRID2
          C
          C        HYBRID2 MODELS OPERATION OF HYBRID VEHICLE OVER SPECIFIED DRIVI
          C        CYCLES.
          C
          C        DATA IN COMMON -
000003              COMMON DISPL,RPM(20),TQMAX(20),BMEP(20),BSFC(20,20),NRPM,NMEP,
                  1EMUM,EMUG,FINNLD,SPMO(20),TMOMAX(20),TMOMIN(20),NSPMO,
                  2CTCZRO,TSF(20),TQR(20),SFR(20),TSP2(20),NTSP,
                  3NLOCK(5),TRATIO(5),CT1(5),CT2(5),EMUT(5),
                  4WB,EBMAX,EMURG,EMURG2,
                  5DRATIO,CD1,CD2,EMUD,FTIRE,CTIRE1,CTIRE2,VMASS,DLI,CDA,
                  6TEOMIN,DBMAX,RPMIDL,VMASS2,PEOMIN,
                  7FUELSG,SKALE,TMSKL,NTP,NODSCH ,CHGEFF,NCYCLE,NCOMP,DSTAV,
                  8NUNITS,THSET(5),UPSHFT(5),DNSHFT(5),DDISCH(20),CYCLES(20),NTC(3
                  9NPRTC(3),DTC(3),TFC(3),DSUP(30),DNC(30),DBAR(30)
                  1,RPMBST,PBEST,PEOP(20),RPMEOP(20),RPMOPM,EMUCVT,RATUP,RATDN,NOP
                  2,PCENS(20),ECENS(20),NCENS
                  3,VMAX,TEOMN2,UPSEL,DNSEL,DWARM,NAX,RPMAX(20),TAX(20)
000003              COMMON TIMC(3,200),SPEEC(3,200),GAMMA(30,3)
          C
          C        VARIABLES IN COMMON -
000003              COMMON FA,FR,FAC,FNET,TCC,TTC,RPMDO,RPMTO,TSO,RPMSC,RPMTCO,TTCO
                  1RPMTCN,TMO,TEC,TMO2,TEO2,TGO,PSC,PEO,PEO2,PMO,PMO2,PGO,PBRK,FC,
                  2PD,PT,PRW,PLTC,THRPC,TTCIN
                  3,RPMEO,RPMEO2,PLTC2,VMPS
                  4,TSO2,RPMSO2,FSO2,RPMTC1,RPMTC2,RPMEP,RPMEP2
          C
000003             REAL YDOT(20),Y(20),INT1,INT2,V(6),A(3),YTMP(20)
000003             REAL EK(80)
000003             REAL DIST(3),FCONS(3),FCONS2(3),ECONS(3),ECONS2(3)
000003             REAL FCBAR(30),SPRAC(30),TIME(200),SPEED(200),
                  1FCBAR2(30),ECBAR(30),ECBAR2(30),RANGE(30),FCMAV(30),ECMAV(30)
000003             REAL ECHE(3),ECSYS(3),EHEBAR(30),ESYSBR(30)
000003             REAL VAVG(3)
000003             REAL VBAR(25),SPPWR(25),SPENG(25)
000003             REAL PMCT(2800),ERG(2800),DEFL(3),BDBAR(30)
000003             INTEGER IBP(20)
          C
000003             CALL HYREAD(NCEAP)
          C
          C        INPUT RUN DATA
          C
000005             READ 600,NCASE
000013             DO 194 JCASE=1,NCASE
000015             PRINT 925,JCASE
000022             READ 610,TEOMIN,TEOMN2,DBMAX,PEOMIN,VMAX
000040             PRINT 930,TEOMIN,TEOMN2,DBMAX,PEOMIN,VMAX
000056             VMAX=VMAX/3.6
000060             READ 610,CTFLTP
000065             DO 190 JCYC=1,NCYCLE
000067             PRINT 700
000072             NTIME=NTC(JCYC)
000074             NPRNT=NPRTC(JCYC)
000076             DELT=DTC(JCYC)
```

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```
000077           TF=TFC(JCYC)
000101           MCT=IFIX(TF/DELT+2.*(DTFLTR/1.0)+1.)
   106           DO 47 J=1,NTIME
000110           TIME(J)=TIMC(JCYC,J)
000114           SPEED(J)=SPEDC(JCYC,J)
000117        47 CONTINUE
000121           DO 48 J=1,MCT
000122           PMOT(J)=0.0
000123        48 CONTINUE
         C
         C       INITIALIZE VARIABLES OF INTEGRATION
         C
000125           DO 50 J=1,20
000127           Y(J)=0.0
000130           IBP(J)=0
000131        50 CONTINUE
000133           T=0.0
000134           ITIBP=0
000135           K=NPRNT
000136           JGEAR=1
000137           JGEAR2=1
000140           NTM=0
         C
         C       COMPUTE VELOCITY AND ACCELERATION
         C
000141           V(1)=0.0
   142           V(3)=SPEED(1)
000143           V(4)=INT1(DELT/2.,TIME,SPEED,NTIME)
000151           V(5)=INT1(DELT,TIME,SPEED,NTIME)
000155           V(6)=INT1(3.*DELT/2.,TIME,SPEED,NTIME)
000163           V(2)=V(3)+V(3)-V(4)
000165           GO TO 70
000166        60 V(1)=V(3)
000170           V(3)=Y(11)
000171           V(2)=(V(1)+V(3))/2.
000174           V(4)=V(6)
000175           V(5)=INT1(T+DELT,TIME,SPEED,NTIME)
000203           V(6)=INT1(T+3.*DELT/2.,TIME,SPEED,NTIME)
000213        70 A(1)=(V(4)-V(2))/(3.6*DELT)
000217           A(1)=AMIN1(A(1),9.8)
000222           A(2)=(V(5)-V(3))/(3.6*DELT)
000226           A(2)=AMIN1(A(2),9.8)
         C
         C       COMPUTE VEHICLE OPERATING CONDITIONS AT MAJOR TIME POINT
         C
000231           IFLAG=0
000232        80 CALL VEHIC(V(3),A(1),T,YDOT,Y,JGEAR,JGEAR2)
000241           NTM=NTM+1
000243           IF(PMO.GE.0.)PMOT(NTM)=PMO/EMUM+PINNLD
000247           IF(PGO.NE.0.0)PMOT(NTM)=PGO*EMUM+PINNLD
000254           IF(IFLAG.EQ.1)GO TO 93
   256           CALL GRSHFT(IFLAG,JGEAR,JGEAR2,NGEAR)
000261           IF(IFLAG.EQ.1)GO TO 80
000263        93  RPI=YDOT(18)*1000.
000265           ABPI=ABS(RPI)
```

```
000267           DO   94 J=1,20,2
000270           JTH=J
000271           IF(ABPI.GT.2*J-4.AND.ABPI.LE.2*J)GO TO 95
000310        94 CONTINUE
000312        95 IF(BPI+2.0.GT.0.0)GO TO 96
000316           IBP(JTH+1)=IBP(JTH+1)+1
000320           GO TO 97
000321        96 IBP(JTH)=IBP(JTH)+1
000324        97 CONTINUE
000324           DO   98 JV=1,19
000326           EK(JV)=YDOT(JV)
000330        98 CONTINUE
         C
         C       TIME TO PRINT RESULTS -
         C
000332           IF(T.EQ.TF)GO TO 100
000334           K=K+1
000335           IF(K.LT.NPRNT)GO TO 110
000337           K=0
000340       100 EKIN=VMASS2*VMPS**2/2.
000343           EB=Y(18)
000345           EB2=Y(19)
000346           JG=JGEAR
000350           JG2=JGEAR2
000351           PRINT 710,T,Y(11),Y(12),FRW,FBRK,Y(1),Y(4),EKIN,
                1JG,RPMTO1,Y(2),Y(5),Y(7),Y(9),Y(13),Y(18),PSO,PEO,PMO,PGO,
                2JG2,RPMTO2,Y(3),Y(6),Y(8),Y(10),Y(19),PSO2,PEO2,PMO2
000451           IF(T.LT.TF)GO TO 110
000454           DIST(JCYC)=Y(12)
000455           DO 101 J=1,NTM
000457           PMOT(J)=PMOT(J)*1000.
000461       101 CONTINUE
000463           CALL FILTER(NTM,0.5,DTFLTR,PMOT)
000466           DO 102 J=1,NTM
000470           IF(PMOT(J).LT.0.0)GO TO 105
000472           ERG(J)=INT1(PMOT(J)/WB,PDENS,EDENS,NDENS)
000502           ERG(J)=ERG(J)*WB
000504           GO TO 102
000505       105 ERG(J)=WB*PBMAX/EMURG
000511       102 CONTINUE
000514           DEPL(JCYC)=2.*PMOT(1)/ERG(1)
000517           NTMS=NTM-1
000521           DO 106 J=1,NTMS
000522           DEPL(JCYC)=DEPL(JCYC)+(3.+(-1.)**(J-1))*PMOT(J+1)/ERG(J+1)
000534       106 CONTINUE
000537           DEPL(JCYC)=DEPL(JCYC)/(3.*3600.)
000541           DEPL(JCYC)=DEPL(JCYC)/DIST(JCYC)
000543           VAVG(JCYC)=DIST(JCYC)*3600./TF
000546           FCONS(JCYC)=Y(16)/Y(12)
000550           ECONS(JCYC)=EB/(3.6*Y(12))
000553           FCONS2(JCYC)=Y(17)/Y(12)
000555           ECONS2(JCYC)=EB2/(3.6*Y(12))
000557           ECHE(JCYC)=Y(8)/Y(12)
000561           ECSYS(JCYC)=(Y(5)+Y(8))/Y(12)
000564           PRINT 840,Y(12),FCONS(JCYC),FCONS2(JCYC),ECONS(JCYC),ECONS2(JC
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000601           PRINT 945,VAVG(JCYC),DEFL(JCYC),Y(14),Y(15)
  0615           DO 108 J=1,19
  0617           ITIBP=ITIBP+IBP(J)
000621       108 CONTINUE
000623           PRINT 1020,IBP(18),IBP(16),IBP(14),IBP(12),IBP(10),IBP(8),IBP(
                1IBP(4),IBP(2),(IBP(J),J=1,19,2),ITIBP
000660           DO 109 J=1,19
000662           IBP(J)=0
000663       109 CONTINUE
000665           ITIBP=0
000666           IF(T.GE.TF)GO TO 190
           C
           C     INTEGRATE TO NEXT TIME STEP
           C
000670       110 TTMP=T
000672           DO 170 JV=1,3
000673           JA=MAX0(2,JV)
000676           IF(JV.EQ.2)GO TO 121
000677           TTMP=TTMP+DELT/2.
000702       121 DT=TTMP-T
000704           IF(JV.NE.3)GO TO 122
000706           A(3)=(Y(6)-(VTMP+VTMPL)/2.)/(3.6*DELT)
000715           A(3)=AMIN1(A(3),9.8)
000720       122 VTMPL=VTMP
000722           VTMP=Y(11)+EK(11+(JV-1)*19)*DT
000731           IFLAG=0
  0732       130 CALL VEHIC(VTMP,A(JA),TTMP,YDOT,Y,JGEAR,JGEAR2)
  0743           IF(IFLAG.EQ.1)GO TO 160
000745           CALL GRSHFT(IFLAG,JGEAR.JGEAR2,NGEAR)
000750           IF(IFLAG.EQ.1)GO TO 130
000752       160 DO 170 JK=1,19
000754           EK(JK+19*JV)=YDOT(JK)
000761       170 CONTINUE
000765           DO 180 JK=1,19
000766           Y(JK)=Y(JK)+DELT*(EK(JK)+2.*(EK(JK+19)+EK(JK+38))+EK(JK+57))/6
000777       180 CONTINUE
001001           T=T+DELT
001002           GO TO 50
001003       190 CONTINUE
001006           FCAV=0.0
001007           ECAV=0.0
001010           EHEAV=0.0
001011           ESYSAV=0.0
001012           DO 300 JC=1,NCOMP
           C
           C     COMPUTE FUEL AND ENERGY CONSUMPTION ON COMPOSITE DRIVING CYCLE
           C     FOR MODES1 AND 2.
           C
001013           DBAR(JC)=0.0
001014           FCBAR(JC)=0.0
  1015           FCBAR2(JC)=0.0
   016           ECBAR(JC)=0.0
001017           ECBAR2(JC)=0.0
001020           EHEBAR(JC)=0.0
001021           ESYSBR(JC)=0.0
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001022          VRECIP=0.0
001023          DO 260 KC=1,NCYCLE
   025          VRECIP=VRECIP+GAMMA(JC,KC)/VAVG(KC)
001033          BOBAR(JC)=BOBAR(JC)+GAMMA(JC,KC)*DEPL(KC)
001040          FCBAR(JC)=FCBAR(JC)+GAMMA(JC,KC)*FCONS(KC)
001045          FCBAR2(JC)=FCBAR2(JC)+GAMMA(JC,KC)*FCONS2(KC)
001053          ECBAR(JC)=ECBAR(JC)+GAMMA(JC,KC)*ECONS(KC)
001060          ECBAR2(JC)=ECBAR2(JC)+GAMMA(JC,KC)*ECONS2(KC)
001066          EHEBAR(JC)=EHEBAR(JC)+GAMMA(JC,KC)*ECHE(KC)
001073          ESYSBR(JC)=ESYSBR(JC)+GAMMA(JC,KC)*ECSYS(KC)
001101      260 CONTINUE
001103          VBAR(JC)=1./VRECIP
001106          SPPWR(JC)=1000.*ECBAR(JC)*VBAR(JC)/WB
        C
        C       CORRECT FUEL CONSUMPTION FOR NON-ZERO ENERGY CONSUMPTION ON MO
        C
001112          FCBAR2(JC)=(FCBAR2(JC)*ECBAR(JC)-FCBAR(JC)*ECBAR2(JC))/(ECBAR(
               1-ECBAR2(JC))
        C
        C       COMPUTE RANGE FOR NEW BATTERY DISCHARGE LIMIT
        C
001120          RANGE(JC)=DFMAX/BOBAR(JC)
        C
        C        COMPUTE FRACTION OF TOTAL DRIVING DONE ON MODE 1 FOR EACH
        C       COMPOSITE CYCLE.
        C
   123          IF(JC.NE.1)GO TO 265
   125          DLOW=0.
001126          GO TO 266
001126      265 DLOW=DSUP(JC-1)
001130      266 IF(DWARM.LE.DSUP(JC))GO TO 267
001134          RFRAC(JC)=0.
001135          GO TO 280
001135      267 IF(RANGE(JC).GT.DLOW-DWARM)GO TO 270
001143          RFRAC(JC)=RANGE(JC)/DBAR(JC)
001145          GO TO 280
001146      270 IF(RANGE(JC).GT.DSUP(JC)-DWARM)GO TO 275
001154          RFRAC(JC)=(RANGE(JC)/DBAR(JC))*(1.-(RANGE(JC)-DLOW+DWARM)**2/
               1(2.*RANGE(JC)*(DSUP(JC)-DLOW)))
001170          GO TO 280
001171      275 RFRAC(JC)=1.-DWARM/DBAR(JC)
001175      280 CONTINUE
        C
        C       COMPUTE MODE-AVERAGED FUEL AND ENERGY CONSUMPTION FOR COMPOSIT
        C       DRIVING CYCLE.
        C
001175          FCMAV(JC)=RFRAC(JC)*FCBAR(JC)+ (1.-RFRAC(JC))*FCBAR2(JC)
001203          ECMAV(JC)=RFRAC(JC)*ECBAR(JC)+(1.-RFRAC(JC))*ECBAR2(JC)
        C
        C       COMPUTE OVERALL FUEL AND ENERGY CONSUMPTION.
        C
   210          FCAV=FCAV+DNC(JC)*FCMAV(JC)
001214          ECAV=ECAV+DNC(JC)*ECMAV(JC)
001217          EHEAV=EHEAV+DNC(JC)*EHEBAR(JC)
001223          ESYSAV=ESYSAV+DNC(JC)*ESYSBR(JC)
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001226          FEAV=1000.*FUELSG/FCAV
   231          WPAV=ECAV/CHGEFF
   233      300 CONTINUE
        C
001235          HEEF=EHEAV/ESYSAV
        C       ESTIMATE BATTERY LIFE.
        C
001237          DOAV=DBMAX
001241          BLIFE=CSTAV*INT1(DOAV,DCISCH,CYCLES,NODSCH)
001246          PRINT 950
001251          PRINT 960,(FCBAR(J),FCBAR2(J),ECBAR(J),RANGE(J),FCMAV(J),ECMAV(
               1VBAR(J),SPPWR(J),J=1,NCOMP)
001302          PRINT 970,FCAV,ECAV,BLIFE
001314          PRINT 975,FEAV,WPAV
001324          PRINT 1010,HEEF
001332      194 CONTINUE
001335      200 STOP
        C       FORMAT STATEMENTS
        C
001337      600 FORMAT(I10,6F10.4)
001337      610 FORMAT(7F10.4)
001337      700 FORMAT(1H0,4X,4HTIME,8X,5HSPEED,5X,8HDISTANCE,4X,9HR.L.POWER,3X
               18HBR.POWER,3X,10HR.L.ENERGY,3X,9HBR.ENERGY,2X,10HKIN.ENERGY/
               21X,2HGN,2X,3HRPM,1X,10HD.T.ENERGY,2X,10HSYS.ENERGY,2X,10HENG.EN
               3Y,4X,                                                         1
               3OTOR SHAFT ENERGY,4X,10HBAT.ENERGY,3X,9HSYS.POWER,3X,9HENG.POWE
               45X,17HMOTOR SHAFT POWER)
001337      710 FORMAT(1H0,2E12.4/I2,F6.0,10E12.4/I2,F6.0,4E12.4,12X,4E12.4)
001337      820 FORMAT(1H ,2E16.6)
001337      925 FORMAT(1H1,27HCONTROL PARAMETERS FOR CASE,I2)
001337      930 FORMAT(1H0,5X,20HMIN. ENGINE TORQUE =,E11.4,9H (MODE 1)
               1/25X,E11.4,9H (MODE 2)/6X,20HBATT. DISCH. LIMIT =,E11.4
               2/6X,21HNOMINAL MOTOR POWER =,E11.4
               3/6X,18HTRANSITION SPEED =,E11.4)
001337      950 FORMAT(1H0,47HFUEL AND ENERGY CONSUMPTION ON COMPOSITE CYCLES/
               113HFUEL - MODE 1,3X,13HFUEL - MODE 2,2X,15HENERGY - MODE 1,1X,
               214HRANGE - MODE 1,4X,10HFUEL - AV.,5X,12HENERGY - AV.,6X,9HAV.
               3FO,5X,13HSP. POWER - 1)
001337      960 FORMAT(1H ,8E16.6)
001337      970 FORMAT(1H0,29HYEARLY AV. FUEL CONSUMPTION =,E16.6/1X,34HYEARLY
               1 BATTERY ENERGY OUTPUT =,E16.6/1X,23HEXPECTED BATTERY LIFE =,E
               2)
001337      975 FORMAT(1H0,25HYEARLY AV. FUEL ECONOMY =,E16.6/1X,
               129HYEARLY AV. WALL PLUG OUTPUT =,E16.6)
001337      940 FORMAT(1H0,16HCYCLE DISTANCE =,E12.4/1X,23HFUEL CONSUMPTION ON
               1E 1 =,E12.4/21X,8HMODE 2 =,E12.4/1X,36HBATT. ENERGY CONSUMPTIO
               2 MODE 1 =,E12.4/29X,8HMODE 2 =,E12.4)
001337     1010 FORMAT(1H0,29HHEAT ENGINE ENERGY FRACTION =,E16.6)
001337      945 FORMAT(1H ,15HAVERAGE SPEED =,E12.4,1X,19HBATTERY DEPLETION =,
               16,1X,21HHEAT ENGINE ON TIME =,E16.6,8H(MODE 1),1X,E16.6,8H(MOD
               2)
   337     1000 FORMAT(1H0,4E12.4)
001337     1020 FORMAT(1H0,*BATTERY POWER DISTRIBUTION*,/50X,*NEGATIVE*,1X,*PO
               1VE*,/1X,    *38-34*,1X,*34-30*,1X,*30-26*,1X,*26-22*,1X,*22-18*
               21X,*18-14*,1X,*14-10*,2X,*10-6*,2X,*6-2*,3X,*2-2*,3X,*2-6*,2X,
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      3*6-10*,1X,*10-14*,1X,*14-18*,1X,*18-22*,1X,*22-26*,1X,*26-30*,
      4*30-34*,1X,*34-38*,1X,*TOTAL*/1(20I6))
1337   END
```

```
                  SUBROUTINE VEHIC(V,A,T,YDOT,Y,NGEAR,NGEAR2)
          C
          C       VEHIC COMPUTES POWER REQUIREMENTS AND LOSSES FROM REAR WHEELS
          C          THROUGH ENGINE
          C
          C       DATA IN COMMON -
          C
000012            COMMON DISPL,RPM(20),TQMAX(20),BMEP(20),BSFC(20,20),NRPM,NMEP,
                 1EMUM,EMUG,FINNLD,SPMO(20),TMCMAX(20),TMCMIN(20),NSPMO,
                 2CTCZRO,TSP(20),TQR(20),SFR(20),TSP2(20),NTSP,
                 3NLOCK(5),TRATIO(5),CT1(5),CT2(5),EMUT(5),
                 4WB,EEMAX,EMURG,EMURG2,
                 5DRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2,VMASS,OLI,CDA,
                 6TEOMIN,DRMAX,RPMIDL,VMASS2,PEOMIN,
                 7FUFLSG,SKALE,THSKL,NTH,NCDSCH ,CHGEFF,NCYCLE,NCOMP,DSTAV,
                 8NUNITS,THSET(5),UPSHFT(5),DNSHFT(5),DDISCH(20),CYCLES(20),NTC(
                 9NPRTC(3),DTC(3),TFC(3),CSUP(30),CNC(30),DBAR(30)
                 1,RPMBST,PBEST,PEOP(20),RPMEOP(20),RPMOPM,EMUCVT,RATUP,RATDN,NC
                 2,PDENS(20),EDENS(20),NDENS
                 3,VMAX,TEOMN2,UPSEL,DNSEL,DWARM,NAX,RPMAX(20),TAX(20)
000012            COMMON TIMC(3,200),SPEDC(3,200),GAMMA(30,3)
          C
          C       VARIABLES IN COMMON -
          C
000012            COMMON FA,FR,FAC,FNET,TDC,TTC,RPMDO,RPMTO,TSO,RPMSO,RPMTCO,TTC
                 1RPMTCN,TMO,TEC,TMO2,TSC2,TGC,PSC,PEO,PEO2,PMC,PMC2,PGO,PBRK,FC
                 2PD,PT,PPW,PLTC,THRRR,TTCIN
                 3,RPMEO,RPMEO2,PLTC2,VMPS
                 4,TSC2,RPMSC2,PSC2,RPMTC1,RPMTC2,PRATP,RPMEP2
          C
000012            REAL YDOT(20),INT1,INT2
          C
          C       COMPUTE SPEEDS AND LOAD-INDEPENDENT LOSSES THROUGH DRIVE TRAIN
          C
000012            VMPS=AMAX1(0.0,V/3.6)
000016            NLCK=NLOCK(NGEAR)
000020            NLCK2=NLOCK(NGEAR2)
000022            RPMDO=9.5492967*VMPS/RTIRE
000025            RPMTO=RPMDO*DRATIO <---
000027            RPMSO=RPMTO*TRATIO(NGEAR)
000031            RPMSO2=RPMTO*TRATIO(NGEAR2)
000033            TLFD=CD1+CD2*RPMTO
000036            TLFT=CT1(NGEAR)+CT2(NGEAR)*RPMSO
000042            TLFT2=CT1(NGEAR2)+CT2(NGEAR2)*RPMSO2
          C       COMPUTE ROAD LOAD POWER REQUIREMENTS
          C       AERODYNAMIC -
          C
000046            FA=0.6125*CDA*VMPS**2
000051            PA=FA*VMPS/1000.
000053            YDOT(1)=PA/1000.
          C
          C       ROLLING RESISTANCE -
          C
000054            FR=9.807*VMASS*(CTIRE1+CTIRE2*V)
000061            PR=FR*VMPS/1000.
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```
000063            YOCT(1)=(FA+FF)/1000.
           C
           C      ACCELERATION -
           C
000065            FAC=VMASS2*A
000067            FNET=FA+FR+FAC+FG
000073            TDO=FNET*RTIRE
000075            PRW=0.0001047197*TDO*RPMCO
000077            IF(FNET.LT.0.0)GO TO 200
           C
           C      NON-NEG. NET DRIVING FORCE TO THE WHEELS IS NEEDED
           C      DIFFERENTIAL -
           C
000100            TTO=TDO/(EMUD*DRATIO)+TLFD
           C
           C      TRANSMISSION -
           C
000103            TSO=TTO/(EMUT(NGEAR)*TRATIO(NGEAR))+TLFT
000110            PSO=TSO*RPMSO*0.0001047197
000112            TSO2=TTO/(EMUT(NGEAR2)*TRATIO(NGEAR2))+TLFT2
000120            PSO2=TSO2*RPMSO2*0.0001047197
           C
           C      IS CAR AT REST AND IDLING -
           C
000122            IF(ABS(VMPS).LT.0.2.AND.ABS(A).LT.0.1)GO TO 300
           C
  0134            CALL PMCVR(1,JBRK,NLCK,NLCK2)
000137       140  GO TO 400
           C
           C      NET DRIVING FORCE AT WHEELS IS NEGATIVE
           C
000143       200  TTO=TDO*EMUD/DRATIO+TLFD
000147            TSO=TTO*EMUT(NGEAR)/TRATIO(NGEAR)+TLFT
000153            PSO=TSO*RPMSO*0.0001047197
000155            TSO2=TTO*EMUT(NGEAR2)/TRATIO(NGEAR2)+TLFT2
000162            PSO2=TSO2*RPMSO2*0.0001047197
000165            NGEAR=NGEAR2
000166            IF(PSO.GE.0.0)GO TO 210
000167            CALL PMCVR(-1,JBRK,NLCK,NLCK2)
000172            IF(JBRK.EQ.0)GO TO 400
           C
           C
000177            PSO=TSO*RPMSO*0.0001047197
000201            PSO2=PSO
000202            TTO=(TSO-TLFT)*TRATIO(NGEAR)/EMUT(NGEAR)
000206            TDO=(TTO-TLFD)*DRATIO/EMUD
000212            GO TO 400
000212       210  CALL PMCVR(1,JBRK,NLCK,NLCK2)
000215       240  GO TO 400
           C
           C      CAR IS AT REST AND IDLING
           C
000221       300  A=0.0
000222            VMPS=0.0
000223            CALL PMCVR(0,JBRK,NLCK)
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)   VEHIC


```
000225          PSO=0.0
  0226          PSO2=0.0
         C
         C      COMPUTE ENGINE FUEL RATE AND DERIVATIVES OF VARIABLES
         C
000227      400 IF(PEO.NE.0.0)GO TO 410
000234          FC=0.0
000235          GO TO 420
000235      410 BRMEP=125.664*TEO/DISPL
000240          SFC=INT2(RPMEC,BRMEP,RPM,BMEP,BSFC,NRPM,NMEP)
000247          FC=SFC*PEO
000251      420 IF(PEO2.NE.0.0)GO TO 430
000256          FC2=0.0
000257          GO TO 440
000257      430 BRMEP2=125.664*TEO2/DISPL
000262          SFC=INT2(RPMEC2,BRMEP2,RPM,BMEP,BSFC,NRPM,NMEP)
000271          FC2=SFC*PEO2
000273      440 PD=TDO*RPMDC*0.0001047197
000276          PBRK=PRW-PD
000300          PT=TTO*RPMTC*0.0001047197
000302          YDOT(2)=(ABS(FT-PD)+ABS(PSO-PT)+ABS(PLTC))/1000.
000320          YDOT(3)=(ABS(FT-PD)+ABS(PSO2-PT)+ABS(PLTC2))/1000.
000333          YDOT(4)=ABS(PBRK)/1000.
000335          YDOT(5)=PSO/1000.
000337          YDOT(6)=PSO2/1000.
000340          YDOT(7)=PEO/1000.
  0342          YDOT(8)=PEO2/1000.
000344          YDOT(9)=PMC/1000.
000345          YDOT(10)=PMC2/1000.
000347          YDOT(11)=A*3.6
000351          YDOT(12)=VMES/1000.
000353          YDOT(13)=FGC/1000.
000354          YDOT(14)=0.
000355          IF(PEO.EQ.0.)GO TO 442
000356          YDOT(14)=1.
000360      442 YDOT(15)=0.
000361          IF(PEO2.EQ.0.)GO TO 444
000362          YDOT(15)=1.
000364      444 YDOT(16)=FC/3600.
000366          YDOT(17)=FC2/3600.
000370          YDOT(18)=(PINNLP+PMC/EMUM+FGC*FMUG*EMURG)/1000.
000377          YDOT(19)=(PINNLP+PMC2/EMUM+FGC*EMUG*EMURG2)/1000.
000406          RETURN
000407          END
```

```
                 SUBROUTINE HYREAD(NGEAR)
          C
          C      HYREAD INPUTS DATA FOR HYBRID2
          C
          C      DATA IN COMMON -
000003           COMMON DISPL,RPM(20),TQMAX(20),BMEP(20),BSFC(20,20),NRPM,NMEP,
                1EMUM,EMUG,PINNLD,SPMO(20),TMOMAX(20),TMOMIN(20),NSPMO,
                2CTCZRO,TSP(20),TQR(20),SFR(20),TSP2(20),NTSP,
                3NLOCK(5),TRATIO(5),CT1(5),CT2(5),EMUT(5),
                4WB,EBMAX,EMURG,EMURG2,
                5DRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2,VMASS,DLI,CCA,
                6TEOMIN,DBMAX,RPMIDL,VMASS2,PEOMIN,
                7FUELSG,SKALE,TMSKL,NTH,NODSCH ,CHGEFF,NCYCLE,NCOMP,DSTAV,
                8NUNITS,THSFT(5),UPSHFT(5),DNSHFT(5),DDISCH(20),CYCLES(20),NTC(
                9NPRTC(3),DTC(3),TFC(3),CSUP(30),DNC(30),CBAR(30)
                1,RPMBST,PBEST,PEOP(20),RPMEOP(20),RPMOPM,EMUCVT,RATUP,RATDN,NO
                2,PDENS(20),EDENS(20),NDENS
                3,VMAX,TEOMN2,UPSEL,DNSEL,DWARM,NAX,RPMAX(20),TAX(20)
000003           COMMON TIMC(3,200),SPEDC(3,200),GAMMA(30,3)
          C
          C      VARIABLES IN COMMON -
000003           COMMON FA,FR,FAC,FNET,TOC,TTC,RPMDO,RPMTC,TSO,RPMSO,RPMTCO,TTC
                1RPMTCN,TMO,TEO,TMO2,TEO2,TGO,PSO,PEO,PEO2,PMO,PMO2,PGO,PBRK,FC
                2PD,PT,PPW,PLTC,THPPC,TTCIN
                3,RPMEO,RPMEO2,PLTC2,VMPS
                4,TSO2,RPMSO2,PSO2,RPMTC1,RPMTC2,RPMEP,RPMEP2
          C
          C      INPUT ENGINE DATA
          C
000003           READ 605,NRPM,NMEP,FUELSG,DISPL,SKALE
000021           READ 610,(RPM(J),TQMAX(J),J=1,NRPM),(BMEP(J),J=1,NMEP),((BSFC(
                1,J=1,NMEP),I=1,NRPM)
000057           READ 600,NOP,RPMBST,PBEST
000071           READ 610,(PEOP(J),RPMEOP(J),J=1,NOP)
000106           DISPL=DISPL*SKALE
000110           PBEST=PBEST*SKALE
000111           DO 11 J=1,NRPM
000113           TQMAX(J)=SKALE*TQMAX(J)
000115        11 CONTINUE
000117           DO 12 J=1,NOP
000121           PEOP(J)=PEOP(J)*SKALE
000123        12 CONTINUE
000125           PRINT 800,FUELSG,DISPL
000135           PRINT 805
000141           DO 1 J=1,NRPM
000144           PRINT 810,RPM(J),TQMAX(J),BMEP(1),BSFC(J,1)
000157           PRINT 806,(BMEP(K),BSFC(J,K),K=2,NMEP)
000176         1 CONTINUE
000202           PRINT 807,RPMBST,PBEST
000211           PRINT 910,(PEOP(J),RPMEOP(J),J=1,NOP)
          C
          C      INPUT MOTOR/GENERATOR DATA
          C
000226           READ 500,NSPMO,EMUM,EMUG,TMSKL,PINNLD,RPMIDL,RPMOPM
000250           READ 610,(SPMO(J),TMOMAX(J),TMOMIN(J),J=1,NSPMO)
```

```
000267          DO 2 J=1,NSPMC
  0272          TMOMAX(J)=TMOMAX(J)*TMSKL
000274          TMOMIN(J)=TMOMIN(J)*TMSKL
000276        2 CONTINUE
000300          PRINT 811
000303          PRINT 812,EMUM,EMUG,FINALD,RPMIDL,RPMOPM
000321          PRINT 813
000325          PRINT 814,(SPMO(J),TMOMAX(J),TMOMIN(J),J=1,NSPMC)
        C
000344          READ 600,JCVT
        C
        C       JCVT=0 FOR TORQUE CONVERTOR, =1 FOR CVT
        C
000352          IF(JCVT.EQ.0)GO TO 4
000354          READ 610,EMUCVT,RATUP,RATDN
000365          PRINT 808,EMUCVT,RATUP,RATDN
000400          GO TO 5
        C       INPUT TORQUE CONVERTOR DATA
        C
000402        4 READ 620,NTSP
000410          READ 610,CTCZRO,(TSP(J),TQR(J),SPR(J),J=1,NTSP)
000431          PRINT 860
000435          PRINT 865,CTCZRO
000443          PRINT 870
000447          PRINT 814,(TSP(J),TQR(J),SPR(J),J=1,NTSP)
000466          DO 3 J=1,NTSP
  0471          TSP2(J)=TSP(J)*SQRT(TQR(J))
000477        3 CONTINUE
        C
        C       INPUT TRANSMISSION DATA
        C
000502        5 READ 605,NGEAR,NTH,UPSEL,DNSEL
000516          READ 601,(NLOCK(J),TRATIO(J),CT1(J),CT2(J),EMUT(J),J=1,NGEAR)
000547          READ 610,(THSET(J),UPSHFT(J),DNSHFT(J),J=1,NTH)
000566          PRINT 840
000572          PRINT 841
000576          PRINT 842,(NLOCK(J),TRATIO(J),CT1(J),CT2(J),EMUT(J),J=1,NGEAR)
000627          PRINT 844,UPSEL,DNSEL
000637          PRINT 843
000643          PRINT 814,(THSET(J),UPSHFT(J),DNSHFT(J),J=1,NTH)
        C
        C       INPUT BATTERY DATA
        C
000662          READ 505,NODSCH,NDENS,WB,EBMAX,EMURG,EMURG2,CHGEFF
000704          READ 610,(DDISCH(J),CYCLES(J),J=1,NODSCH)
000721          READ 610,(PDENS(J),EDENS(J),J=1,NDENS)
000736          PRINT 850
000742          PRINT 855
000746          PRINT 815,WB,EBMAX,EMURG,EMURG2,CHGEFF
000754          PRINT 980
  0770          PRINT 910,(DDISCH(J),CYCLES(J),J=1,NODSCH)
001005          PRINT 925
001011          PRINT 910,(PDENS(J),EDENS(J),J=1,NDENS)
        C
        C       INPUT DIFFERENTIAL AND TIRE DATA
```

```
          C
 001026          READ 510,CRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2
 001050          PRINT 875
 001054          PRINT 885,CRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2
          C
          C      INPUT ACCESSORY DATA
          C
 001076          READ 500,NAX
 001104          READ 610,(PFMAX(J),TAX(J),J=1,NAX)
 001121          PRINT 1000
 001125          PRINT 910,(PFMAX(J),TAX(J),J=1,NAX)
          C
          C      INPUT VEHICLE DATA
          C
 001142          READ 610,VMASS,CLI,CDA
 001154          PRINT 890,VMASS,CLI,CDA
 001166          VMASS2=VMASS+CLI/RTIRE**2
          C
          C      INPUT DRIVING CYCLE DATA
          C
 001172          READ 520,NCYCLE
 001177          PRINT 915
 001203          DO 45 JC=1,NCYCLE
 001206          READ 525,NTC(JC),NPRTC(JC),NUNITS,DTC(JC),TFC(JC)
 001223          NT=NTC(JC)
 001225          READ 610,(TIMC(JC,J),SPEDC(JC,J),J=1,NT)
    245          IF(NUNITS.NE.1)GO TO 41
          C
          C      CONVERT MPH TO KILOMETERS PER HOUR
          C
 001250       30 DO 40 J=1,NT
 001252          SPEDC(JC,J)=SPEDC(JC,J)*1.6093
 001255       40 CONTINUE
 001257       41 PRINT 920
 001263          PRINT 910,(TIMC(JC,J),SPEDC(JC,J),J=1,NT)
 001303       45 CONTINUE
 001307          READ 600,NCOMP,DSTAV,DWARM
 001320          PRINT 990,DSTAV
 001326          PRINT 995
 001332          DO 320 JC=1,NCOMP
 001335          READ 610,DSUF(JC),DNC(JC),(GAMMA(JC,J),J=1,NCYCLE)
 001354          PRINT 815,DSUF(JC),DNC(JC),(GAMMA(JC,J),J=1,NCYCLE)
 001374      320 CONTINUE
 001400          PRINT 991,DWARM
 001405          DBAR(1)=DSUF(1)/2.
 001407          DO 46 J=2,NCOMP
 001412          DBAR(J)=(DSUF(J)+DSUF(J-1))/2.
 001416       46 CONTINUE
 001420          RETURN
          C
          C      FORMAT STATEMENTS
          C
 001420      600 FORMAT(I10,6F10.4)
 001420      601 FORMAT(I10,4F10.4)
 001420      605 FORMAT(2I10,5F10.4)
```

```
001420      610 FORMAT(7F10.4)
001420      620 FORMAT(7I10)
001420      625 FORMAT(3I10,2F10.4)
001420      800 FORMAT(1H0,11HENGINE DATA/1X,23HFUEL SPECIFIC GRAVITY =,E12.4/
               11X,14HDISPLACEMENT =,E12.4)
001420      805 FORMAT(1H0,7X,3HRPM,9X,11HMAX. TORQUE,8X,4HBMEP,12X,4HBSFC)
001420      806 FORMAT(1H ,32X,2E16.6)
001420      807 FORMAT(1H0,30HBEST OPERATING POINT - SPEED =,E12.4,6X,7HPOWER =
               1E12.4//6X,5HPOWER,8X,10HOPT. SPEED)
001420      808 FORMAT(1H0,19HCVT CHARACTERISTICS//1X,12HEFFICIENCY =,E12.4,4X,
               115HSPEEDUP RATIO =,E12.4,4X,16HSLOWDOWN RATIO =,E12.4)
001420      810 FORMAT(1H ,4E16.6)
001420      811 FORMAT(1H0,20HMOTOR/GENERATOR DATA)
001420      812 FORMAT(1H0,13HEFF.(MOTOR) =,E12.4,6X,12HEFF.(GEN.) =,E12.4,6X,
               121HNO LOAD INPUT POWER =,E12.4,6X,12HIDLE SPEED =,E12.4/1X,22HF
               2 OPERATING SPEED =,E12.4)
001420      813 FORMAT(1H0,7X,3HRPM,9X,11HMAX. TORQUE,5X,11HMIN. TORQUE)
001420      814 FORMAT(1H ,3E16.6)
001420      815 FORMAT(1H ,5E16.6)
001420      840 FORMAT(1H0,12HGEARBOX DATA)
001420      841 FORMAT(1H0,5X,7HLOCKUP-,10X,5HRATIO,10X,22HSPIN LOSS COEFFICIEN
               19X,11HTORQUE EFF.)
001420      842 FORMAT(1H ,I8,8X,4F16.6)
001420      843 FORMAT(1H0,4X,10HENG. POWER,5X,11HUPSHIFT RPM,4X,13HDOWNSHIFT R
001420      844 FORMAT(1H0,37HSHIFT POINTS FOR ELECTRIC OPERATION -,2E12.4)
001420      850 FORMAT(1H0,12HBATTERY DATA)
001420      855 FORMAT(1H0,5X,4HMASS,7X,14HENERGY DENSITY,2X,15HAV. REGEN. EFF.
               11X,15HMAX REGEN. EFF.,2X,13HRECHARGE EFF.)
001420      860 FORMAT(1H0,21HTORQUE CONVERTER DATA)
001420      865 FORMAT(1H0,17HNI**2/TI(STALL) =,E16.6)
001420      870 FORMAT(1H0,3X,11HNO/SQRT(TO),8X,5HTO/TI,11X,5HNO/NI)
001420      875 FORMAT(1H0,18HAXLE AND TIRE DATA )
001420      885 FORMAT(1H0,17HDIFF. RATIO =,E16.6/1X,24HSPIN LOSS COEFFICIENTS
               12E16.6/1X,13HTORQUE EFF. =,E16.6/1X,16HROLLING RADIUS =,E16.6/
               21X,33HROLLING RESISTANCE COEFFICIENTS =,2E16.6)
001420      890 FORMAT(1H0,14HVEHICLE MASS =,E16.6,5X,19HDRIVELINE INERTIA =,E
               1,5X,19H(DRAG COEF.)*AREA =,E16.6)
001420      910 FORMAT(1H ,2E16.6)
001420      915 FORMAT(1H0,14HDRIVING CYCLES)
001420      920 FORMAT(1H0,6X,4HTIME,12X,5HSPEED)
001420      925 FORMAT(1H0,1X,14HSPECIFIC POWER,2X,15HSPECIFIC ENERGY)
001420      980 FORMAT(1H0,1X,15HDEPTH OF DISCH.,6X,10HCYCLE LIFE)
001420      990 FORMAT(1H0,24HTRAVEL DISTRIBUTION DATA/1X,11HAV. USAGE =,E12.4
001420      991 FORMAT(1H0,*WARMUP DISTANCE =*,E12.4)
001420      995 FORMAT(1H0,3X,10HMAX. DIST.,4X,15HFRACT. OF TOTAL,14X,21HDRIVI
               1YCLE WEIGHTS)
001420     1000 FORMAT(1H0,14HACCESSORY LOAD/6X,5HSPEED,11X,6HTORQUE)
001420          END
```

```
              SUBROUTINE GRSHFT(IFLAG,JGEAR,JGEAR2,NGEAR)
        C     DATA IN COMMON -
 .0007        COMMON DISPL,RPM(20),TQMAX(20),PMEP(20),BSFC(20,20),NRPM,NMEP,
             1EMUM,EMUG,FINALD,SPMO(20),TMOMAX(20),TMOMIN(20),NSPMO,
             2CTCZRO,TSP(20),TQP(20),SPR(20),TSP2(20),NTSP,
             3NLOCK(5),TRATIO(5),CT1(5),CT2(5),EMUT(5),
             4WB,EBMAX,EMURG,EMURG2,
             5DRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2,VMASS,OLI,CDA,
             6TEOMIN,DBMAX,RPMIDL,VMASS2,PEOMIN,
             7FUELSG,SCALE,TMSKL,NTH,NDDSCH ,CHGEFF,NCYCLE,NCOMP,DSTAV,
             8NUNITS,THSET(5),UPSHFT(5),DNSHFT(5),DDISCH(20),CYCLES(20),NTC(
             9NPRTC(3),DTC(3),TFC(3),CSUP(30),CNC(30),DRAR(30)
             1,RPMBST,PBEST,PEOP(20),RPMEOF(20),RPMOPM,EMUCVT,RATUP,RATDN,NO
             2,PDENS(20),EDENS(20),NDENS
             3,VMAX,TEOMN2,UPSEL,DNSEL,DHAPM,NAX,RPMAX(20),TAX(20)
000007        COMMON TIMC(3,200),SPEDC(3,200),GAMMA(30,3)
        C
        C     VARIABLES IN COMMON -
000007        COMMON FA,FR,FAC,FNET,TCC,TTC,RPMDO,RPMTC,TSO,RPMSC,RPMTCO,TTC
             1RPMTCN,TMO,TEO,TMO2,TEO2,TGO,PSO,PEO,PEO2,PMO,PMO2,PGO,PERK,FC
             2PO,PT,PRW,PLTC,THRPD,TTCIN
             3,RPMEO,RPMEO2,PLTC2,VMPS
             4,TSO2,RPMSO2,PSO2,RPMTC1,RPMTC2,RRMEP,RPMEP2
000007        REAL INT1
        C
000007        IF(PEO.GT.0.0)GO TO 5
        C
        C     MODE 1 SHIFT DETERMINED BY MOTOR/GEN. CHARACTERISTICS
        C
000011        SHFTUP=UPSEL
000012        SHFTDN=DNSEL
000013        GO TO 10
        C
        C     MODE 1 SHIFT DETERMINED BY HEAT ENGINE CHARACTERISTICS
        C
000014      5 SHFTUP=INT1(PEO,THSET,UPSHFT,NTH)
000020        SHFTDN=INT1(PEO,THSET,DNSHFT,NTH)
000024     10 IF(PEO2.GT.0.0)GO TO 15
        C
        C     MODE 2 SHIFT DETERMINED BY MOTOR/GEN. CHARACTERISTICS
        C
000031        SHFUP2=UPSEL
000032        SHFDN2=DNSEL
000033        GO TO 20
        C
        C     MODE 2 SHIFT DETERMINED BY HEAT ENGINE CHARACTERISTICS
        C
000034     15 SHFUP2=INT1(PEO2,THSET,UPSHFT,NTH)
000040        SHFDN2=INT1(PEO2,THSET,DNSHFT,NTH)
000044     20 IF(RPMTC1.GE.SHFTUP.AND.JGEAR.LT.NGEAR)GO TO 25
  1060        IF(RPMTC1.LE.SHFTDN.AND.JGEAR.GT.1)GO TO 30
 .J072        IFLAG=0
000072        GO TO 40
000073     25 JGEAR=JGEAR+1
000075        IFLAG=1
```

```
000075         GO TO 40
000076      30 JGEAR=JGEAR-1
   100         IFLAG=1
000100      40 IF(RPMTC2.GE.SHFUP2.AND.JGEAR2.LT.NGEAR)GO TO 45
000112         IF(RPMTC2.LE.SHFDN2.AND.JGEAR2.GT.1)GO TO 50
000124         GO TO 100
000124      45 JGEAR2=JGEAR2+1
000126         IFLAG=1
000126         GO TO 100
000127      50 JGEAR2=JGEAR2-1
000131         IFLAG=1
000131     100 RETURN
000132         END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO REL * (01-10-73)

```
                  SUBROUTINE EMCVR (NPRV,JBRK,NLCK,NLCK2)
  0007            COMMON DISEL,RPM(20),TQMAX(20),PMEP(20),BSFC(20,20),NRPM,NMEP,
                 1EMUM,EMUG,FINNLD,SPMC(20),TMCMAX(20),TMOMIN(20),NSPMO,
                 2CTCZEO,TSP(20),TOP(20),SFR(20),TSP2(20),NTSP,
                 3NLCCK(5),TRATIO(5),CT1(5),CT2(5),EMUT(5),
                 4WR,EBMAX,EMURG,EMURG2,
                 FDRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2,VMASS,DLI,CDA,
                 6TECMIN,DBMAX,FPMIDL,VMASS2,PEOMIN,
                 7FUELSG,SKALE,TMSKL,NTH,NCDSCH ,CHGEFF,NCYCLE,NCOMP,CSTAV,
                 8NUNITS,THSET(5),UPSHFT(5),DNSHFT(5),DDISCH(20),CYCLES(20),NTC(
                 9NPRTC(3),CTC(3),TFC(3),DSUP(30),DNC(30),DBAR(30)
                 1,RPMEST,PPEST,PECP(20),RPMECP(20),RPMCPM,EMUCVT,RATUP,RATON,NC
                 2,PDENS(20),EDENS(20),NDENS
                 3,VMAX,TEOMN2,UPSEL,DNSEL,DWARM,NAX,RPMAX(20),TAX(20)
000007            COMMON TIMC(3,200),SPEDC(3,200),GAMMA(30,3)
000007            COMMON FA,FR,FAC,FNET,TDC,TTC,RPMDO,RPMTC,TSO,RPMSC,RPMTCO,TTC
                 1RPMTCN,TMO,TEC,TMO2,TEO2,TGO,PSO,PEO,PEO2,PMO,PMO2,PGO,PBRK,FC
                 2PD,PT,PPM,PLTC,THRPD,TTCIN
                 3,RPMEO,RPMEO2,PLTC2,VMPS
                 4,TSO2,RPMSO2,PSO2,RPMTC1,RPMTC2,BRMEP,BRMEP2
000007            REAL INT1,INT2
000007            CC=0.0001047197
000010            IF(NPRV)50,80,10
          C
          C       SYSTEM POWER OUTPUT IS NON-NEGATIVE
          C
  0011         10 PBRK=0.0
000012            TGO=0.0
000013            JBRK=0
000013            TTCO=TSO
000015            RPMTCO=RPMSC
000016            CALL TOCON(1,1,NLCK)
000020            TACC=INT1(RPMTCN,RPMAX,TAX,NAX)
000024            TTCIN=TTCIN+TACC
000025            RPMTC1=RPMTCN
000027            TTCN1=TTCIN
000030            THEMAX=INT1(RPMTCN,RPM,TQMAX,NRPM)
000034            TMMAX=INT1(RPMTCN,SPMC,TMCMAX,NSPMO)
000040            PHEMAX=CC*THEMAX*RPMTCN
000042            PMMAX=CC*TMMAX*RPMTCN
000044            PCOM=CC*TTCIN*RPMTCN
000046            PHEMIN=CC*TECMIN*RPMTCN
000050            PNOM=AMIN1(PEOMIN,PMMAX)
          C
          C       IS POWER REQUIRED MORE THAN NOMINAL MOTOR RATING
          C
000054            IF(PCOM.GT.PNOM.OR.VMPS.GT.VMAX)GO TO 15
          C
          C       NO - TRACTION MOTOR HANDLES EVERYTHING
          C
  0070            TEO=0.0
 .0071            RPMEO=0.0
000072            TMO=TTCIN
000073            GO TO 30
          C
```

```
          C      YES - HEAT ENGINE CUTS IN
          C
  0074       15 RPMEC=RPMTC1
000076       17 IF(PCOM.GT.PHEMIN+PMMAX)GO TO 20
000103          TEC=AMIN1(TTCIN,TECMIN)
000106          TMC=TTCIN-TEC
000110          GO TO 30
          C
          C      YES - TRACTION MOTOR AT MAX, HEAT ENGINE PICKS UP REMAINDER
          C
000110       20 TEC=TTCIN-TMMAX
000112          TMC=TMMAX
          C
          C      MODE 2 CALCULATIONS
          C
000113       30 TTCO=TS02
000115          RPMTCO=RPMSC2
000116          CALL TQCON(1,1,NLCK2)
000121          TACC=INT1(RPMTCN,RPMAX,TAX,NAX)
000125          TTCIN=TTCIN+TACC
000126          RPMTC2=RPMTCN
000130          TTCN2=TTCIN
000131          THEMAX=INT1(RPMTCN,RPM,TQMAX,NRPM)
000135          TMMAX=INT1(RPMTCN,SPMO,TMOMAX,NSPMO)
000141          PHEMAX=CC*THEMAX*RPMTCN
000143          PMMAX=CC*TMMAX*RPMTCN
  0145          PCOM=CC*TTCIN*RPMTCN
  0147          PHEMIN=CC*TECMN2*RPMTCN
000151          IF(PCOM.GT.PHEMIN)GO TO 40
000157          TEC2=0.0
000157          RPMEC2=0.0
000160          TMC2=TTCIN
000162          GO TO 100
000162       40 RPMEC2=RPMTC2
000164          TEC2=AMIN1(THEMAX,TTCIN)
000167          TMC2=TTCIN-TEC2
000171          GO TO 100
          C
          C      SYSTEM POWER OUTPUT IS NEGATIVE
          C
000171       50 TEC=0.0
000172          TEC2=0.0
000173          TMC=0.0
000174          TMC2=0.0
000175          RPMEC=0.0
000176          RPMEC2=0.0
000177          RPMTCO=RPMSC
000200          RPMTC=RPMTCO
000201          DO 60 J=1,10
000203          TMMIN=INT1(RPMTC,SPMO,TMOMIN,NSPMO)
  0207          TACC=INT1(RPMTC,RPMAX,TAX,NAX)
  0213          TTCIN=TMMIN-TACC
000215          CALL TQCON(-1,1,NLCK)
000221          IF(ABS(RPMTC-RPMTCN).LE.5.0)GO TO 65
000230          RPMTC=RPMTCN
```

GOLETA FORTRAN 1.3 * SEMI-AUTO PFL * (01-10-73)

```
000231        60 CONTINUE
000233        65 IF(TTCO.GT.TSO)GO TO 70
000237           TTCO=TSO
000237           TSO2=TSO
000240           CALL TQCON(1,1,NLCK)
000242           TACC=INT1(RPMTCN,RPMAX,TAX,NAX)
000246           TTCIN=TTCIN+TACC
000247           TGO=TTCIN
000250           RPMTC1=RPMTCN
000252           RPMTC2=RPMTCN
000253           TTCN1=TTCIN
000254           TTCN2=TTCIN
000255           GO TO 100
000260        70 TSO=TTCO
000262           TSO2=TTCO
000263           TTCN1=TMMIN
000264           TTCN2=TMMIN
000265           TGO=TMMIN
000266           RPMTC1=RPMTCN
000267           RPMTC2=RPMTCN
000270           JBRK=1
000271           GO TO 100
         C
         C       CAR IS AT REST AND IDLING
         C
000271        80 PBRK=0.0
   272           PGO=0.0
000273           TEO=0.0
000274           TEO2=0.0
000275           TTCO=0.0
000276           RPMEO=0.0
000277           RPMEO2=0.0
000300           RPMTCO=RPMSO
000301           CALL TQCON(1,0,NLCK)
000303           TACC=INT1(RPMTCN,RPMAX,TAX,NAX)
000307           TTCIN=TTCIN+TACC
000310           TMO=TTCIN
000311           TMO2=TTCIN
000312           RPMTC1=RPMTCN
000314           RPMTC2=RPMTCN
000315           TTCN1=TTCIN
000316           TTCN2=TTCIN
000317           JBRK=0
000322       100 PEO=CC*TEO*RPMEO
000325           PEO2=CC*TEO2*RPMEO2
000327           PMO=CC*TMO*RPMTC1
000332           PMO2=CC*TMO2*RPMTC2
000334           PGO=CC*TGO*RPMTC1
000337           PLTC=CC*ABS(TTCN1*RPMTC1-TSO*RPMSO)
000344           PLTC2=CC*ABS(TTCN2*RPMTC2-TSO2*RPMSO2)
000351           RETURN
000351           END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO REL * (01-10-73)

```
                 SUBROUTINE TCCON(JEND,JSTOP,NLCK)
000006           COMMON DISPL,RPM(20),TQMAX(20),BMEP(20),BSFC(20,20),NRPM,NMEP,
                1EMUM,EMUG,FINKLD,SPMO(20),TMCMAX(20),TMOMIN(20),NSPMO,
                2CTCZRO,TSP(20),TQR(20),SPR(20),TSP2(20),NTSP,
                3NLCCK(5),TRATIO(5),CT1(5),CT2(5),EMUT(5),
                4WB,EBMAX,EMURG,EMURG2,
                5DRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2,VMASS,DLI,CDA,
                6TEOMIN,DBMAX,RPMIDL,VMASS2,PEOMIN,
                7FUELSG,SKALE,TMSKL,NTH,NODSCH ,CHGEFF,NCYCLE,NOCMP,DSTAV,
                8NUNITS,THSET(5),UPSHFT(5),DNSHFT(5),DDTSCH(20),CYCLES(20),NTC(
                9NPRTC(3),CTC(3),TFC(3),DSUP(30),DNC(30),DBAR(30)
                1,RPMBST,PBEST,PEOP(20),RPMEOP(20),RPMOPM,EMUCVT,RATUP,RATDN,NC
                2,PDENS(20),EPENS(20),NDENS
                3,VMAX,TEOMN2,UPSEL,DNSEL,DWARM,NAX,RPMAX(20),TAX(20)
000006           COMMON TIMC(3,200),SPEDC(3,200),GAMMA(30,3)
000006           COMMON FA,FB,FAC,FNET,TCC,TTC,RPMDO,RPMTC,TSO,RPMSC,RPMTCO,TTC
                1RPMTCN,TMC,TEC,TMO2,TEO2,TGO,PSO,PEO,PEO2,PMO,PMO2,PGO,PBRK,FC
                2PD,PT,PRW,PLTC,THRPC,TTCIN
                3,RPMEO,RPMEO2,PLTC2,VMPS
                4,TSO2,RPMSO2,PSC2,RPMTC1,RPMTC2,BRMEP,BRMEP2
000006           REAL INT1,INT2
000006           IF(JSTOP.NE.0)GO TO 5
000007           RPMTCN=RPMIDL
000010           TTCIN=RPMIDL**2/CTCZRO
000012           GO TO 100
000012         5 IF(JEND.EQ.-1)GO TO 50
            C
            C    HAVE OUTPUT SPEED AND OUTPUT TORQUE.
            C
000014           IF(NLCK.EQ.0)GO TO 7
000015           TTCIN=TTCO
000016           RPMTCN=RPMTCO
000020           GO TO 100
000020         7 IF(TTCO.NE.0.0)GO TO 10
000021           TTCIN=0.0
000022           RPMTCN=RPMTCO
000024           GO TO 100
000024        10 TSPAR=RPMTCO/SIGN(SQRT(ABS(TTCO)),TTCO)
000035           IF(TSPAR.GE.0.0)GO TO 20
000040           TTCIN=TTCO
000041           SPRAT=1.0/INT1(ABS(TSPAR),TSP,SPR,NTSP)
000047           GO TO 40
000051        20 IF(TSPAR.GT.0.0)GO TO 25
000054           IF(TTCO.GT.0.0)GO TO 22
000056           RPMTCN=RPMIDL
000057           TTCIN=RPMIDL**2/CTCZRC
000061           TTCO=TQR(1)*TTCIN
000062           GO TO 100
000063        22 TTCIN=TTCO/TQR(1)
000065           RPMTCN=SQRT(TTCIN*CTCZRO)
000071           GO TO 100
   073        25 TQRAT=INT1(TSPAR,TSP,TQR,NTSP)
000077           TTCIN=TTCO/TQRAT
000100        30 SPRAT=INT1(TSPAR,TSP,SPR,NTSP)
000104        40 RPMTCN=RPMTCO/SPRAT
```

```
000106          GO TO 100
       C
       C        HAVE OUTPUT SPEED AND INPUT TORQUE
       C
000111       50 IF(NLCK.EQ.0)GO TO 55
000112          TTCO=TTCIN
000114          RPMTCN=RPMTCO
000115          GO TO 100
000116       55 IF(TTCIN.NE.0.0)GO TO 60
000117          TTCO=0.0
000120          RPMTCN=AMAX1(RPMIDL,RPMTCO)
000124          GO TO 100
000125       60 TSPAR2=RPMTCO/SIGN(SQRT(ABS(TTCIN)),TTCIN)
000136          IF(TSPAR2.GE.0.0)GO TO 70
000141          TTCO=TTCIN
000142          SPRAT=1.0/INT1(ABS(TSPAR2),TSP2,SPR,NTSP)
000150          GO TO 90
000152       70 IF(TSPAR2.GT.0.0)GO TO 75
000155          IF(TTCIN.GT.0.0) GO TO 72
000157          RPMTCN=RPMIDL
000160          TTCIN=RPMIDL**2/CTCZRC
000161          TTCO=TQR(1)*TTCIN
000163          GO TO 100
000163       72 TTCO=TTCIN*TQR(1)
000165          RPMTCN=SQRT(TTCIN*CTCZRC)
000171          GO TO 100
   173       75 TQRAT=INT1(TSPAR2,TSP2,TQR,NTSP)
000177          TTCO=TTCIN*TQRAT
000200       80 SPRAT=INT1(TSPAR2,TSP2,SPR,NTSP)
000204       90 RPMTCN=RPMTCO/SPRAT
000206      100 RPMTCN=AMAX1(RPMIDL,RPMTCN)
000212          RETURN
000212          END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO SFL * (01-10-73)


```
                 SUBROUTINE FILTER(NP,DTP,DTFLTR,P)
           C
           C     SMOOTHS A GIVEN PERIODIC FUNCTION BY AVERAGING OVER SUB-INTERV
000007           REAL P(2800)
000007           TEP=FLOAT(NP)*DTP
000010           JDT=IFIX((DTFLTR+0.001)/DTP)
000013           JLAST=NP+JDT
000015           DO 3 J=1,NP
000016           P(NP+JDT+1-J)=P(NP+1-J)
000022         3 CONTINUE
000024           DO 5 J=1,JDT
000025           P(J)=P(JLAST+J-JDT)
000031           P(JLAST+J)=P(JDT+J)
000035         5 CONTINUE
000037           NINTM=2*JDT-1
000040           NINT=2*JDT
000042           DO 20 JP=1,NP
000043           PTEMP=P(JP)+P(JP+NINT)
000050           DO 10 K=1,NINTM
000051           PTEMP=PTEMP+(3.+(-1.)**(K-1))*P(JP+K)
000062        10 CONTINUE
000065           P(JP)=PTEMP*DTP/(6.*DTFLTR)
000071        20 CONTINUE
000073           RETURN
000073           END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO REL * (01-10-73)

```
                  REAL FUNCTION INT1(FX,X,Y,NX)
000007            REAL X(200),Y(200)
000007            IF(FX.GE.X(1))GO TO 5
000011            JRT=2
000012            GO TO 20
000013          5 DO 10 J=1,NX
000015            IF(FX.LT.X(J))GO TO 15
000020         10 CONTINUE
000022         15 JRT=J
000024         20 INT1=Y(JRT-1)+(FX-X(JRT-1))*(Y(JRT)-Y(JRT-1))/(X(JRT)-X(JRT-1
000040            RETURN
000041            END
```

```
GOLETA FORTRAN 1.3 * SEMI-AUTO REL * (01-10-73)

                  REAL FUNCTION INT2(EX,WHY,X,Y,Z,NX,NY)
            C
            C     INT2 INTERPOLATES IN TWO VARIAVLES INTERPOLATION SURFACE IS A
            C     RULED SURFACE.
            C
000012            REAL X(20),Y(20),Z(20,20)
000012            IF(EX.GE.X(1))GO TO 5
000014            JLEFT=1
000015            GO TO 20
000016          5 DO 10 J=1,NX
000020            IF(EX.LT.X(J))GO TO 15
000023         10 CONTINUE
000025         15 JLEFT=J-1
000027         20 IF(WHY.GE.Y(1))GO TO 25
000032            JBOTM=1
000033            GO TO 40
000033         25 DO 30 J=1,NY
000035            IF(WHY.LT.Y(J))GO TO 35
000040         30 CONTINUE
000043         35 JBOTM=J-1
000045         40 RX=(EX-X(JLEFT))/(X(JLEFT+1)-X(JLEFT))
000052            RY=(WHY-Y(JBOTM))/(Y(JBOTM+1)-Y(JBOTM))
000056            RXRY=RX*RY
000060            W1=1.-RX-RY+RXRY
000063            W2=RY-RXRY
000065            W3=RXRY
  0066            W4=RX-RXRY
  0067            INT2=W1*Z(JLEFT,JBOTM)+W2*Z(JLEFT,JBOTM+1)+W3*Z(JLEFT+1,JBOTM+
                 1+W4*Z(JLEFT+1,JBOTM)
000110            RETURN
000110            END
```

ENGINE DATA
FUEL SPECIFIC GRAVITY = 7.1300E-01
DISPLACEMENT = 1.4600E+03

RPM	MAX. TORQUE	BMEP	BSFC
0.	6.000000E+01	8.530000E-01	1.500000E+03
		1.706000E+00	6.500000E+02
		2.559000E+00	4.000000E+02
		3.412000E+00	3.500000E+02
		4.265000E+00	3.500000E+02
		5.118000E+00	3.500000E+02
		5.971000E+00	3.500000E+02
		6.824000E+00	3.500000E+02
		7.677000E+00	3.500000E+02
		8.530000E+00	3.500000E+02
1.740000E+03	8.800000E+01	8.530000E-01	8.420000E+02
		1.706000E+00	4.890000E+02
		2.559000E+00	3.770000E+02
		3.412000E+00	3.300000E+02
		4.265000E+00	3.020000E+02
		5.118000E+00	2.830000E+02
		5.971000E+00	2.840000E+02
		6.824000E+00	3.070000E+02
		7.677000E+00	3.260000E+02
		8.530000E+00	3.450000E+02
2.320000E+03	9.300000E+01	8.530000E-01	7.660000E+02
		1.706000E+00	4.410000E+02
		2.559000E+00	3.670000E+02
		3.412000E+00	3.270000E+02
		4.265000E+00	3.030000E+02
		5.118000E+00	2.870000E+02
		5.971000E+00	2.800000E+02
		6.824000E+00	2.810000E+02
		7.677000E+00	2.950000E+02
		9.530000E+00	3.010000E+02
2.900000E+03	9.800000E+01	8.530000E-01	7.780000E+02
		1.706000E+00	4.450000E+02
		2.559000E+00	3.650000E+02
		3.412000E+00	3.240000E+02
		4.265000E+00	3.000000E+02
		5.118000E+00	2.850000E+02
		5.971000E+00	2.760000E+02
		6.824000E+00	2.760000E+02
		7.677000E+00	2.870000E+02
		8.530000E+00	3.190000E+02
3.480000E+03	1.000000E+02	8.530000E-01	8.020000E+02
		1.706000E+00	4.600000E+02
		2.559000E+00	3.700000E+02
		3.412000E+00	3.270000E+02
		4.265000E+00	3.000000E+02
		5.118000E+00	2.830000E+02
		5.971000E+00	2.740000E+02
		6.824000E+00	2.740000E+02
		7.677000E+00	2.830000E+02
		8.530000E+00	3.150000E+02
4.360000E+03	1.000000E+02	9.530000E-01	8.140000E+02
		1.706000E+00	4.710000E+02
		2.559000E+00	3.790000E+02
		3.412000E+00	3.310000E+02
		4.265000E+00	3.030000E+02
		5.118000E+00	2.850000E+02

ORIGINAL PAGE IS
OF POOR QUALITY

		5.971000E+00	2.760000E+02
		6.824000E+00	2.780000E+02
		7.677000E+00	2.900000E+02
		8.530000E+00	3.070000E+02
4.640000E+03	9.800000E+01	8.530000E-01	8.280000E+02
		1.706000E+00	4.850000E+02
		2.559000E+00	3.880000E+02
		3.412000E+00	3.500000E+02
		4.265000E+00	3.100000E+02
		5.118000E+00	2.910000E+02
		5.971000E+00	2.810000E+02
		6.824000E+00	2.820000E+02
		7.677000E+00	2.960000E+02
		8.530000E+00	3.450000E+02
5.220000E+03	9.400000E+01	8.530000E-01	8.770000E+02
		1.706000E+00	5.120000E+02
		2.559000E+00	4.030000E+02
		3.412000E+00	3.440000E+02
		4.265000E+00	3.130000E+02
		5.118000E+00	2.970000E+02
		5.971000E+00	2.960000E+02
		6.824000E+00	3.040000E+02
		7.677000E+00	3.210000E+02
		8.530000E+00	3.450000E+02
5.800000E+03	8.800000E+01	9.530000E-01	7.900000E+02
		1.706000E+00	4.930000E+02
		2.559000E+00	3.860000E+02
		3.412000E+00	3.350000E+02
		4.265000E+00	3.160000E+02
		5.118000E+00	3.130000E+02
		5.971000E+00	3.200000E+02
		6.824000E+00	3.310000E+02
		7.677000E+00	3.500000E+02
		9.530000E+00	3.600000E+02

BEST OPERATING POINT - SPEED = 3.5000E+03 POWER = 2.6800E+01

POWER	OPT. SPEED
1.000000E+01	1.500000E+03
1.170000E+01	1.750000E+03
1.890000E+01	2.500000E+03
2.680000E+01	3.500000E+03
3.440000E+01	4.500000E+03
3.580000E+01	5.000000E+03
3.600000E+01	6.000000E+03

MOTOR/GENERATOR DATA

EFF.(MOTOR) = 8.5000E-01 EFF.(GEN.) = 8.5000E-01 NO LOAD INPUT POWER = 1.0000E+00 IDLE SPEED = 2.0000E+02
BEST OPERATING SPEED = 3.5000E+03

RPM	MAX. TORQUE	MIN. TORQUE
0.	6.251000E+01	0.
2.040000E+03	6.251000E+01	0.
2.050000E+03	1.250200E+02	0.
2.400000E+03	1.071600E+02	0.
3.100000E+03	8.260250E+01	-1.339500E+02
3.520000E+03	7.277950E+01	-1.339500E+02
4.000000E+03	6.384950E+01	-1.178760E+02
4.900000E+03	5.224050E+01	-9.644400E+01
5.290000E+03	4.465000E+01	-8.930000E+01
6.000000E+03	3.572000E+01	-6.423600E+01

TORQUE CONVERTOR DATA

NI**2/TI(STALL) = 1.917000E+04

NO/SQRT(TO)	TO/TI	NO/NI
0.	2.100000E+00	0.
1.393000E+01	2.040000E+00	1.000000E-01
2.830000E+01	1.920000E+00	2.000000E-01
4.322000E+01	1.820000E+00	3.000000E-01
5.898000E+01	1.700000E+00	4.000000E-01
7.710000E+01	1.560000E+00	5.000000E-01
9.641000E+01	1.420000E+00	6.000000E-01
1.188000E+02	1.270000E+00	7.000000E-01
1.467000E+02	1.140000E+00	8.000000E-01
1.899000E+02	1.000000E+00	9.000000E-01
2.592000E+02	1.000000E+00	9.500000E-01
4.109000E+02	1.000000E+00	9.750000E-01
1.214000E+03	1.000000E+00	1.000000E+00

GEARBOX DATA

LOCKUP-	RATIO	SPIN LOSS COEFFICIENTS		TORQUE EFF.
0	2.450000E+00	0.	0.	9.200000E-01
1	1.450000E+00	0.	0.	9.200000E-01
1	1.000000E+00	0.	0.	9.400000E-01
1	7.500000E-01	0.	0.	9.400000E-01

SHIFT POINTS FOR ELECTRIC OPERATION - 4.5000E+03 2.4000E+03

ENG. POWER	UPSHIFT RPM	DOWNSHIFT RPM
0.	2.500000E+03	1.300000E+03
1.000000E+01	2.500000E+03	1.300000E+03
3.000000E+01	5.100000E+03	3.000000E+03
5.000000E+01	6.000000E+03	3.500000E+03
6.000000E+01	6.000000E+03	3.500000E+03

BATTERY DATA

MASS	ENERGY DENSITY	AV. REGEN. EFF.	MAX REGEN. EFF.	RECHARGE EFF.
2.700000E+02	4.000000E+01	7.000000E-01	9.000000E-01	5.400000E-01

DEPTH OF DISCH.	CYCLE LIFE
2.000000E-01	4.800000E+03
4.000000E-01	3.300000E+03
5.000000E-01	2.700000E+03
6.000000E-01	2.250000E+03
7.000000E-01	1.800000E+03
8.000000E-01	1.500000E+03
9.000000E-01	1.230000E+03
1.000000E+00	1.000000E+03

SPECIFIC POWER	SPECIFIC ENERGY
0.	4.600000E+01
1.500000E+02	0.

AXLE AND TIRE DATA

DIFF. RATIO = 5.120000E+00
SPIN LOSS COEFFICIENTS = 0. 0.
TORQUE EFF. = 9.600000E-01
ROLLING RADIUS = 3.050000E-01

ORIGINAL PAGE IS
OF POOR QUALITY

ROLLING RESISTANCE COEFFICIENTS = 1.000000E-02 0.

ACCESSORY LOAD

SPEED	TORQUE
0.	0.
6.000000E+03	1.800000E+01

VEHICLE MASS = 2.118000E+03 DRIVELINE INERTIA = 6.600000E+00 (DRAG COEF.)*AREA = 8.720000E-01

DRIVING CYCLES

TIME	SPEED
0.	0.
1.000000E+00	8.000000E+00
3.900000E+00	1.600000E+01
9.400000E+00	2.400000E+01
1.900000E+01	3.200000E+01
3.800000E+01	3.200000E+01
4.200000E+01	2.950000E+01
4.700000E+01	0.
7.200000E+01	0.

TIME	SPEED
0.	0.
2.000000E+01	0.
2.690000E+01	2.735810E+01
3.100000E+01	3.637018E+01
3.700000E+01	3.218600E+01
3.900000E+01	2.365671E+01
4.330000E+01	2.542694E+01
4.690000E+01	3.653111E+01
5.020000E+01	3.653111E+01
5.460000E+01	2.413950E+01
5.960000E+01	3.942785E+01
6.020000E+01	4.135981E+01
9.723000E+01	4.908365E+01
1.046000E+02	4.908365E+01
1.123000E+02	5.198039E+01
1.150000E+02	5.133667E+01
1.246000E+02	0.
1.630000E+02	0.
1.699000E+02	3.623925E+01
1.730000E+02	4.264645E+01
1.760000E+02	3.974971E+01
1.800000E+02	4.023250E+01
1.815000E+02	4.425575E+01
1.866000E+02	2.719717E+01
1.900000E+02	3.202507E+01
1.960000E+02	5.841759E+01
2.040000E+02	7.660258E+01
2.100000E+02	7.547617E+01
2.150000E+02	7.595996E+01
2.243000E+02	8.416639E+01
2.270000E+02	8.951159E+01
2.335000E+02	8.851150E+01
2.400000E+02	9.124731E+01
2.493000E+02	9.092545E+01
2.550000E+02	8.609755E+01
2.594000E+02	8.706313E+01
2.700000E+02	9.297995E+01
2.727000E+02	9.297895E+01
2.800000E+02	9.012090E+01

6.570000E+02	8.513197E+01
6.710000E+02	9.416639E+01
6.750000E+02	8.481011E+01
6.827000E+02	7.966035E+01
6.870000E+02	7.966035E+01
7.070000E+02	9.860359E+01
7.137000E+02	9.237382E+01
7.170000E+02	9.527056E+01
7.195000E+02	9.527056E+01
7.290000E+02	9.931615E+01
7.380000E+02	8.143058E+01
7.430000E+02	7.354581E+01
7.450000E+02	6.839525E+01
7.500000E+02	4.184189E+01
7.600000E+02	4.827900E+00
7.625000E+02	0.
8.000000E+02	0.

TRAVEL DISTRIBUTION DATA
AV. USAGE = 5.5780E+01

MAX. DIST.	FRACT. OF TOTAL	DRIVING CYCLE WEIGHTS		
2.000000E+01	4.607400E-02	2.040000E-01	7.960000E-01	0.
3.000000E+01	5.602400E-02	8.160000E-02	9.184030E-01	0.
4.000000E+01	7.592300E-02	5.828600E-02	9.417100E-01	0.
5.000000E+01	7.986700E-02	4.533300E-02	7.973300E-01	1.573300E-01
6.000000E+01	7.690900E-02	3.709100E-02	6.523600E-01	3.105500E-01
7.000000E+01	5.826500E-02	3.138500E-02	5.520000E-01	4.166200E-01
8.000000E+01	6.722800E-02	2.720000E-02	4.784000E-01	4.944000E-01
9.000000E+01	5.790600E-02	2.480000E-02	4.221200E-01	5.538800E-01
1.000000E+02	5.960900E-02	2.147400E-02	3.776800E-01	6.008400E-01
1.200000E+02	9.268600E-02	1.854500E-02	3.261800E-01	6.552700E-01
1.400000E+02	6.525600E-02	1.569200E-02	2.760000E-01	7.083100E-01
1.600000E+02	5.378300E-02	1.360000E-02	2.392000E-01	7.472000E-01
1.800000E+02	4.571500E-02	1.260000E-02	2.110600E-01	7.769400E-01
2.000000E+02	3.065600E-02	1.073700E-02	1.888400E-01	8.004200E-01
2.200000E+02	2.258900E-02	9.714000E-03	1.708600E-01	8.194300E-01
2.400000E+02	2.061700E-02	8.870000E-03	1.560000E-01	8.351300E-01
2.600000E+02	1.344600E-02	8.160000E-03	1.435200E-01	8.483200E-01
2.800000E+02	1.452100E-02	7.556000E-03	1.328900E-01	8.595600E-01
3.000000E+02	1.039800E-02	7.034000E-03	1.237200E-01	8.692400E-01
3.200000E+02	1.111500E-02	6.581000E-03	1.157400E-01	8.776800E-01
3.400000E+02	4.141300E-02	6.182000E-03	1.087300E-01	8.850900E-01

WARMUP DISTANCE = 0.

```
CONTROL PARAMETERS FOR CASE 1

     MIN. ENGINE TORQUE = 4.5000E+01 (MODE 1)
                          0.         (MODE 2)
     BATT. DISCH. LIMIT = 6.0000E-01
     NOMINAL MOTOR POWER = 2.0000E+01
     TRANSITION SPEED = 7.2000E+01

    TIME        SPEED       DISTANCE     R.L.POWER    BR.POWER    R.L.ENERGY    BR.ENERGY   KIN.ENERGY
GN  RPM  D.T.ENERGY  SYS.ENERGY  ENG.ENERGY      MOTOR SHAFT ENERGY      BAT.ENERGY   SYS.POWER   ENG.POWER      MOTOR SHAFT POWER

   0.           0.          0.          0.          0.          0.          0.          0.
1  1129  0.          0.          0.          0.          0.          0.          0.          5.3203E+00  2.7634E+00  0.
1  1129  0.          0.          0.          0.                      0.          0.          8.0837E+00  0.

   2.0000E+00  1.0792E+01  3.7423E-03  5.3647E+00  0.           7.8874E-04  1.8948E-17  0.
1  1387  9.5507E-03  1.2022E-02  8.3289E-03  1.1840E-02  0.           1.5929E-02  6.0742E+00  0.          7.8133E+00  0.
1  1387  9.5507E-03  1.2022E-02  2.0169E-02  0.                       2.0000E-03  6.0742E+00  7.8133E+00  0.

   4.0000E+00  1.6118E+01  1.1246E-02  6.4319E+00 -2.8422E-14  2.4061E-03  3.7896E-17  0.
1  1844  1.3685E-02  2.7560E-02  8.3289E-03  2.9697E-02  0.           3.8937E-02  7.2825E+00  0.          8.2325E+00  0.
1  1844  1.3685E-02  2.7560E-02  3.8025E-02  0.                       4.0000E-03  7.2825E+00  8.2325E+00  0.

   6.0000E+00  1.9854E+01  2.1030E-02  5.6643E+00 -2.8422E-14  4.5643E-03  4.7378E-17  0.
1  2145  1.6963E-02  3.9876E-02  8.3289E-03  4.3852E-02  0.           5.7591E-02  6.6398E+00  0.          7.6527E+00  0.
1  2145  1.6963E-02  3.9876E-02  5.2181E-02  0.                       6.0000E-03  6.6398E+00  7.6527E+00  0.

   8.0000E+00  2.1964E+01  3.2424E-02  6.7844E+00 -2.8422E-14  7.1295E-03  8.2897E-17  0.
1  2456  2.0871E-02  5.4192E-02  8.3289E-03  6.0435E-02  0.           7.9064E-02  7.6816E+00  0.          8.9256E+00  0.
1  2456  2.0871E-02  5.4192E-02  6.8734E-02  0.                       8.0000E-03  7.6816E+00  3.9256E+00  0.

   1.0000E+01  2.4514E+01  4.5403E-02  5.0304E+00  0.           1.0118E-02  1.1132E-16  0.
1  2727  2.5308E-02  6.8909E-02  8.3289E-03  7.7839E-02  0.           1.0158E-01  5.6957E+00  0.          7.1059E+00  0.
2  1593  2.3765E-02  6.8909E-02  8.4625E-02  0.                       1.0000E-02  5.6957E+00  6.1325E+00  0.

   1.2000E+01  2.6167E+01  5.9479E-02  5.3989E+00 -2.8422E-14  1.3415E-02  1.2079E-16  0.
1  2907  2.9673E-02  8.0651E-02  8.3289E-03  9.2575E-02  0.           1.2091E-01  6.1129E+00  0.          7.7811E+00  0.
2  1689  2.6071E-02  8.0651E-02  9.7303E-02  0.                       1.2000E-02  6.1129E+00  6.6111E+00  0.

   1.4000E+01  2.7833E+01  7.4479E-02  5.7703E+00  0.           1.6981E-02  1.3974E-16  0.
1  3089  3.4514E-02  9.3296E-02  8.3289E-03  1.0858E-01  0.           1.4175E-01  6.5334E+00  0.          8.3111E+00  0.
2  1737  2.8609E-02  9.3296E-02  1.1101E-01  0.                       1.4000E-02  6.5334E+00  7.0971E+00  0.

   1.6000E+01  2.9500E+01  9.0404E-02  6.1481E+00  0.           2.0829E-02  1.5632E-16  0.
1  3270  3.9844E-02  1.0679E-01  8.3289E-03  1.2583E-01  0.           1.6404E-01  6.9612E+00  0.          8.9386E+00  0.
2  1995  3.1381E-02  1.0679E-01  1.2570E-01  0.                       1.6000E-02  6.9612E+00  7.5944E+00  0.

   1.8000E+01  3.1167E+01  1.0726E-01  6.5315E+00  0.           2.4969E-02  1.7053E-16  0.
1  3450  4.5683E-02  1.2114E-01  8.3289E-03  1.4435E-01  0.           1.8782E-01  7.3953E+00  0.          9.5825E+00  0.
2  2012  3.4397E-02  1.2114E-01  1.4139E-01  0.                       1.8000E-02  7.3953E+00  8.1021E+00  0.

   2.0000E+01  3.2005E+01  1.2492E-01  2.0803E+00  1.4211E-14  2.9375E-02  1.8296E-16  0.
1  3474  5.1205E-02  1.3120E-01  8.3293E-03  1.5875E-01  0.           2.0677E-01  2.3554E+00  0.          4.4501E+00  0.
2  2066  3.7043E-02  1.3128E-01  1.5292E-01  0.                       2.0000E-02  2.3554E+00  3.1007E+00  0.

   2.2000E+01  3.2000E+01  1.4270E-01  2.2215E+00  0.           3.3818E-02  1.8889E-16  0.
1  3479  5.5993E-02  1.3620E-01  8.3299E-03  1.6795E-01  0.           2.1959E-01  2.5152E+00  0.          4.6178E+00  0.
2  2066  3.9117E-02  1.3620E-01  1.5941E-01  0.                       2.2000E-02  2.5152E+00  3.2603E+00  0.

   2.4000E+01  3.2000E+01  1.6048E-01  2.2214E+00  0.           3.8261E-02  1.9954E-16  0.
1  3479  6.0785E-02  1.4123E-01  8.3293E-03  1.7719E-01  0.           2.3246E-01  2.5152E+00  0.          4.6178E+00  0.
2  2066  4.1195E-02  1.4123E-01  1.6533E-01  0.                       2.4000E-02  2.5152E+00  3.2603E+00  0.
```

```
  5.2500E+02  8.9031E+01  1.1228E+01  1.5263E+01  5.6843E-14  5.3674E+00  4.7570E-02  0.
4  2973  1.4855E+00  6.8260E+00  5.0365E+00  2.8021E+00 -2.6864E-01  3.6617E+00  1.6914E+01  1.4811E+01  4.4457E+00  0.
4  2973  1.3725E+00  6.8337E+00  7.8615E+00  2.1141E-02              3.4437E-01  1.6914E+01  1.8457E+01  0.

  5.5000E+02  9.8107E+01  1.1853E+01  1.1271E+01  5.6843E-14  5.7055E+00  4.7570E-02  0.
4  3009  1.5632E+00  7.2186E+00  5.3904E+00  2.8802E+00 -2.6864E-01  3.7786E+00  1.2490E+01  1.4071E+01  0.          0.
4  3009  1.6502E+00  7.2263E+00  8.2934E+00  2.1141E-02              3.6937E-01  1.2490E+01  1.4071E+01  0.

  5.7500E+02  8.3684E+01  1.2451E+01  1.1537E+01  0.          6.0134E+00  4.7570E-02  0.
4  2795  1.6225E+00  7.4554E+00  5.6580E+00  2.8855E+00 -2.6864E-01  3.8098E+00  1.2785E+01  1.3178E+01  9.7815E-01  0.
4  2795  1.7095E+00  7.4630E+00  8.5664E+00  2.1141E-02              3.9437E-01  1.2785E+01  1.4148E+01  0.

  6.0000E+02  7.7961E+01  1.3004E+01  4.0431E+00  0.          6.2724E+00  4.7570E-02  0.
4  2604  1.6729E+00  7.6559E+00  5.8631E+00  2.9117E+00 -2.6864E-01  3.8657E+00  4.4803E+00  5.6635E+00  0.          0.
4  2604  1.7612E+00  7.6635E+00  8.7990E+00  2.1141E-02              4.1937E-01  4.4803E+00  5.6635E+00  0.

  6.2500E+02  8.5456E+01  1.3546E+01  1.9084E+01  0.          6.5220E+00  4.9527E-02  0.
4  2854  1.7474E+00  8.0557E+00  6.0972E+00  3.1309E+00 -2.9239E-01  4.1344E+00  2.1148E+01  1.3449E+01  9.1282E+00  0.
3  3805  1.8460E+00  8.0633E+00  9.2597E+00  2.2184E-02              4.2742E-01  2.1148E+01  2.3675E+01  0.

  6.5000E+02  8.0260E+01  1.4115E+01  2.3959E+01  0.          6.7999E+00  1.1675E-01  0.
4  2680  1.8235E+00  8.3712E+00  6.3290E+00  3.2990E+00 -3.4387E-01  4.3265E+00  2.6550E+01  1.2631E+01  1.5173E+01  0.
3  3574  1.9974E+00  8.3789E+00  9.6743E+00  2.2184E-02              4.1304E-01  2.6550E+01  2.8779E+01  0.

  6.7500E+02  8.4776E+01  1.4695E+01  8.7251E+00  0.          7.0873E+00  1.1675E-01  0.
4  2831  1.9953E+00  8.7595E+00  6.6096E+00  3.4405E+00 -3.4387E-01  4.5181E+00  9.6688E+00  1.1068E+01  0.          0.
4  2831  2.0740E+00  8.7672E+00  1.0101E+01  2.2184E-02              4.3804E-01  9.6688E+00  1.1068E+01  0.

  7.0000E+02  8.6773E+01  1.5267E+01  2.0505E+01  0.          7.3659E+00  1.1675E-01  0.
4  2898  1.9616E+00  9.1003E+00  6.8599E+00  3.5641E+00 -3.4387E-01  4.6884E+00  2.2723E+01  1.3656E+01  1.3533E+01  0.
4  2898  2.1403E+00  9.1080E+00  1.0475E+01  2.2184E-02              4.6304E-01  2.2723E+01  2.4189E+01  0.

  7.2500E+02  9.1823E+01  1.5904E+01  4.4401E+00 -2.8422E-14  7.7206E+00  1.1675E-01  0.
4  3067  2.0493E+00  9.5777E+00  7.1796E+00  3.7628E+00 -3.4387E-01  4.9473E+00  4.9204E+00  6.5616E+00  0.          0.
4  3067  2.2280E+00  9.5854E+00  1.0990E+01  2.5941E-02              4.9246E-01  4.9204E+00  6.5616E+00  0.

  7.5000E+02  4.1909E+01  1.6442E+01 -2.9110E+01 -8.8818E+00  7.9756E+00  2.0633E-01  0.
2  2706  2.1114E+00  9.3851E+00  7.2053E+00  3.7628E+00 -5.2659E-01  4.8635E+00 -1.7865E+01  0.          0.          -1.6587E+01
2  2706  2.3788E+00  9.3928E+00  1.1016E+01  2.5941E-02              3.7768E-01 -1.7865E+01  0.          0.

  7.6500E+02 -6.7287E-03  1.6509E+01  0.          0.          7.9917E+00  2.6342E-01  0.
1   200  2.1319E+00  9.3189E+00  7.2053E+00  3.7630E+00 -5.8126E-01  4.8462E+00  0.          0.          5.0683E-02  0.
1   200  2.4417E+00  9.3265E+00  1.1016E+01  2.6063E-02              3.5100E-01  0.          0.          5.0683E-02
CYCLE DISTANCE =  1.6509E+01
FUEL CONSUMPTION ON MODE 1 =  3.3152E+01
                   MODE 2 =  6.0482E+01
BATT. ENERGY CONSUMPTION ON MODE 1 =  8.1543E-02
                           MODE 2 =  5.9060E-03
AVERAGE SPEED =  7.7687E+01  BATTERY DEPLETION =   1.814853E-02  HEAT ENGINE ON TIME =   5.930000E+02(MODE 1)    6.740833E+02(MODE 2

BATTERY POWER DISTRIBUTION

                                              NEGATIVE POSITIVE
38-34 34-30 30-26 26-22 22-18 18-14 14-10  10-6   6-2   2-2   2-6  6-10 10-14 14-18 18-22 22-26 26-30 30-34 34-38 TOTAL
  0     0     1     4     4     5    11    66     0   530   329   131   215    89    59    62    13    12     0  1531

FUEL AND ENERGY CONSUMPTION ON COMPOSITE CYCLES
  FUEL - MODE 1   FUEL - MODE 2  ENERGY - MODE 1 RANGE - MODE 1   FUEL - AV.    ENERGY - AV.     AV. SPEED     SP. POWER - 1
   1.525270E+01   6.757435E+01   2.209695E-01   2.083465E+01   1.525270E+01   2.200695E-01   2.675143E+01   2.180432E+01
   1.726629E+01   6.769530E+01   2.095543E-01   2.138757E+01   2.474748E+01   1.800784E-01   2.934803E+01   2.281041E+01
   1.764975E+01   6.771605E+01   2.079078E-01   2.149631E+01   3.696631E+01   1.307996E-01   2.990096E+01   2.302461E+01
```

10.35702
10.69682
10.38104
10.4609

2.109489E+01	6.682517E+01	1.877104E-01	2.379963E+01	4.263931E+01	1.028279E-01	3.321721E+01	2.309339E+01
2.437829E+01	6.595765E+01	1.694077E-01	2.654085E+01	4.589308E+01	8.501416E-02	3.707565E+01	2.312541E+01
2.665128E+01	6.535931E+01	1.550447E-01	2.884051E+01	4.818455E+01	7.270766E-02	4.031820E+01	2.315231E+01
2.831791E+01	6.492160E+01	1.452441E-01	3.079763E+01	4.989084E+01	6.370040E-02	4.308138E+01	2.317524E+01
2.959247E+01	6.458824E+01	1.377501E-01	3.248313E+01	5.121445E+01	5.682480E-02	4.546387E+01	2.319501E+01
3.059864E+01	6.432544E+01	1.318324E-01	3.395036E+01	5.227242E+01	5.140553E-02	4.753992E+01	2.321222E+01
3.176502E+01	6.402241E+01	1.249748E-01	3.582556E+01	5.351660E+01	4.513546E-02	5.019616E+01	2.323428E+01
3.290171E+01	6.372878E+01	1.182937E-01	3.786307E+01	5.475026E+01	3.903992E-02	5.308592E+01	2.325926E+01
3.373503E+01	6.351392E+01	1.133935E-01	3.951119E+01	5.566992E+01	3.457982E-02	5.542620E+01	2.327767E+01
3.437231E+01	6.335031E+01	1.096465E-01	4.087159E+01	5.639339E+01	3.117565E-02	5.735980E+01	2.329372E+01
3.487539E+01	6.322135E+01	1.066877E-01	4.201399E+01	5.695333E+01	2.849256E-02	5.898471E+01	2.330719E+01
3.528298E+01	6.311787E+01	1.042940E-01	4.298580E+01	5.742021E+01	2.632367E-02	6.036826E+01	2.331869E+01
3.561923E+01	6.303196E+01	1.023152E-01	4.382389E+01	5.780877E+01	2.453422E-02	6.156190E+01	2.332857E+01
3.590188E+01	6.296016E+01	1.006533E-01	4.455339E+01	5.813801E+01	2.303272E-02	6.260143E+01	2.333721E+01
3.614293E+01	6.289950E+01	9.923844E-02	4.519389E+01	5.842084E+01	2.175500E-02	6.351461E+01	2.334478E+01
3.635006E+01	6.284619E+01	9.801630E-02	4.576214E+01	5.866509E+01	2.065433E-02	6.432510E+01	2.335151E+01
3.653103E+01	6.280096E+01	9.695445E-02	4.626762E+01	5.888016E+01	1.969663E-02	6.504623E+01	2.335749E+01
3.668984E+01	6.276096E+01	9.602103E-02	4.672125E+01	5.906982E+01	1.885554E-02	6.569367E+01	2.336287E+01

YEARLY AV. FUEL CONSUMPTION = 4.775425E+01
YEARLY AV. BATTERY ENERGY OUTPUT = 7.361339E-02
EXPECTED BATTERY LIFE = 1.255050E+05

YEARLY AV. FUEL ECONOMY = 1.493061E+01
YEARLY AV. WALL PLUG OUTPUT = 1.363211E-01

HEAT ENGINE ENERGY FRACTION = 5.702510E-01

C1.2 HYBRID SYSTEM STARTUP SIMULATION PROGRAMS (VSYS & VSYS2)

1. Program Description

The programs VSYS and VSYS2 simulate the response of a hybrid system to a power demand. Initially all of the power requirements of the vehicle are being met by the electric motor under steady state conditions. The vehicle is travelling at a constant speed, the heat engine is disengaged from the drive train and is turned off.

In response to a demand for increased power output, a clutch between the engine and the motor is closed and the engine is started. The resultant torques, rpms, vehicle speed, and vehicle acceleration, are determined over time scales on the order of a second. The simulation terminates when the engine rpm reaches motor rpm.

The heat engine is modelled as a engine output torque curve that is a function of crankshaft displacement. The engine clutch is modelled as a torque curve as a function of time. Over the range of rpm's considered in the startup simulation, the motor is modelled as a straight line of motor torque versus rpm. The torque converter is modelled as two monotonic functions serving to completely determine input torque, output torque, input rpm, and output rpm, from any combination of two of these variables. The VSYS2 program version has no torque converter. The transmission has gearing, spin losses, and efficiencies. The differential has a differential ratio, spin loss, and an efficiency. The vehicle itself has aerodynamic, rolling resistance, and grade forces.

VSYS

Data	Description	Units
NTHE	number of heat engine torque data points	—
HEI	heat engine inertia	$kg\,m^2$
THE (NTHE)	heat engine torque	nt·m
THETA (NTHE)	heat engine angular displacement	rev.
NTCL	number of clutch torque data points	—
TCL (NTCL)	clutch torque	nt·m
TIME (NTCL)	clutch torque engagement times	sec
CM	slope of motor torque versus r.p.m.	ntm/rpm
EMI	motor inertia	$kg\,m^2$
NTSP	number of torque converter data points	—
CTCZRO	(not used, kept as data convention)	—
TSP (NTSP)	torque-speed ratios	$rpm/\sqrt{ntm}$
TQR (NTSP)	torque ratios	—
SPR (NTSP)	speed ratios	—
NGEAR	number of gears	—
SHFTUP	upshift rpm	rpm
RATIO (NGEAR)	transmission ratios	—
CT1 (NGEAR)	friction coefficient	nt m
CT2 (NGEAR)	friction coefficient	ntm/rpm
EMUT (NGEAR)	transmission efficiency	—
DRATIO	differential ratio	—
CD1	friction coefficient	nt m
CD2	friction coefficient	nt m/rpm
EMUD	differential efficiency	—
RTIRE	tire radius	m
CTIRE1	friction coefficient	—
CTIRE2	friction coefficient	1/km/hr
VMASS	vehicle mass	kg
DLI	drive line inertia	$kg\,m^2$
CDA	drag coefficient * frontal area	m^2
GRAD	road gradient	—
V	vehicle speed	km/hr
ELT	run time interval for RKTTA2	sec
TF	final time in simulation	sec
NPRNT	number of suppressed print times	—

Variables	Description	Units
JGEAR	steady state gear	—
VMPS	vehicle speed	m/sec
RPMDO	differential output r.p.m.	rpm
TLFD	differential torque loss	nt m
RPMTO	transmission output r.p.m	rpm
TLFT	transmission torque loss	nt·m
RPMTCO	torque converter output r.p.m	rpm
FA	aerodynamic force	nt
FR	rolling resistance force	nt
FG	gradient force	nt
FNETØ	steady state net force	nt
TDO	differential output torque	nt·m
TTO	transmission output torque	nt·m
TTCO	torque converter output torque	nt·m
TSPAR	torque - speed ratio	rpm/$\sqrt{nt\,m}$
TQRAT	torque ratio	—
TTCIN	torque converter input torque	nt·m
SPRAT	speed ratio	—
RPMTCN	torque converter input rpm	rpm
TEMØ	steady state motor torque intercept	nt m
K	print skip control flag	—
T	time in simulation	sec
Y(1)	angular speed of engine	rad/sec
Y(2)	angular displacement of engine	rad.
Y(3)	angular speed of motor	rad/sec.
Y(4)	speed of vehicle	m/sec.
YDOT(1)	angular acceleration of engine	rad/sec^2
YDOT(2)	angular speed of engine	rad/sec
YDOT(3)	angular acceleration of motor	rad/sec^2
YDOT(4)	acceleration of vehicle	m/sec^2
RPMHE	engine r.p.m.	rpm
RPMEM	motor r.p.m.	rpm
V	speed of vehicle	km/hr
A	acceleration of vehicle	g_{EARTH}
VMASS2	effective vehicle inertial mass	kg

DERIV Subroutine for VS4S

Variables	Description	Units
TCLN	clutch torque	nt m
THETAN	angular displacement of engine	rev
THEN	engine torque	nt·m
RPMDO	differential output rpm.	rpm
RPMTO	transmission output r.p.m.	rpm
RPMTCO	torque converter output r.p.m.	rpm
SPRAT	speed ratio	—
TSPAR	torque-speed ratio	rpm/$\sqrt{\text{nt m}}$
TQRAT	torque ratio	—
TTCO	torque converter output torque	nt m
TTCIN	torque converter input torque	nt m
TEM	motor torque	nt m
TTO	transmission output torque	nt m
TDO	differential output torque	nt m
FNET	net force on vehicle	nt
FAC	acceleration force of vehicle	nt

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

PROGRAM: VSYS

NAME:

ROUTINE: Input Format

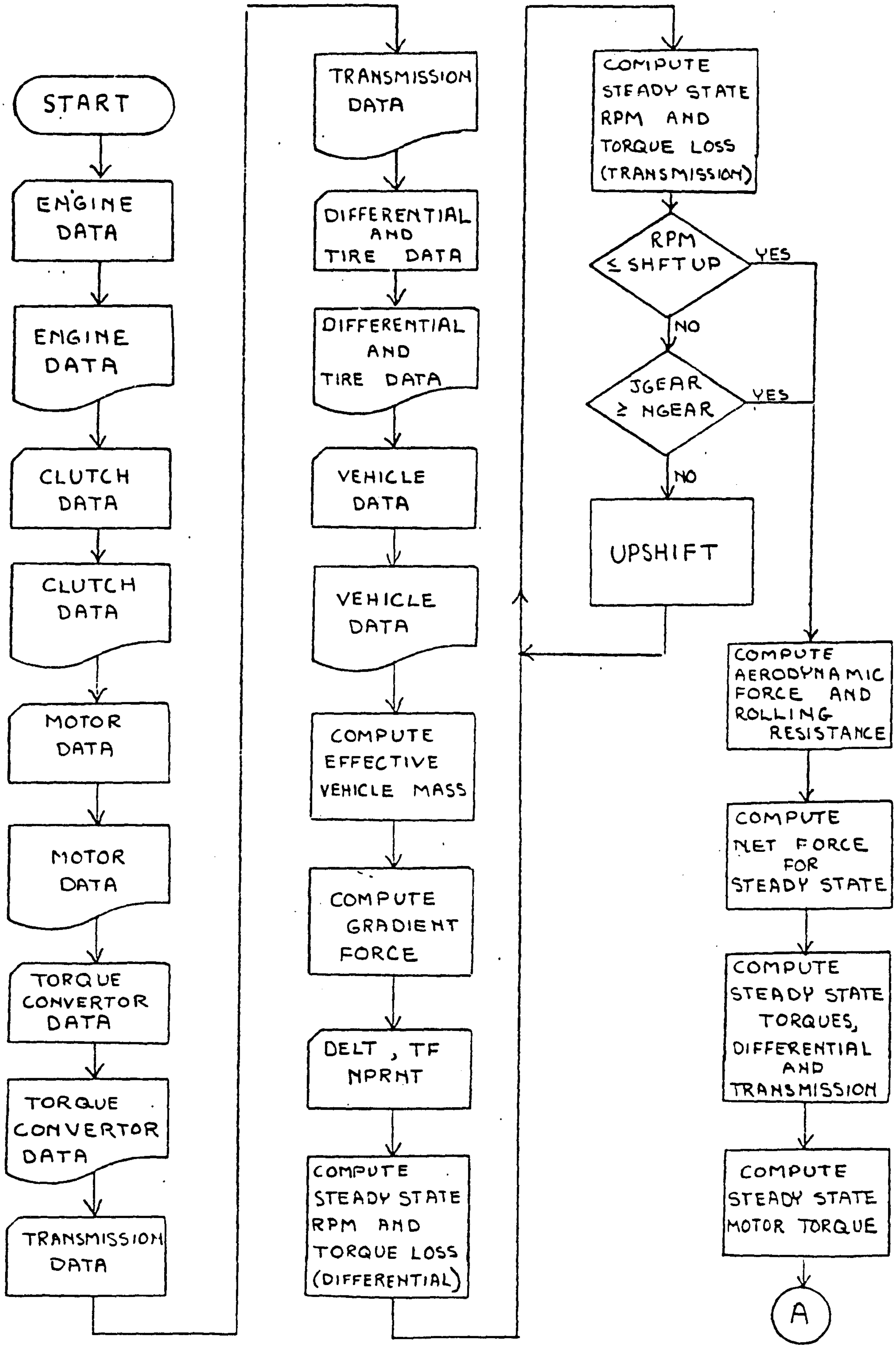
DATE:

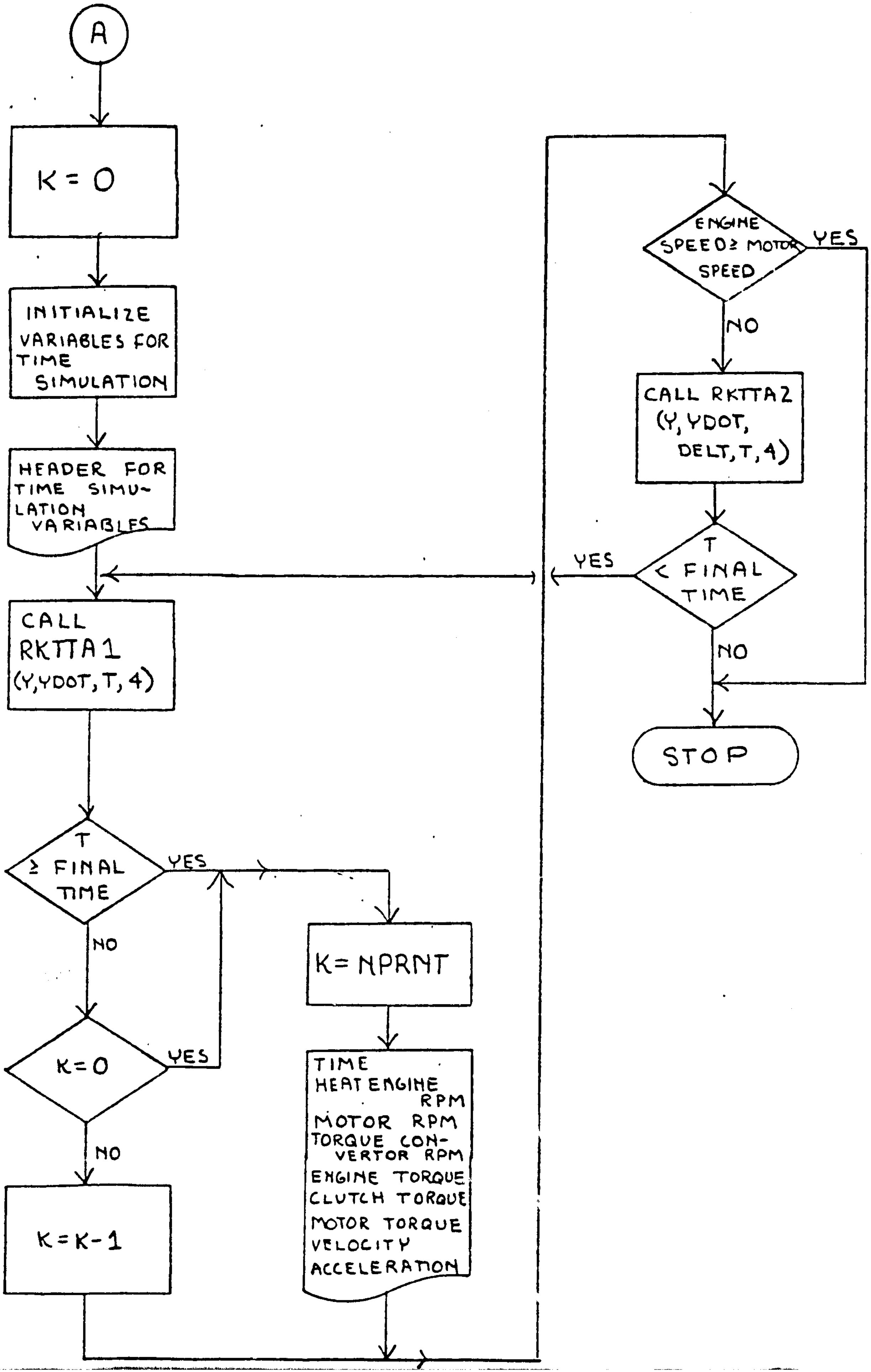
PAGE 1 OF 1

Cols 1–10	11–20	21–30	31–40	41–50	51–60	61–70
NTHE	HEI					
THE(1)	THETA(1)	...	...	THE(NTHE)	THETA(NTHE)	
NTCL						
TCL(1)	TIME(1)	...	...	TCL(NTCL)	TIME(NTCL)	
CM	EMI					
NTSP						
CTCZRO	TSP(1)	TQR(1)	SPR(1)	...	...	...
...	...	...	TSP(NTSP)	TQR(NTSP)	SPR(NTSP)	
NGEAR	SHFTUP					
TRATIO(1)	CT1(1)	CT2(1)	EMUT(1)	...	...	...
...	TRATIO(NGEAR),	CT1(NGEAR),	CT2(NGEAR),	EMUT(NGEAR)		
DRATIO	CD1	CD2	EMUD	RTIRE	CTIRE1	CTIRE2
VMASS	DLI	CD4	ERAD	V		
DELT	TF	NKNT				

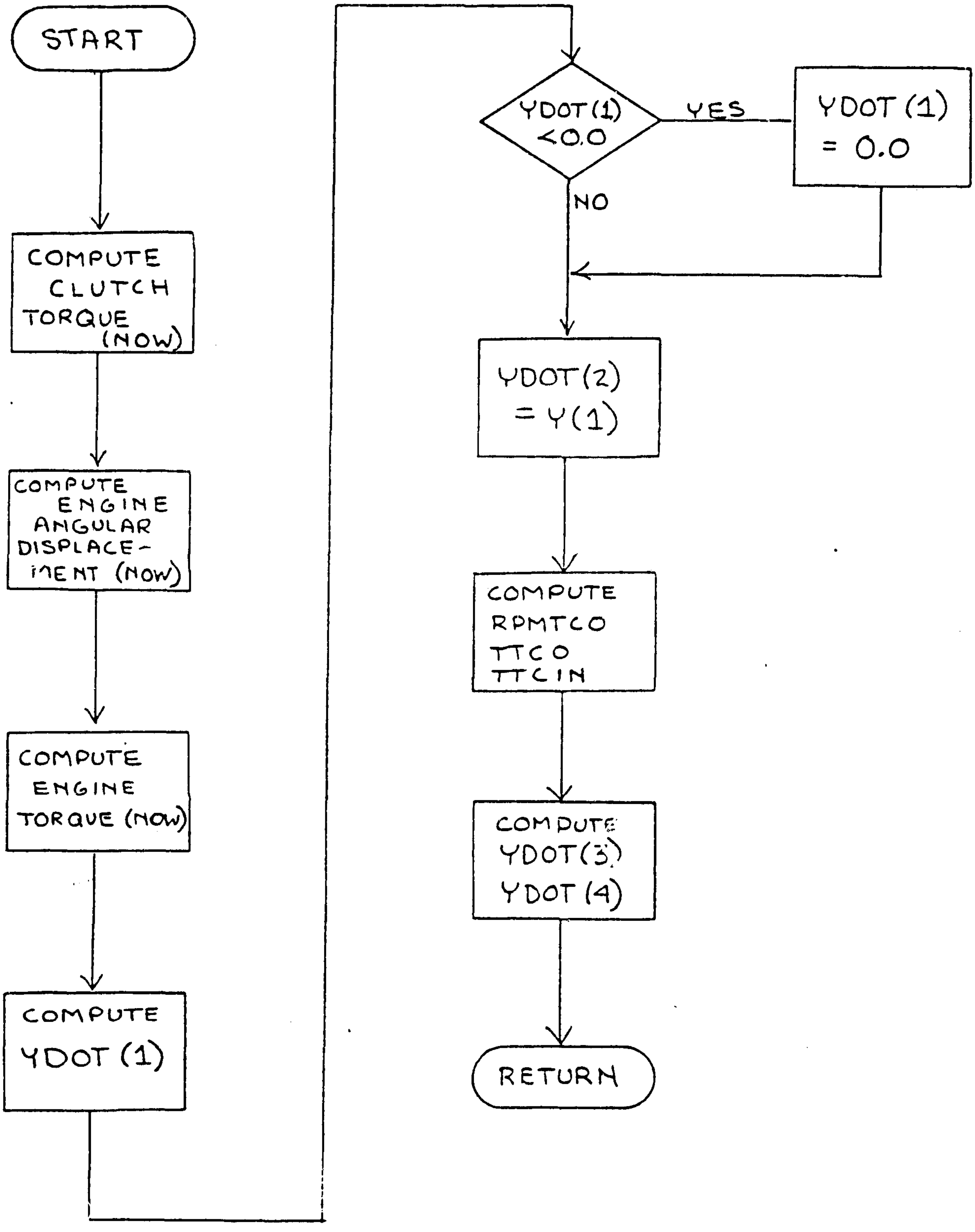
RM NO. GRC 109 Rev. 1

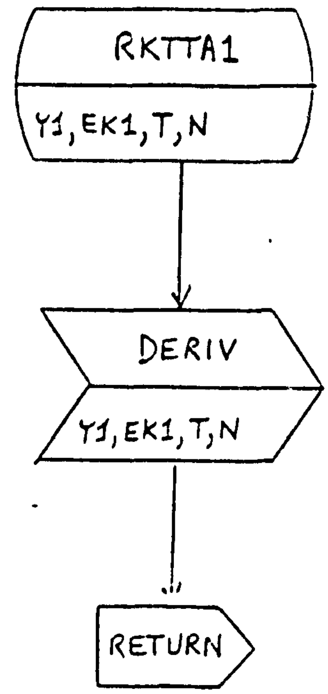
VSYS

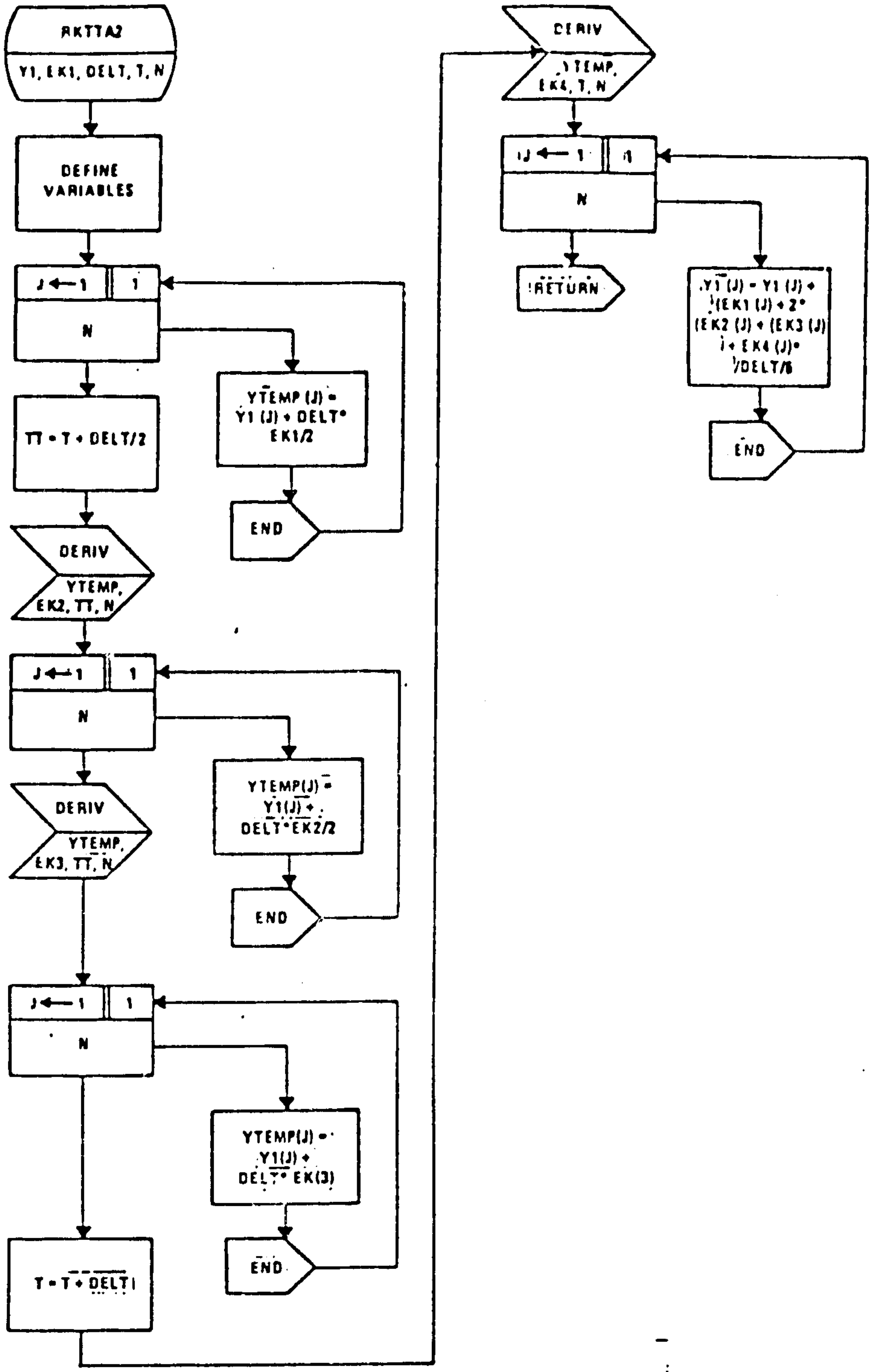

START
ENGINE DATA
ENGINE DATA
CLUTCH DATA
CLUTCH DATA
MOTOR DATA
MOTOR DATA
TORQUE CONVERTOR DATA
TORQUE CONVERTOR DATA
TRANSMISSION DATA
TRANSMISSION DATA
DIFFERENTIAL AND TIRE DATA
DIFFERENTIAL AND TIRE DATA
VEHICLE DATA
VEHICLE DATA
COMPUTE EFFECTIVE VEHICLE MASS
COMPUTE GRADIENT FORCE
DELT , TF NPRNT
COMPUTE STEADY STATE RPM AND TORQUE LOSS (DIFFERENTIAL)
COMPUTE STEADY STATE RPM AND TORQUE LOSS (TRANSMISSION)
RPM ≤ SHFTUP
YES
NO
JGEAR ≥ NGEAR
YES
NO
UPSHIFT
COMPUTE AERODYNAMIC FORCE AND ROLLING RESISTANCE
COMPUTE NET FORCE FOR STEADY STATE
COMPUTE STEADY STATE TORQUES, DIFFERENTIAL AND TRANSMISSION
COMPUTE STEADY STATE MOTOR TORQUE
A

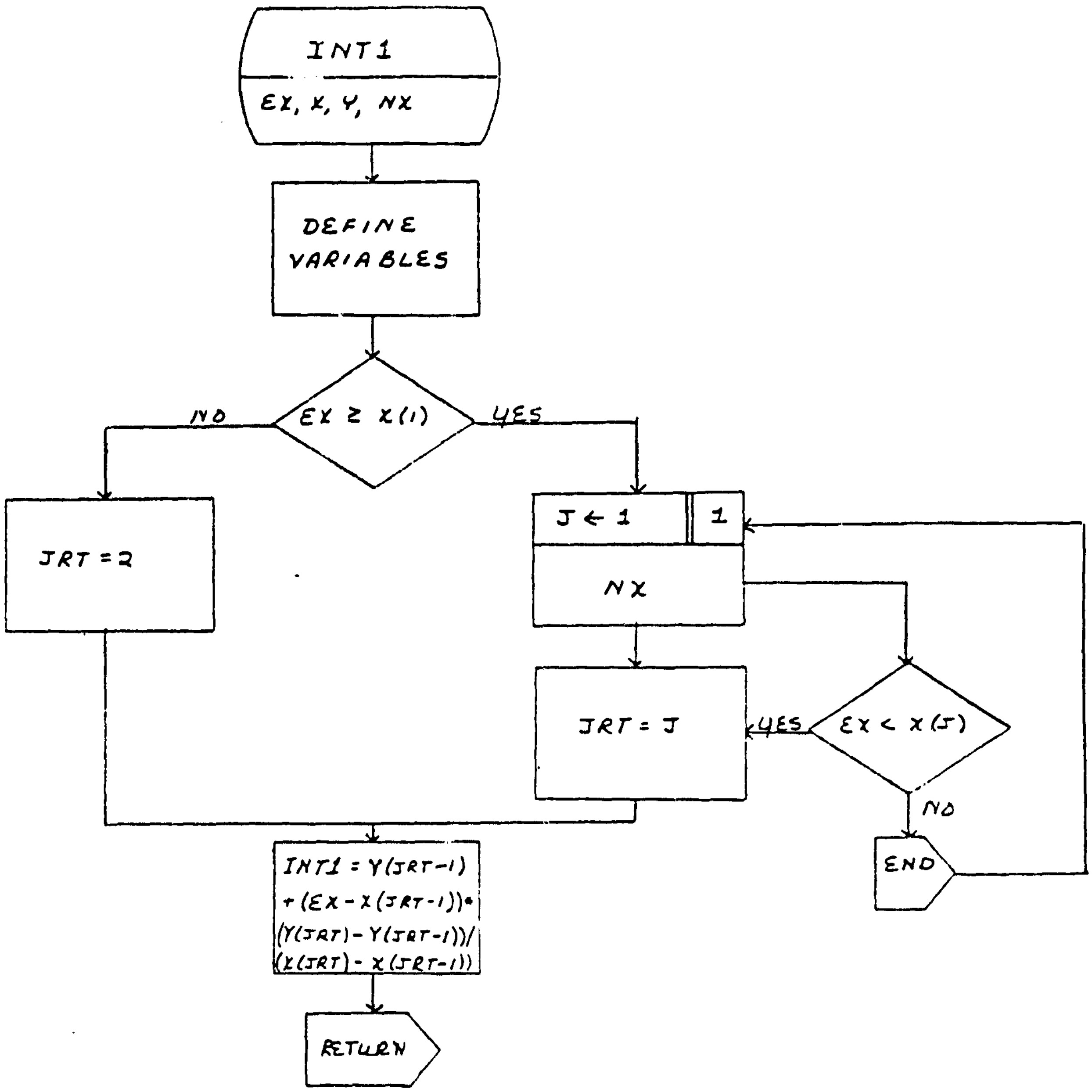

A
K = O
INITIALIZE VARIABLES FOR TIME SIMULATION
HEADER FOR TIME SIMU-LATION VARIABLES
CALL RKTTA1 (Y, YDOT, T, 4)
T ≥ FINAL TIME
YES
NO
K=O
YES
NO
K=K-1
K= NPRNT
TIME
HEAT ENGINE RPM
MOTOR RPM
TORQUE CON-VERTOR RPM
ENGINE TORQUE
CLUTCH TORQUE
MOTOR TORQUE
VELOCITY
ACCELERATION
ENGINE SPEED ≥ MOTOR SPEED
YES
NO
CALL RKTTA2 (Y, YDOT, DELT, T, 4)
T < FINAL TIME
YES
NO
STOP

VSYS Subroutine DERIV




RKTTA1
Y1, EK1, T, N
DERIV
Y1, EK1, T, N
RETURN


RKTTA2
Y1, EK1, DELT, T, N
DEFINE VARIABLES
J ← 1
1
N
YTEMP (J) = Y1 (J) + DELT* EK1/2
END
TT = T + DELT/2
DERIV
YTEMP, EK2, TT, N
J ← 1
1
N
YTEMP(J) = Y1(J) + DELT*EK2/2
END
DERIV
YTEMP, EK3, TT, N
J ← 1
1
N
YTEMP(J) = Y1(J) + DELT* EK(3)
END
T = T + DELT
DERIV
EK4, T, N
N
RETURN
END


INT1
EX, X, Y, NX
DEFINE VARIABLES
EX ≥ X(1)
NO
YES
JRT = 2
J ← 1
1
NX
JRT = J
YES
EX < X(J)
NO
END
INT1 = Y(JRT-1) + (EX - X(JRT-1))* (Y(JRT) - Y(JRT-1))/ (X(JRT) - X(JRT-1))
RETURN

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)


```
                 PROGRAM VSYS
           C
           C     THIS PROGRAM MODELS A HYBRID VEHICLE PROPULSION SYSTEM.
           C     THE ELECTRIC MOTOR IS PRODUCING TORQUE UNDER  STEADY STATE
           C     CONDITIONS AND THE HEAT ENGINE CLUTCH IS ENGAGED.
           C
           C     ALL UNITS IN MKS EXCEPT
           C     THETA, THETAN                                   (REVOLUTIONS)
           C     V, VPL                                          (KM. PER HR.)
           C     A, APL                                          (G)
           C     RPMOO, RPMTC, RPMTCO, RPMTCN                    (REV. PER MIN.)
           C     RPMHE, RPMEM                                    (REV. PER MIN.)
           C     WPL, UPL                                        (REV. PER MIN.)
           C     CM                                              (NEWTON*METERS/RPM)
           C     CT2, CD2, SHFTUP, CTIRE2, TSP, TSPAR, CDA
           C
000003           COMMON RTIRE,CD1,CD2,DRATIC,CT1(6),CT2(6),TRATIO(6),CDA,CTIRE1
                1CTIRE2,VMASS,EMUD,EMUT(6),NGEAR,CLI,GRAD,CM,HEI,EMI.
                2VMASS2,FG,V,JGEAR,
                3TSP(20),TQR(20),SPR(20),NTSP,
                4NTCL,TCL(10),TIME(10),NTHE,THE(10),THETA(10),
                5VMPS,RPMOO,TLFO,RPMTC,TLFT,RPMTCO,FA,FR,FNETO,TCO,TTC,TTCO,TSP
                6TORAT,TTCIN,SPRAT,RPMTCN,TEMO,THETAN,
                7TCLN,THEN,TEM,FNET,FAC
000003           REAL YDOT(4),Y(4),INT1
           C
           C     INPUT ENGINE DATA
           C
000003           READ 640,NTHE,HEI
000013           READ 610,(THE(J),THETA(J),J=1,NTHE)
000030           PRINT 420,HEI
000036           PRINT 820,(THE(J),THETA(J),J=1,NTHE)
           C
           C     INPUT CLUTCH DATA
           C
000053           READ 620,NTCL
[illegible]      READ 610,(TCL(J),TIME(J),J=1,NTCL)
000076           PRINT 400
000102           PRINT 820,(TCL(J),TIME(J),J=1,NTCL)
           C
           C     INPUT MOTOR DATA
           C
000117           READ 610,CM,EMI
000127           PRINT 430,CM,EMI
           C
           C     INPUT TORQUE CONVERTOR DATA
           C
000137           READ 620,NTSP
000145           READ 610,CTCZRO,(TSP(J),TQR(J),SPR(J),J=1,NTSP)
000166           PRINT 860
[illegible] 172  PRINT 865,CTCZRO
[illegible]200   PRINT 870
000204           PRINT 814,(TSP(J),TQR(J),SPR(J),J=1,NTSP)
           C
           C     INPUT TRANSMISSION DATA
```

```
              C
  0223               READ 640,NGEAR,SHFTUP
  J233               READ 610,(TRATIO(J),CT1(J),CT2(J),EMUT(J),J=1,NGEAR)
000254               PRINT 840
000260               PRINT 845
000264               PRINT 810,(TRATIO(J),CT1(J),CT2(J),EMUT(J),J=1,NGEAR)
000305               PRINT 850,SHFTUP
              C
              C      INPUT DIFFERENTIAL AND TIRE DATA
              C
000313               READ 610,DRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2
000335               PRINT 875
000341               PRINT 880
000345               PRINT 885,DRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2
              C
              C      INPUT VEHICLE DATA
              C
000367               READ 610,VMASS,DLI,CDA,GRAC,V
000405               PRINT 890,VMASS,DLI,CDA
000417               PRINT 925,GRAD,V
000427               VMASS2=VMASS+DLI/RTIRE**2
              C
              C     GRADIENT-
              C
000432               FG=9.807*VMASS*SIN(ATAN(GRAD))
              C
              C      INPUT RUN DATA
              C
000441               READ 630,DELT,TF,NPRNT
              C
              C      COMPUTE STEADY STATE CONDITIONS
              C
000452               JGEAR=1
000453               VMPS=V/3.6
000455               RPMDO=9.5492967*VMPS/RTIRE
000457               TLFD=CD1+CD2*RPMDO
000462               RPMTC=RPMDO*DRATIO
000464           15  CONTINUE
000464               TLFT=CT1(JGEAR)+CT2(JGEAR)*RPMTC
000470               RPMTCO=RPMTC*TRATIO(JGEAR)
              C
              C      UPSHIFT IF NECESSARY
              C
000472               IF((RPMTCO.LE.SHFTUP).OR.(JGEAR.GE.NGEAR))GO TO 18
000503               JGEAR=JGEAR+1
000504               GO TO 15
000505           18  CONTINUE
              C
              C      AERODYNAMIC -
              C
  0505               FA=0.6125*CDA*VMPS**2
              C
              C      ROLLING RESISTANCE -
              C
000510               FR=9.807*VMASS*(CTIRE1+CTIRE2*V)
```

```
             C
             C      ACCELERATION -
             C
000514              FNETO=FA+FG+FR
000517              TDO=FNETO*RTIRE
             C
             C      DIFFERENTIAL -
             C
000521              TTO=TDO/(EMUD*DRATIO)+TLFD
             C
             C      TRANSMISSION -
             C
000525              TTCO=TTO/(EMUT(JGEAR)*TRATIO(JGEAR))+TLFT
             C
             C      HAVE OUTPUT SPEED AND OUTPUT TORQUE.
             C
000532              TSPAR=RPMTCO/SQRT(ABS(TTCO))
000536              TQRAT=INT1(TSPAR,TSP,TQR,NTSP)
000542              TTCIN=TTCO/TQRAT
000544              SPRAT=INT1(TSPAR,TSP,SPR,NTSP)
000550              RPMTCN=RPMTCO/SPRAT
000552              TEMO=TTCIN+CM*RPMTCN
             C
             C      SET INITIAL CONDITIONS
             C
000555              K=0
000556              T=0.0
000557              Y(1)=0.0
000560              Y(2)=0.0
000561              Y(3)=.104719755*RPMTCN
000563              Y(4)=V/3.6
000566              PRINT 700
000571           80 CONTINUE
000571              CALL RKTTA1(Y,YDOT,T,4)
000574              IF((T.GE.TF).OR.(K.EQ.0))GO TO 107
000604              K=K-1
000605              GO TO 109
000605          107 CONTINUE
000605               K=NPRNT
             C
             C      TIME TO PRINT RESULTS -
             C
000606              RPMHE=Y(1)/.104719755
000610              RPMEM=Y(3)/.104719755
000612              V=Y(4)*3.6
000614              A=YDOT(4)/9.807
000616              PRINT 886,T,RPMHE,RPMEM,RPMTCO,THEM,TCLN,TEM,V,A
000644          109 CONTINUE
             C
             C      INTEGRATE TO NEXT TIME STEP
             C
000644              IF(Y(1).GE.Y(3))GO TO 190
000647              CALL RKTTA2(Y,YDOT,DELT,T,4)
000652              IF(T.LT.TF)GO TO 80
000655          190 CONTINUE
```

```
000655      200 STOP
          C
          C       FORMAT STATEMENTS
          C
000657      400 FORMAT(1H0,*CLUTCH DATA*//5X,*CLUTCH TQ.*,6X,*TIME*)
000657      420 FORMAT(1H0,*ENGINE DATA*//5X,*ENGINE INERTIA =*,E16.6//
               15X,*ENGINE TQ.*,6X,*THETA*)
000657      430 FORMAT(1H0,*MOTOR DATA*//5X,*MOTOR SPEED DROOP =*,E16.6,4X,
               1*MOTOR INERTIA =*,E16.6)
000657      610 FORMAT(7F10.4)
000657      620 FORMAT(7I10)
000657      630 FORMAT(2F10.4,2I10)
000657      640 FORMAT(I10.6F10.4)
000657      700 FORMAT(1H0,4X,*TIME*, 7X,*ENGINE RPM*,3X,*MOTOR RPM*,4X,*TCO R
               16X,*ENGINE TQ.*,3X,*CLUTCH TQ.*,3X,
               2*MOTOR TQ.*,4X,*SPEED*,8X,*ACCEL.*)
000657      810 FORMAT(1H ,4E16.6)
000657      814 FORMAT(1H ,3E16.6)
000657      820 FORMAT(1H ,2E16.6)
000657      840 FORMAT(1H0,12HGEARBOX DATA)
000657      845 FORMAT(1H0,4X,10HGEAR RATIO,6X,22HSPIN LOSS COEFFICIENTS,10X
               1,*EFFICIENCY*)
000657      850 FORMAT(/T5,*UPSHIFT RPM = *,E16.6)
000657      860 FORMAT(1H0,21HTORQUE CONVERTOR DATA)
000657      865 FORMAT(1H0,4X,17HNI**2/TI(STALL) =,E16.6)
  0657      870 FORMAT(1H0,4X,11HNO/SQRT(TO),5X,5HTO/TI,11X,5HNC/NI)
  0657      875 FORMAT(1H0,18HAXLE AND TIRE DATA )
000657      880 FORMAT(1H0,4X,14HFIN. DR. RATIO,2X,22HSPIN LOSS COEFFICIENTS,1
               1,*EFFICIENCY*,6X,*ROLLING RADIUS*,2X,*ROLL. RESIST. COEFFICIEN
000657      885 FORMAT(1H ,7E16.6)
000657      886 FORMAT(1H ,E12.2,9E13.4)
000657      890 FORMAT(1H0,14HVEHICLE MASS =,E16.6
               1,5X,*DRIVE LINE INERTIA = *,E16.6
               2,5X,19H(DRAG COEF.)*AREA =,E16.6)
000657      925 FORMAT(1H0,16HCYCLE GRADIENT =,E10.3,
               1*STEADY STATE SPEED =*,E10.3)
000657          END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                 SUBROUTINE DERIV(Y,YDOT,T,N)
            C
            C    Y(1) IS ENGINE SPEED
            C    Y(2) IS ENGINE ANGULAR DISPLACEMENT
            C    Y(3) IS MOTOR SPEED
            C    Y(4) IS VEHICLE SPEED
            C
000007           COMMON RTIRE,CD1,CD2,DRATIO,CT1(6),CT2(6),TRATIO(6),CDA,CTIRE
                1CTIRE2,VMASS,EMUD,EMUT(6),NGEAR,CLI,GRAD,CM,HEI,EMI,
                2VMASS2,FG,V,JGEAR,
                3TSP(20),TOR(20),SPR(20),NTSP,
                4NTCL,TCL(10),TIME(10),NTHE,THE(10),THETA(10),
                5VMPS,RPMDO,TLFO,RPMTO,TLFT,RPMTCO,FA,FR,FNETO,TDO,TTO,TTCO,TSI
                6TORAT,TTCIN,SPRAT,RPMTCN,TEMO,THETAN,
                7TCLN,THEN,TEM,FNET,FAC
000007           REAL Y(2),YDOT(2),INT1
            C
000007           TCLN=INT1(T,TIME,TCL,NTCL)
000015           THETAN=Y(2)/6.2831852
000017           THEN=INT1(THETAN,THETA,THE,NTHE)
000023           YDOT(1)=(THEN+TCLN)/HEI
            C
            C    NO NEGATIVE ENGINE ROTATIONAL ACCELERATION
            C
000031           IF(YDOT(1).LT.0.0)YDOT(1)=0.0
000034           YDOT(2)=Y(1)
  0036           RPMDO=9.5492967*Y(4)/RTIRE
 00040           RPMTC=RPMDO*DRATIO
000042           RPMTCO=RPMTC*TRATIO(JGEAR)
000044           SPRAT=.104719755*RPMTCO/Y(3)
000047           TSPAR=INT1(SPRAT,SPR,TSP,NTSP)
000053           TORAT=INT1(SPRAT,SPR,TOR,NTSP)
000057           TTCO=(RPMTCO/TSPAR)**2.
000064           TTCIN=TTCO/TORAT
000066           TEM=TEMO-CM*Y(3)/.104719755
000074           YDOT(3)=(TEM-TCLN-TTCIN)/EMI
000101           TTO=TTCO*EMUT(JGEAR)*TRATIO(JGEAR)
000104           TDO=TTO*EMUD*DRATIO
000106           FNET=TDO/RTIRE
000110           FAC=FNET-FNETO
000112           YDOT(4)=FAC/VMASS2
000114           RETURN
000115           END
```

GOLETA FCFTFAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                SUBROUTINE RKTTA1(Y1,EK1,T,N)
  1007          REAL Y1(20),EK1(20)
000007          CALL DERIV(Y1,EK1,T,N)
000010          RETURN
000011          END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                    SUBROUTINE RKTTA2(Y1,EK1,DELT,T,N)
   010              REAL Y1(20),Y2(20),YTEMP(20),EK1(20),EK2(20),EK3(20),EK4(20)
000010              DO 50J=1,N
000011              YTEMP(J)=Y1(J)+DELT*EK1(J)/2.
000017           50 CONTINUE
000022              TT=T+DELT/2.
000024              CALL DERIV(YTEMP,EK2,TT,N)
000027              DO 60J=1,N
000034              YTEMP(J)=Y1(J)+DELT*EK2(J)/2.
000041           60 CONTINUE
000045              CALL DERIV(YTEMP,EK3,TT,N)
000050              DO 70J=1,N
000055              YTEMP(J)=Y1(J)+DELT*EK3(J)
000061           70 CONTINUE
000064              T=T+DELT
000065              CALL DERIV(YTEMP,EK4,T,N)
000070              DO 80J=1,N
000075              Y1(J)=Y1(J)+(EK1(J)+2.*(EK2(J)+EK3(J))+EK4(J))*(DELT/6.)
000107           80 CONTINUE
000111              RETURN
000112              END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO PFL * (01-10-73)

```
                    REAL FUNCTION INT1(EX,X,Y,NX)
          C
          C         INT1 INTERPOLATES IN ONE VARIABLE
          C
000007              REAL X(10),Y(10)
000007              IF(EX.GE.X(1))GO TO 5
000011              JRT=2
000012              GO TO 20
000013            5 DO 10 J=1,NX
000015              IF(EX.LT.X(J))GO TO 15
000020           10 CONTINUE
000022           15 JRT=J
000024           20 INT1=Y(JRT-1)+(EX-X(JRT-1))*(Y(JRT)-Y(JRT-1))/(X(JRT)-X(JRT-1))
000040              RETURN
000041              END
```

```
ENGINE DATA

    ENGINE INERTIA =    6.250000E-02

    ENGINE TQ.       THETA
   -1.000000E+01     0.
   -1.000000E+01     1.000000E+00
    5.000000E+01     2.000000E+00
    5.000000E+01     3.000000E+00

CLUTCH DATA

    CLUTCH TQ.       TIME
    0.               0.
    1.000000E+02     1.000000E+00

MOTOR DATA

    MOTOR SPEED DROOP =    4.400000E-01    MOTOR INERTIA =    1.050000E-01

TORQUE CONVERTOR DATA

    NI**2/TI(STALL) =    1.300400E+04

    NO/SQRT(TC)      TO/TI            NO/NI
    0.               2.190000E+00     0.
    1.147000E+01     2.040000E+00     1.000000E-01
    2.331000E+01     1.920000E+00     2.000000E-01
    3.560000E+01     1.820000E+00     3.000000E-01
    4.352000E+01     1.700000E+00     4.000000E-01
    6.150000E+01     1.560000E+00     5.000000E-01
    7.340000E+01     1.420000E+00     6.000000E-01
    9.783000E+01     1.270000E+00     7.000000E-01
    1.208600E+02     1.140000E+00     8.000000E-01
    1.564300E+02     1.000000E+00     9.000000E-01
    2.135000E+02     1.000000E+00     9.500000E-01
    3.384300E+02     1.000000E+00     9.750000E-01
    1.000000E+03     1.000000E+00     1.000000E+00

GEARBOX DATA

    GEAR RATIO       SPIN LOSS COEFFICIENTS           EFFICIENCY
    2.450000E+00     0.               0.              9.200000E-01
    1.450000E+00     0.               0.              9.200000E-01
    1.000000E+00     0.               0.              9.400000E-01

   UPSHIFT RPM =    4.000000E+03

AXLE AND TIRE DATA

    FIN. DR. RATIO  SPIN LOSS COEFFICIENTS           EFFICIENCY      ROLLING RADIUS  ROLL. RESIST. COEFFICIENTS
    4.100000E+00     0.               0.              9.600000E-01    3.050000E-01    1.000000E-02    0.

VEHICLE MASS =    [illegible]E+03     DRIVE LINE INERTIA =    5.600000E+00     (DRAG COEF.)*AREA =    [illegible].720000E-01

CYCLE GRADIENT = 0.        STEADY STATE SPEED = 7.000E+01

    TIME         ENGINE RPM    MOTOR RPM     TC RPM        ENGINE TQ.    CLUTCH TQ.    MOTOR TQ.     SPEED         ACCEL.
    0.           0.            3.6561E+03    3.6193E+03   -1.0000E+01    0.            2.4377E+01    7.0000E+01   -2.6717E-15
    2.00E-02     0.            3.6551E+03    3.6132E+03   -1.0000E+01    2.0000E+00    2.4870E+01    7.0000E+01   -4.0090E-04
    4.00E-02     0.            3.6533E+03    3.6192E+03   -1.0000E+01    4.0000E+00    2.5757E+01    6.9999E+01   -1.0947E-03
```

6.00E-02	0.	3.6508E+03	3.6192E+03	-1.0000E+01	6.0000E+00	2.6747E+01	6.9998E+01	-1.7979E-03
8.00E-02	0.	3.6484E+03	3.6191E+03	-1.0000E+01	8.0000E+00	2.7796E+01	6.9997E+01	-2.4948E-03
1.00E-01	0.	3.6459E+03	3.6190E+03	-1.0000E+01	1.0000E+01	2.8862E+01	6.9995E+01	-3.1674E-03
1.20E-01	3.0559E+00	3.6434E+03	3.6189E+03	-1.0000E+01	1.2000E+01	2.9974E+01	6.9992E+01	-3.8145E-03
1.40E-01	1.2723E+01	3.6408E+03	3.6187E+03	-1.0000E+01	1.4000E+01	3.1120E+01	6.9990E+01	-4.4362E-03
1.60E-01	2.7582E+01	3.6381E+03	3.6185E+03	-1.0000E+01	1.6000E+01	3.2300E+01	6.9988E+01	-5.0331E-03
1.80E-01	4.3097E+01	3.6354E+03	3.6183E+03	-1.0000E+01	1.8000E+01	3.3512E+01	6.9982E+01	-5.6057E-03
2.00E-01	7.6396E+01	3.6325E+03	3.6181E+03	-1.0000E+01	2.0000E+01	3.4756E+01	6.9978E+01	-6.1545E-03
2.20E-01	1.1001E+02	3.6295E+03	3.6179E+03	-1.0000E+01	2.2000E+01	3.6031E+01	6.9974E+01	-6.6801E-03
2.40E-01	1.4973E+02	3.6267E+03	3.6176E+03	-1.0000E+01	2.4000E+01	3.7336E+01	6.9969E+01	-7.1834E-03
2.60E-01	1.9557E+02	3.6236E+03	3.6174E+03	-1.0000E+01	2.6000E+01	3.8671E+01	6.9964E+01	-7.6647E-03
2.80E-01	2.4752E+02	3.6205E+03	3.6171E+03	-1.0000E+01	2.8000E+01	4.0035E+01	6.9958E+01	-8.1250E-03
3.00E-01	3.0559E+02	3.6174E+03	3.6169E+03	-1.0000E+01	3.0000E+01	4.1427E+01	6.9952E+01	-8.5649E-03
3.20E-01	3.6975E+02	3.6142E+03	3.6165E+03	-1.0000E+01	3.2000E+01	4.2845E+01	6.9946E+01	-8.9849E-03
3.40E-01	4.4003E+02	3.6109E+03	3.6161E+03	-1.0000E+01	3.4000E+01	4.4289E+01	6.9939E+01	-9.3960E-03
3.60E-01	5.1643E+02	3.6075E+03	3.6158E+03	-1.0000E+01	3.6000E+01	4.5759E+01	6.9933E+01	-9.7697E-03
3.80E-01	5.9993E+02	3.6041E+03	3.6154E+03	-1.0000E+01	3.8000E+01	4.7252E+01	6.9926E+01	-1.0134E-02
4.00E-01	6.9634E+02	3.6007E+03	3.6150E+03	-1.2369E+00	4.0000E+01	4.8759E+01	6.9918E+01	-1.0492E-02
4.20E-01	8.4056E+02	3.5972E+03	3.6146E+03	1.4074E+01	4.2000E+01	5.0308E+01	6.9911E+01	-1.0814E-02
4.40E-01	1.0425E+03	3.5937E+03	3.6142E+03	3.2800E+01	4.4000E+01	5.1859E+01	6.9903E+01	-1.1131E-02
4.60E-01	1.3131E+03	3.5901E+03	3.6138E+03	5.0000E+01	4.6000E+01	5.3459E+01	6.9895E+01	-1.1433E-02
4.80E-01	1.5095E+03	3.5864E+03	3.6134E+03	5.0000E+01	4.8000E+01	5.5050E+01	6.9887E+01	-1.1720E-02
5.00E-01	1.9120E+03	3.5827E+03	3.6130E+03	5.0000E+01	5.0000E+01	5.6659E+01	6.9879E+01	-1.1994E-02
5.20E-01	2.2207E+03	3.5790E+03	3.6125E+03	5.0000E+01	5.2000E+01	5.8307E+01	6.9870E+01	-1.2255E-02
5.40E-01	2.5354E+03	3.5753E+03	3.6121E+03	5.0000E+01	5.4000E+01	5.9951E+01	6.9861E+01	-1.2594E-02
5.60E-01	2.9563E+03	3.5715E+03	3.6116E+03	5.0000E+01	5.6000E+01	6.1631E+01	6.9852E+01	-1.2741E-02
5.80E-01	3.1837E+03	3.5676E+03	3.6111E+03	5.0000E+01	5.8000E+01	5.3317E+01	6.9843E+01	-1.2969E-02
6.00E-01	3.5163E+03	3.5638E+03	3.6107E+03	5.0000E+01	5.9900E+01	5.5918E+01	6.9834E+01	-1.3187E-02

Data	Description	Units
NTHE	number of heat engine data points	—
HEI	heat engine inertia	kg m²
THE(NTHE)	heat engine torque	nt m
THETA (NTHE)	heat engine angular displacement	rev.
NTCL	number of clutch torque data points	—
TCL (NTCL)	clutch torque	nt m
TIME (NTCL)	clutch torque engagement times	sec.
CM	slope of motor torque versus r.p.m.	nt m/rpm
EMI	motor inertia	kg m²
NGEAR	number of gears	—
SHFTUP	upshift rpm.	rpm
TRATIO (NGEAR)	transmission ratios	—
CT1 (NGEAR)	friction coefficient	nt m
CT2 (NGEAR)	friction coefficient	nt m/rpm
EMUT(NGEAR)	transmission efficiency	—
DRATIO	differential ratio	—
CD1	friction coefficient	nt m
CD2	friction coefficient	nt m/rpm
EMUD	differential efficiency	—
KTIRE	tire radius	m
CTIRE1	friction coefficient	—
CTIRE2	friction coefficient	1/km/hr
VMASS	vehicle mass	kg
DLI	drive line inertia	kg m²
CDA	drag coefficient * area	m²
GRAD	road gradient	—
V	vehicle speed	km/hr
DELT	run time interval for RKTTIE	sec
TF	final time in simulation	sec
NPRNT	number of suppressed print times	—

VS4S2

Variables	Description	Units
GEAR	steady state gear	——
VMPS	vehicle speed	m/sec
RPMDO	differential output r.p.m.	rpm
TLFD	differential torque loss	nt m
RPMTO	transmission output r.p.m.	rpm
TLFT	transmission torque loss	nt m
RPMEM	motor rpm	rpm
FA	aerodynamic force	nt
FR	rolling resistance force	nt
FG	gradient force	nt
FNETØ	Steady state net force	nt
TDO	differential output torque	nt m
TTO	transmission output torque	nt m
TSO	motor output torque	nt m
TEMØ	steady state motor torque intercept	nt m
VMASS2	effective vehicle inertial mass	kg
EMI2	effective motor inertia	$kg\ m^2$
K	print skip control flag	——
T	time in simulator	sec
Y(1)	angular speed of engine	rad/sec
Y(2)	angular displacement of engine	rad
Y(3)	angular speed of motor	rad/sec
YDOT(1)	angular acceleration of engine	rad/sec^2
YDOT(2)	angular speed of engine	rad/sec
YDOT(3)	angular acceleration of motor	rad/sec^2
RPMHE	engine r.p.m.	rpm
RPMEM	motor r.p.m.	rpm
V	vehicle speed	km/hr
A	vehicle acceleration	g_{EARTH}

DFKIV Subroutine for VSYS2

Variables	Description	Units
TCLN	clutch torque	nt
THETAN	angular displacement of engine	rev
THEN	engine torque	nt
TEM	motor torque	nt

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

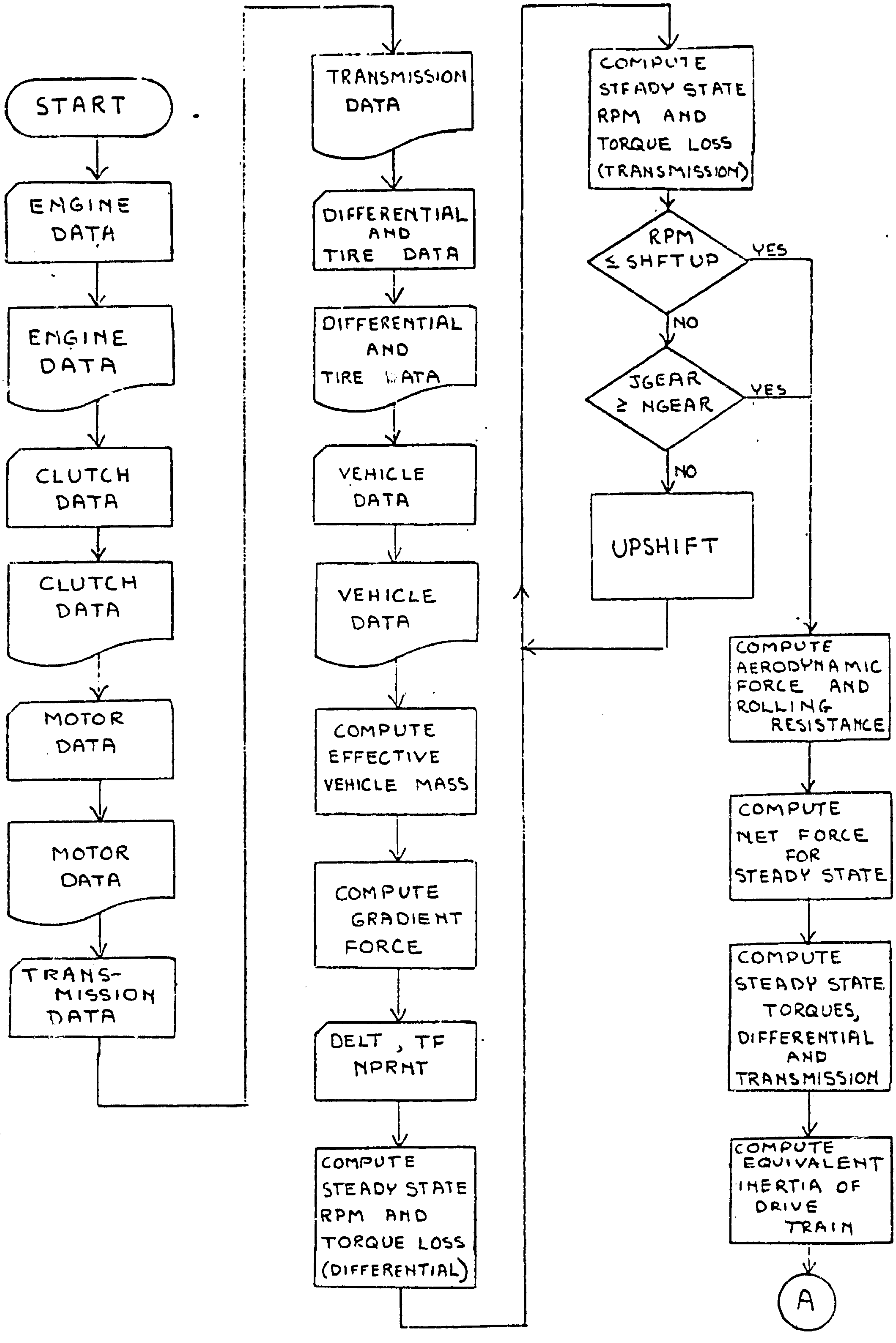
PROGRAM: VSYS2 | NAME:

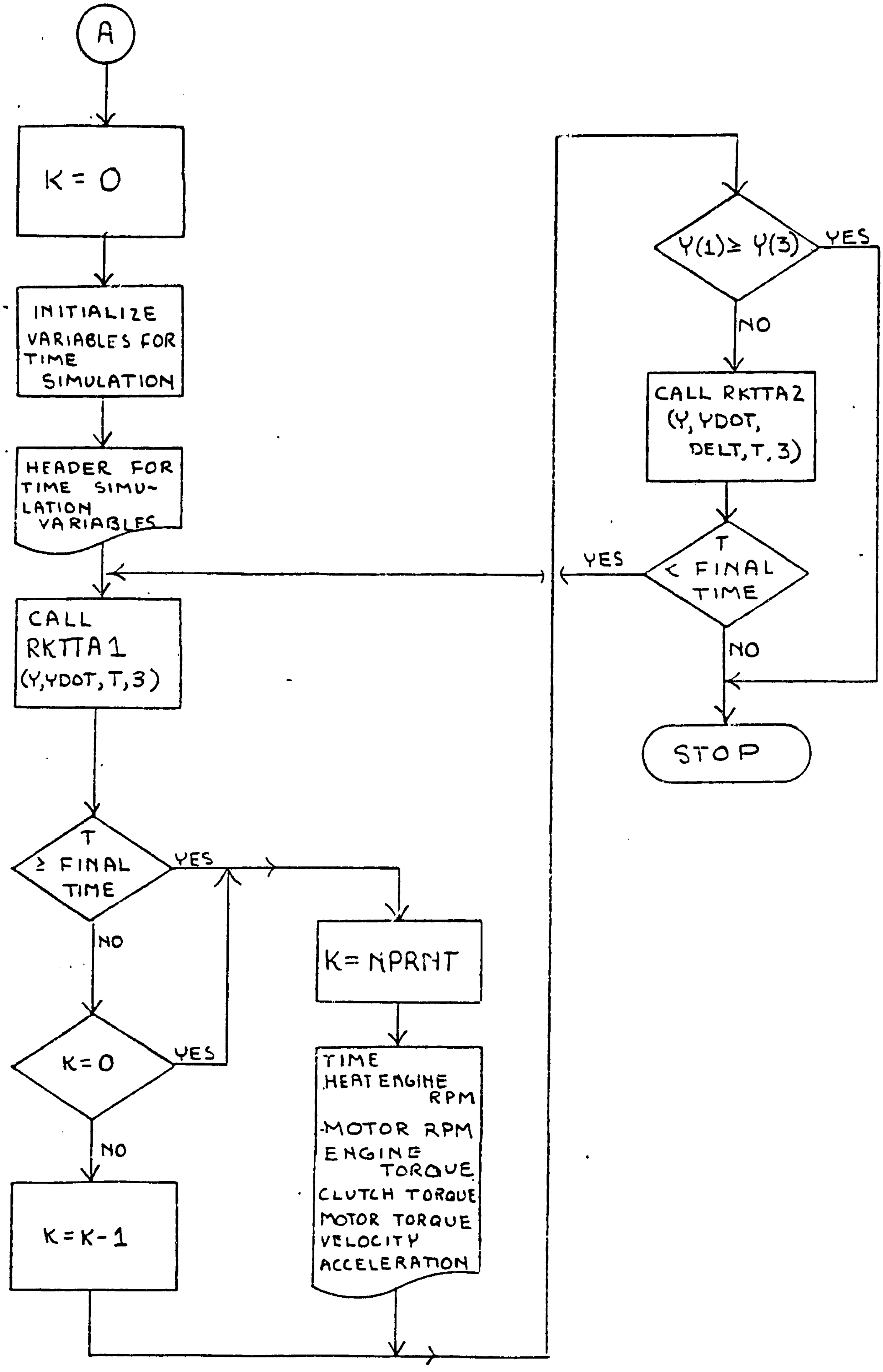
ROUTINE: Input format | DATE: 20 JULY 79 | PAGE 1 OF 1

```
    NTHE      HEI
   THE(1)  THETA(1)   ...       ...       THE(NTHE) THETA(NTHE)
    NTCL
   TCL(1)  TIME(1)    ...       ...       TCL(NTCL) TIME(NTCL)
      CM      EMI
   NGEAR    SHIFTUP
TRATIO(1)    CT1(1)    CT2(1)   EMUT(1)   ...       ...       ...
  ...  TRATIO(NGEAR),CT1(NGEAR),CT2(NGEAR), EMUT(NGEAR)
   DRATIO      CD        CD2       EMUD     RTIRE    CTIRE1    CTIRE2
    VMASS      DLI       CDA       CRAD         V
     DELT       TF     NFRNT
```

C-2

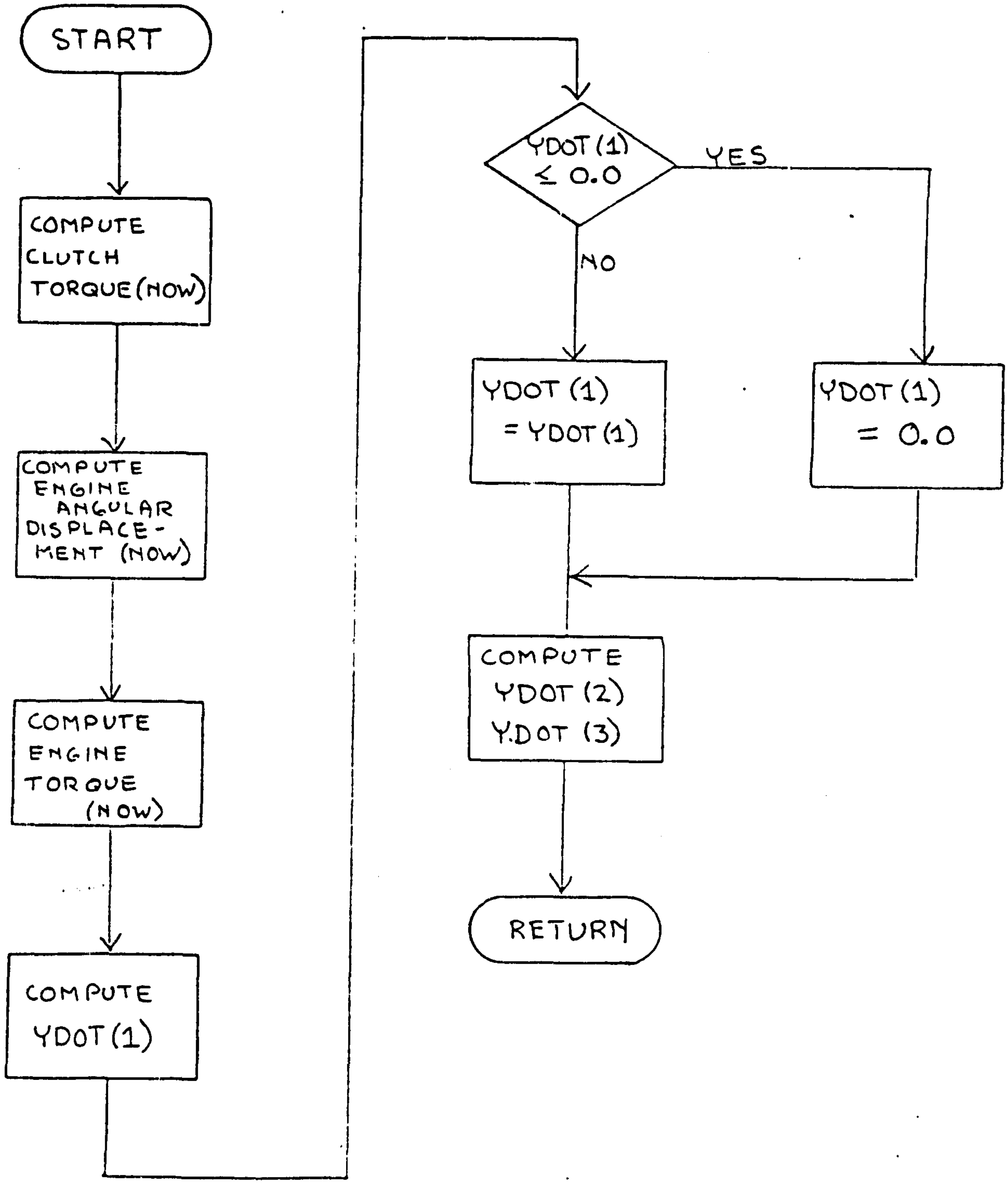
VSYS2

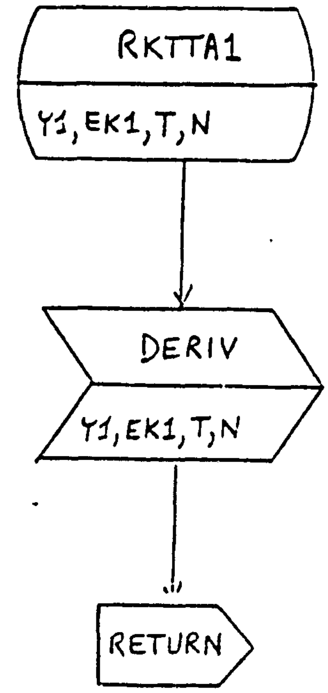

START
ENGINE DATA
ENGINE DATA
CLUTCH DATA
CLUTCH DATA
MOTOR DATA
MOTOR DATA
TRANS-MISSION DATA
TRANSMISSION DATA
DIFFERENTIAL AND TIRE DATA
DIFFERENTIAL AND TIRE DATA
VEHICLE DATA
VEHICLE DATA
COMPUTE EFFECTIVE VEHICLE MASS
COMPUTE GRADIENT FORCE
DELT, TF NPRNT
COMPUTE STEADY STATE RPM AND TORQUE LOSS (DIFFERENTIAL)
COMPUTE STEADY STATE RPM AND TORQUE LOSS (TRANSMISSION)
RPM ≤ SHFTUP
YES
NO
JGEAR ≥ NGEAR
YES
NO
UPSHIFT
COMPUTE AERODYNAMIC FORCE AND ROLLING RESISTANCE
COMPUTE NET FORCE FOR STEADY STATE
COMPUTE STEADY STATE TORQUES, DIFFERENTIAL AND TRANSMISSION
COMPUTE EQUIVALENT INERTIA OF DRIVE TRAIN
A

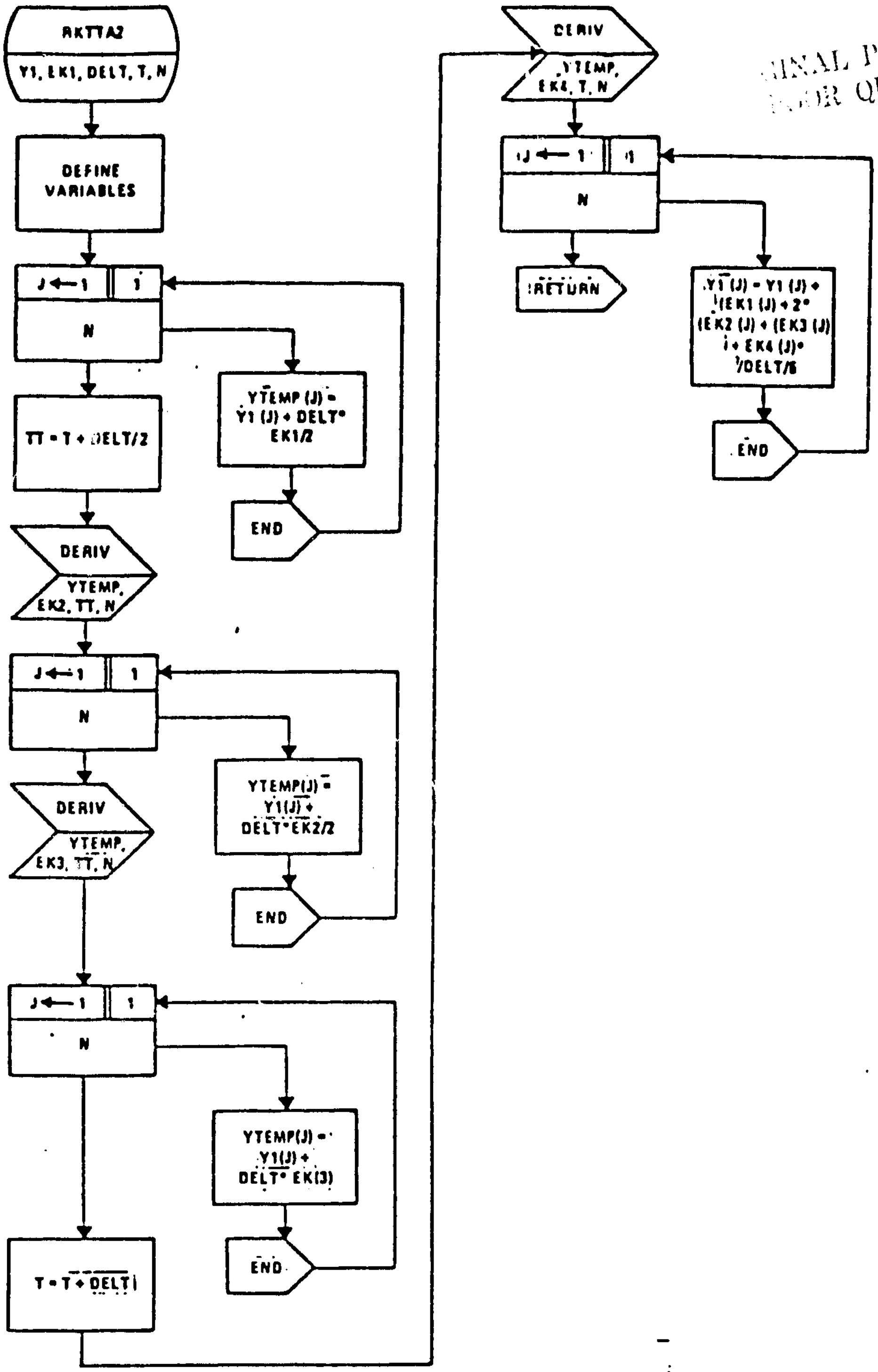

A
K = 0
INITIALIZE VARIABLES FOR TIME SIMULATION
HEADER FOR TIME SIMULATION VARIABLES
CALL RKTTA1 (Y,YDOT,T,3)
T ≥ FINAL TIME
YES
NO
K=0
YES
NO
K=K-1
K=NPRNT
TIME
HEAT ENGINE RPM
MOTOR RPM
ENGINE TORQUE
CLUTCH TORQUE
MOTOR TORQUE
VELOCITY
ACCELERATION
Y(1)≥ Y(3)
YES
NO
CALL RKTTA2 (Y,YDOT, DELT,T,3)
T < FINAL TIME
YES
NO
STOP

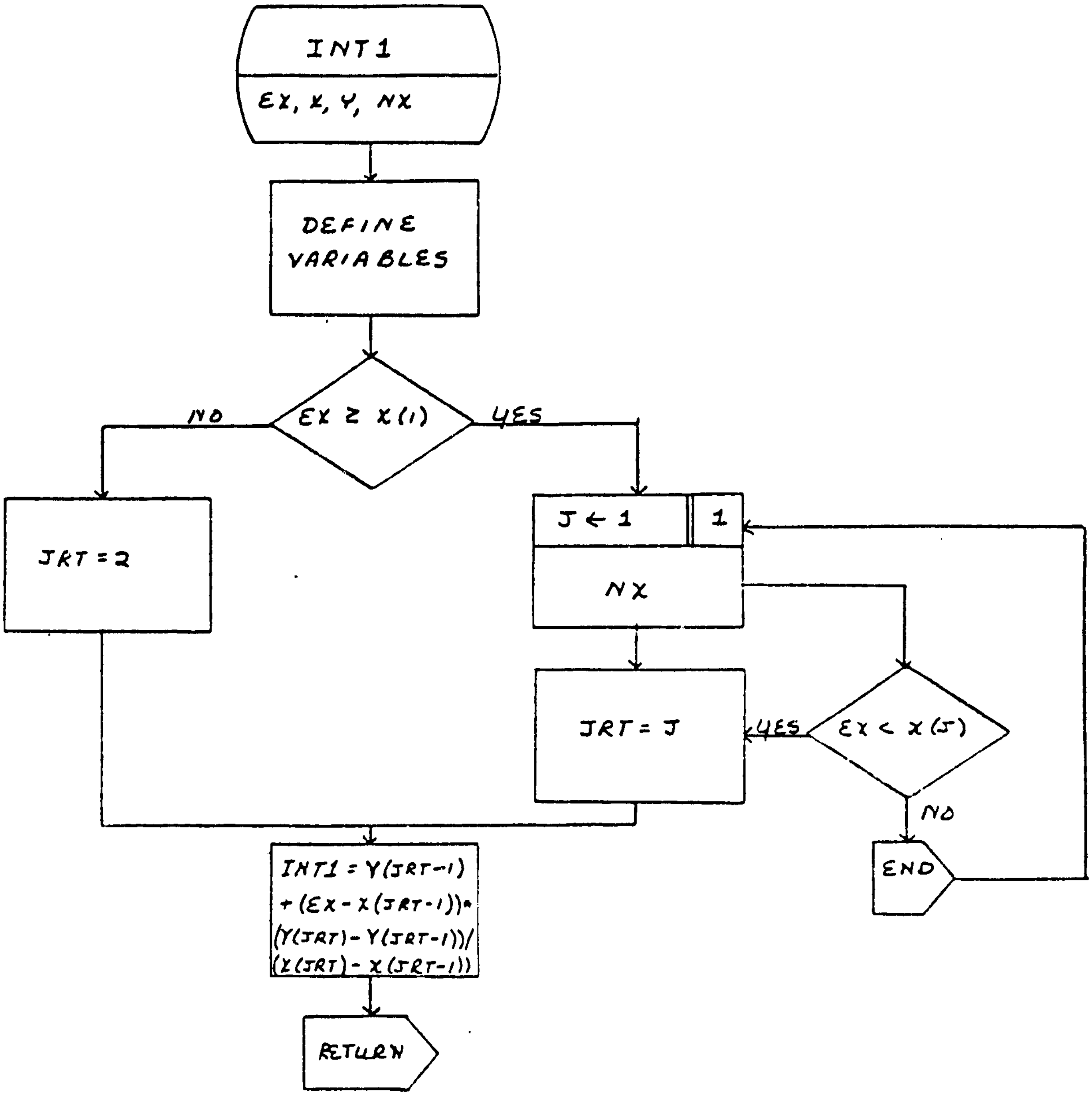
VSYSZ Subroutine DERIV

ORIGINAL PAGE IS
OF POOR QUALITY




RKTTA1
Y1, EK1, T, N
DERIV
Y1, EK1, T, N
RETURN


RKTTA2
Y1, EK1, DELT, T, N
DEFINE VARIABLES
J ← 1
1
N
YTEMP (J) = Y1 (J) + DELT* EK1/2
END
TT = T + DELT/2
DERIV
YTEMP, EK2, TT, N
J ← 1
1
N
YTEMP(J) = Y1(J) + DELT*EK2/2
END
DERIV
YTEMP, EK3, TT, N
J ← 1
1
N
YTEMP(J) = Y1(J) + DELT* EK(3)
END
T = T + DELT
DERIV
YTEMP, EK4, T, N
J ← 1
1
N
Y1 (J) = Y1 (J) + (EK1 (J) + 2* (EK2 (J) + EK3 (J)) + EK4 (J))* DELT/6
END
RETURN


INT1
EX, X, Y, NX
DEFINE VARIABLES
EX ≥ X(1)
NO
YES
JRT = 2
J ← 1
1
NX
JRT = J
YES
EX < X(J)
NO
END
INT1 = Y(JRT-1) + (EX - X(JRT-1))* (Y(JRT) - Y(JRT-1))/ (X(JRT) - X(JRT-1))
RETURN

GOLETA FORTRAN 1.3 * SEMI-AUTO SFL * (01-10-73)

```
                 PROGRAM VSYS2
           C
           C     THIS PROGRAM MODELS A HYBRID VEHICLE PROPULSION SYSTEM.
           C     THE ELECTRIC MOTOR IS PRODUCING TORQUE UNDER  STEADY STATE
           C     CONDITIONS AND THE HEAT ENGINE CLUTCH IS ENGAGED.
           C     VHYSYS2 VERSION HAS NO TORQUE CONVERTER.
           C
           C     ALL UNITS IN MKS EXCEPT :
           C     THETA, THETAN                                (REVOLUTIONS)
           C     V, VPL                                       (KM. PER HR.)
           C     A, APL                                       (G)
           C     RPMDO, RPMTO                                 (REV. PER MIN.)
           C     RPMHE, RPMEM                                 (REV. PER MIN.)
           C     WPL, UPL                                     (REV. PER MIN.)
           C     CM                                           (NEWTON*METERS/RPM)
           C     CT2, CD2, SHFTUP, CTIRE2, TSP, TSPAR, CDA
           C
000003           COMMON RTIRE,CD1,CD2,CRATIO,CT1(6),CT2(6),TRATIO(6),CDA,CTIRE1,
                1CTIRE2,VMASS,EMUD,EMUT(6),NGEAR,DLI,GRAD,CM,HEI,EMI,
                2VMASS2,FG,V,JGEAR,
                3TSO,EMI2,
                4NTCL,TCL(10),TIME(10),NTHE,THE(10),THETA(10),
                5VMPS,RPMDO,TLFD,RPMTO,TLFT,RPMTCO,FA,FR,FNETO,TCO,TTO,
                6TEMO,THETAN,
                7TCLN,THEN,TEM,FNET,FAC
000003           REAL YDOT(3),Y(3),INT1
           C
           C     INPUT ENGINE DATA
           C
000003           READ 640,NTHE,HEI
000013           READ 610,(THE(J),THETA(J),J=1,NTHE)
000030           PRINT 420,HEI
000036           PRINT 820,(THE(J),THETA(J),J=1,NTHE)
           C
           C     INPUT CLUTCH DATA
           C
000053           READ 620,NTCL
000061           READ 610,(TCL(J),TIME(J),J=1,NTCL)
000076           PRINT 400
000102           PRINT 820,(TCL(J),TIME(J),J=1,NTCL)
           C
           C     INPUT MOTOR DATA
           C
000117           READ 610,CM,EMI
000127           PRINT 430,CM,EMI
           C
           C     INPUT TRANSMISSION DATA
           C
000137           READ 640,NGEAR,SHFTUP
000147           READ 610,(TRATIO(J),CT1(J),CT2(J),EMUT(J),J=1,NGEAR)
000170           PRINT 840
000174           PRINT 845
   200           PRINT 810,(TRATIO(J),CT1(J),CT2(J),EMUT(J),J=1,NGEAR)
000221           PRINT 850,SHFTUP
           C
```

```
              C      INPUT DIFFERENTIAL AND TIRE DATA
              C
  000227             READ 610,DRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2
  000251             PRINT 875
  000255             PRINT 880
  000261             PRINT 885,DRATIO,CD1,CD2,EMUD,RTIRE,CTIRE1,CTIRE2
              C
              C      INPUT VEHICLE DATA
              C
  000303             READ 610,VMASS,DLI,CDA,GRAD,V
  000321             PRINT 890,VMASS,DLI,CDA
  000333             PRINT 925,GRAD,V
  000343             VMASS2=VMASS+DLI/RTIRE**2
              C
              C     GRADIENT-
              C
  000346             FG=9.807*VMASS*SIN(ATAN(GRAD))
              C
              C      INPUT RUN DATA
              C
  000355             READ 630,DELT,TF,NPRNT
              C
              C      COMPUTE STEADY STATE CONDITIONS
              C
  000366             JGEAR=1
  000367             VMPS=V/3.6
  000371             RPMDO=9.5492967*VMPS/RTIRE
  000373             TLFD=CD1+CD2*RPMDO
  000376             RPMTO=RPMDO*DRATIO
  000400          15 CONTINUE
  000400             TLFT=CT1(JGEAR)+CT2(JGEAR)*RPMTO
  000404             RPMEM=RPMTO*TRATIO(JGEAR)
              C
              C      UPSHIFT IF NECESSARY
              C
  000405             IF((RPMEM .LE.SHFTUP).OR.(JGEAR.GE.NGEAR))GO TO 18
  000417             JGEAR=JGEAR+1
  000420             GO TO 15
  000421          18 CONTINUE
              C
              C      AERODYNAMIC -
              C
  000421             FA=0.6125*CDA*VMPS**2
              C
              C      ROLLING RESISTANCE -
              C
  000424             FR=9.807*VMASS*(CTIRE1+CTIRE2*V)
              C
              C      ACCELERATION -
              C
  000430             FNET0=FA+FG+FR
  000433             TDO=FNET0*RTIRE
              C
              C      DIFFERENTIAL -
              C
```

```
000435            TTO=TDO/(EMUD*DRATIO)+TLFD
         C
         C        TRANSMISSION -
         C
000441            TSO =TTO/(EMUT(JGEAR)*TRATIO(JGEAR))+TLFT
000446            TEMO=TSO+CM*RPMEM
         C
         C        COMPUTE EQUIVALENT INERTIA OF DRIVE TRAIN
         C
000451            EMI2=EMI+(VMASS2*RTIRE**2.
                 1/(EMUD*EMUT(JGEAR)*(DRATIO*TRATIO(JGEAR))**2.))
         C
         C        SET INITIAL CONDITIONS
         C
000466            K=0
000467            T=0.0
000470            Y(1)=0.0
000471            Y(2)=0.0
000472            Y(3)=.104719755*RPMEM
000475            PRINT 700
000500         80 CONTINUE
000500            CALL RKTTA1(Y,YDOT,T,3)
000503            IF((T.GE.TF).OR.(K.EQ.0))GO TO 107
000513            K=K-1
000514            GO TO 109
000514        107 CONTINUE
  0514            K=NPRNT
         C
         C        TIME TO PRINT RESULTS -
         C
000515            RPMHE=Y(1)/.104719755
000517            RPMEM=Y(3)/.104719755
000521            V=Y(3)*RTIRE*3.6/(DRATIO*TRATIO(JGEAR))
000526            A=YDOT(3)*RTIRE/(DRATIO*TRATIO(JGEAR)*9.807)
000533            PRINT 885,T,RPMHE,RPMEM,THEN,TCLN,TEM,V,A
000556        109 CONTINUE
         C
         C        INTEGRATE TO NEXT TIME STEP
         C
000556            IF(Y(1).GE.Y(3))GO TO 190
000561            CALL RKTTA2(Y,YDOT,DELT,T,3)
000564            IF(T.LT.TF)GO TO 80
000567        190 CONTINUE
000567        200 STOP
         C
         C        FORMAT STATEMENTS
         C
000571        400 FORMAT(1H0,*CLUTCH DATA*//5X,*CLUTCH TQ.*,6X,*TIME*)
000571        420 FORMAT(1H0,*ENGINE DATA*//5X,*ENGINE INERTIA =*,E16.6//
                 15X,*ENGINE TQ.*,6X,*THETA*)
000571        430 FORMAT(1H0,*MOTOR DATA*//5X,*MOTOR SPEED DROOP =*,E16.6,4X,
                 1*MOTOR INERTIA =*,E16.6)
   571        610 FORMAT(7F10.4)
000571        620 FORMAT(7I10)
000571        630 FORMAT(2F10.4,2I10)
```

```
000571     640 FORMAT(I10,6F10.4)
  0571     700 FORMAT(1H0,4X,*TIME*, 7X,*ENGINE RPM*,3X,*MOTOR RPM*,
              14X,*ENGINE TQ.*,3X,*CLUTCH TQ.*,3X,
              2*MOTOR TQ.*,4X,*SPEED*,8X,*ACCEL.*)
000571     810 FORMAT(1H ,4E16.6)
000571     820 FORMAT(1H ,2E16.6)
000571     840 FORMAT(1H0,12HGEARBOX DATA)
000571     845 FORMAT(1H0,4X,10HGEAR RATIO,6X,22HSPIN LOSS COEFFICIENTS,10X
              1,*EFFICIENCY*)
000571     850 FORMAT(/T5,*UPSHIFT RPM = *,E16.6)
000571     875 FORMAT(1H0,18HAXLE AND TIRE DATA )
000571     880 FORMAT(1H0,4X,14HFIN. DR. RATIO,2X,22HSPIN LOSS COEFFICIENTS,10X
              1,*EFFICIENCY*,6X,*ROLLING RADIUS*,2X,*ROLL. RESIST. COEFFICIENTS
000571     885 FORMAT(1H ,7E16.6)
000571     886 FORMAT(1H ,E12.2,9E13.4)
000571     890 FORMAT(1H0,14HVEHICLE MASS =,E16.6
              1,5X,*DRIVE LINE INERTIA = *,E16.6
              2,5X,19H(DRAG COEF.)*AREA =,E16.6)
000571     925 FORMAT(1H0,16HCYCLE GRADIENT =,E10.3,
              1*STEADY STATE SPEED =*,E10.3)
000571          END
```

```
                  SUBROUTINE DERIV(Y,YDOT,T,N)
         C
         C        Y(1) IS ENGINE SPEED
         C        Y(2) IS ENGINE ANGULAR DISPLACEMENT
         C        Y(3) IS MOTOR SPEED
         C
000007            COMMON RTIME,CD1,CD2,DRATIO,CT1(6),CT2(6),IRATIO(6),CDA,CTIRE1,
                 1CTIRE2,VMASS,EMUD,EMUT(6),NGEAR,DLI,GRAD,CM,HEI,EMI,
                 2VMASS2,FG,V,JGEAR,
                 3TSO,EMI2,
                 4NTCL,TCL(10),TIME(10),NTHE,THE(10),THETA(10),
                 5VMPS,RPMDO,TLFO,RPMTO,TLFT,RPMTCO,FA,FR,FNETO,TCO,TTO,
                 6TEMO,THETAN,
                 7TCLN,THEN,TEM,FNET,FAC
000007            REAL Y(2),YDOT(2),INT1
         C
000007            TCLN=INT1(T,TIME,TCL,NTCL)
000015            THETAN=Y(2)/6.2831852
000017            THEN=INT1(THETAN,THETA,THE,NTHE)
000023            YDOT(1)=(THEN+TCLN)/HEI
         C
         C        NO NEGATIVE ENGINE ROTATIONAL ACCELERATION
         C
000031            YDOT(1)=AMAX1(0.0,YDOT(1))
000035            YDOT(2)=Y(1)
000036            TEM=TEMO-CM*Y(3)/.104719755
  0042            YDOT(3)=(TEM-TCLN-TSO)/EMI2
  0047            RETURN
000047            END
```

GOLETA FCRTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                SUBRCUTINE RKTTA1(Y1,EK1,T,N)
  ""0007        REAL Y1(20),EK1(20)
    J007        CALL DERIV(Y1,EK1,T,N)
  000010        RETURN
  000011        END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)


```
                    SUBROUTINE RKTTA2(Y1,EK1,DELT,T,N)
000010              REAL Y1(20),Y2(20),YTEMP(20),EK1(20),EK2(20),EK3(20),EK4(20)
000010              DO 50J=1,N
000011              YTEMP(J)=Y1(J)+DELT*EK1(J)/2.
000017           50 CONTINUE
000022              TT=T+DELT/2.
000024              CALL DERIV(YTEMP,EK2,TT,N)
000027              DO 60J=1,N
000034              YTEMP(J)=Y1(J)+DELT*EK2(J)/2.
000041           60 CONTINUE
000045              CALL DERIV(YTEMP,EK3,TT,N)
000050              DO 70J=1,N
000055              YTEMP(J)=Y1(J)+DELT*EK3(J)
000061           70 CONTINUE
000064              T=T+DELT
000065              CALL DERIV(YTEMP,EK4,T,N)
000070              DO 80J=1,N
000075              Y1(J)=Y1(J)+(EK1(J)+2.*(EK2(J)+EK3(J))+EK4(J))*(DELT/6.)
000107           80 CONTINUE
000111              RETURN
000112              END
```

```
                  REAL FUNCTION INT1(EX,X,Y,NX)
          C
          C       INT1 INTERPOLATES IN ONE VARIABLE
          C
000007            REAL X(10),Y(10)
000007            IF(EX.GE.X(1))GO TO 5
000011            JRT=2
000012            GO TO 20
000013          5 DO 10 J=1,NX
000015            IF(EX.LT.X(J))GO TO 15
000020         10 CONTINUE
000022         15 JRT=J
000024         20 INT1=Y(JRT-1)+(EX-X(JRT-1))*(Y(JRT)-Y(JRT-1))/(X(JRT)-X(JRT-1))
000040            RETURN
000041            END
```

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ENGINE DATA

ENGINE INERTIA = 6.250000E-02

ENGINE TQ.	THETA
-1.000000E+01	0.
-1.000000E+01	1.000000E+00
5.000000E+01	2.000000E+00
5.000000E+01	3.000000E+00

CLUTCH DATA

CLUTCH TQ.	TIME
0.	0.
1.000000E+02	1.000000E+00

MOTOR DATA

MOTOR SPEED DROOP = 4.400000E-01 MOTOR INERTIA = 1.060000E-01

GEARBOX DATA

GEAR RATIO	SPIN LOSS COEFFICIENTS		EFFICIENCY
2.450000E+00	0.	0.	9.200000E-01
1.450000E+00	0.	0.	9.200000E-01
1.000000E+00	0.	0.	9.400000E-01

UPSHIFT RPM = 4.000000E+03

AXLE AND TIRE DATA

FIN. DR. RATIO	SPIN LOSS COEFFICIENTS		EFFICIENCY	ROLLING RADIUS	ROLL. RESIST. COEFFICIENTS	
4.100000E+00	0.	0.	9.600000E-01	3.050000E-01	1.000000E-02	0.

VEHICLE MASS = 2.220000E+03 DRIVE LINE INERTIA = 5.600000E+00 (DRAG COEFF.)*AREA = 9.720000E-01

CYCLE GRADIENT = 0. STEADY STATE SPEED = 7.000E+01

TIME	ENGINE RPM	MOTOR RPM	ENGINE TQ.	CLUTCH TQ.	MOTOR TQ.	SPEED	ACCEL.
0.	0.	3.6193E+03	-1.0000E+01	0.	2.4177E+01	7.0000E+01	-3.4311E-16
2.00E-02	0.	3.6192E+03	-1.0000E+01	2.0000E+00	2.4309E+01	6.9995E+01	-1.4999E-03
4.00E-02	0.	3.6191E+03	-1.0000E+01	4.0000E+00	2.4425E+01	5.9990E+01	-2.9818E-03
6.00E-02	0.	3.6190E+03	-1.0000E+01	6.0000E+00	2.4485E+01	5.9995E+01	-4.4458E-03
8.00E-02	0.	3.6189E+03	-1.0000E+01	8.0000E+00	2.4560E+01	6.9992E+01	-5.8921E-03
1.00E-01	0.	3.6185E+03	-1.0000E+01	1.0000E+01	2.4674E+01	5.9987E+01	-7.3211E-03
1.20E-01	3.0558E+00	3.6183E+03	-1.0000E+01	1.2000E+01	2.4803E+01	6.3981E+01	-8.7328E-03
1.40E-01	1.2223E+01	3.6179E+03	-1.0000E+01	1.4000E+01	2.4956E+01	5.3975E+01	-1.0129E-02
1.60E-01	2.7502E+01	3.6175E+03	-1.0000E+01	1.6000E+01	2.5128E+01	6.9967E+01	-1.1505E-02
1.80E-01	4.8892E+01	3.6171E+03	-1.0000E+01	1.8000E+01	2.5324E+01	5.3958E+01	-1.2867E-02
2.00E-01	7.5394E+01	3.6166E+03	-1.0000E+01	2.0000E+01	2.5541E+01	6.9949E+01	-1.4212E-02
2.20E-01	1.1001E+02	3.6161E+03	-1.0000E+01	2.2000E+01	2.5790E+01	5.9938E+01	-1.5540E-02
2.40E-01	1.4971E+02	3.6155E+03	-1.0000E+01	2.4000E+01	2.6041E+01	6.9927E+01	-1.6853E-02
2.60E-01	1.9557E+02	3.6148E+03	-1.0000E+01	2.6000E+01	2.6322E+01	6.3315E+01	-1.8150E-02
2.80E-01	2.4757E+02	3.6141E+03	-1.0000E+01	2.8000E+01	2.6624E+01	6.3301E+01	-1.9431E-02
3.00E-01	3.3354E+02	3.6134E+03	-1.0000E+01	3.0000E+01	2.5946E+01	6.3937E+01	-2.0637E-02
3.20E-01	3.6975E+02	3.6126E+03	-1.0000E+01	3.2000E+01	2.7289E+01	6.3872E+01	-2.1946E-02
3.40E-01	4.4007E+02	3.6118E+03	-1.0000E+01	3.4000E+01	2.7651E+01	5.9856E+01	-2.3197E-02
3.60E-01	5.1543E+02	3.6109E+03	-1.0000E+01	3.6000E+01	2.3033E+01	6.9839E+01	-2.4404E-02
3.80E-01	5.9593E+02	1.6100E+03	-1.0000E+01	3.8000E+01	2.3435E+01	5.9822E+01	-2.5610E-02
4.00E-01	6.3534E+02	3.6091E+03	-1.2969E+00	4.0000E+01	2.3356E+01	6.9803E+01	-2.6801E-02
4.20E-01	8.4056E+02	3.6081E+03	1.4174E+01	4.2000E+01	2.9298E+01	5.9784E+01	-2.7078E-02

4.40E-01	1.0425E+03	3.5970E+03	3.7900E+01	4.4000E+01	2.9755E+01	6.9764E+01	-2.9141E-02
4.60E-01	1.3131E+03	3.6059E+03	5.0000E+01	4.6000E+01	3.0232E+01	6.9747E+01	-3.0290E-02
4.80E-01	1.6095E+03	3.6048E+03	5.0000E+01	4.8000E+01	3.0729E+01	6.9721E+01	-3.1425E-02
5.00E-01	1.9120E+03	3.5937E+03	5.0000E+01	5.0000E+01	3.1242E+01	6.9698E+01	-3.2546E-02
5.20E-01	2.2207E+03	3.5924E+03	5.0000E+01	5.2000E+01	3.1773E+01	6.9675E+01	-3.3654E-02
5.40E-01	2.5354E+03	3.6012E+03	5.0000E+01	5.4000E+01	3.2323E+01	6.9651E+01	-3.4749E-02
5.60E-01	2.8563E+03	3.5799E+03	5.0000E+01	5.6000E+01	3.2890E+01	6.9626E+01	-3.5930E-02
5.80E-01	3.1832E+03	3.5986E+03	5.0000E+01	5.8000E+01	3.3474E+01	6.9600E+01	-3.6898E-02
6.00E-01	3.5163E+03	3.5972E+03	5.0000E+01	6.0000E+01	3.4075E+01	6.9574E+01	-3.7954E-02

C1.3 CRASH SIMULATION PROGRAM (CRASH)

1. Program Description

CRASH is a program which simulates the impact response of a general non-linear spring/mass system. The masses are constrained to translation along one axis; i.e., planar or 3 dimensional translation and notations are not simulated. The springs which interconnect the masses can be nonlinear and have different characteristics in unloading than they do in loading; i.e., they can dissipate energy in heat as well as storing it. The equation of motion of the masses are solved using a Runge-Kutta integration routine. By appropriately modelling a vehicle (or vehicles) as such a spring/mass system, the vehicle response in a barrier or vehicle-to-vehicle impact can be simulated.

A 3.2 Equations

Equation of Motion for i^{th} Mass

$$M_i \frac{d^2 x_i}{dt^2} = \sum_{j \neq i} F_{ij} - \sum_{i \neq j} F_{ji} \quad ; \quad \begin{matrix} i=1,\cdots n, \\ j=0,\cdots n \end{matrix}$$

where n is the number of masses in the system and F_{ij} is the force generated by a spring coupling mass i to mass j. The sign convention on the F_{ij} is such that $F_{ij} > 0$ if it is in a direction to accelerate mass i and decelerate mass j. See Figure A 3-1 for an example of the nomenclature and sign conventions.

Generation of Spring Forces

$$F_i = \begin{cases} f_{ij}\ (x_j - x_i), \text{ loading with } x_j - x_i \geq x_{sav} \\ \text{MAX}\ \left(0, f\ (x_{sav}) - \frac{dF}{dx}\ (x_{sav} - (x_j - x_i)\right) \quad , \\ \qquad \text{unloading or loading with } x_j - x_i < x_{sav} \end{cases}$$

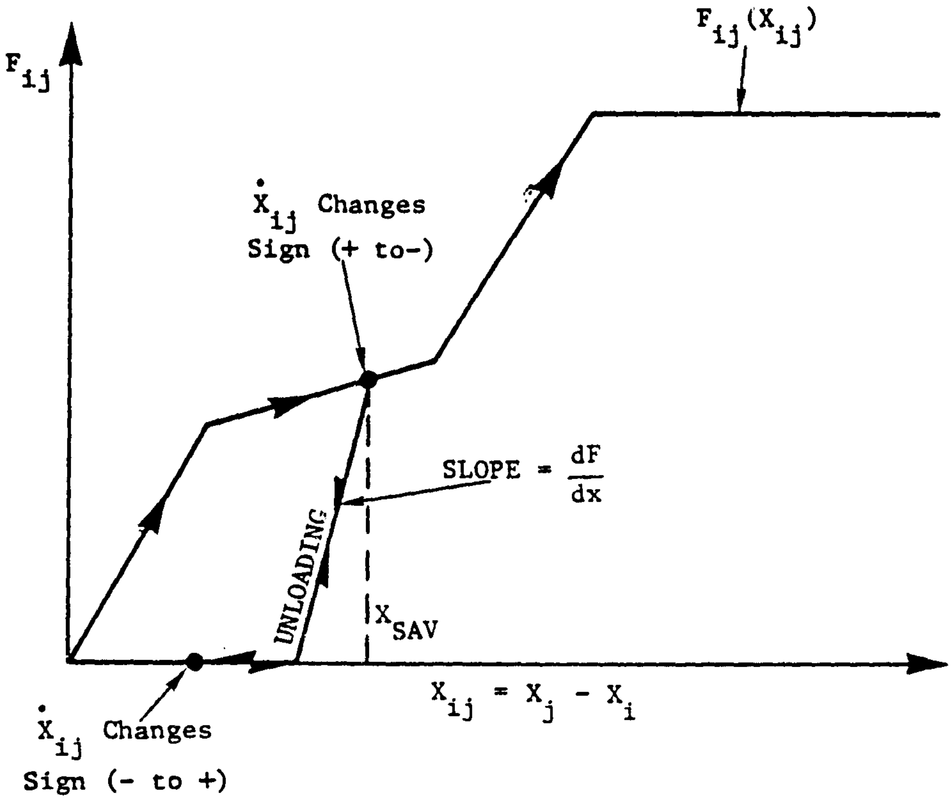


Figure A3-1 Generation of Generalized Non-Linear Spring Forces where x_{sav} is the last value of $x_j - x_i$ at which unloading started (i.e., $\dot{x}_j - \dot{x}_i$ changed sign from positive to negative) and $\frac{dF}{dx}$ is the unloading slope. See Figure A for an illustration of how F_{ij} is generated. Note that, if there is a spring element between M_i and M_j such that the force can go negative for negative values of deflection, it is necessary to represent it as two springs. For example, the coupling between M_1 and M_2 in Figure A would be represented by two functions f_{12} and f_{21}.

PARAMETERS		UNITS	DESCRIPTION
EQUATION	PROGRAM		
	NCASE		NUMBER OF CASES
	NMASS		NUMBER OF MASSES
	NCOUP		NUMBER OF COUPLINGS
	DAF		DYNAMIC AMPLICATION FACTOR
m	EMASS(10)	KG	MASS OF ELEMENTS
	NCOUPTB(50,3)		COLUMNS 1 AND 2 CONTAIN MASS NUMBERS OF COUPLED MASSES, THIRD COLUMN CONTAINS NUMBER OF VALUES IN F AND X ARRAYS FOR SPECIFIED COUPLING
x_i	X(50,10)	m	DEFLECTION VALUES FOR EACH COUPLING
F_{ij}	F(50,10)	N/m	FORCE VALUES FOR FORCE DEFLECTION CHARACTERISTICS FOR EACH COUPLING
dF/dx	SLOPE(50)		SLOPE OF LINE ALONG WHICH UN-LOADING OCCURS FOR EACH COUPLING
	TF	SEC	FINAL TIME
	DELT	SEC	TIME INCREMENT
	NPRNT		FREQUENCY OF OUTPUT PRINTING (IN RELATION TO TIME STEP)
	VØ	m/sec	INITIAL VELOCITY

VARIABLES EQUATION	VARIABLES PROGRAM	UNITS	DESCRIPTION
	DDELX	m/sec	INSTATANEOUS VALUE OF VELOCITY FOR EACH COUPLI[illegible]
$x_j - x_i$	DELX(50)	m	INSTATANEOUS VALUE OF DEFORMATION FOR EACH COUPLING
	DY(1,3,...19)	m/sec	VELOCITY OF MASS (1,2, ... 10)
	Y1(2,4,...20)	m/sec	
d^2x_i/dt	DY(2,4,...20)	m/sec²	ACCELERATION OF MASS (1,2,...10)
$f(x_{SAV})$	FSAV(50)	n/m	VALUE OF FORCE AT POINT WHERE UNLOADING BEGINS
	FT(50)	n/m	INSTANTANEOUS VALUE OF FORCE EXERTED FOR EACH COUPLING
	IFLAG(50)		FLAGS OCCURRENCE OF UNLOADING FOR EACH COUPLING (UNLOADING = -1, LOADING = 1)
	K1 (20)		STORAGE FOR VARIABLES OF INTEGRATI[illegible]
	NMASST		2* NUMBER OF MASSES
	NTIMES		NUMBER OF TIME STEPS
x_{SAV}	XSAV(50)	m	VALUE OF DEFORMATION AT WHICH UNLOADING BEGINS
	Y1(1,3,...19)	m	DISPLACEMENT OF MASS (1,2, ... 10)

GENERAL RESEARCH CORPORATION

FORTRAN CODING FORM

PROGRAM CRASH

ROUTINE Input FORMAT

NAME

DATE

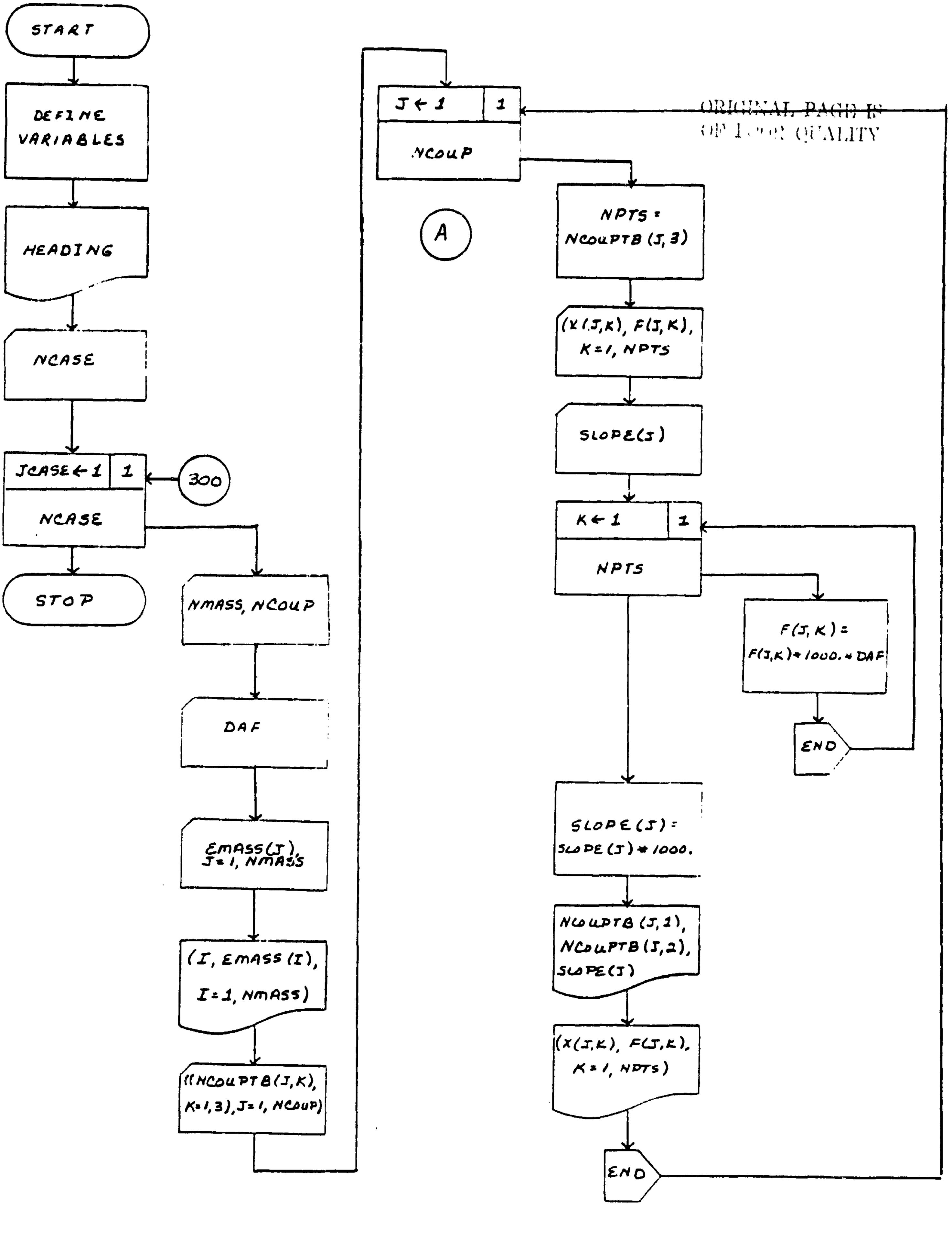
PAGE OF

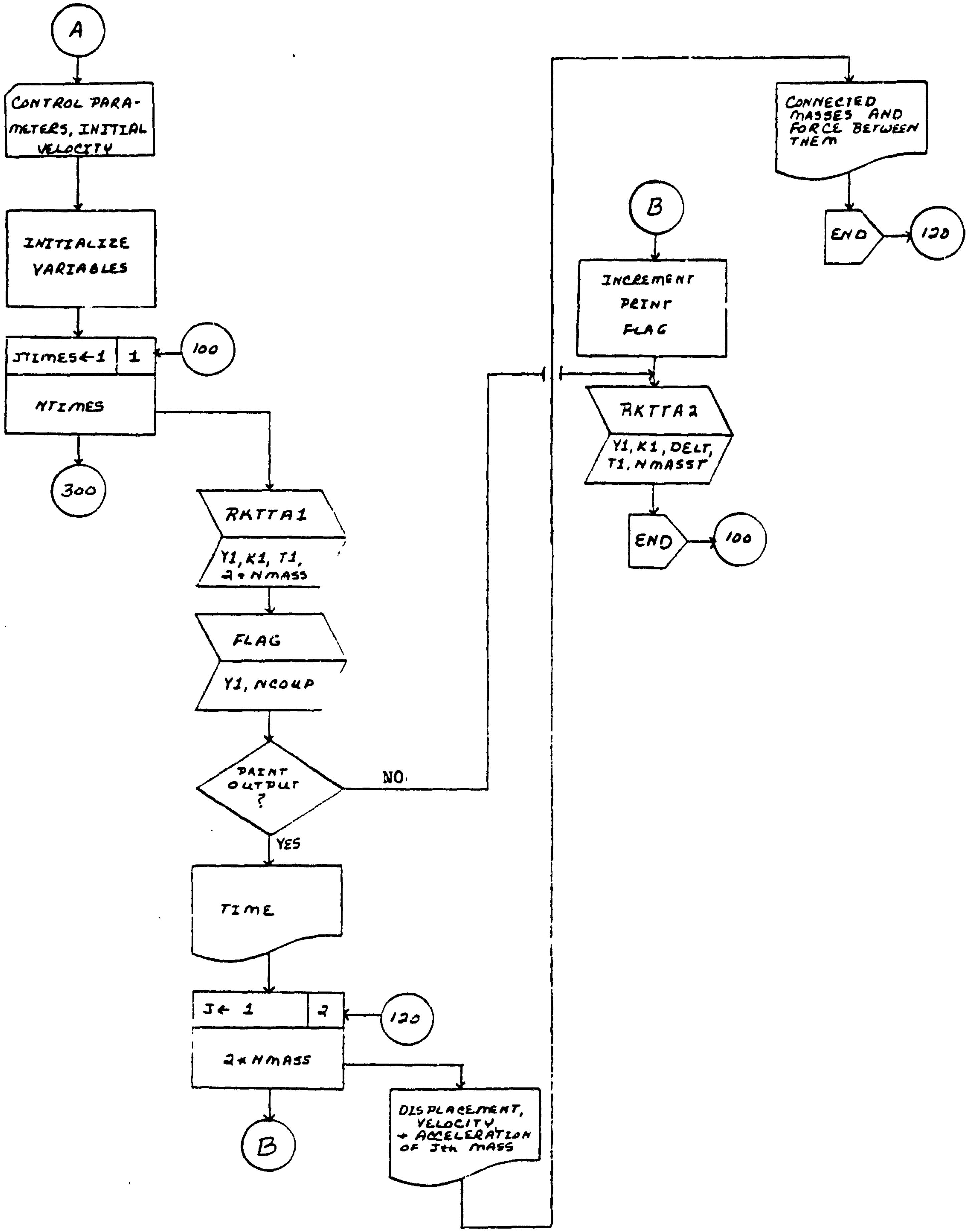
FORTRAN STATEMENT — 0 ZERO, Ø ALPHA O; 1 = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z

```
     NMASS     NCOUP
        DAF
 EMASS(1)      . . .     EMASS(NMASS)
NCOUPTB(1,1)   . . .     NCOUPTB(3,NCOUP)
       X(1,1)      F(1,1)     . . .     X(NCOUP,NCOUPTB(NCOUP,3))  F(NCOUP,NCOUPTB(NCOUP,3))
 SLOPE(1)      . . .     SLOPE(NCOUP)
         TF        DELT
     NPRNT
         VØ
        NPM        N3PM
 NPMASS(1)     . . .     NPMASS(NPM)
```

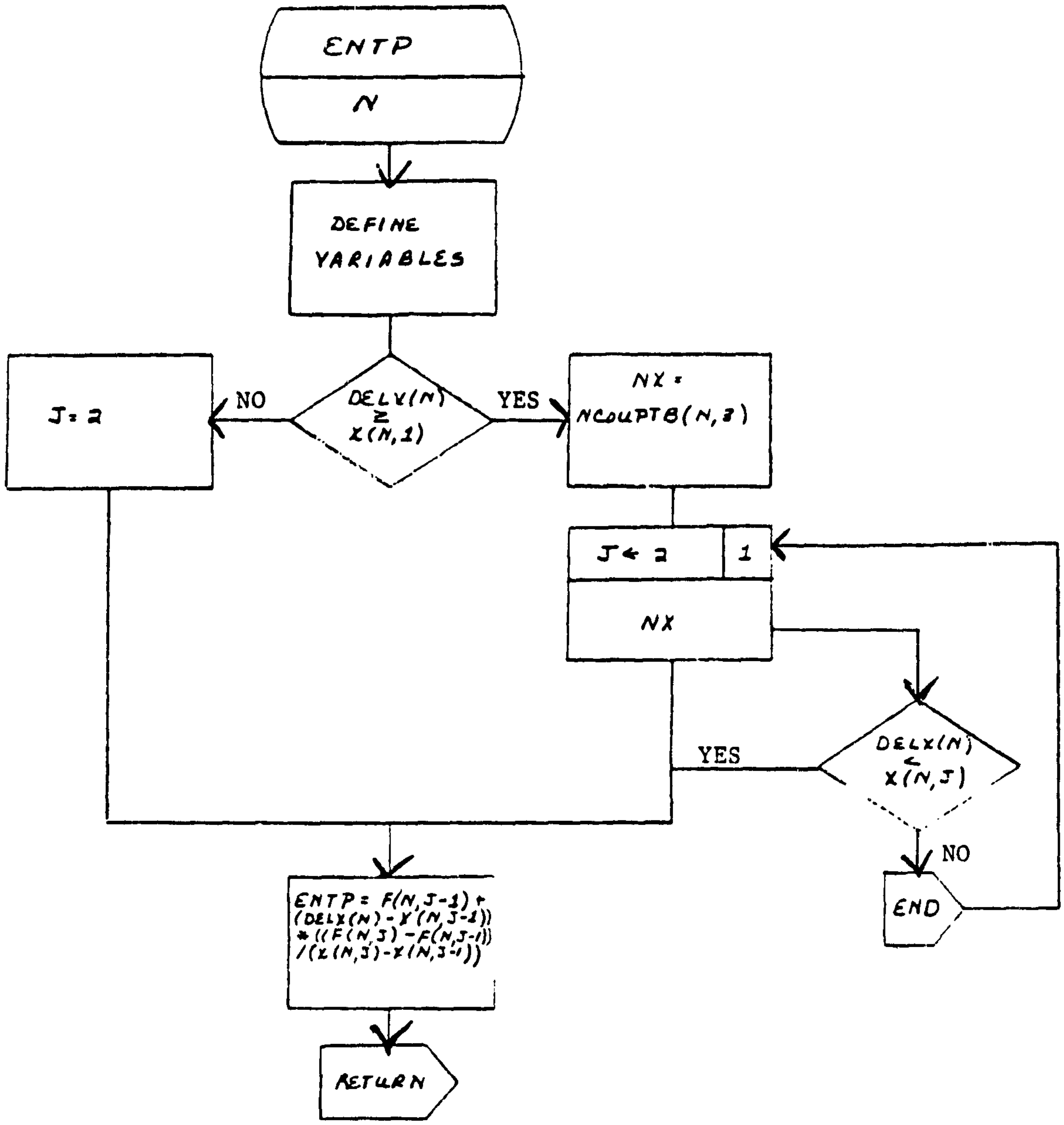

FORM NO. SPC 159 REV. 1

CRASH

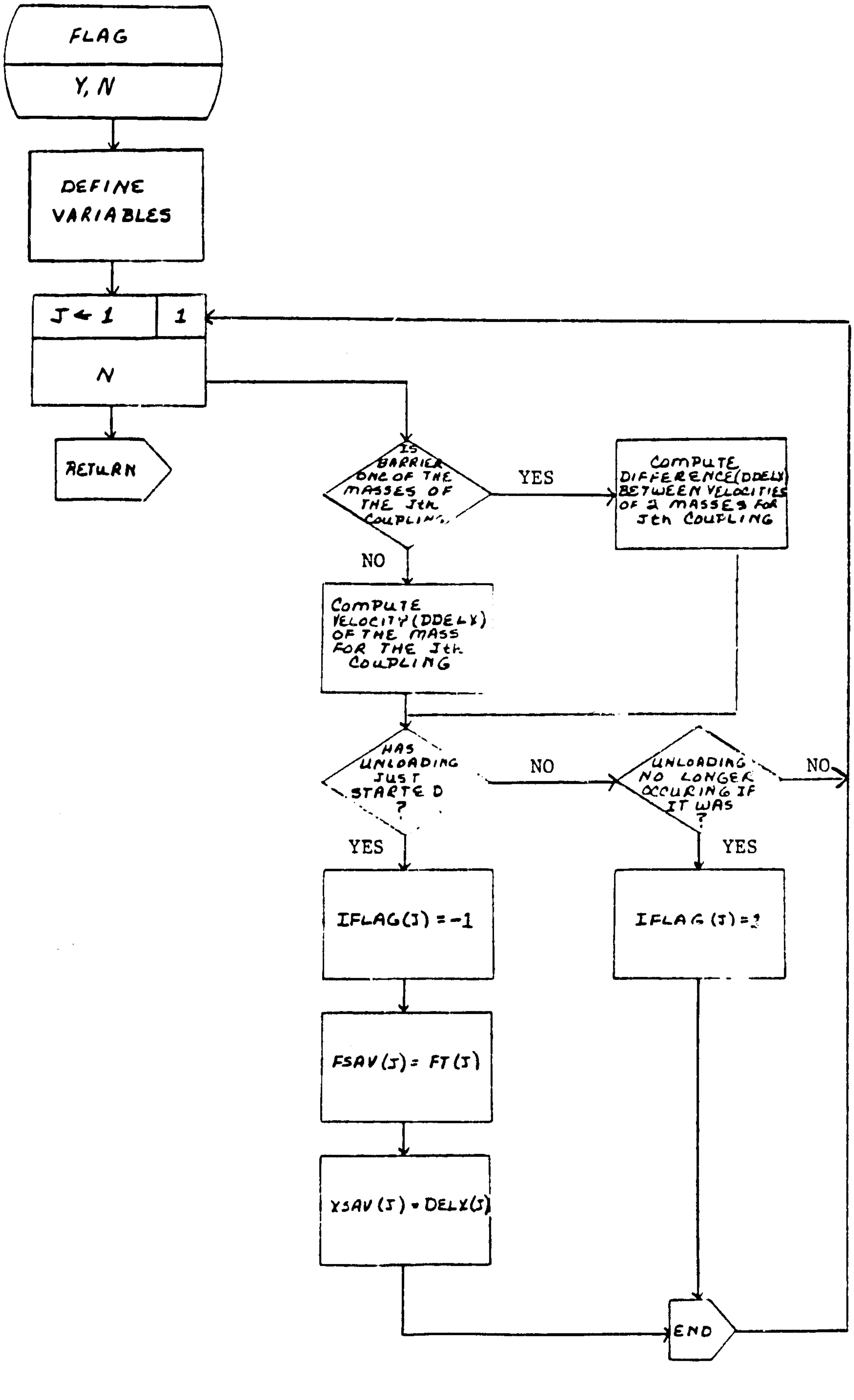

START
DEFINE VARIABLES
HEADING
NCASE
JCASE ← 1
1
NCASE
300
STOP
NMASS, NCOUP
DAF
EMASS(J), J=1, NMASS
(I, EMASS (I), I=1, NMASS)
((NCOUPTB(J,K), K=1,3), J=1, NCOUP)
J ← 1
1
NCOUP
A
NPTS = NCOUPTB (J, 3)
(X(J,K), F(J,K), K=1, NPTS
SLOPE(J)
K ← 1
1
NPTS
F(J,K) = F(J,K) * 1000. * DAF
END
SLOPE(J) = SLOPE(J) * 1000.
NCOUPTB (J,1), NCOUPTB (J,2), SLOPE(J)
(X(J,K), F(J,K), K=1, NPTS)
END


A
CONTROL PARAMETERS, INITIAL VELOCITY
INITIALIZE VARIABLES
JTIMES←1
1
100
NTIMES
300
RKTTA1
Y1, K1, T1, 2*NMASS
FLAG
Y1, NCOUP
PRINT OUTPUT ?
NO
YES
TIME
J← 1
2
120
2*NMASS
B
DISPLACEMENT, VELOCITY + ACCELERATION OF Jth MASS
CONNECTED MASSES AND FORCE BETWEEN THEM
END
120
B
INCREMENT PRINT FLAG
RKTTA2
Y1, K1, DELT, T1, NMASST
END
100

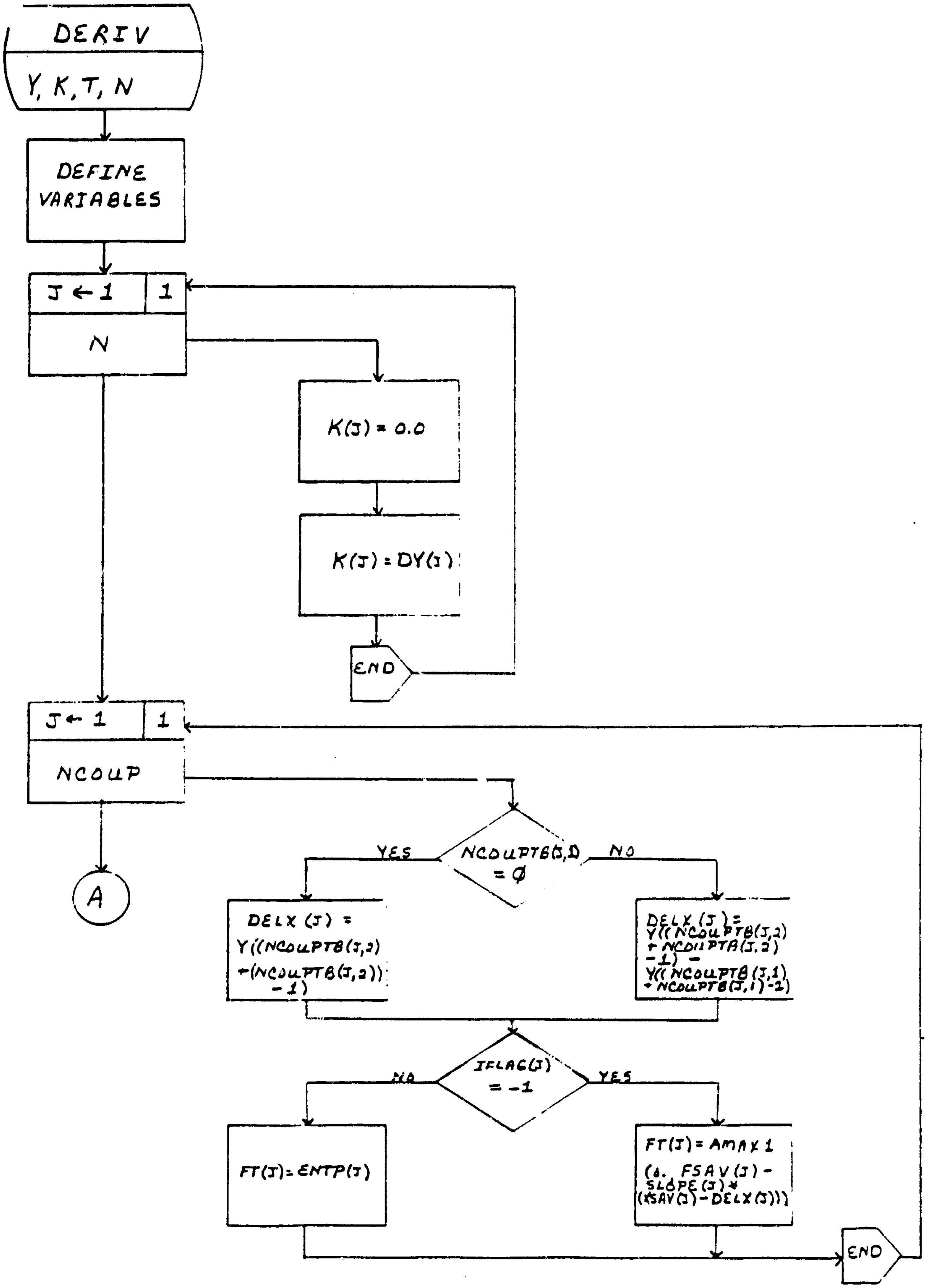
REAL FUNCTION ENTP



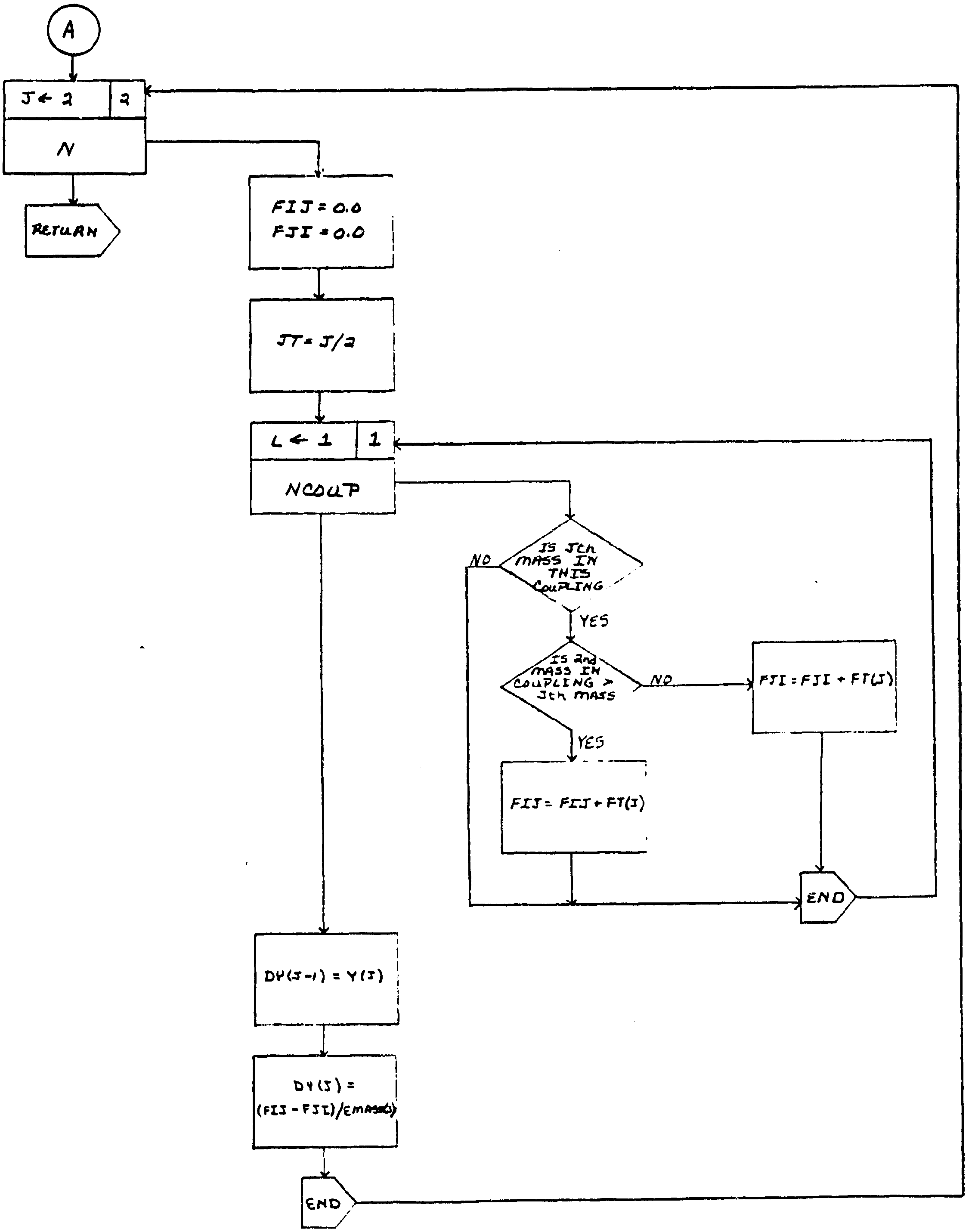
SUBROUTINE FLAG



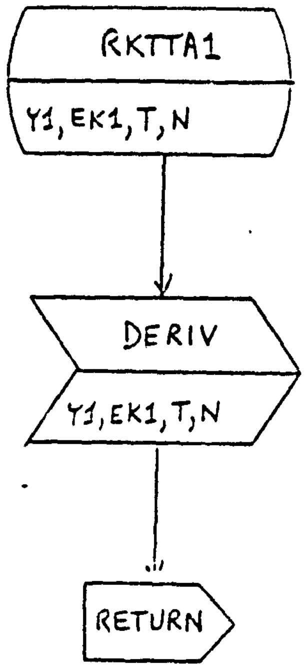
SUBROUTINE DERIV

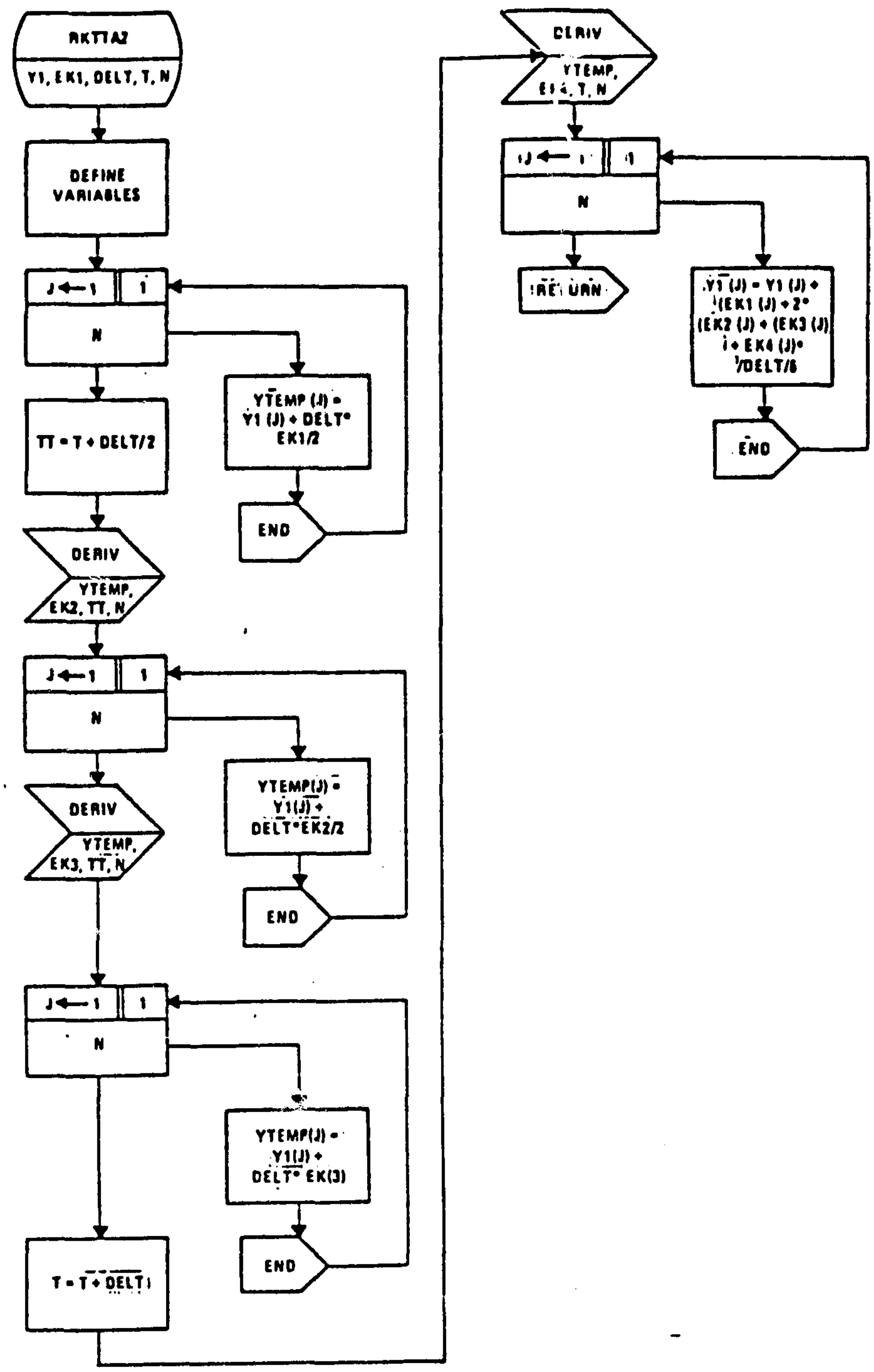


DERIV (cont'd)



A
J ← 2
2
N
RETURN
FIJ = 0.0
FJI = 0.0
JT = J/2
L ← 1
1
NCOUP
IS Jth MASS IN THIS COUPLING
NO
YES
IS 2nd MASS IN COUPLING > Jth MASS
NO
FJI = FJI + FT(J)
YES
FIJ = FIJ + FT(J)
END
DY(J-1) = Y(J)
DY(J) = (FIJ - FJI)/EMASS(J)
END


RKTTA1
Y1, EK1, T, N
DERIV
Y1, EK1, T, N
RETURN


RKTTA2
Y1, EK1, DELT, T, N
DEFINE VARIABLES
J ← 1
1
N
YTEMP (J) = Y1 (J) + DELT* EK1/2
END
TT = T + DELT/2
DERIV
YTEMP, EK2, TT, N
J ← 1
1
N
YTEMP(J) = Y1(J) + DELT*EK2/2
END
DERIV
YTEMP, EK3, TT, N
J ← 1
1
N
YTEMP(J) = Y1(J) + DELT* EK(3)
END
T = T + DELT
DERIV
YTEMP, EK4, T, N
J ← 1
1
N
RETURN
Y1 (J) = Y1 (J) + (EK1 (J) + 2* (EK2 (J) + EK3 (J)) + EK4 (J))* DELT/6
END

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

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```
                       PROGRAM CRASH
                 C
                 C     CRASH SIMULATES THE BEHAVIOR OF UP TO 10 CONNECTED MASSES IN AN
                 C     IMPACT SITUATION, CALCULATING THE DISPLACEMENT, VELOCITY, AND
                 C     ACCELERATION OF EACH MASS AND THE FORCE EXERTED ON THE COUPLED
                 C     MASSES.
                 C
                 C     DEFINE VARIABLES
                 C
000003                 COMMON EMASS(10),F(50,10),X(50,10),FT(50),XSAV(50),FSAV(50),
                      1SLOPE(50),NCOUPTB(50,3),IFLAG(50),DELX(50),DY(20),NMASST,NCOUP
000003                 REAL Y1(20),K1(20)
000003                 REAL TPL(203),XPL(10,200),XPL1(203),DXPL(203),DDXPL(203)
000003                 DIMENSION NPMASS(10),NSYMB(10)
000003                 DATA NSYMB/1,2,6,7,10,12,14,11,4,26/
                 C
                 C     PRINT HEADINGS
                 C
000003                 PRINT 500
000007                 READ 400,NCASE,NPLOT
000017                 IF(NPLOT.EQ.1)CALL PLOTS
                 C
                 C     CASE LOOP
                 C
000022                 DO 300 JCASE=1,NCASE
000024                 READ 400, NMASS, NCOUP
000033                 READ 420,DAF
000041                 READ 420,(EMASS(J), J=1,NMASS)
000054                 PRINT 502
000060                 PRINT 503, (I, EMASS(I), I=1,NMASS)
000074                 PRINT 505
000100                 READ 400, ((NCOUPTB(J,K), K=1,3), J=1,NCOUP)
000120                 DO 10 J=1,NCOUP
000122                     NPTS=NCOUPTB(J,3)
000124                     READ 420, (X(J,K), F(J,K), K=1,NPTS)
000145                     READ 420, SLOPE(J)
000153                 DO 15 K=1,NPTS
000155                 F(J,K)=F(J,K)*1000.*DAF
000162             15  CONTINUE
000164                 SLOPE(J)=SLOPE(J)*1000
000167                     PRINT 506, NCOUPTB(J,1),NCOUPTB(J,2),SLOPE(J)
000201             10      PRINT 507, (X(J,K), F(J,K), K=1,NPTS)
000225                 READ 420, TF, DELT
000234                 READ 400, NPRNT
000242                 READ 420, V0
000250                 READ 400, NPM, N3PM
000263                 READ 400, (NPMASS(J),J=1,NPM)
000273                 PRINT 508
000277                 PRINT 509, DELT,TF,V0,NPRNT
000313                 PRINT 510
000317                 PRINT 515
                 C
                 C     INITTALIZE VARIABLES
                 C
000323                 T1=0.0
```

```
000324              NMASST=NMASS*2
000326              NTIMES=(TF/DELT+0.5)+1
000333              JPL=0
000334              JPRNT=0
000335              DO 20 J=1,NMASST
000336                  Y1(J)=0.0
000337        20        DY(J)=0.0
000342              DO 25 J=2,NMASST,2
000344                  Y1(J)=V0
000346        25    CONTINUE
000350              DO 30 J=1,NCOUP
000351                  IFLAG(J)=1
000353                  DELX(J)=0.0
000354                  FT(J)=0.0
000355                  XSAV(J)=0.0
000356        30        FSAV(J)=0.0
              C
              C     LOOP TO INTEGRATE EQUATIONS, STORE PLOT RECORDS AND [illegible] SELEC
              C     RECORDS
              C
000361              JPRNT=1
000362              DO 100 JTIMES=1,NTIMES
000363                  CALL RKTTA1 (Y1,K1,T1,NMASST)
000366                  CALL FLAG(Y1,NCOUP)
000370              IF(NPLOT.EQ.0)GO TO 106
000371                  JPL=JPL+1
000373                  TPL(JPL)=T1
000375                  DO 105 K=1,NPM
000376                      XPL(K,JPL)=Y1((NPMASS(K)+NPMASS(K))-1)
000404       105        CONTINUE
000406                  DXPL(JPL)=Y1(N3PM+N3PM)
000411                  DDXPL(JPL)=DY(N3PM+N3PM)
              C
              C             PRINT ROUTINE
              C
000414       106        IF(JPRNT.NE.JTIMES)GO TO 110
000416                  PRINT 520, T1
000424                  L=1
000425                  DO 120 J=1,NMASST,2
000427                      PRINT 525, Y1(J),Y1(J+1),DY(J+1)
000440                      PRINT 540, NCOUPTB(L,1),NCOUPTB(L,2),FT(L)
000452                      PRINT 550
000456       120            L=L+1
000462                  IF(L.GT.NCOUP)GO TO 140
000465                  DO 130 K=L,NCOUP
000466                      PRINT 540, NCOUPTB(K,1),NCOUPTB(K,2),FT(K)
000477                      PRINT 550
000503       130        CONTINUE
000505       140        JPRNT=JPRNT+NPRNT
000510       110        CALL RKTTA2(Y1,K1,DELT,T1,NMASST)
000514       100    CONTINUE
000517              IF(NPLOT.EQ.0)GO TO 300
              C
              C     PLOT
              C
```

```
000520          CALL SCALE(TPL,10.0,JPL,1)
000523          CALL SCALE(DXPL,10.0,JPL,1)
000526          CALL SCALE(DDXPL,10.0,JPL,1)
000531          CALL AXIS(0.0,0.0,4HTIME,-4,10.0,0.0,TPL(JPL+1),TPL(JPL+2),0)
000545          CALL AXIS(0.0,0.0,23HVELOCITY OF MASS       ,23,10.0,90.0,
               1DXPL(JPL+1),DXPL(JPL+2),0)
000561          CALL AXIS(-0.5,0.0,27HACCELERATION OF MASS       ,27,10.0,90.0,
               1DDXPL(JPL+1),DDXPL(JPL+2),0)
000575          CALL NUMBER(-.28,5.2,0.15,N3PM,90.0,2HI2)
000601          CALL NUMBER(-.78,5.5,0.15,N3PM,90.0,2HI2)
000605          CALL LINE(TPL,DXPL,JPL,1,5,0)
000611          CALL LINE(TPL,DDXPL,JPL,1,5,5)
000615          XAXIS=-0.5
000617          DO 200 JPM=1,NPM
000620          DO 210 LPL=1,JPL
000621          XPL1(LPL)=XPL(JPM,LPL)
000625      210 CONTINUE
000627          XAXIS=XAXIS-0.5
000631      200 CALL PLOT1(TPL,JPL,XPL1,NPMASS(JPM),NSYMB(JPM),XAXIS)
000643          CALL PLOT(15.0,0.0,-3)
000645      300 CONTINUE
000650          STOP
000652      410 FORMAT(10F10.0)
000652      400 FORMAT(8I10)
000652      420 FORMAT(08F10.4)
000652      500 FORMAT(1H1,58X,*CRASH SIMULATION*)
 00652      502 FORMAT(1H-,10X,*MASS*,10X,*WEIGHT*)
000652      509 FORMAT(1H ,12X,F10.4,7X,F10.2,8X,F10.2,14X,I2)
000652      503 FORMAT(1H ,11X,I2,9X,F10.4)
000652      505 FORMAT(1H-,10X,*COUPLING*,5X,*UNLOADING SLOPE*,5X,*DEFLECTION
               1FORCE*)
000652      506 FORMAT(1H ,10X,I2,3X,I2,6X,F14.2)
000652      507 FORMAT(1H ,38X,F10.3,3X,F10.2)
000652      508 FORMAT(1H-,10X,*TIME INCREMENT*,5X,*FINAL TIME*,5X,*INITIAL VEL
               1TY*,5X,*PRINT INTERVAL*)
000652      510 FORMAT(1H-,5X,4HTIME,13X,1HX,16X,2HDX,16X,3HDDX,10X,6HMASS I,5X
               1MASS J,10X,21HFORCE BETWEEN I AND J)
000652      515 FORMAT(1H0)
000652      520 FORMAT(1H+,2X,E8.2)
000652      525 FORMAT(1H+,10X,3(6X,E12.4))
000652      540 FORMAT(1H+,   70X,I2,9X,I2,14X,E16.6)
000652      550 FORMAT(1H )
000652          END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                SUBROUTINE RKTTA1(Y1,EK1,T,N)
          C
          C     RKTTA1 SETS EK1 EQUAL TO INITIAL CONDITIONS FOR USE IN
          C     INTEGRATION ROUTINE
          C
000007          REAL Y1(50),EK1(50)
000007          CALL DERIV(Y1,EK1,T,N)
000010          RETURN
000011          END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                  SUBROUTINE RKTTA2(Y1,EK1,DELT,T,N)
          C
          C       RKTTA2 USES RUNGE-KUTTA TECHNIQUE FOR NUMERICAL INTEGRATION.
          C
000010            REAL Y1(50),Y2(50),YTEMP(50),EK1(50),EK2(50),EK3(50),EK4(50)
000010            DO 50J=1,N
000011            YTEMP(J)=Y1(J)+DELT*EK1(J)/2.
000017         50 CONTINUE
000022            TT=T+DELT/2.
000024            CALL DERIV(YTEMP,EK2,TT,N)
000027            DO 60J=1,N
000034            YTEMP(J)=Y1(J)+DELT*EK2(J)/2.
000041         60 CONTINUE
000045            CALL DERIV(YTEMP,EK3,TT,N)
000050            DO 70J=1,N
000055            YTEMP(J)=Y1(J)+DELT*EK3(J)
000061         70 CONTINUE
000064            T=T+DELT
000065            CALL DERIV(YTEMP,EK4,T,N)
000070            DO 80J=1,N
000075            Y1(J)=Y1(J)+(EK1(J)+2.*(EK2(J)+EK3(J))+EK4(J))*(DELT/6.)
000107         80 CONTINUE
000111            RETURN
000112        650 FORMAT(1H ,8E14.6)
000112            END
```

```
                  SUBROUTINE DERIV(Y,K,T,N)
          C
          C       DERIV COMPUTES FORCE VALUES FOR EACH COUPLING AND ACCELERATION
          C       EACH MASS
          C
000007            COMMON EMASS(10),F(50,10),X(50,10),FT(50),XSAV(50),FSAV(50),
                 1SLOPE(50),NCOUPTB(50,3),IFLAG(50),DELX(50),DY(20),NMASST,NCOUP
000007            REAL Y(20), K(20)
000007            DO 5 I=1,N
000010               K(I)=0.0
000012          5 CONTINUE
000013            DO 7 I=1,N
000015              K(I)=DY(I)
000017          7 CONTINUE
000021            DO 10 J=1,NCOUP
000022               IF(NCOUPTB(J,1).EQ.0)GO TO 15
000024               DELX(J)=Y((NCOUPTB(J,2)+NCOUPTB(J,2))-1)-Y((NCOUPTB(J,1)+NC
               1   TB(J,1))-1)
000034               GO TO 20
000035        15     DELX(J)=Y((NCOUPTB(J,2)+NCOUPTB(J,2))-1)
000043        20     IF(IFLAG(J).EQ.-1)GO TO 25
000046               FT(J)=ENTP(J)
000051               GO TO 10
000054        25     FT(J)=AMAX1(0.,FSAV(J)-SLOPE(J)*(XSAV(J)-DELX(J)))
000066        10 CONTINUE
000071            DO 30 J=2,N,2
 00072               FIJ=0.0
000073               FJI=0.0
000074               JT=J/2
000075               DO 40 L=1,NCOUP
000077                  IF(NCOUPTB(L,1).NE.JT.AND.NCOUPTB(L,2).NE.JT)GO TO 40
000106                  IF(NCOUPTB(L,2).GT.JT)GO TO 50
000112                  FJI=FJI+FT(L)
000114                  GO TO 40
000114        50        FIJ=FIJ+FT(L)
000117        40     CONTINUE
000122               DY(J-1)=Y(J)
000125               DY(J)=(FIJ-FJI)/EMASS(JT)
000131        30 CONTINUE
000133       525 FORMAT(1H ,10X,4(6X,E12.4))
000133            RETURN
000133            END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                      SUBROUTINE FLAG(Y,N)
                C
                C     FLAG CHECKS EACH COUPLING FOR UNLOADING
                C
000005                REAL Y(20)
000005                COMMON EMASS(10),F(50,10),X(50,10),FT(50),XSAV(50),FSAV(50),
                     1SLOPE(50),NCOUPTB(50,3),IFLAG(50),DELX(50),DY(20),NMASST,NCOUP
000005                DO 10 J=1,N
000006                    IF(NCOUPTB(J,1).EQ.0)GO TO 15
000010                    DDELX=Y(NCOUPTB(J,2)+NCOUPTB(J,2))-Y(NCOUPTB(J,1)+NCCUPTB(J
                     1    ))
000015                    GO TO 18
000016           15       DDELX=Y(NCOUPTB(J,2)+NCOUPTB(J,2))
000022           18       IF(DDELX.GE.0 .OR. IFLAG(J).EQ.-1)GO TO 20
000034                    IFLAG(J)=-1
000035                    FSAV(J)=FT(J)
000040                    XSAV(J)=DELX(J)
000042           20       IF(DELX(J).LE.XSAV(J))GO TO 10
000046                IFLAG(J)=1
000047           10 CONTINUE
000052                RETURN
000052                END
```

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GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                 REAL FUNCTION ENTP(N)
          C
          C      ENTP INTERPOLATES FORCE FOR SPECIFIED COUPLING
          C
000003           COMMON EMASS(10),F(50,10),X(50,10),FT(50),XSAV(50),FSAV(50),
                1SLOPE(50),NCOUPTB(50,3),IFLAG(50),DELX(50),DY(20),NMASST,NCOUP
000003           IF(DELX(N).GE.X(N,1))GO TO 10
000006           J=2
000007           GO TO 30
000010        10 NX=NCOUPTB(N,3)
000012           DO 20 J=2,NX
000014              IF(DELX(N).LT.X(N,J))GO TO 30
000021        20 CONTINUE
000024        30 ENTP=F(N,J-1)+(DELX(N)-X(N,J-1))*((F(N,J)-F(N,J-1))/(X(N,J)-
                1X(N,J-1)))
000043           RETURN
000044           END
```

CRASH SIMULATION

MASS	WEIGHT
1	173.4000
2	393.8030
3	513.0016
4	327.3050
5	273.0055

COUPLING		UNLOADING SLOPE	DEFLECTION	FORCE
0	1	*2500000.00		
			0.000	0.00
			.100	85000.00
			.170	119000.00
			.175	467500.00
			.190	297500.00
			.650	297500.00
			.670	680000.00
0	2	1975000.00		
			0.000	0.00
			.430	0.00
			.560	21250.00
			.500	55000.00
0	3	5200000.00		
			0.000	0.00
			.200	0.00
			.300	17000.00
			.325	127500.00
			.350	25500.00
			.500	25500.00
			.900	152000.00
			1.000	192000.00
1	2	400000.00		
			-.100	0.00
			0.000	0.00
			.050	17000.00
			.200	17000.00
2	3	400000.00		
			-.100	0.00
			0.000	0.00
			.050	17000.00
			.200	17000.00
1	3	24125000.00		
			0.000	0.00
			.016	392500.00
			.020	212500.00
			.250	212500.00
			.256	510000.00
2	4	4000000.00		
			0.000	0.00
			.350	9500.00
			.270	45000.00
3	4	[illegible]		
			[illegible]	[illegible]

		.320	170000.00
		.340	34000.00
		.120	0.00
3 5	1500000.00	.200	0.00
		0.300	0.00
		.350	21250.00
		.150	21250.00
		.200	45100.00

TIME INCREMENT	FINAL TIME	INITIAL VELOCITY	PRINT INTERVAL
.0005	.10	13.42	10

TIME	X	CX	DDX	MASS I	MASS J	FORCE BETWEEN I AND J
0.	0.	1.3417E+01	0.	0	1	0.
	0.	1.3417E+01	0.	0	2	0.
	0.	1.3417E+01	0.	0	3	0.
	0.	1.3417E+01	0.	1	2	0.
	0.	1.3417E+01	0.	2	1	0.
				1	3	0.
				2	3	0.
				2	4	0.
				3	4	0.
				3	5	0.
5.00E-03	6.4991E-02	1.2917E+01	-1.8436E+02	0	1	5.523355E+04
	6.5965E-02	1.3416E+01	-9.4521E-01	0	2	0.
	6.5943E-02	1.3335E+01	-2.7923E+01	0	3	0.
	6.5965E-02	1.3416E+01	-1.6773E+00	1	2	3.345733E+02
	6.5965E-02	1.3417E+01	-4.1304E-02	2	1	0.
				1	3	2.293017E+04
				2	3	0.
				2	4	1.643946E+03
				3	4	2.129544E+02
				3	5	1.098215E+01
1.00E-02	1.2754E-01	1.2418E+01	9.3950E+01	0	1	9.837613E+04
	1.3396E-01	1.3433E+01	-4.7322E+00	0	2	0.
	1.3219E-01	1.3037E+01	-1.2929E+02	0	3	0.
	1.3294E-01	1.3333E+01	-5.0033E+01	1	2	1.864039E+03
	1.3395E-01	1.3415E+01	-1.3551E+00	2	1	0.
				1	3	1.118632E+05
				2	3	0.
				2	4	0.
				3	4	6.399953E+03
				3	5	3.658793E+02
1.50E-02	1.9953E-01	1.1730E+01	-9.3994E+02	0	1	3.025839E+05
	1.9997E-01	1.3371E+01	-9.3134E+00	0	2	0.
	1.9562E-01	1.2310E+01	-1.4553E+02	0	3	0.
	1.9954E-01	1.2755E+01	-1.3541E+02	1	2	3.550399E+03
	2.0009E-01	1.3336E+01	-7.3556E+00	2	1	0.
				1	3	1.451890E+05
				2	3	0.
				2	4	0.
				3	4	2.499293E+04
				3	5	1.907723E+03
2.00E-02	[illegible]	[illegible]	[illegible]	0	1	[illegible]

C1.4 HANDLING PROGRAMS (HYSIM and HYSSG)

1. Program Description

HYSIM and HYSSG are programs designed to provide a coarse indication of how changes in mass distribution, vehicle dimensions, and tire characteristics affect handling properties. HYSIM simulates the transient response of an automobile to a step in steer angle, and HYSSG computes the steady-state gain of yaw rate to steer angle as a function of forward speed. Both programs are based on a mathematical model which represents the automobile as a single mass with 3 degrees of freedom: lateral displacement, yaw and roll.

In HYSIM, the dynamics of tire force buildup are neglected, which means the front and rear tire force equations become algebraic expressions for the tire forces Y_f and Y_r. Thus, if

$$Y = \begin{matrix} \dot{y}_1 \\ \dot{\psi} \\ \dot{\phi} \\ \phi \end{matrix} \quad \text{and} \quad Z = \begin{matrix} Y_f \\ Y_r \end{matrix}$$

the above differential equations can be written in the form

$$A\dot{Y} = BY + CZ$$

$$Z = DY + E$$

or

$$\dot{Y} = A^{-1}((B + CD)\,Y + CE\delta)$$

This is the form in which HYSIM solves the differential equations of motion for the vehicle.

For HYSSG, $\ddot{y}_1$, $\ddot{\psi}$, $\dot{\phi}$, $\dot{Y}_f$, and $\dot{Y}_r$ are all set equal to zero and the steady gain of the vector Y, (and hence of its component $\dot{\psi}$, the yaw rate), to δ, is computed as follows:

$$BY = -CZ = -C\,(DY + ES), \text{ or } \frac{1}{\delta} Y = -\,(B + CD)^{-1}\,CE$$

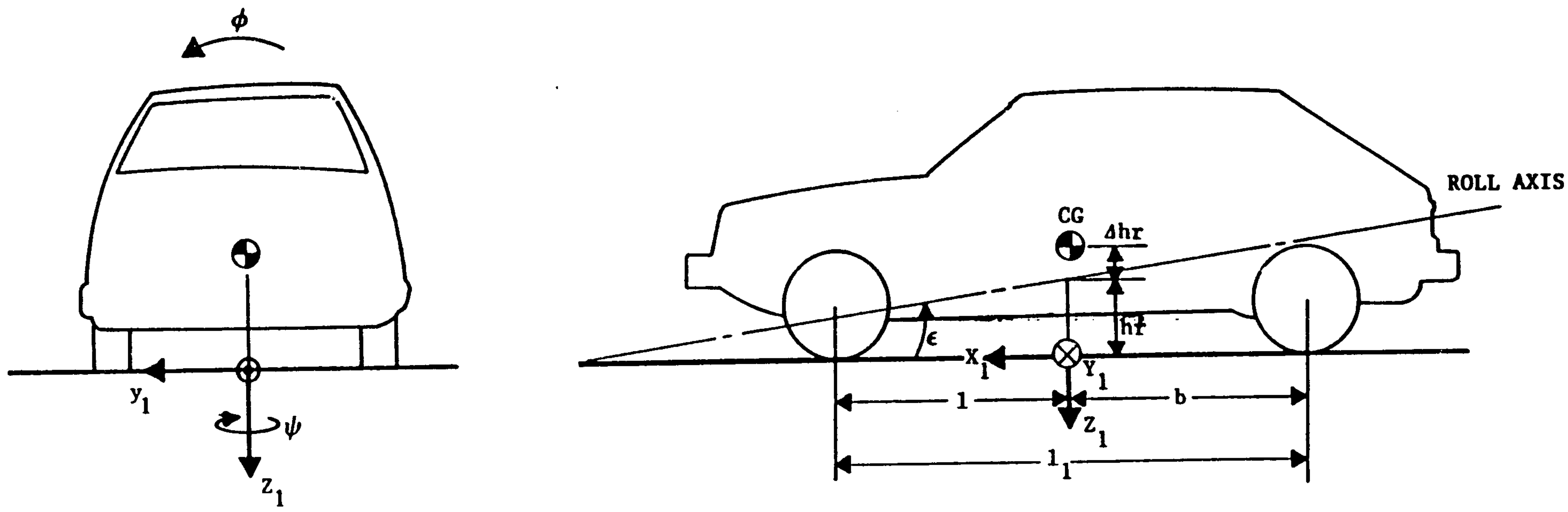

Figure A4-1 Vehicle Geometry and Coordinate Systems

Summary of Equations for Linear, Constant-Speed Model

Lateral:

$$m_r \ddot{y}_1 + m_r \Delta h_r \ddot{\phi} = -\left(m_r + \frac{i_{ry}}{R^2}\right) \dot{x}_1 \dot{\psi} + Y_f + Y_r$$

Yaw:

$$I_{r_z} \ddot{\psi} - C_{r_{xz}} \ddot{\phi} = \frac{i_{ry}}{R^2} \dot{x}_1 \dot{y}_1 + F_A (\Delta h_r + h_r - h_a)\phi + \ell Y_f - b Y_r$$

Roll:

$$m_r \Delta h_r \ddot{y}_1 - C_{r_{xz}} \ddot{\psi} + (I_{r_x} + m_r \Delta h_r^2)\ddot{\phi} =$$

$$-m_r \Delta h_r \dot{x}_1 \dot{\psi} - (C_{\phi f} + C_{\phi r})\dot{\phi} + (m_r g \Delta h_r - K_{\phi f} - K_{\phi r})\phi$$

$$-(h_r - \ell\epsilon) Y_f - (h_r + b\epsilon) Y_r$$

Front Tires

$$\frac{\sigma_f}{\dot{x}_1} \dot{Y}_f = -Y_f - \frac{C_{\alpha f} Z_f}{\dot{x}_1} \dot{y}_1 - \frac{C_{\alpha f} Z_f}{\dot{x}_1} \ell \dot{\psi} + C_{\alpha f} Z_f \delta$$

Rear Tires:

$$\frac{\sigma_f}{\dot{x}_1} \dot{Y}_r = -Y_r - \frac{C_{\alpha r} Z_r}{\dot{x}_1} \dot{y}_1 - \frac{C_{\alpha r} Z_r}{\dot{x}_1} b \dot{\psi}$$

Miscellaneous:

$$F_A = 0.6125\, C_D A \dot{x}_1^2$$

$$Z_f = \theta_f m_r g - \frac{F_A h_A}{} \qquad Z_r = m_r g - Z_f$$

PARAMETERS		UNITS	DESCRIPTION
EQUATION	PROGRAM		
	NCASE	—	NUMBER OF CASES
	NSPD	—	NUMBER OF SPEEDS
	NSTEPS	—	NUMBER OF INTEGRATION STEPS
	NPSTEP	—	PRINT FREQUENCY
	DELT	SEC	TIME INCREMENT
	SPEED(10)	KM	SPEEDS
	TM	SEC	FINAL TIME
	Y(4)	—	LATERAL VELOCITY, YAW RATE, ROLL RATE, ROLL ANGLE
m	EM	KG	MASS OF VEHICLE
I_{rx}	ENRTX	$KG\text{-}m^2$	MOMENTS OF INERTIA WITH RESPECT TO X, Y, AND Z AXES
I_{ry}	ENRTY	$KG\text{-}m^2$	
I_{rz}	ENRTZ	$KG\text{-}m^2$	
C_{rxz}	CXZ	$KG\text{-}m^2$	PRODUCT OF INERTIA WITH RESPECT TO X+Z AXES
l_1	EL1	m	WHEELBASE LENGTH
l	EL	m	LENGTH FRONT AXLE TO CENTER OF GRAVITY
h_r	H	m	ROLL CENTER HEIGHT
Δh_r	CH	m	(CENTER OF GRAVITY - ROLL CENTER) HEIGHT
Θ	THETA	—	FRACTION WT. ON FRONT WHEEL W/STATIC CONDITIONS
ϵ	EPSLN	RAD	INCLINATION OF ROLL AXIS
R	R	m	WHEEL RADIUS
h_a	HA	m	AERO-DYNAMIC CENTER OF EFFORT
$C_D A$	CDA	—	DRAG COEFFICIENT * FRONTAL AREA
δ	DELTA	RAD	STEER ANGLE
$C_{\phi f}$	CPF	N/RAD	ROLL DAMPING - FRONT
$C_{\phi r}$	CPR	N/RAD	ROLL DAMPING - REAR
$K_{\phi f}$	EKPF	N/RAD	ROLL STIFFNESS - FRONT
$K_{\phi r}$	EKPR	N/RAD	ROLL STIFFNESS - REAR
$C_{\alpha f}$	CAF	N/RAD	LATERAL FORCE - FRONT
$C_{\alpha r}$	CAR	N/RAD	LATERAL FORCE - REAR
σ_F	SIGMAF	m	RELAXATION LENGTH - FRONT
σ_r	SIGMAR	m	RELAXATION LENGTH - REAR

VARIABLES: EQUATION	VARIABLES: PROGRAM	UNITS	DESCRIPTION
	ACCLAT	m/sec^2	LATERAL ACCELERATION
	AINV(4,4)	—	INVERSE OF AM
	AM(4,4)	—	COEFFICIENT MATRIX
b	B	m	EL1-EL (see list of input parameters)
	BED(4,4)	—	BM-MATRIX + ED-MATRIX
	BM(4,4)	—	COEFFICIENT MATRIX
	BMT(3,3)	—	MATRICES USED IN MATRIX INVERSION ROUTINE
	BMTT(3,3)	—	(see BMT)
	C(4,4)	—	AINV-MATRIX * BED-MATRIX
$C_{\alpha f} Z_f$	CAFZF	N/RAD	LATERAL FORCE * LATERAL LOAD ON FRONT TIRE
$C_{\alpha f} Z_r$	CARZR	N/RAD	LATERAL FORCE * LATERAL LOAD ON REAR TIRE
	DD(2,4)	—	COEFFICIENT MATRIX
	ED(4,4)	—	EE-MATRIX * DD-MATRIX
	EE(4,2)	—	COEFFICIENT MATRIX
	EF(4)	—	EE-MATRIX * F-MATRIX
$m_r \Delta h_r$	EMCH	—	MASS * (CENTER GRAVITY - ROLL CENTER) HEIGHT
	EMT(3,3)	—	MATRIX USED IN MATRIX INVERSION ROUTINE
	ENRTYR	$KG\text{-}m^2$	ROTATIONAL INERTIA OF WHEELS
	F(2)	—	COEFFICIENT MATRIX
F_A	FA	—	FACOEF * SPEED
$0.612 C_D A$	FACOEF	—	0.612 * DRAG COEFFICIENT * FRONTAL AREA
g	G	N/RAD	[illegible]
	GG(4)	—	AINV-MATRIX * EF-MATRIX
	K1(10)	—	VARIABLES OF INTEGRATION
	SUBA(3,3)	—	MATRICES USED IN MATRIX INVERSION ROUTINE
	SUBANV(3,3)	—	(see SUBA)
	TRAN(3,3)	—	(see SUBA)
	TRI(3,3)	—	(see SUBA)
$\dot{x}_1$	XDOT	m/sec	SPEED FOR SPECIFICIED SPEED [illegible]
	Y1(10)	—	VARIABLES OF INTEGRATION
Z_f	ZF	KG	LATERAL LOAD ON FRONT TIRES
Z_r	ZR	KG	LATERAL LOAD ON REAR TIRES

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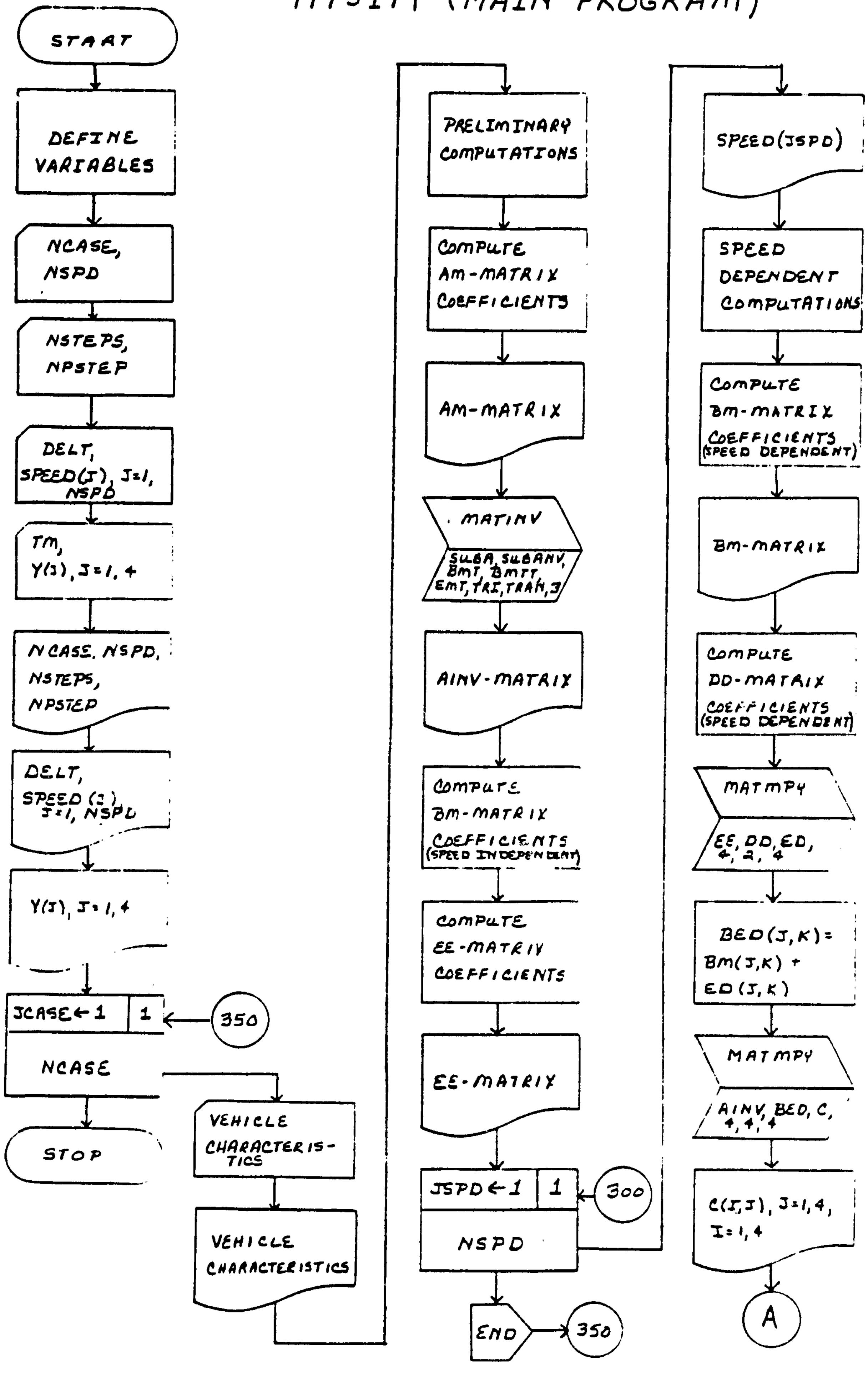
FORTRAN CODING FORM

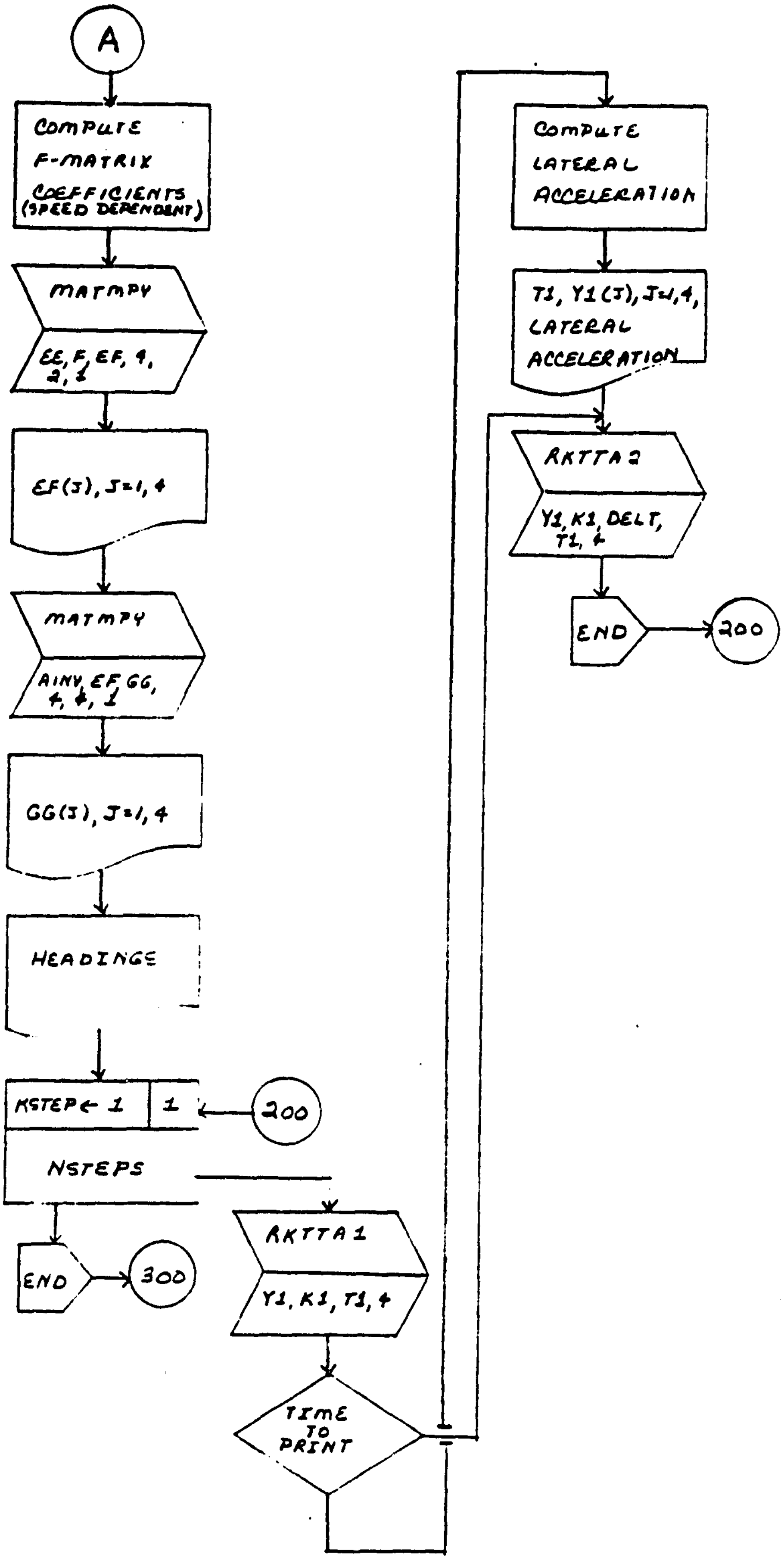
PROGRAM: HYSIM
ROUTINE: Input Format
NAME:
DATE:
PAGE OF

FORTRAN STATEMENT (0 - ZERO, 0 - ALPHA O; 1 = ONE, I = ALPHA I; 2 = TWO, Z = ALPHA Z)

```
     NCASE     NSPD
    NSTEPS    NPSTEP
     DELT
SPEED(1)     . . .      SPEED(NSPD)
        TM     Y(1)     . . .               Y(4)
          MASS PROPERTIES
        EM     ENRTX     ENRTY     ENRTZ     CXZ
          GEOMETRICAL PROPERTIES
       EL1        EL         H        CH     THETA     EPSLN         R
        HA       CDA     DELTA
          TIRE PROPERTIES
       CPF       CPR      EKPF      EKPR       CAF       CAR     SIGMAF
    SIGMAR
```

HYSIM (MAIN PROGRAM)





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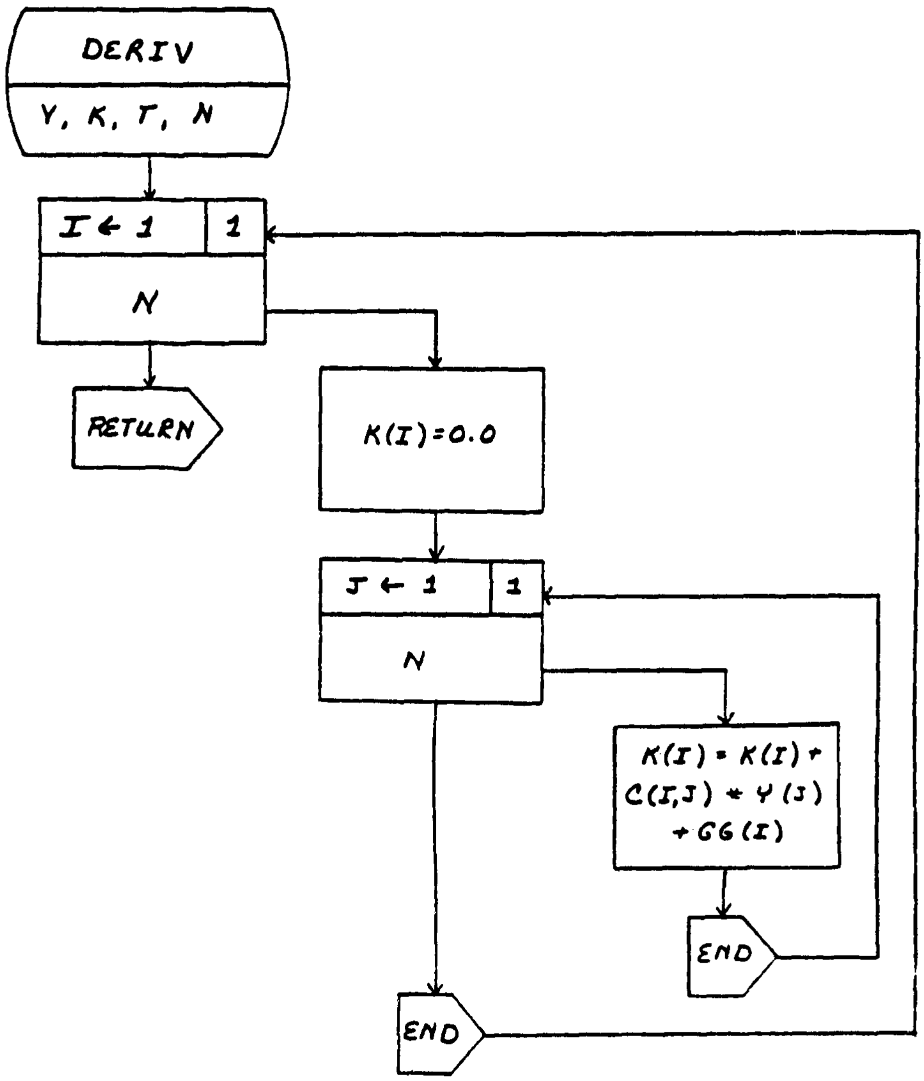
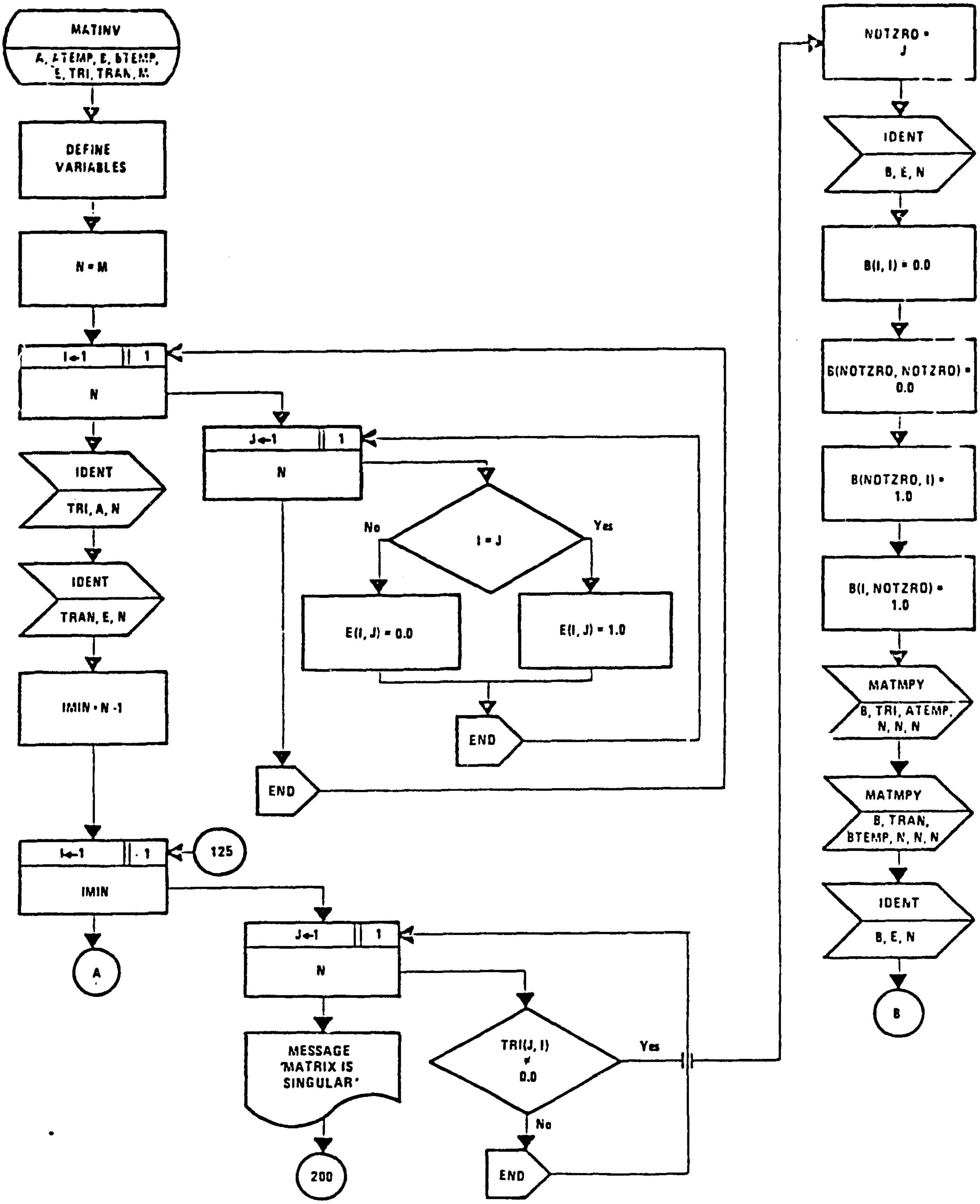
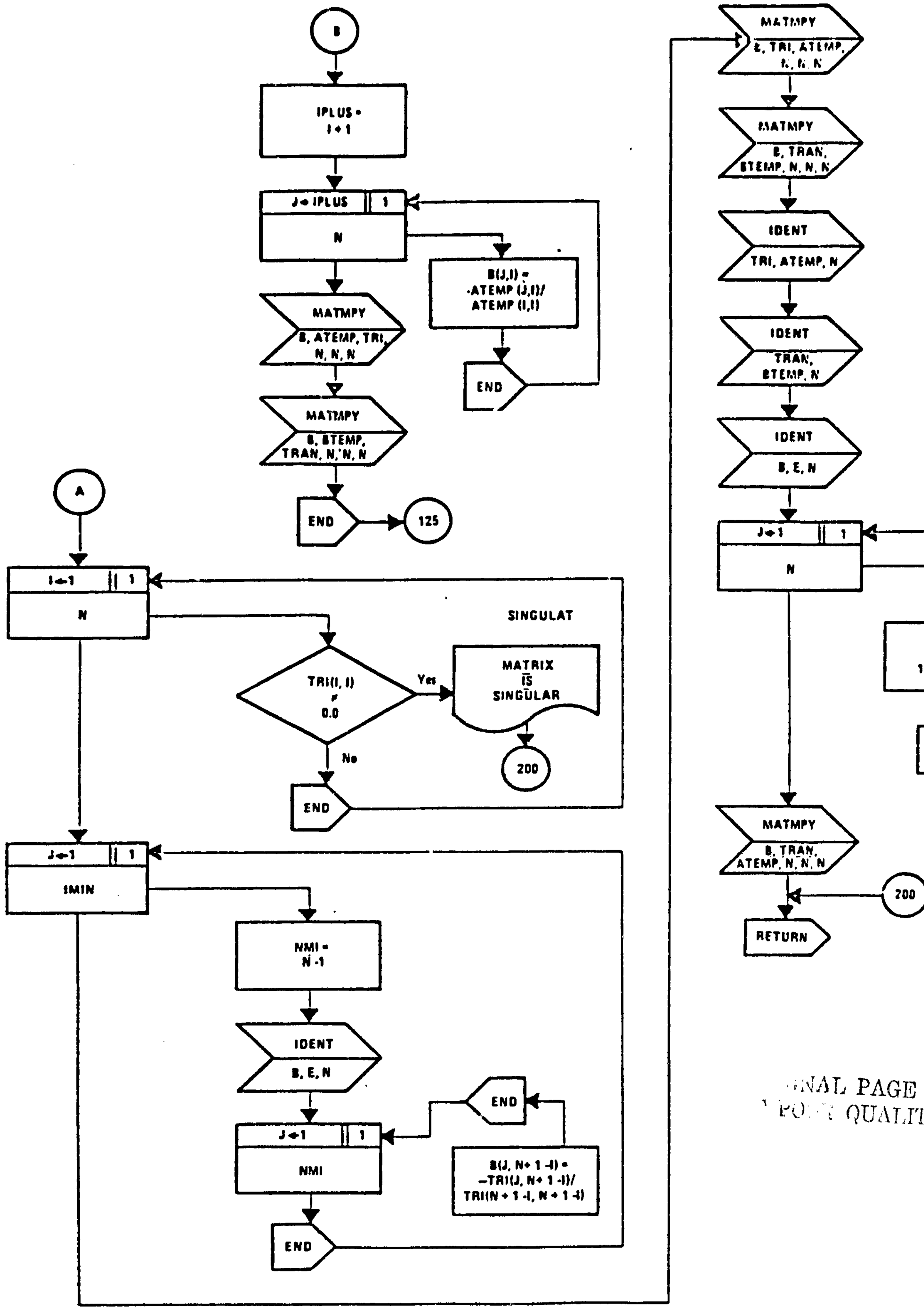
SUBROUTINE DERIV

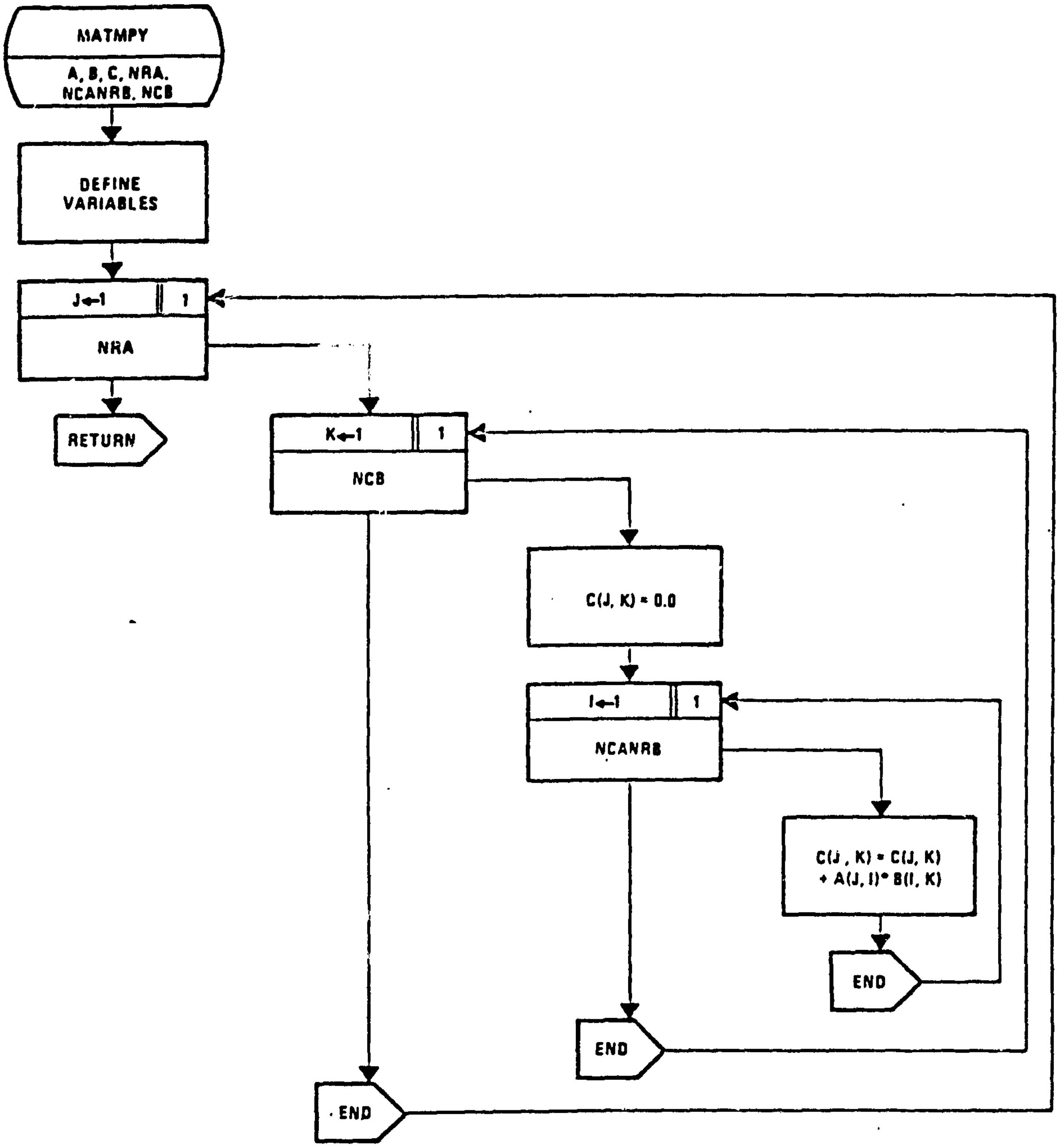


ORIGINAL PAGE IS
OF POOR QUALITY

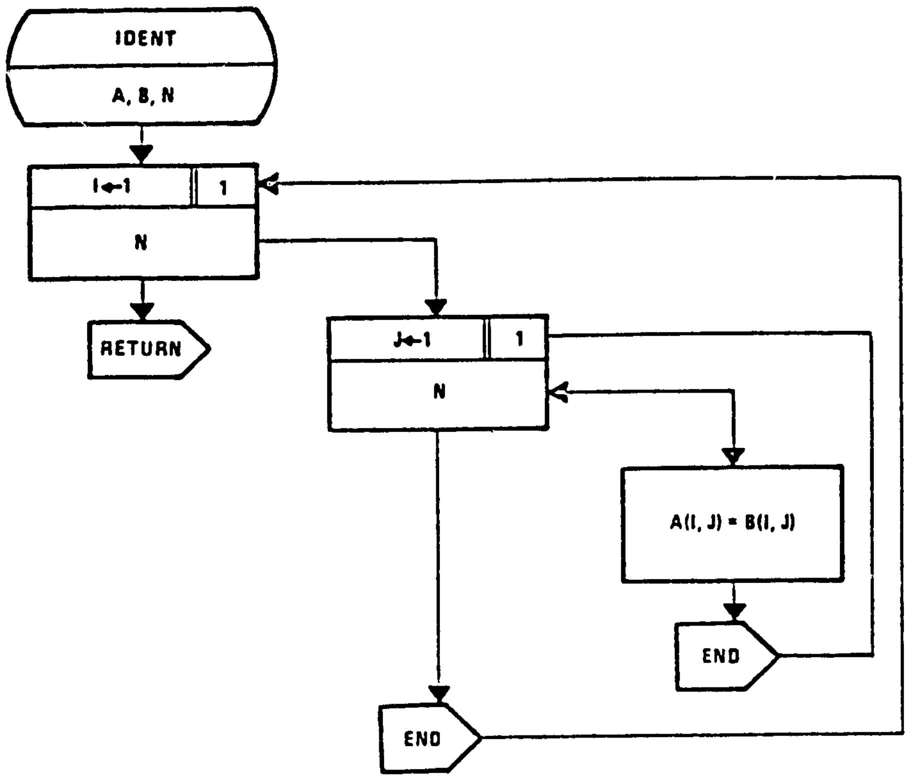

MATINV
A, ATEMP, E, BTEMP, E, TRI, TRAN, M
DEFINE VARIABLES
N = M
I←1 || 1
N
IDENT
TRI, A, N
IDENT
TRAN, E, N
IMIN = N - 1
J←1 || 1
N
No
I = J
Yes
E(I, J) = 0.0
E(I, J) = 1.0
END
END
I←1 || 1
IMIN
125
A
J←1 || 1
N
MESSAGE 'MATRIX IS SINGULAR'
200
TRI(J, I) ≠ 0.0
Yes
No
END
NOTZRO = J
IDENT
B, E, N
B(I, I) = 0.0
B(NOTZRO, NOTZRO) = 0.0
B(NOTZRO, I) = 1.0
B(I, NOTZRO) = 1.0
MATMPY
B, TRI, ATEMP, N, N, N
MATMPY
B, TRAN, BTEMP, N, N, N
IDENT
B, E, N
B

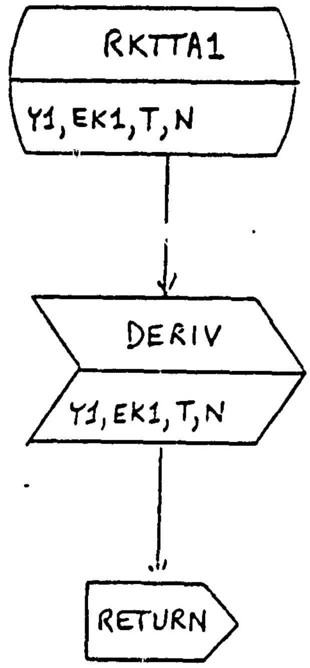


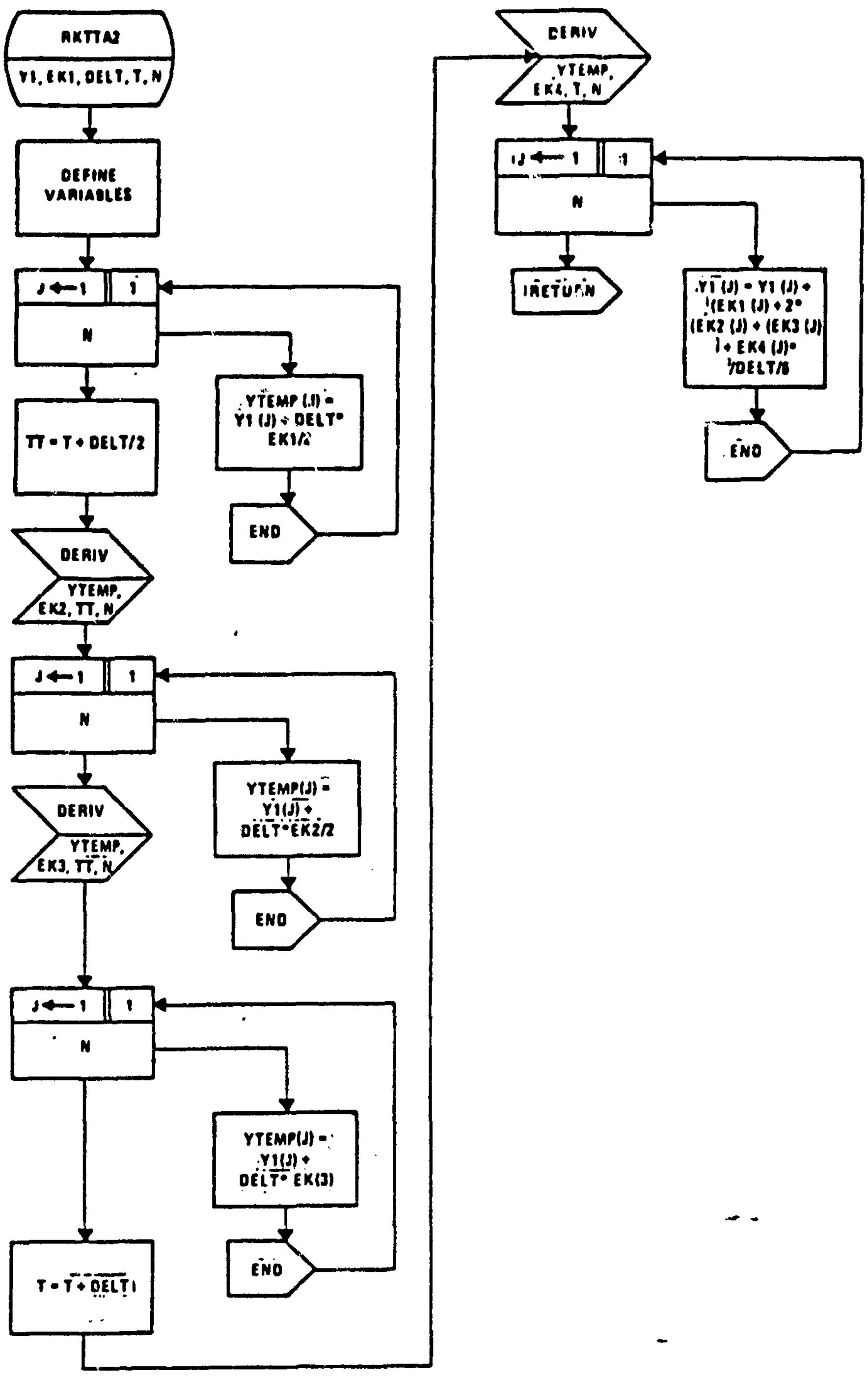
ORIGINAL PAGE IS OF POOR QUALITY


MATMPY
A, B, C, NRA, NCANRB, NCB
DEFINE VARIABLES
J←1
1
NRA
RETURN
K←1
1
NCB
C(J, K) = 0.0
I←1
1
NCANRB
C(J , K) = C(J, K) + A(J, I)* B(I, K)
END
END
END

SUBROUTINE IDENT




RKTTA1
Y1, EK1, T, N
DERIV
Y1, EK1, T, N
RETURN


RKTTA2
Y1, EK1, DELT, T, N
DEFINE VARIABLES
J ← 1
1
N
YTEMP (J) = Y1 (J) + DELT* EK1/2
END
TT = T + DELT/2
DERIV
YTEMP, EK2, TT, N
J ← 1
1
N
YTEMP(J) = Y1(J) + DELT*EK2/2
END
DERIV
YTEMP, EK3, TT, N
J ← 1
1
N
YTEMP(J) = Y1(J) + DELT* EK(3)
END
T = T + DELT
DERIV
YTEMP, EK4, T, N
J ← 1
1
N
Y1 (J) = Y1 (J) + (EK1 (J) + 2* (EK2 (J) + (EK3 (J)) + EK4 (J)* DELT/6
END
RETURN

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                   PROGRAM HYSIM
          C
          C        DEFINE VARIABLES
          C
000003             REAL AM(4,4),BM(4,4),AINV(4,4),SUBA(3,3),SUBANV(3,3)
000003             REAL EE(4,2),DD(2,4),F(2),ED(4,4),EF(4),BED(4,4)
000003             REAL BMT(3,3),BMTT(3,3),EMT(3,3),TRI(3,3),TRAN(3,3)
000003             REAL SPEED(10)
000003             REAL Y1(10),K1(10),Y(10)
000003             COMMON C(4,4),GG(4)
          C
          C        READ INPUT
          C
000003             READ 410, NCASE,NSPD
000013             READ 410,NSTEPS,NPSTEP
000023             READ 400,DELT
000031             READ 400,(SPEED(J), J=1,NSPD)
000044             READ 400,TM,(Y(J),J=1,4)
000060             PRINT 500
000064             PRINT 498,NCASE,NSPD,NSTEPS,NPSTEP
000100             PRINT 499,DELT,(SPEED(J),J=1,NSPD)
000115             PRINT 505
000121             PRINT 520,(Y(J),J=1,4)
000133             PRINT 507
          C
          C        CASE LOOP
          C
000137             DO 350 JCASE=1,NCASE
          C
          C        INPUT MASS PROPERTIES
          C
          C
          C        INPUT GEOMETRICAL PROPERTIES
000141             READ 400,EM,ENRTX,ENRTY,ENRTZ,CXZ
000156             READ 400,EL1,EL,H,CH,THETA,EPSLN,R,HA,CDA,DELTA
          C
          C        TIRE PROPERTIES
          C
000206             READ 400,CPF,CPR,EKPF,EKPR,CAF,CAR,SIGMAF,SIGMAR
          C
          C        PRINT VEHICLE CHARACTERISTICS
000232             PRINT 510
000236             PRINT 520,EM,ENRTX,ENRTY,ENRTZ,CXZ
000254             PRINT 530
000260             PRINT 520,EL1,EL,H,CH,THETA,EPSLN
000300             PRINT 540
000304             PRINT 520,R,HA,CDA,DELTA
000320             PRINT 550
000324             PRINT 520,CPF,CPR,EKPF,EKPR
000340             PRINT 560
000344             PRINT 520,CAF,CAR,SIGMAF,SIGMAR
          C
          C        PRILIMINARY COMPUTATIONS
          C
000360             B=EL1-EL
```

```
000362          FACOEF=0.612*CDA
000364          G=9.807
000366          EMCH=EM*CH
       C
       C        A-MATRIX COEFFICIENTS(SPEED INDEPENDENT)
       C
000370          DO 100 J=1,4
000371          DO 100 K=1,4
000372          AM(J,K)=0.0
000375     100  CONTINUE
000400          AM(1,1)=EM
000402          AM(1,3)=EMCH
000403          AM(2,2)=ENRTZ
000405          AM(2,3)=-CXZ
000406          AM(3,1)=EMCH
000407          AM(3,2)=-CXZ
000410          AM(3,3)=ENRTX+EM*CH**2
000413          AM(4,4)=1.0
000415          PRINT 570
000420          PRINT 580,((AM(I,J),J=1,4),I=1,4)
       C
       C        INVERSE OF A-MATRIX
       C
000436          DO 110 J=1,3
000440          DO 110 K=1,3
000441          SUBA(J,K)=AM(J,K)
000446     110  CONTINUE
000451          CALL MATINV(SUBA,SUBANV,BMT,BMTT,EMT,TRI,TRAN,3)
000461          DO 120 J=1,4
000463          DO 120 K=1,4
000464          IF(J.LE.3.AND.K.LE.3)GO TO 130
000474          AINV(J,K)=0.0
000476          GO TO 120
000476     130  AINV(J,K)=SUBANV(J,K)
000503     120  CONTINUE
000507          AINV(4,4)=1.0
000511          PRINT 590
000514          PRINT 580,((AINV(I,J),J=1,4),I=1,4)
       C
       C        B-MATRIX COEFFICIENTS(SPEED INDEPENDENT)
       C
000532          DO 140 J=1,4
000534          DO 140 K=1,4
000535          BM(J,K)=0.0
000540     140  CONTINUE
000543          BM(3,3)=-CPF-CPR
000546          BM(3,4)=EMCH*G-EKPF-EKPR
000552          BM(4,3)=1.0
       C
       C        E-MATRIX COEFFICIENTS(SPEED INDEPENDENT)
       C
000553          DO 150 J=1,2
000555          DO 150 K=1,4
000556          FE(J,K)=0.0
000561     150  CONTINUE
```

```
000564          EE(1,1)=1.0
000566          EE(1,2)=1.0
000567          EE(2,1)=EL
000570          EE(2,2)=-B
000572          EE(3,1)=-H+EL*EPSLN
000575          EE(3,2)=-H-B*EPSLN
000577          PRINT 490,((EE(I,J),J=1,2),I=1,4)
        C
        C       SPEED LOOP
        C
000614          DO 300 JSPD=1,NSPD
000616          JPL=0
000617          T1=TM
000621          DO 165 J=1,4
000622          Y1(J)=Y(J)
000624      165 CONTINUE
000626          XDOT=SPEED(JSPD)
000630          PRINT 600,XDOT
        C
        C       SPEED DEPENDENT COMPUTATIONS
        C
000635          FA=FACOEF*XDOT**2
000640          ZF=THETA*EM*G-FA*HA/EL1
000645          ZR=EM*G-ZF
000647          CAFZF=CAF*ZF
000650          CARZR=CAR*ZR
000652          ENRTYR=ENRTY/R**2
000655          PRINT 610, ZF,ZR
        C
        C       B-MATRIX COEFFICIENTS(SPEED DEPENDENT)
        C
000664          BM(1,2)=-XDOT*(EM+ENRTYR)
000667          BM(2,1)=XDOT*ENRTYR
000670          BM(2,4)=FA*(CH+H-HA)
000674          BM(3,2)=-XDOT*EMCH
000676          PRINT 620
000702          PRINT 580,((BM(I,J),J=1,4),I=1,4)
        C
        C       D-MATRIX COEFFICIENTS(SPEED DEPENDENT)
        C
000720          DO 170 J=1,4
000722          DO 170 K=1,2
000723          DD(J,K)=0.0
000725      170 CONTINUE
000731          DD(1,1)=-CAFZF/XDOT
000733          DD(1,2)=-CAFZF*EL/XDOT
000735          DD(2,1)=-CARZR/XDOT
000737          DD(2,2)=CARZR*B/XDOT
        C
        C       COMPUTE C-MATRIX
        C
000741          CALL MATMPY(EE,DD,ED,4,2,4)
000745          DO 180 J=1,4
000747          DO 180 K=1,4
000750          BED(J,K)=BM(J,K)+ED(J,K)
```

```
 00757       180 CONTINUE
 00763           CALL MATMPY(AINV,BED,C,4,4,4)
 000767          PRINT 630
 000773          PRINT 580,((C(I,J),J=1,4),I=1,4)
           C
           C     F-MATRIX COEFFICIENTS(SPEED DEPENDENT)
           C
 001011          F(1)=CAFZF
 001013          F(2)=0.0
           C
           C     COMPUTE GG-MATRIX
           C
 001014          CALL MATMPY(EE,F,EF,4,2,1)
 001020          PRINT 491,(EF(J),J=1,4)
 001032          CALL MATMPY(AINV,EF,GG,4,4,1)
 001036          PRINT 492,(GG(J),J=1,4)
 001050          DO 160 J=1,4
 001052          GG(J)=GG(J)*DELTA
 001054      160 CONTINUE
 001056          PRINT 492,(GG(J),J=1,4)
           C
           C     PRINT HEADINGS
           C
 001067          PRINT 640
           C
           C     INTEGRATE EQUATIONS
           C
 001073          KPSTEP=1
 001074          DO 200 KSTEP=1,NSTEPS
 001076          CALL RKTTA1(Y1,K1,T1,4)
 001101          IF(KPSTEP.NE.KSTEP)GO TO 210
 001103          ACCLAT=XDOT*Y1(2)+K1(1)
 001106          PRINT 650,T1,(Y1(J),J=1,4),ACCLAT
 001124          KPSTEP=KPSTEP+NPSTEP
 001126      210 CALL RKTTA2(Y1,K1,DELT,T1,4)
 001132      200 CONTINUE
 001135      300 CONTINUE
 001137      350 CONTINUE
 001142          STOP
 001144      400 FORMAT(7F10.4)
 001144      410 FORMAT(2I10)
 001144      498 FORMAT(1H ,4I4)
 001144      499 FORMAT(1H ,10E16.6)
 001144      490 FORMAT(1H ,*EE-MATRIX*/8E14.6)
 001144      491 FORMAT(1H ,*EF-MATRIX*/8E14.6)
 001144      492 FORMAT(1H ,*GG-MATRIX*/8E14.6)
 001144      500 FORMAT(1H1,*VEHICLE CHARACTERISTICS*)
 001144      505 FORMAT(1H0,*Y-VECTOR*)
 001144      507 FORMAT(1H-,*FRAME*)
 001144      510 FORMAT(1H0,8X,*MASS*,9X,*X-INERTIA*,7X,*Y-INERTIA*,7X,*Z-INERTIA
                1 6X,*X-Z PRODUCT*)
   1144      520 FORMAT(1H ,8E16.6)
  01144      530 FORMAT(1H0,*GEOMETRY*//6X,*WHEELBASE*,6X,*FR. AXLE CG*,6X,*RC HE
                1HT*,5X,*(CG - RC) HT.*,8X,*THETA*,11X,*EPSLN*)
 001144      540 FORMAT(1H0,5X,*WHL. RAD.*,4X,*CG - AERO. LOAD*,5X,*CD AREA*,9X,*
```

```
              1LTA*)
 001144       550 FORMAT(1H0,*SUSPENSION*//10X,*ROLL DAMPING*,23X,*ROLL STIFFNESS
              1X,*FRONT*,12X,*REAR*,11X,*FRONT*,12X,*REAR*)
 001144       560 FORMAT(1H0,*TIRE PROPERTIES*//9X,*LATERAL FORCE*,19X,*RELAXATIO
              1ENGTH*/8X,*FRONT*,12X,*REAR*,11X,*FRONT*,12X,*REAR*)
 001144       570 FORMAT(1H0,*A-MATRIX*)
 001144       580 FORMAT(1H ,4E14.6)
 001144       590 FORMAT(1H0,*A-INVERSE MATRIX*)
 001144       600 FORMAT(1H-,*SPEED =*,E14.6)
 001144       610 FORMAT(1H ,*ZF =*,E14.6,5X,*ZR =*,E14.6)
 001144       620 FORMAT(1H0,*B-MATRIX*)
 001144       630 FORMAT(1H0,*C-MATRIX*)
 001144       640 FORMAT(1H0,3X,*TIME*,6X,*Y1DOT*,7X,*PSIDOT*,6X,*PHIDOT*,7X,*PHI
              16X,*LAT. ACC.*)
 001144       650 FORMAT(1H ,E8.2,10E12.4)
 001144           END
```

```
                    SUBROUTINE MATINV(A,ATEMP,B,BTEMP,E,TRI,TRAN,M)
              C     MATINV DETERMINES THE INVERSE OF A REAL MATRIX
              C     ATEMP IS THE INVERSE OF THE INPUT MATRIX A.
000013              REAL A(M,M),ATEMP(M,M),B(M,M),BTEMP(M,M),TRI(M,M),TRAN(M,M),
                   1E(M,M)
000013              N=M
              C     STORE THE IDENTITY MATRIX
000014              DO 20 I=1,N
000016              DO 20 J=1,N
000017              IF(I.EQ.J)GO TO 10
000023              E(I,J)=0.
000024              GO TO 20
000025           10 E(I,J)=1.
000033           20 CONTINUE
              C
              C     INITIALIZE TRANSFORMED AND TRANSFORMATION MATRICES
              C
000040              CALL IDENT(TRI,A,N)
000043              CALL IDENT(TRAN,E,N)
              C
              C     TRANSFORM A-MATRIX TO UPPER TRIANGULAR FORM
              C
000051              IMIN=N-1
000053              DO 125 I=1,IMIN
              C     LOCATE NONZERO ELEMENT IN I-TH COLUMN
000060              DO 100 J=I,N
 10061              IF(TRI(J,I).NE.0.)GO TO 110
 J0065          100 CONTINUE
000070              PRINT 500
000074              GO TO 200
000100          110 NOTZRO=J
000102              CALL IDENT(B,E,N)
000104              B(I,I)=0.
000114              B(NOTZRO,NOTZRO)=0.
000120              B(NOTZRO,I)=1.
000124              B(I,NOTZRO)=1.
              C     GET NONZRO ELEMENT IN (I,I) LOCATION)
000127              CALL MATMPY(B,TRI,ATEMP,N,N,N)
000133              CALL MATMPY(B,TRAN,BTEMP,N,N,N)
              C     GET ZEROES IN (I+1,I)-(N,I) LOCATIONS
000143              CALL IDENT(B,E,N)
000151              IPLUS=I+1
000153              DO 120 J=IPLUS,N
000160              B(J,I)=-ATEMP(J,I)/ATEMP(I,I)
000173          120 CONTINUE
000176              CALL MATMPY(B,ATEMP,TRI,N,N,N)
000201          125 CALL MATMPY(B,BTEMP,TRAN,N,N,N)
              C
              C     TRANSFORM A-MATRIX TO DIAGONAL FORM
              C
              C     CHECK DIAGONAL ELEMENTS
 00217              DO 130 I=1,N
  0221              IF(TRI(I,I).EQ.0.)GO TO 140
000225          130 CONTINUE
000230              GO TO 150
```

```
000232      140 WRITE(6,500)
000234          GO TO 200
000240      150 DO 170 I=1,IMIN
          C     GET ZEROES IN UPPER TRIANGLE
000242          NMI=N-I
000244          CALL IDENT(B,E,N)
000246          DO 160 J=1,NMI
000253          B(J,N+1-I)=-TRI(J,N+1-I)/TRI(N+1-I,N+1-I)
000274      160 CONTINUE
000277          CALL MATMPY(B,TRI,ATEMP,N,N,N)
000303          CALL MATMPY(B,TRAN,BTEMP,N,N,N)
000313          CALL IDENT(TRI,ATEMP,N)
000321      170 CALL IDENT(TRAN,BTEMP,N)
          C
          C     NORMALIZE THE DIAGONAL ELEMENTS
          C
000335          CALL IDENT(B,E,N)
000337          DO 180 J=1,N
000344          B(J,J)=1./TRI(J,J)
000354      180 CONTINUE
000356          CALL MATMPY(B,TRAN,ATEMP,N,N,N)
000363      200 RETURN
000364      500 FORMAT(1H0,18HMATRIX IS SINGULAR)
000364          END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                        SUBROUTINE IDENT(A,B,N)
                C
                C       IDENT EQUATES MATRICES
                C
000006                  REAL A(N,N),B(N,N)
000006                  DO 10 I=1,N
000007                  DO 10 J=1,N
000010                  A(I,J)=B(I,J)
000017               10 CONTINUE
000022                  RETURN
000022                  END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                    SUBROUTINE MATMPY(A,B,C,NRA,NCANRB,NCB)
            C
            C       MATMPY MULTIPLIES MATRICES
            C
000011              REAL A(NRA,NCANRB),B(NCANRB,NCB),C(NRA,NCB)
000011              DO 10 J=1,NRA
000012              DO 10 K=1,NCB
000013              C(J,K)=0.
000017              DO 10 I=1,NCANRB
000020              C(J,K)=C(J,K)+A(J,I)*B(I,K)
000035           10 CONTINUE
000044              RETURN
            C
000044              END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                  SUBROUTINE RKTTA1(Y1,EK1,T,N)
 000007           REAL Y1(20),EK1(20)
 000007           CALL DERIV(Y1,EK1,T,N)
 000010           RETURN
 000011           END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                    SUBROUTINE RKTTA2(Y1,EK1,DELT,T,N)
              C
              C     RKTTA2 USES RUNGE-KUTTA TECHNIQUE FOR NUMERICAL INTEGRATION
              C
000010              REAL Y1(50),Y2(50),YTEMP(50),EK1(50),EK2(50),EK3(50),EK4(50)
000010              DO 50J=1,N
000011              YTEMP(J)=Y1(J)+DELT*EK1(J)/2.
000017           50 CONTINUE
000022              TT=T+DELT/2.
000024              CALL DERIV(YTEMP,EK2,TT,N)
000027              DO 60J=1,N
000034              YTEMP(J)=Y1(J)+DELT*EK2(J)/2.
000041           60 CONTINUE
000045              CALL DERIV(YTEMP,EK3,TT,N)
000050              DO 70J=1,N
000055              YTEMP(J)=Y1(J)+DELT*EK3(J)
000061           70 CONTINUE
000064              T=T+DELT
000065              CALL DERIV(YTEMP,EK4,T,N)
000070              DO 80J=1,N
000075              Y1(J)=Y1(J)+(EK1(J)+2.*(EK2(J)+EK3(J))+EK4(J))*(DELT/6.)
000107           80 CONTINUE
000111              RETURN
000112          650 FORMAT(1H ,8E14.6)
000112              END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                    SUBROUTINE DERIV(Y,K,T,N)
              C
              C     DERIV SETS UP K-MATRIX FOR USE IN INTEGRATION ROUTINE
              C
000007              COMMON C(4,4),GG(4)
000007              REAL Y(10),K(10)
000007              DO 10 I=1,4
000010              K(I)=GG(I)
000012              DO 10 J=1,4
000014              K(I)=K(I)+C(I,J)*Y(J)
000022           10 CONTINUE
000026              RETURN
000026              END
```

```
VEHICLE CHARACTERISTICS
   1   3 500   5
   1.000000E-02    1.000000E+01    2.000000E+01    3.000000E+01

Y-VECTOR
   0.              0.              0.              0.


FRAME

      MASS           X-INERTIA       Y-INERTIA       Z-INERTIA       X-Z PRODUCT
   1.857000E+03    8.420000E+02    5.000000E+00    4.870000E+03   -5.100000E+01

GEOMETRY

     WHEELBASE      FR. AXLE CG      RC HEIGHT      (CG - RC) HT.       THETA           EPSLN
   2.900000E+00    1.290000E+00    1.860000E-01    4.600000E-01    5.550000E-01    1.440000E-01

     WHL. RAD.    CG - AERO. LOAD    CD AREA          DELTA
   3.120000E-01    5.500000E-01    1.260000E+00    2.000000E-02

SUSPENSION

       ROLL DAMPING                            ROLL STIFFNESS
     FRONT             REAR                FRONT            REAR
   4.900000E+03    1.350000E+03    3.190000E+04    6.700000E+03

TIRE PROPERTIES

      LATERAL FORCE                         RELAXATION LENGTH
     FRONT             REAR                FRONT            REAR
   5.430000E+00    9.460000E+00    2.500000E-01    2.500000E-01

A-MATRIX
  1.857000E+03  0.            8.542200E+02  0.
  0.            4.870000E+03  6.100000E+01  0.
  8.542200E+02  6.100000E+01  1.234941E+03  0.
  0.            0.            0.            1.000000E+00

A-INVERSE MATRIX
  7.930376E-04  6.849216E-06 -5.465145E-04  0.
  6.849216E-06  2.055253E-04 -1.488960E-05  0.
 -5.465145E-04 -1.488960E-05  1.159727E-03  0.
  0.            0.            0.            1.000000E+00
EE-MATRIX
 1.000000E+00  1.000000E+00  1.230000E+00 -1.610000E+00 -2.400000E-04 -4.178400E-01  0.            0.


SPEED =   1.000000E+01
ZF =  1.003351E+04     ZR =  8.118030E+03

B-MATRIX
  0.           -1.909364E+04  0.            0.
  5.136423E+02  0.            0.            7.050240E+00
  0.           -8.542200E+03 -6.253000E+03 -3.022266E+04
  0.            0.            1.000000E+00  0.

C-MATRIX
 -1.453232E+01 -6.719015E+00  3.417531E+00  1.652624E+01
  2.321369E-01 -6.919577E+00  9.305031E-02  4.514524E-01
  1.254974E+01 -6.109063E+00 -7.429545E+00 -3.592661E+01
  0.            0.            1.000000E+00  0.
```

EF-MATRIX
9.509820E+04 1.097639E+05 -2.042119E+01 0.
GG-MATRIX
6.799591E+01 2.314235E+01 -4.818612E+01 0.
GG-MATRIX
1.359719E+00 4.629470E-01 -9.637224E-01 0.

TIME	YIDOT	PSIDOT	PHIDOT	PHI	LAT. ACC.
0.	0.	0.	0.	0.	1.3597E+00
5.00E-02	4.3070E-02	1.3746E-02	-2.8607E-02	-8.5186E-04	6.8674E-01
1.00E-01	5.7267E-02	3.3880E-02	-3.6977E-02	-2.5355E-03	4.7039E-01
1.50E-01	5.9726E-02	4.3898E-02	-3.9280E-02	-4.4532E-03	4.2795E-01
2.00E-01	5.7622E-02	5.0940E-02	-4.0232E-02	-6.4428E-03	4.4549E-01
2.50E-01	5.3940E-02	5.5950E-02	-4.0995E-02	-8.4739E-03	4.7894E-01
3.00E-01	4.9914E-02	5.9245E-02	-4.1555E-02	-1.0539E-02	5.1254E-01
3.50E-01	4.6050E-02	6.1567E-02	-4.1633E-02	-1.2621E-02	5.4163E-01
4.00E-01	4.2550E-02	6.3135E-02	-4.0996E-02	-1.4690E-02	5.6562E-01
4.50E-01	3.9491E-02	6.4178E-02	-3.9539E-02	-1.6707E-02	5.8516E-01
5.00E-01	3.6889E-02	6.4850E-02	-3.7279E-02	-1.8631E-02	6.0113E-01
5.50E-01	3.4740E-02	6.5291E-02	-3.4317E-02	-2.0423E-02	6.1429E-01
6.00E-01	3.3018E-02	6.5558E-02	-3.0812E-02	-2.2053E-02	6.2523E-01
6.50E-01	3.1692E-02	6.5712E-02	-2.6942E-02	-2.3498E-02	5.3437E-01
7.00E-01	3.0722E-02	6.5810E-02	-2.2892E-02	-2.4745E-02	6.4200E-01
7.50E-01	3.0067E-02	6.5862E-02	-1.8830E-02	-2.5787E-02	6.4835E-01
8.00E-01	2.9680E-02	6.5891E-02	-1.4902E-02	-2.6630E-02	6.5356E-01
8.50E-01	2.9517E-02	6.5910E-02	-1.1228E-02	-2.7282E-02	6.5778E-01
9.00E-01	2.9533E-02	6.5926E-02	-7.8960E-03	-2.7750E-02	6.6111E-01
9.50E-01	2.9688E-02	6.5943E-02	-4.9651E-03	-2.8078E-02	6.6365E-01
1.00E+00	2.9943E-02	6.5963E-02	-2.4682E-03	-2.8262E-02	6.6550E-01
1.05E+00	3.0264E-02	6.5987E-02	-4.1432E-04	-2.8332E-02	6.6677E-01
1.10E+00	3.0624E-02	6.6014E-02	1.2068E-03	-2.8311E-02	6.6753E-01
1.15E+00	3.0996E-02	6.6043E-02	2.4208E-03	-2.8218E-02	6.6789E-01
1.20E+00	3.1363E-02	6.6074E-02	3.2647E-03	-2.8075E-02	6.6791E-01
1.25E+00	3.1709E-02	6.6105E-02	3.7828E-03	-2.7897E-02	6.6769E-01
1.30E+00	3.2024E-02	6.6135E-02	4.0237E-03	-2.7701E-02	6.6728E-01
1.35E+00	3.2300E-02	6.6163E-02	4.0373E-03	-2.7499E-02	6.6675E-01
1.40E+00	3.2534E-02	6.6190E-02	3.8722E-03	-2.7300E-02	6.6614E-01
1.45E+00	3.2725E-02	6.6213E-02	3.5744E-03	-2.7114E-02	6.6552E-01
1.50E+00	3.2874E-02	6.6233E-02	3.1854E-03	-2.6945E-02	6.6499E-01
1.55E+00	3.2982E-02	6.6250E-02	2.7419E-03	-2.6796E-02	6.6430E-01
1.60E+00	3.3055E-02	6.6264E-02	2.2748E-03	-2.6671E-02	6.6377E-01
1.65E+00	3.3097E-02	6.6274E-02	1.8095E-03	-2.6569E-02	6.6329E-01
1.70E+00	3.3112E-02	6.6282E-02	1.3657E-03	-2.6489E-02	6.6289E-01
1.75E+00	3.3106E-02	6.6287E-02	9.5819E-04	-2.6432E-02	6.6256E-01
1.80E+00	3.3083E-02	6.6290E-02	5.3669E-04	-2.6393E-02	6.6231E-01
1.85E+00	3.3049E-02	6.6291E-02	2.8700E-04	-2.6371E-02	6.6212E-01
1.90E+00	3.3005E-02	6.6290E-02	3.1398E-05	-2.6363E-02	6.6199E-01
1.95E+00	3.2958E-02	6.6289E-02	-1.7370E-04	-2.6367E-02	6.6192E-01
2.00E+00	3.2910E-02	6.6286E-02	-3.2201E-04	-2.6379E-02	6.6189E-01
2.05E+00	3.2862E-02	6.6293E-02	-4.2691E-04	-2.6398E-02	6.6190E-01
2.10E+00	3.2818E-02	6.6290E-02	-4.9083E-04	-2.6421E-02	6.6194E-01
2.15E+00	3.2777E-02	6.6276E-02	-5.1990E-04	-2.6447E-02	6.6200E-01
2.20E+00	3.2742E-02	6.6273E-02	-5.2008E-04	-2.6473E-02	6.6207E-01
2.25E+00	3.2712E-02	6.6270E-02	-4.9782E-04	-2.6499E-02	6.6215E-01
2.30E+00	3.2697E-02	6.6267E-02	-4.5983E-04	-2.6523E-02	6.6223E-01
2.35E+00	3.2669E-02	6.6264E-02	-4.0837E-04	-2.6544E-02	6.6232E-01
2.40E+00	3.2654E-02	6.6262E-02	-3.5110E-04	-2.6563E-02	6.6239E-01
2.45E+00	3.2645E-02	6.6261E-02	-2.9096E-04	-2.6579E-02	6.6246E-01
2.50E+00	3.2640E-02	6.6259E-02	-2.3115E-04	-2.6592E-02	6.6252E-01
2.55E+00	3.2638E-02	6.6258E-02	-1.7420E-04	-2.6602E-02	6.6257E-01
2.60E+00	3.2639E-02	6.6259E-02	-1.2195E-04	-2.6610E-02	6.6262E-01
2.65E+00	3.2642E-02	6.6257E-02	-7.5651E-05	-2.6615E-02	6.6265E-01

PARAMETERS EQUATION	PARAMETERS PROGRAM	UNITS	DESCRIPTION
	NCASE	—	NUMBER OF CASES
	NSPD	—	NUMBER OF SPEEDS
	SPEED(12)	m/sec	SPEEDS
m_r	EM	KG.	MASS OF VEHICLE
I_{rx}	ENRTX	KG·m²	MOMENTS OF INERTIA WITH RESPECT
I_{ry}	ENRTY	KG·m²	TO X, Y, AND Z AXES
I_{rz}	ENRTZ	KG·m²	
C_{rxz}	CXZ	KG·m²	PRODUCT OF INERTIA WITH RESPECT TO X + Z AXES
ℓ_1	EL1	m	WHEEL BASE LENGTH
ℓ	EL	m	LENGTH FRONT AXLE TO CENTER OF GRAVITY
h_r	H	m	ROLL CENTER HEIGHT
Δh_r	CH	m	(CENTER OF GRAVITY - ROLL CENTER) HEIGHT
θ	THETA	—	FRACTION WT. ON FRONT WHEEL W/STATIC CONDITION
ϵ	EPSLN	RAD	INCLINATION OF ROLL AXIS
R	R	m	WHEEL RADIUS
h_a	HA	m	AERODYNAMIC CENTER OF EFFORT
$C_D A$	CDA	—	DRAG COEFFICIENT * FRONTAL AREA
δ	DELTA	RAD	STEER ANGLE
$C_{\phi f}$	CPF	N/RAD	ROLL DAMPING - FRONT (COEFFICIENT)
$C_{\phi r}$	CPR	N/RAD	ROLL DAMPING - REAR (COEFFICIENT)
$K_{\phi f}$	EKPR	N/RAD	ROLL STIFFNESS - FRONT (COEFFICIENT)
$K_{\phi r}$	EKPF	N/RAD	ROLL STIFFNESS - REAR (COEFFICIENT)
$C_{\alpha f}$	CAF	N/RAD	LATERAL FORCE - FRONT (COEFFICIENT)
$C_{\alpha r}$	CAR	N/RAD	LATERAL FORCE - REAR (COEFFICIENT)
σ_f	SIGMAF	m	RELAXATION LENGTH - FRONT
σ_r	SIGMAR	m	RELAXATION LENGTH - REAR

HYSSG

VARIABLES		UNITS	DESCRIPTION
EQUATION	PROGRAM		
b	B	m	EL1 - EL (see list of input parameters)
	BED(4,4)	—	BM-MATRIX + ED-MATRIX
	BEDINV(4,4)	—	INVERSE OF BED-MATRIX
	BM(4,4)	—	COEFFICIENT MATRIX
	BMT(4,4)	—	MATRICES USED IN MATRIX INVERSION
	BMTT(4,4)	—	ROUTINE
$C_{\alpha f} Z_f$	CAFZF	N/RAD	$C_{\alpha f} * Z_f$
$C_{\alpha r} Z_r$	CARZR	N/RAD	$C_{\alpha r} * Z_r$
	DD(2,4)	—	COEFFICIENT MATRIX
	ED(4,4)	—	EE-MATRIX * DD-MATRIX
	EF(4)	—	EE-MATRIX * F-MATRIX
	EE(4,2)	—	COEFFICIENT MATRIX
	EMT(4,4)	—	MATRIX USED IN MATRIX INVERSION ROUTINE
$m_r \Delta h_r$	EMCH	—	MASS * (CENTER GRAVITY - ROLL CENTER) HEIGHT
	ENRTYR	KG-m^2	ROTATIONAL INERTIA OF WHEELS
	F(2)	—	COEFFICIENT MATRIX
F_A	FA	—	FACDEF * SPEED
$0.612 C_D A$	FACDEF	—	0.612 * DRAG COEFFICIENT * FRONTAL AREA
g	-	N/RAD	GRAVITY
	TRAN(4,4)	—	MATRICES USED IN MATRIX INVERSION
	TRI(4,4)	—	ROUTINE
$\dot{x}_1$	XDOT	m/sec	VEHICLE SPEED FOR SPECIFIED SPEED LOOP
	Y(10)	—	BEDINV-MATRIX * EF-MATRIX
	Y1(10)	—	Y-MATRIX / DELTA
Z_f	ZF	KG.	LATERAL LOAD ON FRONT TIRES
Z_r	ZR	KG.	LATERAL LOAD ON REAR TIRES

GENERAL RE[SEA]RCH CORPORATION

FORTRAN CODING FORM

PROGRAM HYSSG

ROUTINE Input Format

NAME

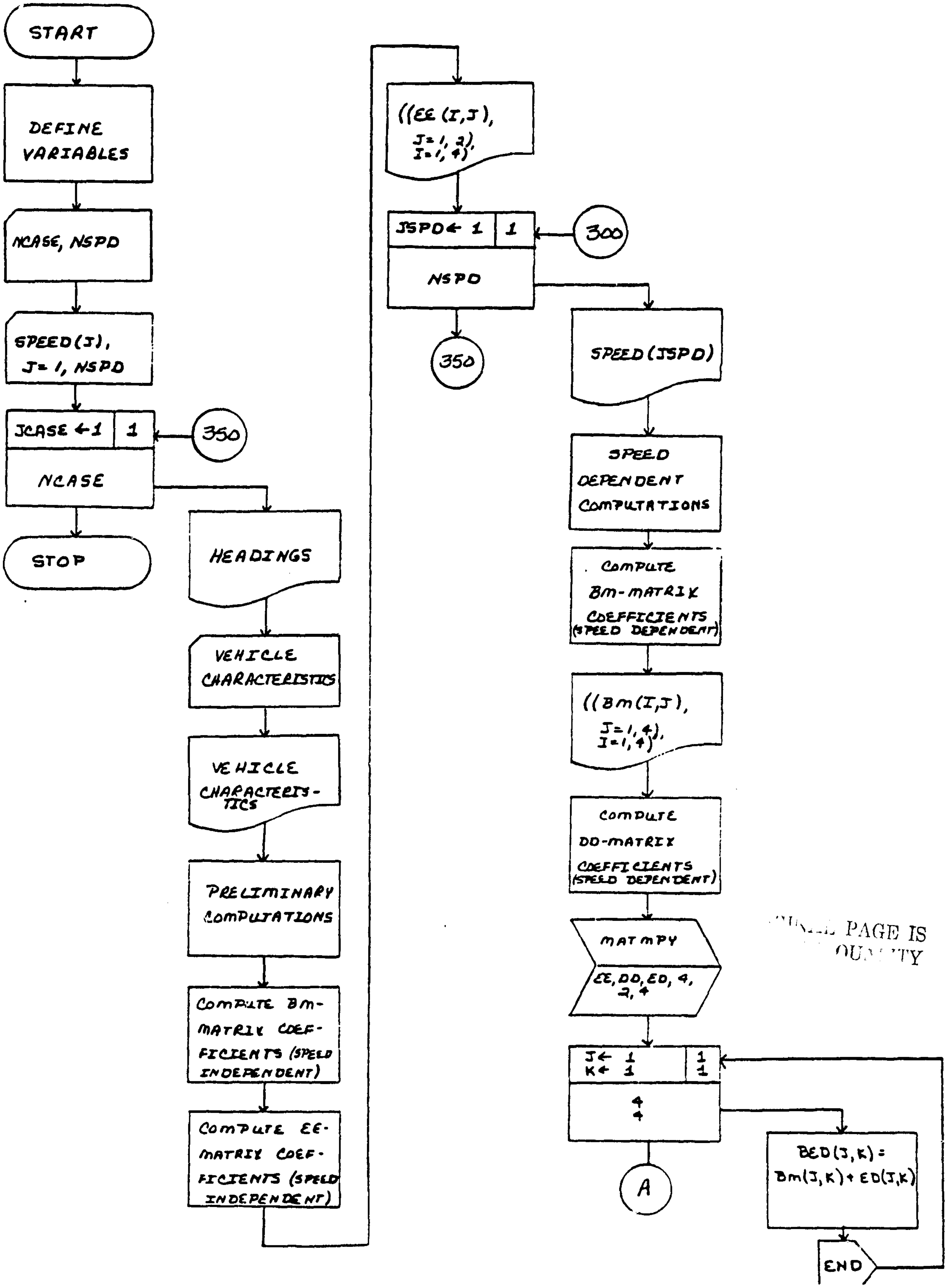
DATE

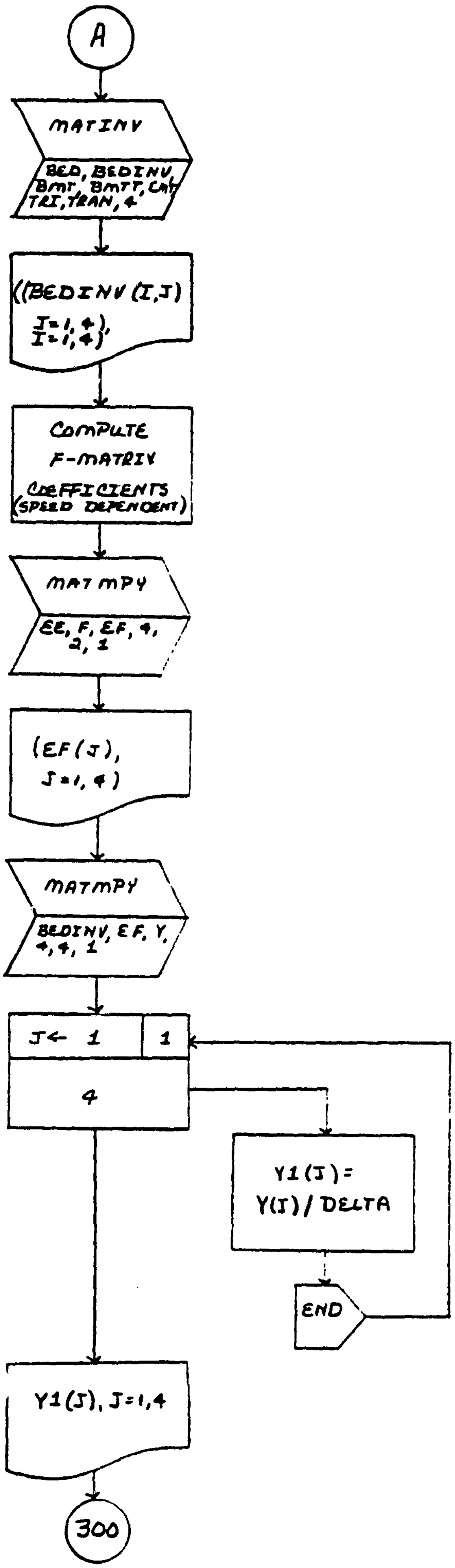
PAGE OF

```
     NCASE     NSPD
SPEED(1)   . . .    SPEED(NSPD)

      MASS PROPERTIES
   EM      ENRTX     ENRTY     ENRTZ      CXZ
      GEOMETRICAL PROPERTIES
  EL1        EL         H        CH     THETA     EPSLN         R
   HA       CDA     DELTA
      TIRE PROPERTIES
  CPF       CPR      EKPF      EKPR       CAF       CAR    SIGMAF
    S1GMAR
```

HYSSG


START
DEFINE VARIABLES
NCASE, NSPD
SPEED(J), J= 1, NSPD
JCASE ← 1 | 1
NCASE
350
STOP
HEADINGS
VEHICLE CHARACTERISTICS
VEHICLE CHARACTERIS-TICS
PRELIMINARY COMPUTATIONS
COMPUTE BM-MATRIX COEF-FICIENTS (SPEED INDEPENDENT)
COMPUTE EE-MATRIX COEF-FICIENTS (SPEED INDEPENDENT)
((EE (I,J), J= 1, 2), I= 1, 4)
JSPD ← 1 | 1
NSPD
300
350
SPEED (JSPD)
SPEED DEPENDENT COMPUTATIONS
COMPUTE BM-MATRIX COEFFICIENTS (SPEED DEPENDENT)
((BM(I,J), J= 1, 4), I= 1, 4)
COMPUTE DD-MATRIX COEFFICIENTS (SPEED DEPENDENT)
MATMPY
EE, DD, ED, 4, 2, 4
J ← 1 K ← 1 | 1 1
4 4
A
BED(J,K) = BM(J,K) + ED(J,K)
END


A
MATINV
BED, BEDINV, BMT, BMTT, CMT, TRI, TRAN, 4
((BEDINV(I,J) J=1,4), I=1,4)
COMPUTE F-MATRIX COEFFICIENTS (SPEED DEPENDENT)
MATMPY
EE, F, EF, 4, 2, 1
(EF(J), J=1,4)
MATMPY
BEDINV, EF, Y, 4, 4, 1
J← 1
1
4
Y1(J) = Y(J)/DELTA
END
Y1(J), J=1,4
300

PAGE IS ... ITY

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                   PROGRAM HYSSG
          C
          C        DEFINE VARIABLES
          C
000003             REAL BM(4,4),BEDINV(4,4)
000003             REAL EE(4,2),DD(2,4),F(2),ED(4,4),EF(4),BED(4,4)
000003             REAL BMT(4,4),BMTT(4,4),EMT(4,4),TRI(4,4),TRAN(4,4)
000003             REAL SPEED(12)
000003             REAL Y(10),Y1(10)
          C
          C        READ INPUT
          C
000003             READ 410, NCASE,NSPD
000013             READ 400,(SPEED(J), J=1,NSPD)
          C
          C        CASE LOOP
          C
000026             DO 350 JCASE=1,NCASE
          C
          C        PRINT HEADINGS
          C
000030             PRINT 500
000033             PRINT 507
          C
          C        INPUT MASS PROPERTIES
          C
000037             READ 400,EM,ENRTX,ENRTY,ENRTZ,CXZ
          C
          C        INPUT GEOMETRICAL PROPERTIES
000055             READ 400,EL1,EL,H,CH,THETA,EPSLN,R,HA,CDA,DELTA
          C
          C        TIRE PROPERTIES
          C
000105             READ 400,CPF,CPR,EKPF,EKPR,CAF,CAR,SIGMAF,SIGMAR
          C
          C        PRINT VEHICLE CHARACTERISTICS
000131             PRINT 510
000135             PRINT 520,EM,ENRTX,ENRTY,ENRTZ,CXZ
000153             PRINT 530
000157             PRINT 520,EL1,EL,H,CH,THETA,EPSLN
000177             PRINT 540
000203             PRINT 520,R,HA,CDA,DELTA
000217             PRINT 550
000223             PRINT 520,CPF,CPR,EKPF,EKPR
000237             PRINT 560
000243             PRINT 520,CAF,CAR,SIGMAF,SIGMAR
          C
          C        PRELIMINARY COMPUTATIONS
          C
000257             B=EL1-EL
000261             FACCEF=0.612*CDA
000263             G=9.807
  0265             EMCH=EM*CH
          C
          C        B-MATRIX COEFFICIENTS(SPEED INDEPENDENT)
```

```
              C
000267              DO 140 J=1,4
000270              DO 140 K=1,4
000271              BM(J,K)=0.0
000274          140 CONTINUE
000277              BM(3,3)=-CPF-CPR
000302              BM(3,4)=EMCH*G-EKPF-EKPR
000306              BM(4,3)=1.0
              C
              C     E-MATRIX COEFFICIENTS(SPEED INDEPENDENT)
              C
000307              DO 150 J=1,2
000311              DO 150 K=1,4
000312              EE(J,K)=0.0
000315          150 CONTINUE
000320              EE(1,1)=1.0
000322              EE(1,2)=1.0
000323              EE(2,1)=EL
000324              EE(2,2)=-B
000326              EE(3,1)=-H+EL*EPSLN
000331              EE(3,2)=-H-B*EPSLN
000333              PRINT 490,((EE(I,J),J=1,2),I=1,4)
              C
              C     SPEED LOOP
              C
000350              DO 300 JSPD=1,NSPD
000352              XDOT=SPEED(JSPD)
000354              PRINT 600,XDOT
              C
              C     SPEED DEPENDENT COMPUTATIONS
              C
000361              FA=FACOEF*XDOT**2
000364              ZF=THETA*EM*G-FA*HA/EL1
000371              ZR=EM*G-ZF
000373              CAFZF=CAF*ZF
000374              CARZR=CAR*ZR
000376              ENRTYR=ENRTY/R**2
000401              PRINT 610, ZF,ZR
              C
              C     B-MATRIX COEFFICIENTS(SPEED DEPENDENT)
              C
000410              BM(1,2)=-XDOT*(EM+ENRTYR)
000413              BM(2,1)=XDOT*ENRTYR
000414              BM(2,4)=FA*(CH+H-HA)
000420              BM(3,2)=-XDOT*EMCH
000422              PRINT 620
000426              PRINT 580,((BM(I,J),J=1,4),I=1,4)
              C
              C     D-MATRIX COEFFICIENTS(SPEED DEPENDENT)
              C
000444              DO 170 J=1,4
000446              DO 170 K=1,2
000447              DD(J,K)=0.0
000451          170 CONTINUE
000455              DD(1,1)=-CAFZF/XDOT
```

```
000457          DD(1,2)=-CAFZF*EL/XDOT
000461          DD(2,1)=-CARZR/XDOT
000463          DD(2,2)=CARZR*B/XDOT
        C
        C       COMPUTE BEDINV MATRIX
        C
000465          CALL MATMPY(EE,DD,ED,4,2,4)
000471          DO 180 J=1,4
000473          DO 180 K=1,4
000474          BED(J,K)=BM(J,K)+ED(J,K)
000503      180 CONTINUE
000507          CALL MATINV(BED,BEDINV,BMT,BMTT,EMT,TRI,TRAN,4)
000516          PRINT 590
000522          PRINT 580,((BEDINV(I,J),J=1,4),I=1,4)
        C
        C       F-MATRIX COEFFICIENTS(SPEED DEPENDENT)
        C
000540          F(1)=CAFZF
000542          F(2)=0.0
        C
        C       COMPUTE Y-MATRIX
        C
000543          CALL MATMPY(EE,F,EF,4,2,1)
000547          PRINT 491,(EF(J),J=1,4)
000561          DO 190 J=1,4
000563          EF(J)=EF(J)*DELTA
000565          DO 190 K=1,4
000567          BEDINV(J,K)=-BEDINV(J,K)
000572      190 CONTINUE
000575          CALL MATMPY(BEDINV,EF,Y,4,4,1)
000601          DO 200 J=1,4
000603          Y1(J)=Y(J)/DELTA
000606      200 CONTINUE
000607          PRINT 640
000613          PRINT 650,(Y1(J),J=1,4)
000625      300 CONTINUE
000630      350 CONTINUE
000632          STOP
000634      400 FORMAT(7F10.4)
000634      410 FORMAT(2I10)
000634      490 FORMAT(1H0,*EE-MATRIX*,2(/4E14.6))
000634      491 FORMAT(1H0,*EF-MATRIX*/2(4E14.6)
000634      500 FORMAT(1H1,*VEHICLE CHARACTERISTICS*)
000634      507 FORMAT(1H-,*FRAME*)
000634      510 FORMAT(1H0,8X,*MASS*,9X,*X-INERTIA*,7X,*Y-INERTIA*,7X,*Z-INERTI
               16X,*X-Z PRODUCT*)
000634      520 FORMAT(1H ,5E16.6)
000634      530 FORMAT(1H0,*GEOMETRY*//6X,*WHEELBASE*,6X,*FR. AXLE CG*,6X,*RC H
               1HT*,5X,*(CG - RC) HT.*,8X,*THETA*,11X,*EPSLN*)
000634      540 FORMAT(1H0,5X,*WHL. RAD.*,4X,*CG - AERO. LOAD*,5X,*CD AREA*,6X,
               1EER ANGLE*)
000634      550 FORMAT(1H0,*SUSPENSION*//10X,*ROLL DAMPING*,23X,*ROLL STIFFNESS
               1X,*FRONT*,12X,*REAR*,11X,*FRONT*,12X,*REAR*)
000634      560 FORMAT(1H0,*TIRE PROPERTIES*//9X,*LATERAL FORCE*,19X,*RELAXATIC
               1ENGTH*/8X,*FRONT*,12X,*REAR*,11X,*FRONT*,12X,*REAR*)
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
000634      580 FORMAT(1H ,4E14.6)
000634      590 FORMAT(1H0,*BED-INVERSE MATRIX*)
000634      600 FORMAT(1H-,*SPEED =*,E14.6)
000634      610 FORMAT(1H ,*ZF =*,E14.6,5X,*ZR =*,E14.6)
000634      620 FORMAT(1H0,*B-MATRIX*)
000634      640 FORMAT(1H0,4X,*Y1DOT*,7X,*PSIDOT*,6X,*PHIDOT*,7X,*PHI*)
000634      650 FORMAT(1H ,10E12.4)
000634          END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                      SUBROUTINE MATINV(A,ATEMP,B,BTEMP,E,TRI,TRAN,M)
                C     MATINV DETERMINES THE INVERSE OF A REAL MATRIX
                C     ATEMP IS THE INVERSE OF THE INPUT MATRIX A.
000013                REAL A(M,M),ATEMP(M,M),B(M,M),BTEMP(M,M),TRI(M,M),TRAN(M,M),
                     1E(M,M)
000013                N=M
                C     STORE THE IDENTITY MATRIX
000014                DO 20 I=1,N
000016                DO 20 J=1,N
000017                IF(I.EQ.J)GO TO 10
000020                E(I,J)=0.
000024                GO TO 20
000025             10 E(I,J)=1.
000033             20 CONTINUE
                C
                C     INITIALIZE TRANSFORMED AND TRANSFORMATION MATRICES
                C
000040                CALL IDENT(TRI,A,N)
000043                CALL IDENT(TRAN,E,N)
                C
                C     TRANSFORM A-MATRIX TO UPPER TRIANGULAR FORM
                C
000051                IMIN=N-1
000053                DO 125 I=1,IMIN
                C     LOCATE NONZERO ELEMENT IN I-TH COLUMN
000060                DO 100 J=I,N
000061                IF(TRI(J,I).NE.0.)GO TO 110
000065            100 CONTINUE
000070                PRINT 500
000074                GO TO 200
000100            110 NOTZRO=J
000102                CALL IDENT(B,E,N)
000104                B(I,I)=0.
000114                B(NOTZRO,NOTZRO)=0.
000120                B(NOTZRO,I)=1.
000124                B(I,NOTZRO)=1.
                C     GET NONZRO ELEMENT IN (I,I) LOCATION)
000127                CALL MATMPY(B,TRI,ATEMP,N,N,N)
000133                CALL MATMPY(B,TRAN,BTEMP,N,N,N)
                C     GET ZEROES IN (I+1,I)-(N,I) LOCATIONS
000143                CALL IDENT(B,E,N)
000151                IPLUS=I+1
000153                DO 120 J=IPLUS,N
000160                B(J,I)=-ATEMP(J,I)/ATEMP(I,I)
000173            120 CONTINUE
000176                CALL MATMPY(B,ATEMP,TRI,N,N,N)
000201            125 CALL MATMPY(B,BTEMP,TRAN,N,N,N)
                C
                C     TRANSFORM A-MATRIX TO DIAGONAL FORM
                C
                C     CHECK DIAGONAL ELEMENTS
000217                DO 130 I=1,N
000221                IF(TRI(I,I).EQ.0.)GO TO 140
000225            130 CONTINUE
000230                GO TO 150
```

```
000230      140 WRITE(6,500)
000234          GO TO 200
000240      150 DO 170 I=1,IMIN
          C     GET ZEROES IN UPPER TRIANGLE
000242          NMI=N-I
000244          CALL IDENT(B,E,N)
000246          DO 160 J=1,NMI
000253          B(J,N+1-I)=-TRI(J,N+1-I)/TRI(N+1-I,N+1-I)
000274      160 CONTINUE
000277          CALL MATMPY(B,TRI,ATEMP,N,N,N)
000303          CALL MATMPY(B,TRAN,BTEMP,N,N,N)
000313          CALL IDENT(TRI,ATEMP,N)
000321      170 CALL IDENT(TRAN,BTEMP,N)
          C
          C     NORMALIZE THE DIAGONAL ELEMENTS
          C
000335          CALL IDENT(B,E,N)
000337          DO 180 J=1,N
000344          B(J,J)=1./TRI(J,J)
000354      180 CONTINUE
000356          CALL MATMPY(B,TRAN,ATEMP,N,N,N)
000363      200 RETURN
000364      500 FORMAT(1H0,18HMATRIX IS SINGULAR)
000364          END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                    SUBROUTINE IDENT(A,B,N)
          C
          C         IDENT EQUATES MATRICES
          C
000006              REAL A(N,N),B(N,N)
000006              DO 10 I=1,N
000007              DO 10 J=1,N
000010              A(I,J)=B(I,J)
000017           10 CONTINUE
000022              RETURN
000022              END
```

GOLETA FORTRAN 1.3 * SEMI-AUTO RFL * (01-10-73)

```
                  SUBROUTINE MATMPY(A,B,C,NRA,NCANRB,NCB)
          C
          C       MATMPY MULTIPLIES MATRICES
          C
000011            REAL A(NRA,NCANRB),B(NCANRB,NCB),C(NRA,NCB)
000011            DO 10 J=1,NRA
000012            DO 10 K=1,NCB
000013            C(J,K)=0.
000017            DO 10 I=1,NCANRB
000020            C(J,K)=C(J,K)+A(J,I)*B(I,K)
000035         10 CONTINUE
000044            RETURN
          C
000044            END
```

VEHICLE CHARACTERISTICS

FRAME

MASS	X-INERTIA	Y-INERTIA	Z-INERTIA	X-Z PRODUCT
1.857000E+03	8.420000E+02	5.000000E+00	4.870000E+03	-6.100000E+01

GEOMETRY

WHEELBASE	FR. AXLE CG	RC HEIGHT	(CG - RC) HT.	THETA	EPSLN
2.980000E+00	1.290000E+00	1.860000E-01	4.600000E-01	5.550000E-01	1.440000E-01

WHL. RAD.	CG - AERO. LOAD	CP AREA	STEER ANGLE
3.120000F-01	5.500000E-01	1.200000E+00	2.000000E-01

SUSPENSION

ROLL DAMPING FRONT	ROLL DAMPING REAR	ROLL STIFFNESS FRONT	ROLL STIFFNESS REAR
4.900000E+03	1.350000E+03	3.190000E+04	6.700000E+03

TIRE PROPERTIES

LATERAL FORCE FRONT	LATERAL FORCE REAR	RELAXATION LENGTH FRONT	RELAXATION LENGTH REAR
9.430000E+00	9.460000E+00	2.500000E-01	2.500000E-01

EE-MATRIX

1.000000E+00	1.000000E+00	1.290000E+00	-1.610000E+00
-2.400000E-04	-4.179600E-01	0.	0.

SPEED = 5.000000E+00
ZF = 1.010296F+04 ZP = 9.107644F+03

B-MATRIX

0.	-9.541821E+03	0.	0.
2.560212E+02	0.	0.	1.762560E+00
0.	-4.271100F+03	-6.250000E+03	-3.022266E+04
0.	0.	1.000000E+00	0.

BEO-INVERSE MATRIX

-3.060613E-05	3.064812E-06	1.797372F-10	1.117108E-06
-1.339429F-06	-1.454785F-05	-8.484193F-10	-5.302614E-06
-1.421085E-19	1.421085E-19	0.	1.000000E+00
-5.849076E-06	7.671040E-06	-3.109710F-05	-2.057956E-01

EF-MATRIX

8.517634E+04	1.098775E+05	-2.044232E+01	0.

YIDOT	PSIDOT	PHIDOT	PHI
2.2702E+00	1.7125E+00	-3.5192F-15	-3.4535E-01

SPEED = 1.000000E+01
ZF = 1.009551F+04 ZP = 9.118990F+03

B-MATRIX

0.	-1.909364E+04	0.	0.
5.136427F+02	0.	0.	7.050240E+00
0.	-9.542290E+03	-6.250000F+03	-3.922266E+04

C1.5 Life Cycle Costs

Two changes have been made in LYFECC since its summarization appeared in the report from Phase I, "Mission Analysis and Performance Specification Studies Report". First, the method of computing the discount factor now matches the one described in "Hybrid Vehicle Potential Assessment Interim Progress Report", Appendix C, Electric and Hybrid Cost Handbook, R. Left, S. Heller, Draft #5030-162, Jet Propulsion Laboratory, Pasadena, California.

The second change involves the inclusion of replacement batteries down payment. This was omitted from operating and life cycle costs in the first version of the program.

```
                    PROGRAM LYFECC
            C
            C       IFUEL CAN EQUAL 1 THRU 5 WITH THE FOLLOWING RESULTS
            C       IF IFUEL=1, PETROLEUM AND ELECTRICITY ARE BOTH NOMINAL
            C       IF IFUEL=2, PETROLEUM IS +30%
            C       IF IFUEL=3, PETROLEUM IS -30%
            C       IF IFUEL=4, ELECTRICITY IS +30%
            C       IF IFUEL=5, ELECTRICITY IS -10%
            C
000003              INTEGER KBR(11)
000003              REAL EKPY(11),RKF(11),TRCKF(11),AOC(5,11),YLCC(5,11),DF(11),
                   1DAOC(11),DYLCC(5,11),VKT(11),PFCKM(11),PFCKN(11),PFCKP(11),
                   1EFCKM(11),EFCKN(11),EFCKP(11),TFCK(5,11),TAOC(5),AOCK(5),
                   1TLCC(5),ALCCK(5),TDLCC(5),DLCCK(5)
            C
            C       PRINT HEADING
            C
000003              PRINT 500
000007              READ 400,NCASE
000015              READ 400,NYEARS
000023              NYRM1=NYEARS-1
            C
            C       DISCOUNT FACTOR
            C
000025              DO 1 J=1,NYEARS
000027              DF(J)=1./(1.+.02)**(J-1)
 00037            1 CONTINUE
            C
            C       CASE LOOP
            C
000041              DO 350 JCASE=1,NCASE
000043              TK=0.
000044              BR=0.
000045              DO 5 J=1,NYEARS
000046              KBR(J)=0
000047            5 CONTINUE
            C
            C       INPUT
            C
000051              READ 410,CV,WV,WB,PHE,PM,POP
000071              READ 410,GGPK,GDPK,EKWHPK,BOEM,BRK
000107              READ 410,(VKT(J),J=1,NYEARS),AVKT,EKT
000125              READ 410,(RKF(J),J=1,NYEARS)
000140              PRINT 510
000144              PRINT 520,CV,WV,WB,PHE,PM,POP
000164              PRINT 530
000170              PRINT 520,GGPK,GDPK,EKWHPK,BRK,BOEM
            C
            C       MILEAGE
            C
000206              FACT=EKT/AVKT
 00210              DO 10 J=1,NYEARS
 00212              EKPY(J)=FACT*VKT(J)
000215           10 CONTINUE
            C
```

```
         C      SET BATTERY REPLACEMENT FLAG
         C
000217          DO 15 J=1,NYRM1
000220          BR=BR+EKPY(J)
000222          TK=TK+EKPY(J)
000224          IF(BR.LT.BRK)GO TO 15
000227          KBR(J)=1
000230          BR=BR-BRK
000231       15 CONTINUE
000234          IF(BR+EKPY(NYEARS).LE.BRK.OR.PM.EQ.0.)GO TO 18
000245          EKPY(NYEARS)=BRK-BR
000247          BR=BRK
000247          GO TO 19
000250       18 BR=BR+EKPY(NYEARS)
000253       19 TK=TK+EKPY(NYEARS)
000256          PRINT 533
000261          PRINT 534
000265          PRINT 590,(EKPY(J),J=1,11),TK
         C
         C      MAINTENANCE COSTS
         C
000301          HEMC=PHE/.746*.003106+.111818
000304          CMC=WV*.000006+.021742
000307          EMMC=PM/.746*.001242+.037273
000312          IF(PM.EQ.0.)EMMC=0.
000314          BMC=WB*.000248
000316          FMC=0.
000317          TMCK=HEMC+CMC+EMMC+BMC+FMC
         C
         C      REPAIR COST
         C
000324          HERC=PHE/.746*.00497+.173939
000327          CRC=WV*.000124+.59015
000332          EMRC=PM/.746*.00124+.05591
000335          IF(PM.EQ.0.)EMRC=0.
000337          ARC=WV*.00005
000341          TRC=(PHE+PM)/.746*.000808+.031061
000345          TRCK=HERC+CRC+EMRC+ARC+TRC
000352          DO 20 J=1,NYEARS
000354          TRCKF(J)=TRCK*RKF(J)
000357       20 CONTINUE
         C
         C      FUEL COST
         C
000361          IF(GGPK.EQ.0)GO TO 30
000362          DO 25 J=1,NYEARS
000363          PFCKN(J)=(20.90+.7479*(J-1))*GGPK
000371          PFCKP(J)=(27.17+.9723*(J-1))*GGPK
000377          PFCKM(J)=(14.63+.5235*(J-1))*GGPK
000405          EFCKN(J)=(4.23+.0108*(J-1))*EKWHPK
000413          EFCKM(J)=(3.81+.0097*(J-1))*EKWHPK
000421       25 EFCKP(J)=(5.50+.014*(J-1))*EKWHPK
000431          GO TO 36
000432       30 DO 35 J=1,NYEARS
000434          PFCKN(J)=(19.36+.6599*(J-1))*GDPK
```

```
000442          PFCKP(J)=(25.17+.8579*(J-1))*GOPK
000450          PFCKM(J)=(13.55+.4619*(J-1))*GOPK
000456          EFCKN(J)=(4.23+.0108*(J-1))*EKWHPK
000464          EFCKM(J)=(3.81+.0097*(J-1))*EKWHPK
000472       35 EFCKP(J)=(5.50+.014*(J-1))*EKWHPK
000502       36 PRINT 540
000506          PRINT 550,HEMC,CMC,EMMC,BMC,FMC,TMCK
000526          PRINT 560
000532          PRINT 550,HERC,CRC,EMRC,ARC,TRC,TRCK
000552          PRINT 570
000556          PRINT 571
000562          PRINT 572,(PFCKN(J),J=1,11)
000574          PRINT 573,(PFCKP(J),J=1,11)
000606          PRINT 574,(PFCKM(J),J=1,11)
000620          PRINT 575,(EFCKN(J),J=1,11)
000632          PRINT 576,(EFCKP(J),J=1,11)
000644          PRINT 577,(EFCKM(J),J=1,11)
000656          DO 37 J=1,11
000660          TFCK(1,J)=PFCKN(J)+EFCKN(J)
000664          TFCK(2,J)=PFCKP(J)+EFCKN(J)
000670          TFCK(3,J)=PFCKM(J)+EFCKN(J)
000674          TFCK(4,J)=PFCKN(J)+EFCKP(J)
000700       37 TFCK(5,J)=PFCKN(J)+EFCKM(J)
000706          PRINT 578
000711          PRINT 584,(TFCK(1,J),J=1,11)
        C
        C       COST LOOP
        C
000724          DO 300 JCOST=1,2
000726          TOCC=0.
000727          DOCK=0.
000730          DO 38 J=1,5
000731          TAOC(J)=0.
000732          AOCK(J)=0.
000733          TLCC(J)=0.
000734          ALCCK(J)=0.
000735          TDLCC(J)=0.
000736       38 DLCCK(J)=0.
        C
        C       PAYMENTS
        C
000741          PV=CV*2
000743          IF(JCOST.EQ.1)PV=7646.+1.25*(CV-3823.)
000751          PV=PV+PV*.05
000754          AL=PV-PV*POP
000756          AP=(AL+AL*.065*4.)/4.
        C
        C       YEARLY DEPENDENT COST
        C
000761          YDC1=33.+PV*.01+125.
000766          YDC2=33.+PV*.006+75.
        C
        C       BATTERY REPLACEMENT COST
        C
000772          BRC=2.*BOEM
```

```
000774          IF(JCOST.EQ.1)BRC=1.25*BOEM
000777          BRC=BRC+BRC*.05
001002          ADPBR=BRC*PDP
001003          ALBR=BRC-ADPBR
001005          APBR=(ALBR+ALBR*.065*3.)/3.
001010          PRINT 585
001014          PRINT 586
001020          PRINT 590,BRC,ALBR,APBR,BR
        C
        C       OPERATING COSTS
        C
001034          DO 39 IFUEL=1,5
001036          AOC(IFUEL,1)=YOC1
001040          YOC=YOC1
001041          DO 40 J=2,NYEARS
001042          IF(J.GE.7)YOC=YOC2
001046          AOC(IFUEL,J)=(TMCK+TRCKF(J)+TFCK(IFUEL,J))/100.*EKPY(J)+YOC
001061       40 CONTINUE
001064          AOC(IFUEL,NYEARS)=AOC(IFUEL,NYEARS)-YOC2
001070          IF(NYEARS.LE.6)AOC(IFUEL,NYEARS)=AOC(IFUEL,NYEARS)+YOC2-YOC1
001076          DO 50 J=1,NYEARS
001100          IF (KBR(J).EQ.0)GO TO 50
001102          L=J+2
001104          DO 60 K=J,L
001105          IF(K.GT.NYEARS)GO TO 50
001110          AOC(IFUEL,J)=AOC(IFUEL,J)+ADPBR
001114          AOC(IFUEL,K)=AOC(IFUEL,K)+APBR
001120       60 CONTINUE
001122       50 TAOC(IFUEL)=TAOC(IFUEL)+AOC(IFUEL,J)
001131       39 AOCK(IFUEL)=TAOC(IFUEL)/TK
        C
        C       DISCOUNTED OPERATING COSTS
        C
001135          DO 80 J=1,NYEARS
001137          DAOC(J)=AOC(1,J)*DF(J)
001143       80 TDOC=TDOC+DAOC(J)
001147          DOCK=TDOC/TK
        C
        C       LIFE CYCLE COSTS COMPONENTS
        C
001151          VSV=.01*PV
001153          BSV=.5*BRC*(1.-BR/BRK)
        C
        C       LIFE CYCLE COSTS
        C
001157          DO 85 IFUEL=1,5
001161          YLCC(IFUEL,1)=AOC(IFUEL,1)+PV*PDP
001165          YLCC(IFUEL,NYEARS)=AOC(IFUEL,NYEARS)-BSV-VSV
001174          TLCC(IFUEL)=YLCC(IFUEL,1)+YLCC(IFUEL,NYEARS)
001200          DO 90 J=2,NYRM1
001201          YLCC(IFUEL,J)=AOC(IFUEL,J)
001206          IF(J.GE.2.AND.J.LE.5)YLCC(IFUEL,J)=YLCC(IFUEL,J)+AP
001222       90 TLCC(IFUEL)=TLCC(IFUEL)+YLCC(IFUEL,J)
001231          ALCCK(IFUEL)=TLCC(IFUEL)/TK
        C
```

```
          C     DISCOUNTED LIFE CYCLE COSTS
          C
001234          DO 100 J=1,NYEARS
001235          DYLCC(IFUEL,J)=YLCC(IFUEL,J)*DF(J)
001243      100 TDLCC(IFUEL)=TDLCC(IFUEL)+DYLCC(IFUEL,J)
001250          DLCCK(IFUEL)=TDLCC(IFUEL)/TK
001252       85 CONTINUE
          C
          C     OUTPUT
          C
001254          PRINT 535,JCOST
001262          PRINT 588
001266          PRINT 591
001272          PRINT 590,( AOC(1,J),J=1,11),TAOC(1), AOCK(1)
001311          PRINT 595
001315          PRINT 591
001321          PRINT 590,(DAOC(J),J=1,11),TDOC,DOCK
001337          PRINT 600
001343          PRINT 591
001347          PRINT 590,(YLCC(1,J),J=1,11),TLCC(1),ALCCK(1)
001366          DO 120 IFUEL=1,5
001370          PRINT 610
001373          IF(IFUEL.EQ.1)GO TO 125
001375          IF(IFUEL.EQ.2)PRINT 579
001402          IF(IFUEL.EQ.3)PRINT 580
001410          IF(IFUEL.EQ.4)PRINT 581
001416          IF(IFUEL.EQ.5)PRINT 582
001424      125 PRINT 591
001430      120 PRINT 590,(DYLCC(IFUEL,J),J=1,11),TDLCC(IFUEL),DLCCK(IFUEL)
001451      300 CONTINUE
001453      350 CONTINUE
001456          STOP
001460      400 FORMAT(7I10)
001460      405 FORMAT(1H0,10I4)
001460      410 FORMAT(7E10.4)
001460      500 FORMAT(1H1,*LIFE CYCLE COST ESTIMATION*)
001460      510 FORMAT(1H1,*VEHICLE CHARACTERISTICS*/9X,*COST*,11X,*WEIGHT*,7X
               1TTERY WT.*,3X,*HEAT ENG. RATING*,1X,*ELEC. MOTOR RATING*,2X,*Z
               1N*)
001460      520 FORMAT(1H ,8E16.6)
001460      530 FORMAT(1H ,5X,*GAS LT/KM*,6X,*DIESEL LT/KM*,8X,*KWH/KM*,4X,*BA
               1Y REPLACE/KM*,4X,*BOEM*)
001460      533 FORMAT(1H0,*ANNUAL MILEAGE*)
001460      534 FORMAT(1H ,4X,*YEAR 0*,4X,*YEAR 1*,4X,*YEAR 2*,4X,*YEAR 3*,4X,
               1R 4*,4X,*YEAR 5*,4X,*YEAR 6*,4X,*YEAR 7*,4X,*YEAR 8*,4X,*YEAR
               1X,*YEAR 10*,4X,*TOTAL*)
001460      535 FORMAT(1H0,*COST CASE=*,I2)
001460      540 FORMAT(1H0,*MILEAGE DEPENDENT COSTS(CENTS/KM)*/2X,*MAINTENANCE
               15X,*HEAT ENGINE*,7X,*CHASSIS*,7X,*ELEC. MOTOR*,7X,*BATTERY*,9X
               1YWHEEL*,06X,*TOTAL*)
001460      550 FORMAT(1H ,8F15.4)
001460      560 FORMAT(1H ,1X,*REPAIR*/5X,*HEAT ENGINE*,7X,*CHASSIS*,7X,*ELEC.
               1OR*,5X,*ACCESSORIES*,5X,*TRANSMISSION*,4X,*TOTAL*)
001460      570 FORMAT(1H ,1X,*FUEL*)
001460      571 FORMAT(1H+,17X,*YEAR 0*,4X,*YEAR 1*,4X,*YEAR 2*,4X,*YEAR 3*,4X
```

```
                 1AR 4*,4X,*YEAR 5*,4X,*YEAR 6*,4X,*YEAR 7*,4X,*YEAR 8*,4X,*YEAR
                 13X,*YEAR 10*)
001460       572 FORMAT(1H ,*PETRO(NOMIN)*,1X,12F10.4)
001460       573 FORMAT(1H ,*PETRO(+30%)*,2X,12F10.4)
001460       574 FORMAT(1H ,*PETRO(-30%)*, 2X,12F10.4)
001460       575 FORMAT(1H ,*ELECT(NOMIN)*,1X,12F10.4)
001460       576 FORMAT(1H ,*ELECT(+30%)*,2X,12F10.4)
001460       577 FORMAT(1H ,*ELECT(-10%)*, 2X,12F10.4)
001460       578 FORMAT(1H ,*TOTAL*)
001460       579 FORMAT(1H+,27X,*(PETROLEUM +30%)*)
001460       580 FORMAT(1H+,27X,*(PETROLEUM -30%)*)
001460       581 FORMAT(1H+,27X,*(ELECTRICITY +30%)*)
001460       582 FORMAT(1H+,27X,*(ELECTRICITY -10%)*)
001460       584 FORMAT(1H+,13X,12F10.4)
001460       585 FORMAT(1H0,*BATTERY REPLACEMENT*)
001460       586 FORMAT(1H ,3X,*BR COST*,3X,*BR LOAN*,2X,*BR PAYMT*,1X,*MILEAGE-
                 1T BATTERY SET*)
001460       588 FORMAT(1H ,*ANNUAL OPERATING COSTS*)
001460       589 FORMAT(1H ,11F10.4)
001460       590 FORMAT(1H ,12F10.2,F10.5)
001460       591 FORMAT(1H ,4X,*YEAR 0*,4X,*YEAR 1*,4X,*YEAR 2*,4X,*YEAR 3*,4X,*
                 1R 4*,4X,*YEAR 5*,4X,*YEAR 6*,4X,*YEAR 7*,4X,*YEAR 8*,4X,*YEAR 9
                 1X,*YEAR 10*,4X,*TOTAL*,5X,*PER KM*)
001460       595 FORMAT(1H0,*DISCOUNTED ANNUAL OPERATING COSTS*)
001460       600 FORMAT(1H0,*LIFE CYCLE COSTS*)
001460       610 FORMAT(1H0,*DISCOUNTED LIFE CYCLE COSTS*)
 01460           END
```

APPENDIX C 3

"ENERGY AND MATERIALS - CURRENT MODEL AUTOMOBILES"

ENERGY AND MATERIALS - CURRENT MODEL AUTOMOBILES

Materials Composition

Excellent agreement has been obtained among the several recent studies which describe the materials composition of modern automobiles.[1-5] Percentage compositions of ferrous metals, aluminum alloys, copper and copper alloys, zinc, glass, rubber, and plastics are changing slowly due to the gradual substitution of lighter materials. In any given year, however, the mass fraction of each particular material appears to be reasonably constant over a range of car weights.

Table I shows the estimated weight breakdown for automobiles as estimated by a 1975 study.[2] The same table gives the author's estimate for 1979 model cars, in the form of a rounded-off interpolation.* These estimated 1979 values will be carried forward to the manufacturing energy estimates.

Energy to Manufacture Automobiles

The investigators Hirst and Herendeen have estimated that it requires 123 million Btu to manufacture a typical American automobile.[6] This figure is similar to a value of 126 million Btu cited by Berry and Fels.[7] McGowan and Kirchoff, by contrast, calculated the manufacturing energy per car to be only 34 million Btu.[8]

* The author of this section was also a principal contributor to the materials accounting in Reference (2).

Table I - Weight Percentage Materials Composition of Automobiles

(Based on Estimates from Reference 2 for 1975, 1980,

and 1990 and an updated estimate by the author for 1979)

Material	Est. for 1975	Projections for 1980	Projections for 1990	Author's Est. for 1979
Low carbon and alloy steel	61.2	56.9	54.2	60.0
Cast and malleable iron	16.2	13.6	7.9	14.0
Aluminum alloys	2.9	6.3	11.9	4.5
Copper and copper alloys	1.0	1.0	0.6	1.0
Zinc	0.8	0.4	0.3	0.6
Lead	0.7	0.8	0.7	0.8
Other metals, incl. magnesium	0.3	0.7	1.4	0.5
Rubber	4.6	5.1	5.0	5.0
Glass	2.4	2.6	2.8	2.6
Plastic	3.5	6.7	9.2	5.0
Other non-metal	6.5	5.9	6.0	6.0
Totals	100.1	100.0	100.0	100.0

Energy requirements to produce basic materials and components has not been a subject of close agreement. References differ, of course on the basis for the estimates; some include only the energy for smelting or processing, while others include the activities of mining, ore transportation, rolling and component fabrication. One must also distinguish between electrical energy and powerplant fuel consumed.

Table II identifies manufacturing energy estimates from several sources, and also sets forth the figures which will be assumed for this present task. These last figures represent our best present estimates of total energy typical for components made of each material, from mine or petroleum feed stock to finished parts. Actual total energies can vary widely with the characteristics of the ore, transportation, method of fabrication, and percentages of scrap vs. virgin materials used.

A final step is to do a trial accounting of the total energy to produce a complete automobile. We have taken as a 1979 baseline a U.S.-produced automobile of 3,620 lb. curb weight, such as the Ford LTD 4-door sedan. This is a six-passenger vehicle with a 302 CID V-8 engine and a wheelbase of 114.4 inches. The results of the energy accounting are given in Table III. A subtotal of 122.6 million Btu is the estimated energy to produce the parts from which the vehicle is assembled. To this must be added the energy to transport the components to the assembly plant, and then the energy to assemble and paint the vehicle. If subassemblies and parts equal to the car's total mass were transported an average of 100 miles, the fuel energy for truck transportation would be about 430,000 Btu. This is based on a referenced figure of 0.0176 gallon of diesel fuel per ton-mile of freight hauled. (15)

A rough estimate of energy expended at the assembly plant can be based on an assumption that about 10 kW might be expended over a ten hour period per car. This is for conveying and hoisting, welding, power tools, paint drying,

Table II - Estimates of Manufacturing and Processing Energy for Materials and Components Used in Automobile Production

Material or Component	Quoted Energy, Btu /lb	Quoted from Reference	Value Used, This Study, Btu/lb
Alloy Steel	22,300	(9)	
Stainless Steel	34,000	(9)	
Steel (Material Processing)	21,500	(3)	
Iron (Material Processing)	15,500	(3)	
Steel (Material Processing)	13,250	(10)	
Steel Auto Hood (Mine to formed part)	28,000	(11)	
Aluminum Hood (45% virgin mat'l)	108,300	(11)	
Aluminum - Primary (Mat'l Processing)	110,000	(3)	
Aluminum - from Scrap (Mat'l. Processing)	10,000	(3)	
Aluminum smelting (Present processes)	22,180	(12)	
Aluminum smelting (New Alcoa process)	15,350	(12)	
Alum (Total energy of metal, from 50% bauxite)	140,900	(13)	
Copper (Total energy metal, from 1.5% ore)	26,780	(13)	
Copper (Total energy metal, from 0.6% ore)	49,540	(13)	
Copper and Alloys	65,700	(9)	
Zinc Castings	45,500	(9)	45,500
Lead	14,700	(14)	15,000
Plastics	25,000	(9)	
Plastics (Incl. feed stock)	78,500	(10)	78,500
Fiber Glass-Reinforced Plastic Hood	40,100	(11)	
Fuel Value, Resin Raw Mtl.	20,000	(11)	
Rubber	37,000	(3)	37,000
Glass	13,000	(3)	13,000

(Table II continued on next page)

Table II - Continued

Material or Component	Quoted Energy, Btu /lb	Quoted from Reference	Value Used, This Study, Btu /lb
Other Materials	37,000	(3)	37,000
Stamped Steel Parts	- -	- -	28,000
Cast Iron Parts, Incl. Machining	- -	- -	20,000
Formed Aluminum Parts (45% Virgin)	- -	- -	108,000
Finished Copper and Cu Alloy Parts	- -	- -	50,000

Table III - Estimate of Manufacturing Energy for an

Automobile of 3,620 lb Curb Weight

(1979 Model Year 4-Door Sedan)

Material, Component, or Process	Mass Fraction,%	Mass, lb	Specific Energy, Btu/lb	Total Energy, Thous. Btu
Steel Components	60.0	2,172	28,000	60,816
Cast and Malleable Iron Parts	14.0	507	20,000	10,140
Aluminum Alloy Parts	4.5	163	108,000	17,604
Copper, Cu Alloy Components	1.0	36	50,000	1,800
Zinc Castings	0.6	22	45,500	1,001
Lead	0.8	29	15,000	435
Rubber	5.0	181	37,000	6,697
Glass	2.6	94	13,000	1,222
Plastic	5.0	181	78,500	14,209
Other Materials and Parts	6.5	235	37,000	8,695
Subtotals	100.0	3,620		122,619
Transportation, Parts and Subassemblies				430
Assembly Plant Energy				1,140
Est. Total Manufacturing Energy				124,189

(Or Approximately 124 million Btu per Car) and general utility supply to the plant. The electrical energy required is about 100 kWh or 341,200 Btu this is raised to 1.14 million Btu fuel energy input if the conversion of fuel to delivered electricity is 30% efficient.

Our estimate of total manufacturing energy per car is 124 million Btu. It is interesting how close this independent estimate is to the 123 million Btu calculated by Hirst and Herendeen.[6]

The energy to produce batteries is of interest from the point of view of manufacturers and owners of electric or hybrid vehicles. From estimates given by Williams in Ref. (14), we calculate that the energy to manufacture an advanced lead-acid battery will be about 15,700 Btu per lb of battery weight. Williams has identified such a battery as having a specific energy of 18 Wh/lb. It should be noted that since 15,700 Btu is the equivalent of the 4,600 Wh of energy to manufacture a pound of battery, the battery would have to undergo the equivalent of over 250 complete discharges before the cumulative stored energy would exceed the original manufacturing energy. In other words, the manufacturing energy is very significant in relationship with the total energy the battery will store over its lifetime.

THE SCRAPPING AND RECYCLING OF AUTOMOBILES: MATERIALS AND ENERGY IMPLICATIONS

Materials Recovery

The materials composition of present and possible future automobiles was given in Table I, and is discussed in detail by References (2) and (5). Approximately ten years after the date of manufacture, cars of these compositions will appear in large numbers in the junkyards.

Ford Motor Co. investigators have stated that the motor vehicle registrations are terminated on about 9 million cars/yr at this time, and that about 90% of these are now being recycled for their metal content - primarily the ferrous metals.[5] These authors further estimate that of the available automotive scrap (in 1974), 85% of the ferrous metal was recovered. Similarly, the recycling ratios for copper, aluminum, and zinc were 62%, 53%, and 27% respectively. It may be inferred that with currently improving techniques for the separation of shredded scrap, the recycling ratios for aluminum and copper will improve. Zinc, since much of it is in the form of galvanized panels and trim, will continue to be difficult to recover.

Not much in the way of plastics is now being recycled, although in the future some economical methods of doing this may be developed. At least two alternatives are to somehow reconstitute the scrap by chemical means, or else to use the scrap plastic as fuel. The average heating value of such material is probably in the range 15,000 - 20,000 Btu /lb. A present objection to burning many plastics is the toxic nature of the combustion products.

The lead from storage batteries is eminently recyclable, and each automobile uses about three or four batteries during its lifetime. Most of the replacement batteries are salvaged in the trade-in process, as are those finally ending up in wrecking yards.

Steps in Resource Recovery

Usually the steps involved in recycling automobiles are:

1. The vehicle is transported to a local wrecking yard (dismantler).
2. A dismantler salvages parts worth reselling, which is a larger fraction in the case of late-model wrecks than for worn-out obsolete cars. In the latter instance, the tires, battery, radiator, and other easy-to-remove parts with a high scrap value are removed. Sometimes the engine and drive train are also removed at this point. The bulk is then flattened or compacted for efficient transport.
3. The bulk is shipped to a processing center, where it is either baled or shredded. Shredding is becoming the preferred technique since it results in a higher grade of ferrous scrap and allows segregation of the other materials. Many shredding plants can take engine blocks and all.
4. Recovered materials are shipped to smelters or foundries. Not all of the material finds its way back to Detroit; much of the ferrous scrap (for example) goes to regional steel mills to be turned into reinforcing bar and structural shapes.

Energy Consumption in Resource Recovery

Transportation- The average number of ton-miles of transportation is not known to us, but one scenario might be the following:

- The entire car, 3620 lb is shipped 20 miles to dismantler.
- After removing 300 lb of material, the remaining 3320 lb is forwarded to shredder, 100 miles away.
- Non-metallics and some lost metal are landfilled near the shedder; assume 2,700 lb metal to be reclaimed is shipped 500 miles further to regional smelters.

- If most of the ferrous material goes to regional steel mills, this might still leave about 1000 lb. smelted metal to be sent another 1000 miles to new users including the auto industry.

The above shipments total 1377 ton-miles. Again using a payload-specific fuel consumption of 0.0176 gal diesel fuel/ton-mile,[15] the aggregate transportation fuel energy would be 3.27 million Btu per recycled automobile. Other assumptions or conditions could alter this outcome appreciably.

<u>Dismantler's Activities</u> - Since dismantling is a labor- intensive activity, not much fuel energy is expended during this part of the process. Hoisting, flame-cutting, in-yard movements, and flattening of the hulk may consume 4 kWh per car at 20% efficiency, or a gross expenditure of 68,240 Btu per car. If 3,620 lb scrap is handled, the specific energy would be 19 Btu /lb.

<u>Shredder</u> - Based on conversations with the operators of shredding plants, one automobile can be shredded in 15 seconds to one minute even with engine block and drive train still in the vehicle. This is a very energy-intense operation, since around 4000 hp is used to drive a hammer mill. Another 2000 hp or so is dedicated to segregation of the resulting scrap particles, and this process is expected to keep pace with the shredding. Our very provisional estimate, based on an assumed 20 seconds for a "car" to pass through each process and then adding 20% more energy for plant idling and overhead consumption, is 339,000 Btu per hulk.

<u>Total Energy for Resource Recovery</u> - The above energy elements are summed up in Table IV. The total energy for scrapping a 3620-lb passenger car and recovering an appreciable fraction of its resources is roughly estimated as 3.7 million Btu. This does not include smelting or process energy to be charged against the next use.

Table IV - Provisional Estimate of Energy Required to Recover Resources from a Junked Automobile

Basis: Original curb weight 3620 lb, and assumptions given in text. These assumed conditions are subject to wide variations.

Activity	Energy for Activity Thous. Btu
Shipping, aggregate of 1408 ton-miles	3,270
Dismantling and Flattening	68
Shredding and Sorting	339
Total Energy Required	3,677

(Approximately 3.7 million Btu. Does not include smelting or process energy for the next use.)

Approximate Mass Accountability:

Removed by dismantler for materials recycling - - -	200 lb *
Removed by dismantler for parts resale - - - - - -	100
Metal salvaged by shredder - - - - - - - - - - - -	2,700
Lost metal and non-metal to landfill - - - - - -	620 **
Original Curb Weight - - - - - - - -	3,620 lb

* Includes some eventual loss such as battery case materials.

** Includes 5% loss of iron and steel, 25% loss of aluminum, and 12 lb loss of zinc.

The largest energy element by far in this total is transportation fuel. Even if this transportation component were assumed to be much less (perhaps through the economies of rail shipment, rather than by truck), it would still dominate the recycling energy requirement.

A recycling energy of almost 4 million Btu per car is to be compared with 124 million Btu to manufacture that car. While the 124 million Btu already includes the energy benefit of some scrap metal recycling, further study could reveal something of the sensitivity to ratio of recycled to virgin materials.

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