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WAY-VEHICLE-OBJECT SIMULATION MODEL--1976

Vol. 1 Users Manual

February 1976
Final Report

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16. Abstract

A series of reports have been written to document revised and updated versions of the simulation of highway-vehicle-object interactions in a single vehicle highway environment. The programs documented were developed under FHWA sponsorship to provide the highway safety community with an analytical means of evaluating the effects of highway/roadside environment on safety.

This manual is the most general of the manuals describing the simulation. It provides an introduction to the simulation and enough information for a user to submit a run, obtain results, and interpret the HVOSM output. No description of the inertial subroutine structure or the derivation of the equations used is supplied.

This manual is one of four volumes.

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FOREWORD

This report is one of a set of manuals prepared under Contract Number DOT-FH-11-8265 for the Federal Highway Administration, U. S. Department of Transportation for the purpose of summarizing and upgrading documentation of the Highway-Vehicle-Object Simulation Model (HVOSM). The HVOSM had been previously developed for the Federal Highway Administration (FHWA) by the Calspan Corporation (formerly Cornell Aeronautical Laboratory) under Contract Number CPR-11-3988 during the period from 1966 to 1971. Contained in this report are summary descriptions of the mathematical models that constitute the two versions of the HVOSM, solution procedures, input requirements, output descriptions, sample applications and descriptions of auxiliary programs used with the HVOSM.

Complete documentation of the HVOSM is contained in the following manuals:

- Highway-Vehicle-Object Simulation Model
  Volume 1 - Users Manual
- Highway-Vehicle-Object Simulation Model
  Volume 2 - Programmers Manual
- Highway-Vehicle-Object Simulation Model
  Volume 3 - Engineering Manual - Analysis
- Highway-Vehicle-Object Simulation Model - Volume 4 -
  Engineering Manual - Validation

This report has been reviewed and is approved by:

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1. INTRODUCTION

In 1966 Calspan Corporation (formerly Cornell Aeronautical Laboratory, Inc.) began development of a general mathematical model and computer simulation of the dynamic responses of an automobile in accident situations under Contract CPR-11-3988 with the Bureau of Public Roads.

The mathematical model of vehicle dynamics developed in the first year of that effort included the general three-dimensional motion resulting from vehicle control inputs, traversal of irregular terrain, or from collisions with simple roadside barriers. The model was subsequently named the Highway-Vehicle-Object Simulation Model (HVOSM). Later, the model was further developed and a comprehensive validation program was carried out including a series of repeatable full-scale tests with an instrumented vehicle in order to objectively assess the degree of validity of the vehicle model. Extensive measurements of the vehicle parameters required for input to the HVOSM were made under a subcontract with the Ford Motor Company as a part of the validation procedure. This effort was reported in Reference 1 and the model as described therein has been referred to as the V-3 version of the HVOSM.

Modifications were subsequently made to the simulation in order to study the effects of terrain (specifically, railroad grade crossings) on vehicle controllability. The impact routines were removed and extended terrain definition capabilities were added along with a more realistic model of suspension properties. This program version (Reference 2) has been informally referred to as the V-4 version of the HVOSM and has since been used extensively for study of roadway and roadside geometrics.

Further developments of HVOSM aimed at providing a simulation model more suitable for the study of the complex dynamics resulting from accident avoidance evasive maneuvers were reported in Reference 3. This version, informally called the V-7 version of the HVOSM, includes a detailed model of the braking and engine-driveline systems and an empirically based definition of the relationships between longitudinal and lateral tire forces through the inclusion of rotational degrees of freedom of the four vehicle wheels.

During development of the HVOSM, documentation efforts primarily fulfilled the objectives of maintaining communication within the program development structure, ensuring quality control of the development and providing a historical reference. It was, however, recognized early in the development of the HVOSM, that this state-of-the-art advance in the modeling of a vehicle and its environment could be put to best use through its widespread distribution to organizations interested in its application to highway safety. As a result, distribution of the HVOSM was begun before its development was complete and before instructional documentation could be provided.

Recognizing the need to bring documentation of the several HVOSM versions together and to provide the highway safety community with an effective description of the programs and their use, the Federal Highway Administration (FHWA) awarded Calspan Corporation contract number DOT-FH-11-8265 for the purpose of providing such documentation for the then existing versions of the HVOSM.

Three versions of the HVOSM were covered by this documentation. They were, the HVOSM-SMI1 (Sprung Mass Impact) version (formerly known as the V-3 version), the HVOSM-RD1 (Roadside Design) version (formerly known as the V-4 version) and the HVOSM-VD1 (Vehicle Dynamics) version (formerly known as the V-7 version). Under the first phase of that effort, only those versions as developed by Calspan were covered by the documentation.

The second phase of contract number DOT-FH-11-8265 called for extension of the capabilities of the HVOSM by adding new features, including some additional modifications made by other research organizations, and providing additional ease of use features.

Accordingly, Calspan has:

- Generalized the basic vehicle model to include the capability for simulating an independent front and rear suspension vehicle and a vehicle with solid front and rear axles.

- Generalized the tire model to allow specification of up to four different tires on a vehicle and revised the friction ellipse tire model.

- Combined the sprung mass impact version with the roadside design version resulting in only two program versions at the end of the second phase.

- Incorporated the Preview-Predictor Driver Model described in Reference 9 into the vehicle dynamics model.

- Incorporated impact forces due to localized structural hardpoints into the sprung mass impact algorithm. This modification was originally developed by the Texas Transportation Institute (TTI) and was added as reported in Reference 10.

- Extended the curb impact algorithm to allow up to six planes to describe a curb. This modification was also developed by TTI and was reported in Reference 11.

- Developed a road roughness algorithm to allow determination of the effects of road roughness on vehicle performance.

- Revised input and output format to provide an easy to use, more flexible data interface.

- Developed a Pre-Processing Program to calculate a number of program inputs including vehicle and terrain data or to supply input cards from a stored library of vehicle data.

The documentation provided now covers the two program versions: the HVOSM-RD2 Version (Roadside Design) and the HVOSM-VD2 Version (Vehicle Dynamics). It is intended to be a base to which further developments and modifications to the HVOSM can be added, thus providing a uniform reporting format and centralized source of information for the many HVOSM users. It consists of four volumes, each describing a separate aspect of the HVOSM. Two volumes are directed toward the engineer/analyst containing the analysis (derivation of governing equations, assumptions, and development of controlling logic) and experimental validation. Another volume is directed toward the general program user and contains analysis/program symbology, descriptions of the models and solution procedures, descriptions of input requirements and program output, and a number of program application examples. The fourth volume of documentation is intended for use by those interested in the detailed computer programs. This fourth volume contains descriptions of the computer code including a discussion of subroutine functions, annotated flowcharts and program listings. Also included are a list of program changes, a description of program stops and messages, and computer system requirements necessary to run the programs.

This report constitutes a guide for HVOSM users. Section 2 contains a cross-referenced listing of both analytical and program symbols. Section 3 contains a general discussion of program capabilities and limitations, a description of the mathematical model, and a discussion of general program solution procedures. Program input and output is described in Section 4 and sample applications are presented in Section 5. The last section of text, Section 6, describes usage of an auxiliary HVOSM Vehicle Graphics Program and the HVOSM Pre-Processing Program.

2. SYMBOLOGY

The HVOSM symbology is presented in this section with a cross-reference between analytical and programming symbols. The first listing of symbols is ordered with respect to analytical symbol and includes a corresponding program symbol, a brief definition and an equation number referencing the calculation of the variable in the "HVOSM Engineering Manual - Analysis". Input variables are indicated by an I in the equation number column.

The second listing of variables is organized by program symbol name and includes a corresponding analytical variable or expression and variable usage in each program version. The codes U and A under the program version name indicate that the variable is used, or appears but is not used respectively in that version.

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
a	A	I	Distance along vehicle fixed x axis from the sprung mass center of gravity to the center line of the front wheels	in.
a_i, b_i, c_i		155	Directional components of a line perpendicular to both the normal to the wheel plane and the radial tire force, F_{R_i}	
APD APDMAX	APD APDMAX	345 I	Accelerator pedal deflection and maximum accelerator pedal deflection	in
$a_{s_i}, b_{s_i}, c_{s_i}$	AS(4) BS(4) CS(4)	258	Directional components of a line perpendicular to both a normal to the tire-terrain contact plane and the line of intersection of the wheel and ground planes	
$a_{x_i}, b_{x_i}, c_{x_i}$	AX(4) BX(4) CX(4)	99	Direction components of a line perpendicular to both a normal to the tire-terrain contact plane and the vehicle fixed y axis	
$a_{y_i}, b_{y_i}, c_{y_i}$	AY(4) BY(4) CY(4)	104	Direction component of a line perpendicular to both a normal to the tire-terrain contact plane and the vehicle fixed x axis	
$[A]$	AMTX(3,3)	53	Transformation matrix from vehicle fixed to space fixed coordinate systems	
$(A_{INT})_i$	AINTI	287	Intersection area of cutting plane i with the sprung mass	in^2
$[A_j]$	AJMTX(3,3)	134	Transformation matrix from wheel fixed to vehicle fixed coordinate systems	
AMU	AMU	I	Tire-terrain friction coefficient at zero speed and nominal tire loading	
AMUG	AMUG(5)	I	Tire-terrain friction coefficient factor for 5 terrain tables	
$(AP)_F$	APF(21)	I	Anti-pitch coefficients for front suspension positive for anti-pitch for forward braking	lb/lb-ft
$(AP)_R$	APR(21)	I	Anti-pitch coefficients for rear suspension, effective at the wheels; positive for anti-pitch effect for forward braking	lb/lb-ft
$(AR)_j$	ARBRF ARBRR	I	Drive axle ratio (propeller shaft speed/wheel speed). Default of 1.0	
A_0, A_1, A_2	A0,A1,A2	I	Constant coefficients for tire side force due to slip angle	
A_3, A_4	A3,A4	I	Constant coefficients for tire side force due to camber angle	
b	B	I	Distance along the vehicle fixed x axis from the sprung mass center of gravity to the centerline of the rear wheels (entered positive)	in.
$[B]$	BMTX(3,3)	134	Transformation matrix from wheel fixed to space fixed coordinate systems	
B_{FP1} B_{FP2}	BFP1 BFP2	I	First and second order coefficients for relationship between brake pedal force and brake system pressure	psi/lb$_2$ psi/lb^2
$[B_n]$	BNMTX(3,3)	60	Transformation matrix from orientation of vehicle axes at indexing to space fixed axes (Euler angles= $\psi_n', \theta_n', \phi_n'$)	
C_{co}		215	Small angle camber stiffness	lb/rad
C_F, C_R	CF CR	I	Front and rear viscous damping coefficient for a single wheel, effective at the wheel for the front and at the spring at the rear	lb-sec/in
C'_F, C'_R	CFP CRP	I	Front and rear coulomb damping for a single wheel, effective at the wheel for the front and at spring for the rear	lb
$[C_i]$	CMTX(3,4)	110	Coefficient matrix for simultaneous solution of the ground contact point	
$\overline{CONS}$	CONS	I	Ratio of conserved energy to total energy absorbed by the sprung mass	
$[C_n]$	CNMTX(3,3)	60	Transformation matrix from vehicle fixed axes to most recently indexed axes (Euler angles= $\psi_t', \theta_t', \phi_t$)	
C_{RRMi}	RRMC(4)	I	Rolling resistance moment coefficient	lb-in/lb
C_{So}		214	Small angle cornering stiffness	lb/rad
(CT)	TCT(12)	I	Closed throttle engine torque	lb-ft

2

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO	DEFINITION	UNITS
C_{Ti}	CT(4)	I	Circumferential tire force stiffness	lb
C'_ψ	CPSP	I	Coulomb resistance torque in the steering system effective at the wheels	lb-in
C_1, C_2, C_3	CONE CTWO CTHREE	I	Coefficients in relationship approximating aerodynamic and rolling resistance	
[D]	DMTX(10,11)	46	Mass matrix of coupled second order differential equations. Column 11 contains the forcing functions	
Dax	DELTAX	342	Desired vehicle acceleration	in/sec^2
DELB DELE DDEL	DELB DELE DDEL	I I I	Beginning, end, and incremental wheel deflection for entered front wheel camber table	in
DIST	DIST	I	Desired speed differential nulling distance	in
DRWHJ	DRWHJ	I	Incremental tire deflection for calculation of the equivalent tire force-deflection characteristic in the radial mode	in
D_{1i}, D_{2i}, D_{3i}	D1(4) D2(4) D3(4)	87	Direction components of a line perpendicular to the normals of both the wheel plane and the tire-terrain contact plane	
e_i	EI	320	Error between predicted and desired path at the ith viewing position	in
EN	EN	I	Number of points at which e_i is determined	
F_{APi}	APITCH	188	Anti-pitch force at wheel i	lb
F_{ARi}		187	Force at wheel i due to auxiliary roll stiffness	lb
F_B	FB		Resistance force normal to the contact surface of a deformable barrier	lb
FBRK	FBRK	346	Brake pedal force	lb
F_{c_i}	FC(4)	225	Circumferential tire force	lb
Fcxui Fcyui Fczui	FCXU(4) FCYU(4) FCZU(4)	254	Components of the circumferential tire force along the x,y, and z axes	lb
F_j	FJP(35)	144	Table of equivalent radial spring forces as a function of deflection	lb
F_{JFi}	FJF(4)	179	Jacking force at wheel i	lb
$(Fn)_t$	FN	298	Vehicle force produced by deformation of the vehicle structure normal to the contacted surface	lb
F_{NSTi}	FNSTI(3)	300	Structural hard point force	lb
F_{R_i}	FR(4)	114	Radial tire force in the plane of the wheel	lb
F'_{Ri}	FRCP(4)	212	Tire force perpendicular to the tire-terrain contact plane	lb
(FRICT)	FRICT	306	Friction force acting between the vehicle sprung mass and barrier	lb
F_{Rxui} F_{Ryui} FRzui	FRXU(4) FRYU(4) FRZU(4)	253	Components of F'_{Ri} along the sprung mass axes for wheel i	lb
$\Sigma F_{Rx}{}'_i$ $\Sigma F_{Ry}{}'_i$ $\Sigma F_{Rz}{}'_i$	SFRX(4) SFRY(4) SFRZ(4)	144 145 146	Summation of the components of radial spring mode forces over tire i, with respect to space	lb
F_{Si}	FS(4)	227	Tire side force in the plane of the tire-terrain contact patch perpendicular to the line of intersection of the wheel plane and ground plane	lb
F'_{Si}		220	Resultant side force corresponding to small angle properties for slip and camber angles	lb
$(F_{si})_{max}$		224	Maximum achievable side force as limited by the available friction	lb
ΣF_{xs}	SFXS	307 351	Sprung mass impact force or combination of rolling resistance and aerodynamic drag acting along the vehicle x axis	lb
Fsxui Fsyui Fszui	FSXU(4) FSYU(4) FSZU(4)	256	Components of tire side force, F_{si} along the sprung mass axes	lb
Fxui Fyui Fzui	FXU(4) FYU(4) FZU(4)	259 260 261	Total tire force components along the vehicle axes	lb
Σ Fxu Σ Fyu	SFXU SFYU	353 354	Resultant forces acting on the vehicle through the unsprung masses in the x and y directions	lb
Σ Fys	SFYS	307	Sprung mass impact force acting along the vehicle y axis	lb
Σ Fzs	SFZS	307	Sprung mass impact force acting along the vehicle z axis	lb
ΣF_{Z1}	SFZ1	356	Resultant force transmitted through the suspensions in the z direction	lb
F_{1Fi} F_{1Ri}	F1FI(2) F1RI(2)	174 184	Front and rear suspension coulomb damping forces for a wheel, effective at the wheel for the front and at the spring for the rear	lb

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
F_{2Fi} F_{2Ri}	F2FI(2) F2RI(2)	175 185	Front and rear suspension spring and bumper forces for a wheel, effective at the wheel for the front and at the spring for the rear	lb
g	G	I	Acceleration due to gravity	in/sec^2
$GEAR_1$ $GEAR_2$ $GEAR_3$ $GEAR_4$	GEAR1 GEAR2 GEAR3 GEAR4	I	Transmission gear ratios	—
G_{1j}	GN(1,J)	I	Lever arm lengths in brake types 1,2 and 3	in
G_{2j}	GN(2,J)	I	Brake actuation constant, assumed to be equal for both shoes of brake types 1 and 2	
G_{3j}	GN(3,J)	I	Effective lining-to-drum or lining to-disk friction coefficient at design temperature for all shoes or disks in types 1,2 and 4 and for the primary shoe of type 3	
G_{4j}	GN(4,J)	I	Cylinder area for actuation of leading shoe of brake type 1, or for each shoe in types 2 and 3. Also used for total cylinder area per side of disk in type 4	in^2
G_{5j}	GN(5,J)	I	Cylinder area for actuation of trailing shoe of brake Type 1	in^2
G_{6j}-G_{11j}	GN(6,J)- GN(11,J)	I	Brake dimensions for type 3.	in
G_{12j}	GN(12,J)	I	Effective lining to drum friction coefficient for secondary shoe of brake type 3	
G_{13J}	GN(13,J)	I	Mean lining radius for brake type 4	in
G_{14j}	GN(14,J)	I	Coefficient of heat transfer for convective losses	
G_{15j}	GN(15,J)	I	Specific heat of brake assembly	BTU/lb/°F
G_{16j}	GN(16,J)	I	Effective weight of brake assembly for heat absorption	lb
h_i	HI(4)		Tire rolling radius	in
I_{Dj}	FIDJ(2)	I	Driveline inertia for front or rear (Note that a value of zero is entered at the non-driving end of the vehicle)	$lb\text{-}sec^2\text{-}in$

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
I_R	XIR	I	Rear unsprung mass moment of inertia about a line through its center of gravity and parallel to the vehicle x axis	$lb\text{-}sec^2\text{-}in$
I_{wj}	FIWJ(4)	I	Rotational inertia of an individual wheel at the front or rear	$lb\text{-}sec^2\text{-}in$
Ix,Iy,Iz	XIX XIY XIZ	I	Spring mass moments of inertia about the vehicle axes	$lb\text{-}sec^2\text{-}in$
Ixz	XIXZ	I	Spring mass roll-yaw product of inertia	$lb\text{-}sec^2\text{-}in$
(I'x)t		47	Effective inertial term due to time varying positions of the unspring masses	
(I'z)t		47	Effective inertial term due to time varying positions of the unspring masses	
(I'xz)t		47	Effective inertial term due to time varying positions of the unspring masses	
(I'yz)t		47	Effective inertia term due to time varying positions of the unspring masses	
I_ψ	XIPS	I	Moment of inertia of the steering system effective at the front wheels (includes both wheels)	$lb\text{-}sec^2\text{-}in$
K_d	FKD	I	Performance parameter characterizing understeer/oversteer properties of the vehicle	sec^2/in
K_F,K_R	AKF AKR	I	Front and rear suspension load deflection rate in the quasi-linear range about the design position effective at the front wheels and the rear springs	lb/in
K_{FC},K_{RC}	AKFC AKRC	I	Coefficients for the compression bumpers of the front and rear suspension effective at the front wheels and rear springs	
K'_{FC},K'_{RC}	AKFCP AKRCP	I	Coefficients for the cubic terms of the suspension compression bumpers	
K_{FE},K_{RE}	AKFF AKRE	I	Coefficients for the extension bumpers of the front and rear suspension effective at the front wheels and rear springs	

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO	DEFINITION	UNITS
K_{FE}', K_{RE}'	AKFEP AKREP	I	Coefficients for the cubic terms of the suspension extension bumpers	
K_P	FKP	328	Driver steer control gain	
K_{RS}	AKRS	I	Rear axle roll-steer coefficient, positive for roll understeer	
K_{S1}, K_{S2}	FKS1 FKS2	I	Drivers estimate of vehicle braking and accelerating gains	
K_{STi}	AKST(3)	I	Structural hard point spring rates	lb/in
K_T	AKT	I	Radial tire rate in the quasi-linear range	lb/in
K_V	AKV	I	Load-deflection characteristic of the vehicle structure	lb/in^3
$K_{\delta S}, K_{\delta S1}, K_{\delta S2}, K_{\delta S3}$	AKDS AKDS1 AKDS2 AKDS3	I	Coefficients of the cubic representation of rear wheel steer as a function of deflection for independent rear suspension	
K_ψ	AKPS	I	Load-deflection rate for the linear steering stop, effective at the wheels	lb-in/rad
K_1	AK1	I	Slope of P_R vs P_F for values of P_F between P_1 and P_2	
K_2	AK2	I	Slope of P_R vs P_F for values of P_F greater than P_2	
$(LF)_i$	FLF	I	Fade coefficient for brake at wheel i	
M_S	XMS	I	Sprung mass	$lbsec^2/in$
M_{UF}, M_{UR}	XMUF XMUF	I	Front (both sides) and rear unsprung masses. Note $M_1=M_2=M_{UF}/2$, $M_3=M_{UR}$	$lbsec^2/in$
M_1, M_2	$\frac{XMUF}{2}$		Right and left front unsprung masses	$lbsec^2/in$
M_3	XMUR	I	Rear unsprung mass	$lbsec^2/in$
NBX	NBX(5)	I	Number of x' boundaries supplied for 5 terrain tables	
NBY	NBY(5)	I	Number of y' boundaries supplied for 5 terrain tables	
NDEL	NDEL		Number of entries in the front wheel camber table	
NX	NX(5)		Number of x' grid points in 5 terrain tables	
NY	NY(5)		Number of y' grid points in 5 terrain tables	
NZTAB	NZTAB	I	Number of terrain tables entered	

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
P_1, P_2	PONE PTWO	I	"Break" pressures for brake system proportioning valve	psig
$(RATIO)_i$			Factor used to modify the nominal tire-terrain friction coefficient at wheel i to reflect the effects of vehicle speed and tire loading	
R_{BB}	RBB	280	Constant for harrier bottom plane	in
R_{Bi}	RBI	269	Constant for barrier face plane	in
R_{BT}	RBT	281	Constant for barrier top plane	in
R_{B_1}	RB1	273	Constant for the plane perpendicular to the barrier face plane and containing the axis of rotation	in
NZ5	NZ5	I	Flag to indicate whether the variable increment terrain table is supplied, =0,no,≠0, yes	
$\Sigma N_{\phi F}$	SNPF	347	Roll moment acting on the front axle	lb-in
$\Sigma N_{\phi R}$	SNPR	360	Roll moment acting on the rear axle	lb-in
$\Sigma N_{\phi S}$	SNPS	308	Roll moment on the sprung mass resulting from sprung mass impact forces	lb-in
$\Sigma N_{\theta S}$	SNTS	309	Pitch moment on the sprung mass resulting from sprung mass impact forces	lb-in
$\Sigma N_{\psi S}$	SNPSS	310	Yaw moment on the sprung mass resulting from sprung mass impact forces	lb-in
$\Sigma N_{\phi U}$ $\Sigma N_{\theta U}$ $\Sigma N_{\psi U}$	SNPU SNTU SNPSU	357 358 359	Moments acting on the sprung mass produced by forces acting on the unsprung masses	lb-in
P,Q,R	P,Q,R	48	Scalar components of the sprung mass angular velocity along the vehicle x,y and z axes	rad/sec
P_C	PC	I	Hydraulic pressure in brake system master cylinder	psig
P_j	PP(2)	197	Hydraulic pressure in brake cylinders at front or rear brakes	psig
(PS)			Prop shaft speed	rpm

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
(PT)	XPS	I	Pneumatic trail of front tires	in
R_F, R_R	RF,RR	I	Auxiliary roll stiffness of the front and rear suspensions	lb/in/rad
(RPME)	RPME	211	Engine speed	rpm
$(RPS)_i$	RPSI(4)	44	Rotational velocity of wheel i, positive for forward motion of the vehicle	rad/sec
R_{RMi}	RRM(4)	352	Rolling resistance moment acting on wheel i	lb-in
R_W	RW	I	Undeflected tire radius	in
RWHJB RWHJE	RWHJB RWHJE	I	Beginning and ending radii for calculation of the radial tire force-deflection characteristic used in the radial tire mode	in
SET	SET	I	Ratio of permanent deflection to maximum deflection of deformable barrier	
S_i	SI(4)	173 183	Total suspension force for a wheel, acting at the front wheels and rear springs	lb
$(SLIP)_i$	SLIP(I)	241	The amount by which the rotational speed of wheel i is less than that of free rotation expressed as a decimal portion of the speed of free rotation	
$(SLIP)_{pi}$	SLIPP	198	The value of (SLIP)i, at a given wheel center speed U_{Gi} for which the value of μ_{x_i} is a maximum	
SP_n	ST(5,2)	I	Coefficients for straight line segments defining the desired path	
$(S_1)_i$, $(S_2)_i$, $(S_3)_i$	S1I S2I S3I	284 285 286	Characteristic lengths of intersection area between the sprung mass and barrier	in
t	T		Time	sec
T_b	TESTB	I	Braking indifference level	in/sec
T_B, T_E TINCR	TB,TE TINCR	I	Beginning, ending and incremental times for entry of control tables $(TQ)_F$, $(TQ)_R$ and ψ_F	sec
T_F, T_R	TF,TR	I	Front and rear track	in
T_i	TI(4)	225	Circumferential tire force resulting from applied torque	lb
T_I, T_L	TIL TL	I	Driver steering model lag and lead times	sec
$(TQ)_{Bi}$	TQB(4)	204	Brake torque at wheel i	lb-ft
$(TQ)_{Dj}$	TQD(4)	211	Drive line torque at prop shaft at vehicle end j	lb-ft
$(TQ)_E$	TQE	210	Engine torque	lb-ft
$(\overline{TO})_F(\overline{TD})_R$	TQF(5D) TQR(5D)	I	Front and rear torque tables for a single wheel and effective at the wheel (positive for traction, negative for braking)	lb-ft
(TR)	TTTR	I	Transmission ratio (speed ratio of engine to prop shaft)	
T_{R_1}, T_{R_2}	TESTR1 TESTR2	I	Lower and upper skid thresholds	
T_S	TS	I	Distance between spring mounts for a solid rear axle	in
T_{SF}	TSF	I	Distance between spring mounts for a solid front axle	in
(TS)	TTTS	I	Throttle setting expressed as the decimal portion of wide open throttle	
T_{S1}, T_{S2}	TESTS1 TESTS2	I	Driver threshold/indifference levels for positive and negative speed errors	in/sec
(TYPE)	NBTYPE	I	Brake type indicator	
$T_{1\psi}$	T1PSI	36	Coulomb friction torque in steering system effective at the wheel	lb-in
$T_{2\psi}$	T2PSI	36	Resistance torque produced by the front wheel steer stops, effective at the wheel	lb-in
u,v,w	U,V,W	48	Scalar components of linear velocity of the sprung mass along the sprung mass x,y and z axes	in/sec
u',v',w'	DXCP DYCP DZCP	64	Scalar components of linear velocity of the sprung mass along the space fixed x',y' and z' axes	in/sec
u_i, v_i, w_i	UI(4) VI(4) WI(4)	90- 98	Scalar components of the tire contact points linear velocity along the vehicle axes	in/sec
U_{Gi}	UG(4)	103	Wheel center forward velocity in direction parallel to the tire-terrain contact plane	in/sec
U_{Gwi}	UGW(4)	195	Ground contact point velocity along the circumferential direction of the wheel	in/sec
u'_n v'_n w'_n	UNP(17) VNP(17) WNP(17)	282	Components of the velocity of the three or four points that define the intersection area of the barrier and vehicle along the space-fixed axes	in/sec

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
u'_r v'_r w'_r	URP VRP WRP	303	Components of the velocity of the point of application of the sprung mass impact force along the space-fixed axes	in/sec
U'_{STi} V'_{STi} W'_{STi}	UPT(4) VPT(4) WPT(4)	299	Components of the velocity of the deformed structural hard points along the space fixed axes	in/sec
U_T	UT	313	Total vehicle velocity	in/sec
v_{Gi}	VG(4)	106	Contact point lateral velocity in the direction parallel to the tire-terrain contact plane	in/sec
VGR_{12} VGR_{21} VGR_{23} VGR_{32} VGR_{34} VGR_{43}	VGR12 VGR21 VGR23 VGR32 VGR34 VGR43	I	Vehicle speed at which transmission upshifts and downshifts occur	mph
(VTAN)	VTAN	305	Tangential velocity between the vehicle and barrier	in/sec
WE_i	WEIGHT(I)	328	Driver steering error weighting function	
WI_i	XIMPOR(I)	I	Driver steering error importance weighting function	
(WOT)	TWOT		Wide open throttle torque	lb-ft
X_B, X_E XINCR	XB(5) XE(5) XINCR(5)	I	Beginning, ending and incremental x' for terrain tables	in
x_{BB}, y_{BB} z_{BB}	XBB YBB ZBB	279	Coordinates of the intersection of the z' axis with the barrier bottom plane in the vehicle axes	in
X_{BDRY}	XBDRY(4,5)	I	x' intercept for angled boundaries within terrain tables	in
x_{Bi} y_{Bi} z_{Bi}	XBI YBI ZBI	267	Coordinates of the intersection of the y' axis with cutting plane i, in the vehicle axes	in
x_{BT} y_{BT} z_{BT}	XBT YBT ZBT	278	Coordinates of the intersection with the barrier top plane in the vehicle axes	in
x'_c, y'_c, z'_c	XCP YCP ZCP	65 66 67	Coordinates of the origin of the vehicle axes (sprung mass center of gravity) with respect to the space fixed axes	in
x_{cpn} y_{cpn} z_{cpn}	XCPN(3) YCPN(3) ZCPN(3)	214	Coordinates of the vehicle corner n in the vehicle axes	in
x'_{cpn} y'_{cpn} z'_{cpn}	XCPNP(3) YCPNP(3) ZCPNP(3)	214	Coordinates of the vehicle corner n in the space-fixed axes	in
$X'_{GP_i}, Y'_{GP_i},$ Z'_{GP_i}	XGPP(4) YGPP(4) ZGPP(4)	150 151	Coordinates of the ground contact points with respect to the space-fixed axes	in
x'_i, y'_i, z'_i	XP(4) YP(4) ZP(4)	68- 82	Coordinates of the wheel centers with respect to the space fixed axes	in
x_n y_n z_n	XNN(17) YNN(17) ZNN(17)	276	Coordinates of intercept points between the barrier and sprung mass in the vehicle axes	in
X'_{Pi} y'_{Pi}	X Y	318	Coordinates of the location on the desired path at which the ith error is determined	in
x_{Ri} y_{Ri} z_{Ri}	XRI YRI ZRI	294	Coordinates of the centroid of the intersection area on cutting plane i, projected on to the actual vehicle barrier interface of the previous time increment	in
$(\Sigma x_R)_t$ $(\Sigma y_R)_t$ $(\Sigma z_R)_t$	SXR SYR SZR	295 296 297	Coordinates of the point of application of the sprung mass impact force	in
X_{STi} y_{STi} z_{STi}	XSTI(3) YSTI(3) ZSTI(3)	301	Coordinates of the deformed structural hard points in the vehicle axes	in
X_{STi_o} y_{STi_o} z_{STi_o}	XSTIO(3) YSTIO(3) ZSTIO(3)	I	Coordinates of the underformed structural hard points in the vehicle axes	in
x_{VF}	XVF	I	Distance from the sprung mass c.g. to the vehicle front along the x axis	in
x_{VR}	XVR	I	Distance from the sprung mass c.g. to the vehicle rear along the x axis	
X'_{VP_i} y'_{VP_i}	XVP YVP	312 313	Driver prediction of vehicle location at the ith sample increment in the future	in
X_1, Y_1, Z_1 X_2, Y_2, Z_2	X1,Y1,Z1 X2,Y2,Z2	I	Coordinates of accelerometer positions with respect to the vehicle axes for which acceleration components are output	in
$\{y\}$	VAR		System dependent variable, integral of $\{\dot{y}\}$	
$\{\dot{y}\}$	DER	47	First derivatives with respect to time of the system dependent variables	
Y_B Y_E YINCR	YB(5) YE(5) YINCR(5)	I	Beginning, ending and incremental y' for terrain tables	in
Y_{BDRY}	YBDRY(4,5)	I	Lateral position of y' terrain boundaries with respect to space	in
y'_B	YBP	I	Lateral position of the barrier face plane with respect to space	in
y'_{C1}, y'_{C2} y'_{C3}, y'_{C4} y'_{C5}, y'_{C6}	YC1P YC2P YC3P YC4P YC5P YC6P	I	Lateral positions of slope changes defining a curb	in
y_v	YV	I	Distance from the sprung mass c.g. to the vehicle side	in
z'_{BB}	ZBBP	I	Elevation of the bottom barrier plane in space	in

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
Z'_{BT}	ZBTP	I	Elevation of the top barrier plane in space	in
Z'_{C2}, Z'_{C3}	ZC2P	I	Elevation of curb at slope_{C2}	in
Z'_{C4}, Z'_{C5} Z'_{C6}	ZC3P ZC4P ZC5P ZC6P	I	Change lateral positions	
Z_F	ZF	I	Static distance along z axis between the sprung mass center of gravity and the center of gravity of the front unsprung masses	in
$\bar{Z}'_G$	ZGP(21,21,5)	I	Input elevations of the terrain table grid points	in
Z'_{Gi}	ZPGI(4)	126	Ground elevation with respect to the space axes of the point beneath the wheel centers	in
Z'_{Gi}			A vector through the ground contact point normal to the actual or equivalent ground contact plane	
Z_R	ZR	I	Static distance along the z axis between the sprung mass center of gravity and the rear axle roll center	in
Z_{VB}	ZBV	I	Distance from the sprung mass c.g. to the plane defining the bottom of the vehicle along the z axis	in
Z_{VT}	ZVT	I	Distance from the sprung mass c.g. to the plane defining the top of the vehicle, along the z axis	in
$\alpha_B, \beta_B, \gamma_B$		266	Direction angles of a normal to the barrier face plane in the vehicle axes	
$\alpha_{BT}, \beta_{BT}, \gamma_{BT}$		277	Direction angles of a normal to the barrier top plane in the vehicle axes	
$\alpha_{B1}, \beta_{B1}, \gamma_{B1}$		273	Direction angles of a normal to the plane perpendicular to the barrier face plane and containing the axis of rotation	

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
$\alpha_{ci}, \beta_{ci}, \gamma_{ci}$		255	Direction angles of a line perpendicular to the normals of both the wheel plane and tire-terrain contact plane with respect to space	rad
$\alpha_{GZ'_i}, \beta_{GZ'_i}, \gamma_{GZ'_i}$		84	Direction angles of a normal to the tire-terrain contact plane at wheel i with respect to space	rad
$\alpha_{ki}, \beta_{ki}, \gamma_{ki}$		116	Direction angles of the resultant radial force on wheel i with respect to the vehicle axes	rad
$\alpha_j, \beta_j, \gamma_j$		143	Direction angles of a line from wheel center i to the ground contact point of tire radial spring j with respect to the vehicle axes	
$\alpha_{Ri}, \beta_{Ri}, \gamma_{Ri}$		148	Direction angles of the resultant radial force on wheel i with respect to the space axes	rad
$\alpha_{s_i}, \beta_{s_i}, \gamma_{s_i}$		257	Direction angles of a line perpendicular to both a normal to the tire-terrain contact plane and the wheel axis with respect to space	rad
$\alpha_x, \beta_x, \gamma_x$		102	Direction angles of the x axis with respect to space	
$\alpha_y, \beta_y, \gamma_y$		100	Direction angles of the y axis with respect to space	
$\alpha_{yw_i}, \beta_{yw_i}, \gamma_{yw_i}$		85	Direction angles of a normal to the wheel i with respect to space	
$\alpha_{w_i}, \beta_{w_i}, \gamma_{w_i}$		88	Direction angles of kingpin axis of wheel i	
β_i			Slip angle at wheel i	rad
β'_i	BETP(4)	219	Equivalent slip angle produced by camber of wheel i	rad
$\bar{\beta}_i$	BETBR(4)	223	Non dimensional slip angle variable for wheel i	
γ_1 $(\gamma_2)_t$ $(\gamma_3)_t$	GAM1 GAM2 GAM3	47	Inertial expressions	

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
$(\tau_4)_t$	GAM4	47	Inertial expressions	
$(\tau_5)_t$	GAM5			
$(\tau_6)_t$	GAM6			
$(\tau_7)_t$	GAM7			
$(\tau_8)_t$	GAM8			
$(\tau_9)_t$	GAM9			
	DELBB		Barrier deflection	in
δ_1	DEL1		Right front suspension deflection for independent front suspension or front axle roll center deflection relative to the vehicle from position of statis equilibrium	in
δ_2	DEL2		Left front suspension deflection relative to the vehicle from static equilibrium position	in
δ_3	DEL3		Right rear suspension deflection for independent rear suspension or rear axle roll center deflection relative to the vehicle from static equilibrium position	in
δ_4	DEL4		Left rear suspension deflection relative to the vehicle from static equilibrium position	in
Δ_G	DELG	I	Distance between road roughness input points	in
Δ_i	DELTA(4)	112	Distance between the wheel center and ground contact point	in
Δt	DT	I	Numerical integration step interval	sec
Δt_B	DELTB	I	Time increment for use during barrier impacts	sec
Δt	DELTC	I	Numerical integration step size for curb impact option	sec
Δt_n	DTR		Integration step size for use with wheel spin equations of motion	sec
$\Delta\bar{T}_{HFi}$ ΔT_{HRi}	DTHF1 DTHF2 DTHR3 DTHR4	I	Front and rear half-track changes with suspension deflection	in
$\Delta y'_B$	DELYBP	I	Incremental deflection of the barrier position	in
$\Delta\bar{\psi}_{Fj}$	DPSILF	328	Ideal steer angle change	rad
$\bar{\epsilon}_B$	EPSB	I	Acceptable error in the force balance between the vehicle structure and barrier	lbs

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
ϵ_F, ϵ_R	EPSF EPSR	I	Friction lag in front and rear suspensions	in/sec
ϵ_n	EPSL		Permanent set of the barrier for secondary impacts	in
ϵ_V	EPSV	I	Friction lag in the vehicle-barrier friction force	in/sec
ϵ_ψ	EPSPS	I	Friction lag in steering system	deg/sec
ζ_B	ZETAB	I	Threshold value of wheel rotational velocity below which logic is applied to limit brake torques	rad/sec
ζ_i		171	Suspension displacement of the relative to the vehicle from the position of static equilibrium	in
$(\zeta_0)_n, (\zeta_1)_n$ $(\zeta_2)_n$	CD0 CD1 CD2		Coefficients for unloading force deflection characteristic of the barrier	
θ_C	THESKD	336	Vehicle slip angle	rad
θ_{G_i}	THGI(4)	124	Pitch angle of terrain under wheel i relative to the space axes	rad
θ'_n	THETN		Value of θ at t=0 or at the nth indexing of the axes	rad
ϕ'_t	THETT	57	integrated value of $\dot{\theta}$ from t=0 or the nth indexing of the axes	
θ'_{xG_i}		101	Angle between the x axis and the tire-terrain contact plane at wheel i	rad
λ_B	TLAMB	204	Coefficient for inertial coupling terms in relationships for driving end of vehicle	
$\lambda_F\ \lambda_R$	XLAMF XLAMR	I	Ratio of conserved to absorbed energy in the front and rear suspension bumpers or multiple of K_F, K_R for use in simulating suspension bumpers	
λ_T	XLAMT	I	Multiple of K_T for use in non-linear range of tire deflection	
$\lambda_{1i}\ \lambda_{2i}$ λ_{3i}	XLM1(4) XLM2(4) XLM3(4)	107 108 109	Contants for simultaneous solution of the ground contact point	
μ_B	AMUB	I	Effective coefficient of friction between the vehicle sprung mass and barrier	
μ_C	AMUC	I	Tire-curb friction factor	

ANALYTICAL SYMBOL	PROGRAM SYMBOL	EQN NO.	DEFINITION	UNITS
μ_{G_i}	XMUGI(4)	I	Nominal coefficient of friction between tire i and ground	
μ_i	XMUI(4)	I	Peak value of friction coefficient for side forces for prevailing conditions of speed and load at wheel i	
μ_{m_i}	XMUM(4)	I	Nominal test surface friction coefficient on which tire properties were measured	
μ_{x_i}	XMUX(4)	240	Effective friction coefficient between tire and terrain at wheel i in the direction along the tire circumference	
$\mu_{x_{p_i}}$	XMUXP(4)	I	Peak circumferential friction coefficient for tire i	
$\mu_{x_{s_i}}$	XMUXS(4)	I	Sliding circumferential friction coefficient for tire i	
π	PI		3.14159...	
ρ	RHO	I	Distance between rear axle center of gravity and roll center, positive for roll center above c.g.	in
ρ_F	RHOF	I	Distance between front axle center of gravity and roll center, positive for roll center above c.g.	in
ρ_{si}	RHOS(I)	198	Ratio of circumferential to peak side force friction coefficients for prevailing conditions of speed and load	
$(\rho_{Si})_{max}$	RHOMAX	198	Maximum value of si at the existing forward velocity of wheel i	
σ_R	SIGR	I	Coefficients for the polynominal form of barrier load deflection characteristic	
σ_T	SIGT	I	Maximum radial tire deflection for quasi-linear load-deflection characteristic	in
τ_A	TAUA	I	Ambient temperature	°F
τ_i	TAU(4)		Temperature of brake assembly	°F
τ_{i_o}	TAUO(4)	I	Initial temperature of brake assembly	°F
ϕ, θ, ψ	PHIT THETT PSIT		Euler angles of sprung mass axes relative to inertial axes	rad
ϕ_C ϕ_{C_R}	PHIC(50) PHIRC(50)	I	Table of front and rear wheel camber as a function of deflection	deg
ϕ_{CG_i}	PHICI(4)	86	Camber angles of wheels relative to the normal to tire-terrain contact plane	rad
ϕ_{C_1}, ϕ_{C_2} ϕ_{C_3}, ϕ_{C_4} ϕ_{C_5}, ϕ_{C_6}	PHIC1, PHIC2 PHIC3, PHIC4 PHIC5, PHIC6	I	Curb slope angles	rad
ϕ_F	PHIF		Angular displacement of front axle relative to the vehicle about a line parallel to the x-axis through the front roll center	rad
ϕ_{G_i}	PHGI(4)	125	Camber angle of terrain under wheel i	rad
ϕ_i	PHII(4)		Camber angles of four wheels relative to vehicle	rad
ϕ'_n	PHIN		Value of at t=0 or at the nth indexing of the axes	rad
ϕ_R	PHIR		Angular displacement of rear axle relative to the vehicle about a line parallel to the x - axis through the rear roll center	rad
ϕ'_T	PHIT	58	Integrated value of $\dot{\phi}$ from t=0 or the nth axis indexing	rad
ϕ_{yG_i}		105	Angle between y axis and tire-terrain contact plane	rad
ψ_{BDRY}	PSBDRY(4,5)	I	Angle of interpolation boundaries in terrain tables, measured from the x'axis	rad
ψ_f	PSIF(50)	I	Table of front wheel steer angle vs time	rad
ψ_i	PSII(4)		Steer angles of wheels relative to vehicle (positive-clockwise as viewed from above)	rad
ψ'_i	PSIIP(4)	89	Steer angles of wheels in tire-terrain contact plane	rad
ψ'_n	PSIN		Value of ψ at t=0 or the nth indexing of the axes	rad
ψ'_t	PSIT	59	Integrated value of $\dot{\psi}$ from t=0 or the nth axis indexing	rad
Ω_F Ω_R	OMEGF OMEGR	I	Maximum suspension deflections from the equilibrium position for linear load-deflection characteristic of the springs	in
Ω_{FC} Ω_{RC}	OMEGFC OMEGRC	I	Front and rear suspension deflections at which the compression bumpers are contacted, measured at the front wheels and the rear springs	in
Ω_{FE} Ω_{RE}	OMEGFE OMEGRE	I	Front and rear suspension deflections at which the extension bumpers are contacted, measured at the front wheels and rear springs.	in
Ω_T	OMEGT	I	Multiple of A_2 at which the assumed parabolic variations of small angle cornering and camber stiffnesses with tire loading are abandoned	
Ω	OMGPS	I	Front wheel steering angle at which the linear steering stops are engaged	rad

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
AK2		U	INPT5	K_2
AMTX	U	U	DIMV	[A]
AMU	U	U	TIRIN	μ
AMUB	U		INPT2	μ_B
AMUC	U	U	INPT1	μ_C
AMUCMP	A	A	COMPN	NOT USED
AMUF	U	U	COMP	aM_{UF}
AMUG	U	U	INPT	AMUG(n)
ANG1	A	A	COMP	NOT USED
ANG2	A	A	COMP	NOT USED
A02APB	U	U	COMP	$aM_s g/2(a+b)$
APB		U	DRIVE	$a + b$
APD		U	DRIVE	APD
APDMAX		U	DRIVE	APDMAX
APSI		U	DRIVE	
APSIM		U	DRIVE	
APF	U	U		$\overline{AP}_F$
APFR	U	U	APTABL	$\overline{AP}_F, \overline{AP}_R$
APITCH	U	U		F_{APi}
APR	U	U		$\overline{AP}_R$
APTCH1	U	U	ADTNL	F_{AP1}
APTCH2	U	U	ADTNL	F_{AP2}
APTCH3	U	U	ADTNL	F_{AP3}
APTCH4	U	U	AFTNL	F_{AP4}
ARBR		U	INPT4	$\overline{AR}_F, \overline{AR}_R$
ARBRF		U		$\overline{AR}_F$
ARBRI		U	COMP4	$\overline{AR}_F, \overline{AR}_R$
ARBRR		U		$\overline{AR}_R$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
A	U	U	INPT	a
AA1	U		BARIER	AA_1
AA2	U		BARIER	AA_2
AAA	U	U	INPT	α
AAR		A	INPT4	NOT USED
ABSUGW		U	COMP5	$/U_{GW_i}/$
AE		U	DRIVE	$\mid e_i \mid$
AINTI	U		BARIER	$(A_{INT})_i$
AINTP	U		BARIER	$(A_{INT})_{t-1}$
AJMTX	U	U	COMPN	$[A_j]$
AKDS	U	U	INSUS	$K_{\delta s}$
AKDS1	U	U	INSUS	$K_{\delta s1}$
AKDS2	U	U	INSUS	$K_{\delta s2}$
AKDS3	U	U	INSUS	$K_{\delta s3}$
AKF	U	U	INPT	K_F
AKFC	U	U	INPT3	K_{FC}
AKFCP	U	U	INPT3	K'_{FC}
AKFE	U	U	INPT3	K_{FE}
AKFEP	U	U	INPT3	K'_{FE}
AKPS	U	U	INPT1	K_ψ
AKR	U	U	INPT	K_R
AKRC	U	U	INPT3	K_{RC}
AKRCP	U	U	INPT3	K'_{RC}
AKRE	U	U	INPT3	K_{RE}
AKREP	U	U	INPT3	K'_{RE}
AKRS	U	U	INPT	K_{RS}
AKST	U		BARSTR	K_{ST}
AKT	U	U	TIRIN	K_T
AKV	U		INPT2	K_V
AK1		U	INPT5	K_1

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
ARCAPE		U	DRIVE	$WE_i WI_i e_i$
AREI		U	DRIVE	e_i
ARFAC1		U	COMP4	$\frac{6\ \overline{AR}_j I_{wj}}{(I_{wj} + 1/4\ I_{Dj}\overline{AR}_j^{\,2})^2 + (1/4\ I_{Dj}\overline{AR}_j^{\,2})^2}$
ARFAC2		U	COMP4	$6\ \overline{AR}_j/(I_{wj} + 1/4(I_{Dj}\overline{AR}_j^{\,2}))$
ARFAC3		U	COMP5	$12\ I_{wj}$
ARTQ6		A	COMP4	NOT USED
AS	U	U	DIMV	a_{s_i}
AX	U	U	DIMV	a_{x_i}
AXP		U	DRIVE	a'_x
AXMF02	U	U	COMP	$aM_{UF}/2$
AY	U	U	DIMV	a_{y_i}
AYP		U	DRIVE	a'_y
AO	U	U	TIRIN	A_o
A1	U	U	TIRIN	A_1
A12	U	U	TIRIN	A_1/A_2
A2	U	U	TIRIN	A_2
A23	U	U	TIRIN	A_2A_3/A_1
A234	U	U	TIRIN	A_2A_3/A_4
A3	U	U	TIRIN	A_3
A4	U	U	TIRIN	A_4
B	U	U	INPT	b
BB1	U		BARIER	BB_1
BB2	U		BARIER	BB_2
BET	U	U	INPI	β
BETBR	U	U	DIMV	$\overline{\beta}_i$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
BETP	U	U	DIMV	β'_i
BETR		A	INPT4	NOT USED
BFP1		U	DRIVI	B_{FP1}
BFP2		U	DRIVI	B_{FP2}
BMTX	U	U	COMPN	[B]
BMUR	U	U	COMP	bM_{UR}
BNMTX	U	U	EINDEX	$[B_n]$
B02APB	U	U	COMP	$bM_s g/2(a+b)$
BROMUR	U	U	COMP	ρbM_{UR}
BRPM		U	INPT5	
BS	U	U	DIMV	b_{s_i}
BTLF		U	INPT5	
BTT		U	INPT5	
BX	U	U	DIMV	b_{x_i}
BXMR02	U	U	SUSCMP	$bM_{UR}/2$
BY	U	U	DIMV	b_{y_i}
CAB	U		BARIER	$\cos\alpha_B$
CABT	U		BARIER	$\cos\alpha_{BT}$
CAB1	U		BARIER	$\cos\alpha_{B_1}$
CAC	U	U	DIMV	$\cos\alpha_{C_i}$
CAGZ	U	U	DIMV	$\cos\alpha_{GZ'_i}$
CAH	U	U	DIMV	$\cos\alpha_{h_i}$
CAR	U	U	DIMV	$\cos\alpha_{R_i}$
CAS	U	U	DIMV	$\cos\alpha_{S_i}$
CAX	U	U	COMP	$\cos\alpha_x$
CAXW	A	A	DIMV	NOT USED

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
CAY	U	U	COMP	$\cos\alpha_Y$
CAYW	U	U	DIMV	$\cos\alpha_{YW_i}$
CBB	U		BARIER	$\cos\beta_B$
CBBT	U		BARIER	$\cos\beta_{BT}$
CBB1	U		BARIER	$\cos\beta_{B1}$
CBC	U	U	DIMV	$\cos\beta_{C_i}$
CBGZ	U	U	DIMV	$\cos\beta_{GZ'_i}$
CBH	U	U	DIMV	$\cos\beta_{h_i}$
CBR	U	U	DIMV	$\cos\beta_{R_i}$
CBS	U	U	DIMV	$\cos\beta_{S_i}$
CBX	U	U	COMP	$\cos\beta_X$
CBXW	A	A	DIMV	NOT USED
CBY	U	U	COMP	$\cos\beta_Y$
CBYW	U	U	DIMV	$\cos\beta_{YW_i}$
CC1	U		BARIER	CC_1
CC2	U		BARIER	CC_2
CF	U	U	INPT	C_F
CFP	U	U	INPT	C'_F
CGB	U		BARIER	$\cos\gamma_B$
CGBT	U		BARIER	$\cos\gamma_{BT}$
CGB1	U		BARIER	$\cos\gamma_{B1}$
CGC	U	U	DIMV	$\cos\gamma_{C_i}$
CGGZ	U	U	DIMV	$\cos\gamma_{GZ'_i}$
CGH	U	U	DIMV	$\cos\gamma_{h_j}$
CGR	U	U	DIMV	$\cos\gamma_{R_i}$
CGS	U	U	DIMV	$\cos\gamma_{S_i}$
CGX	U	U	COMP	$\cos\gamma_X$
CGXW	A	A	DIMV	NOT USED
CGY	U	U	COMP	$\cos\gamma_Y$
CGYW	U	U	DIMV	$\cos\gamma_{YW_1}$
CHED	U	U	HEAD	CONTROL TITLE
CMTX	U	U	DIMV	$[C_j]$
CNMTX	U	U	EINDEX	$[C_n]$
COMEN4		U	INPT4	CØMEN4
COMEN5		A	COMP5	NOT USED
CONE		U	INPT5	C_1
CONMPH		U	DRIVE	3600/(12x5280)
CONS	U	A	INPT2	$\overline{\text{CONS}}$
COSPH	U	U	COMP	$\cos Ø$
COSPHN	U	U	EINDEX	$\cos Ø_n$
COSPS	U	U	COMP	$\cos\psi$
COSPSN	U	U	EINDEX	$\cos\psi_n$
COSTH	U	U	COMP	$\cos\theta$
COSTHN	U	U	EINDEX	$\cos\theta_n$
CPG	U	U	DIMV	$\cos Ø_{G_i}$
CPHI	A	A	COMP	NOT USED
CPHIC	U	A	ADTNL	$\cos Ø_{C_i}$
CPHICI		U	COMP4	$\cos Ø_{C_i}$
CPHTP	U	U	COMP	$\cos Ø_t$
CPSI	A	A	COMP	NOT USED
CPSP	U	U	INPT1	C'_ψ
CPSTP	U	U	EINDEX	$\cos\psi'_t$
CPYG	U	U	DIMV	$\cos Ø_{y_{Gi}}$
CR	U	U	INPT	C_R
CRP	U	U	INPT	C_R'

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
CS	U	U	DIMV	C_{Si}
CT		U	INPT4	C_{Ti}
CTG	U	U	DIMV	$\cos \emptyset_{G_i}$
CTHETP	U	U	EINDEX	$\cos \Theta_t$
CTHREE		U	INPT5	C_3
CTWO		U	INPT5	C_2
CTXG	U	U	DIMV	$\cos\Theta_{XGi}$
CX	U	U	DIMV	C_{x_i}
CY	U	U	DIMV	C_{y_i}
DADE	U	U	INPT	DATE ARRAY
DAPFB	U	U	APTABL	
DADFE	U	U	APTBL	
DAPRB	U	U	APTABL	
DAPRE	U	U	APTABL	
DDAPF	U	U	APTABL	
DDAPR	U	U	APTABL	
DDD	A		INPT2	NOT USED
DDEL	U	U	INPT	DDEL
DDEL1	U	U		$\dot{\delta}_1$
DDEL1D	U	U		$\ddot{\delta}_1$
DDEL2	U	U		$\dot{\delta}_2$
DDEL2D	U	U		$\ddot{\delta}_2$
DDEL3	U	U		$\dot{\delta}_3$
DDEL3D	U	U		$\ddot{\delta}_3$
DDEL4	U	U		$\dot{\delta}_4$
DDEL4D	U	U		$\ddot{\delta}_4$
DDPSFI	U	U		$\ddot{\psi}_F$
DDIM2	U	U	COMP	$\dot{\delta}_I-\dot{\delta}_2$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
DD1P2	U	U	COMP	$\dot{\delta}_1+\dot{\delta}_2$
DD3M4	U	U	SUSCMP	$\dot{\delta}_3-\dot{\delta}_4$
DD3P4	U	U	SUSCMP	$\dot{\delta}_3+\dot{\delta}_4$
DELB	U	U	INPT	DELB
DELBB	U		BARIER	δ_B
DELBBP		U	BARIER	$(\delta_B)_{t-1}$
DELE	U	U	INPT	DELE
DELG	U	U	RUFNES	ΔG
DELPTH	U	U	DRFVTT	EMDT
DELTA	U	U	DIMV	Δ_i
DELTAE		U	COMP5	ΔE_i
DELTAX		U	DRIVE	D_{ax}
DELTB	U		INPT2	Δt_B
DELTC	U	U	INPT1	Δt_c
DELTY		U	DRIVE	
DELX	U		BARIER	
DELYBP	U		INPT2	$\Delta y'_B$
DEL1	U	U		δ_1
DEL1D	U	U		$\dot{\delta}_1$
DEL10	U	U	INPT	δ_{Io}
DEL10D	U	U	INPT	$\dot{\delta}_{Io}$
DEL2	U	U		δ_2
DEL2D	U	U		$\dot{\delta}_2$
DEL20	U	U	INPT	δ_{2o}
DEL20D	U	U	INPT	$\dot{\delta}_{2o}$
DEL3	U	U		δ_3
DEL3D	U	U		$\dot{\delta}_3$
DEL30	U	U	INPT	δ_{3o}
DEL30D	U	U	INPT	$\dot{\delta}_{3o}$
DEL4	U	U		δ_4
DEL4D	U	U		$\dot{\delta}_4$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
DPSIFI	U	U		$\dot{\psi}_F$
DPSILF		U	DRIVE	$\Delta\psi_{Fj}(t)$
DPSINT	A	A	COMPN	NOT USED
DPSISF		U	DRIVE	$\Delta\psi_{fi}$
DPSITP	U	U		$\ddot{\psi}'_t$
DQ	U	U		$\dot{Q}$
DR	U	U		$\dot{R}$
DRIEND		A	DRIVI	NOT USED
DRPSI		U		$\frac{d}{dt}\ (RPS)_i$
DRWHJ	U	U	INPT1	DRWHJ
DS		U	DRIVI	ΔS
DSØES		U	DRIVE	
DT	U	U	INTG	Δt
DTCMP1	A	A	INPT	NOT USED
DTCOMP	U	U	INPT	Δt
DTDD1	U	U	SUSCMP	$d(\Delta T_{HF1})/d\delta_1$
DTDD2	U	U	SUSCMP	$d(\Delta T_{HF2})/d\delta_2$
DTDD3	U	U	SUSCMP	$d(\Delta T_{HR3})/d\delta_3$
DTDD4	U	U	SUSCMP	$d(\Delta T_{HR4})/d\delta_4$
DTHF	U	U	INSUS	
DTHF1	U	U	SUSCMP	ΔT_{HF1}
DTHF2	U	U	SUSCMP	ΔT_{HF2}
DTHR	U	U	INSUS	
DTHR3	U	U	SUSCMP	ΔT_{HR3}
DTHR4	U	U	SUSCMP	ΔT_{HR4}
DTHTTP	U	U		$\dot{\Theta}'_t$
DTINT		U	COMP4	$(RPS)_i/\frac{d(RPS_i)}{dt}$
DTLF		U	INPT5	

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
DEL40	U	U	INSUS	δ_{40}
DEL40D	U	U	INSUS	$\dot{\delta}_{40}$
DEND		U	DRIVE	
DER	U	U	INTG	y
DERR		A	INTR	NOT USED
DESS		U	DRIVE	DS
DESSI		U	DRIVI	
DGMAX	U	U	RUFNES	
DI		U	DRIVE	
DISS	U		BARIER	
DIST		U	DRIVE	DIST
DISTC		U	DRIVE	
DISTD	U	U	COMP	$\sqrt{D_{1_i}^2 + D_{2_i}^2 + D_{3_i}^2}$
DISTI		U	DRIVI	
DISTS	U	U	COMP	$\sqrt{a_{s_i}^2 + b_{s_i}^2 + c_{s_i}^2}$
DISTX	U	U	COMP	$\sqrt{a_{x_i}^2 + b_{x_i}^2 + c_{x_i}^2}$
DISTY	U	U	COMP	$\sqrt{a_{y_i}^2 + b_{y_i}^2 + c_{y_i}^2}$
DMATX	U	U	DIMV	[D] and [E]
DP	U	U		$\dot{P}$
DPHIF	U	U		$\dot{\phi}_F$
DPHIFD	U	U		$\ddot{\phi}_F$
DPHIR	U	U		$\dot{\phi}_R$
DPHIRD	U	U		$\ddot{\phi}_R$
DPHITP	U	U		$\dot{\phi}'_t$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
ENRGY	U		BARIER	ΣE t
EPSB	U		INPT2	ε_B
EPSE	U	U	INPT	ε_F
EPSL	A		BARIER	
EPSPS	U	U	INPT1	ε_ψ
EPSR	U	U	INPT	ε_R
EPSS		U	COMP4	ε_{s_i}
EPSSFC		U	COMP4	$\varepsilon_{Si} F_{Ci}$
EPST	A		INPT2	NOT USED
EPSV	U		INPT2	ε_V
ERPM		U	INPT5	
ES		U	DRIVE	
ET		U	DRIVE	$\Sigma WE_i WI_i e_i$
ETLF		U	INPT5	
ETT		U	INPT5	
EWT		U	DRIVE	$WE_i WI_i e_i$
FP	U		BARIER	F_B
FBRK		U	DRIVE	F_{BRK}
FC	U	U	DIMV	F_{Ci}
FCAV		U	COMP4	$(\Sigma F_{C_j} \Delta t_n)/\Delta t$
FCSLSM		U	COMP4	
FCXFAC		U	COMP4	$A_{11}\cos\alpha_{C_i} + A_{21}\cos\beta_{C_i} + A_{31}\text{cis}\gamma_{C_i}$
FCXU	U	U	DIMV	F_{CXU_i}
FCYFAC		U	COMP4	$A_{12}\cos\alpha_{C_i} + A_{22}\cos\beta_{C_i} + A_{32}\cos\gamma_{C_i}$
FCYU	U	U	DIMV	F_{cyu_i}
FCZFAC		U	COMP4	$A_{13}\cos\alpha_{C_i} + A_{23}\cos\beta_{C_i} + A_{33}\cos\gamma_{C_i}$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
DTPRNT	U	U	INPT	
DTR		U	INTR	Δt_n
DTSTEP		U	COMP4	
DTT		U	INPT5	
DTTEST		U	COMP4	$(RPS)/\frac{d(RPS)_i}{dt}$
DU	U	U		$\dot{u}$
DV	U	U		$\dot{v}$
DW	U	U		$\dot{w}$
DXCP	U	U		$\dot{u}'$
DYCP	U	U		$\dot{v}'$
DZCP	U	U		$\dot{w}'$
D1	U	U	DIMV	D_{1i}
D1MD2	U	U	COMP	$\delta_1-\delta_2$
D1PD2	U	U	COMP	$\delta_1+\delta_2$
D2	U	U	DIMV	D_{2i}
D21	U	U	COMP	$\delta_2-\delta_1$
D3	U	U	DIMV	D_{3i}
D3MD4	U	U	SUSCMP	$\delta_3-\delta_4$
D3PD4	U	U	SUSCMP	$\delta_3+\delta_4$
D43	U	U	SUSCMP	$\delta_4-\delta_3$
EBAR	U	U	INPT	$\overline{E}$
EEE	U		BARIER	$(E_1)_t$
EI		U	DRIVE	
EPSL	U		BARIER	ε_{n-1}
EM	U	U	INPT	$\overline{M}$
EN		U	DRIVE	EN
ENDEIN	A	A	EINDEX	NOT USED
EMDT		U	DRIVI	EMDT
END3	A	A	INPT3	NOT USED

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
FCZU	U	U	DIMV	$FCZU_i$
FIDAR		A	COMP4	NOT USED
FIDIW		A	COMP4	NOT USED
FIDJ		U	INPT4	I_{DF}, I_{DR}
FIDJF		U		I_{DF}
FIDJR		U		I_{DR}
FIDWR2		A	COMP4	NOT USED
FIWJ		U	INPT4	I_{WF}, I_{WR}
FIWJF		U		I_{WF}
FIWJR		U		I_{WR}
FJF	U	U	SUSCMP	F_{JFi}
FJP	U	U	TIRIN	F_j'
FKD		U	DRIVE	Kd
FKDO		U	DRIVI	Kd
FKP		U	DRIVE	K_p
FKPO		U	DRIVI	K_p
FKS1		U	DRIVE	K_{s_I}
FKSIO		U	DRIVI	K_{s_1}
FKS2		U	DRIVE	K_{s_2}
FKS20		U	DRIVI	K_{s_2}
FKSKDO		U	DRIVI	K_s
FKSKID		U	DRIVE	K_s
FN	U		BARIER	F_N
FNP	U		BARIER	$(F_N)_{t-I}$
FNSTI	U		BARSTR	F_{NSTi}
FR	U	U	DIMV	F_{Ri}
FRCP	U	U	COMPN	F'_{R_i}
FRCPAV		U	COMP4	$(\Sigma F'_{R_i} \Delta t_n)/\Delta t$
FRCMPU		U	COMP4	$\mu_i F'_{R_i}$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
FRICF	U		HARDPT	$\mu_B F_{NSTi}$
FRICT	U		BARIER	FRICT
FRSP	A	A	COMPN	NOT USED
FRTEST		U	COMP4	$F_{R_i} - F_{S_i} \sin \emptyset_{C_i}$
FRXFAC		U	COMP4	$A_{II}\cos\alpha_{GZ'_i} + A_{21}\cos\beta_{GZ'_i} + A_{3I}\cos\gamma_{GZ'_i}$
FRXU	U	U	DIMV	F_{Rxu_i}
FRYFAC		U	COMP4	$A_{12}\cos\alpha_{GZ'_i} + A_{22}\cos\beta_{GZ'_i} + A_{32}\cos\gamma_{GZ'_i}$
FRYU	U	U	DIMV	F_{Ryu_i}
FRZFAC		U	COMP4	$A_{I3}\cos\alpha_{GZ'_i} + A_{23}\cos\beta_{GZ'_i} + A_{33}\cos\gamma_{GZ'_i}$
FRZU	U	U	DIMV	F_{Rzu_i}
FS	U	U	DIMV	F_{S_i}
FSAV		U	COMP4	$(\Sigma F_{S_i} \Delta t_n)/\Delta t$
FSXFAC		U	COMP4	$A_{1I}\cos\alpha_{S_i} + A_{2I}\cos\beta_{S_i} + A_{3I}\cos\gamma_{S_i}$
FSXU	U	U	DIMV	$F_{SX_{ui}}$
FSYFAC		U	COMP4	$A_{12}\cos\alpha_{S_i} + A_{22}\cos\beta_{S_i} + A_{32}\cos\gamma_{S_i}$
FSYU	U	U	DIMV	F_{Syu_i}
FSZFAC		U	COMP4	$A_{I3}\cos\alpha_{S_i} + A_{23}\cos\beta_{S_i} + A_{33}\cos\gamma_{S_i}$
FSZU	U	U	DIMV	F_{Szu_i}
FXU	U	U	DIMV	F_{xu_i}
FYU	U	U	DIMV	F_{yu_i}
FZU	U	U	DIMV	F_{zu_i}
F1FI	U	U	DIMV	F_{IFi}
FIRI	U	U	DIMV	F_{IRi}
F2FI	U	U	DIMV	F_{2Fi}

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
F2RI	U	U	DIMV	F_{2Ri}
G	U	U	INPT	g
GAM1	U	U	COMP	γ_1
GAM2	U	U	COMP	$(\gamma_2)_t$
GAM3	U	U	COMP	$(\gamma_3)_t$
GAM4	U	U	COMP	$(\gamma_4)_t$
GAM5	U	U	COMP	$(\gamma_5)_t$
GAM6	U	U	COMP	$(\gamma_6)_t$
GAM7	U	U	COMP	$(\gamma_7)_t$
GAM8	U	U	COMP	$(\gamma_8)_t$
GAM9	U	U	COMP	$(\gamma_9)_t$
GCTCP	U	U	COMP	$g\ A_{33}$
GCTH	U	U	COMP	$g \cos \Theta$
GCTSP	U	U	COMP	$g\ A_{32}$
GEAR1		U	DRIVI	$GEAR_1$
GEAR2		U	DRIVI	$GEAR_2$
GEAR3		U	DRIVI	$GEAR_3$
GEAR4		U	DRIVI	$GEAR_4$
GHED	U	U	HEAD	TERRAIN TITLE
GN		U	INPT5	G_{iF}, G_{iR}
GSTH	U	U	COMP	$g \sin \Theta$
HCAH	U	U		$h_i \cos\alpha_{h_i}$
HCAH1	U	U	COMP	$h_1 \cos\alpha_{h_i}$
HCAH2	U	U	COMP	$h_2 \cos\alpha_{h_2}$
HCAH3	U	U	COMP	$h_3 \cos\alpha_{h_3}$
HACH4	U	U	COMP	$h_4 \cos\alpha_{h_4}$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
HCBH	U	U		$h_i \cos\beta_{h_i}$
HCBH1	U	U	COMP	$h_1 \cos\beta_{h_1}$
HCBH2	U	U	COMP	$h_2 \cos\beta_{h_2}$
HCBH3	U	U	COMP	$h_3 \cos\beta_{h_3}$
HCBH4	U	U	COMP	$h_4 \cos\beta_{h_4}$
HCGH	U	U		$h_i \cos\gamma_{h_i}$
HCGH1	U	U	COMP	$h_1 \cos\gamma_{h_1}$
HCGH2	U	U	COMP	$h_2 \cos\gamma_{h_2}$
HCGH3	U	U	COMP	$h_3 \cos\gamma_{h_3}$
HCGH4	U	U	COMP	$h_4 \cos\gamma_{h_4}$
HED	U	U	INPT	RUN TITLE
HI	U	U	DIMV	h_i
HMAX	U	U	INPT	h_{max}
HMIN	U	U	INPT	h_{min}
HMINR		A	INPT4	NOT USED
HRPSFA		A	COMP4	NOT USED
HRPSFB		A	COMP4	NOT USED
HRPSFC		A	COMP4	NOT USED
HTRERM		U	COMP4	$/h_i(RPS)_i/$
IAPFR	U	U	APTABL	
IBHIT	U		BARIER	
IBTYP		U	INPT5	TYPE
IBUG		U	INPT5	
ICBHIT	U	U	COMPN	
IDPT	U		BARIER	
IDRIVE		U	DRIVTT	

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
IDRIVER		U	DRIVTT	
IDTCNT		U	COMP4	
IGEAR		U	DRIVE	
IHIT	U	U	COMPN	
ILOAD	U		BARIER	
INDB	U		INPT2	
INDCRB	U	U	INPT1	
INDXPT	U			
ININD	U		BARIER	
IPATHT		U	DRIVTT	
IPLN	U		BARIER	
IPT	U		BARIER	
IRPS		U	COMP4	
IRUF	U	U	RUFNES	
ISKIDP		U	DRIVE	
ISMAIN		U	DRIVE	
ISTEP		U	COMP4	
ISTOP		U	COMP4	
ISTOP	U		NSTOP	
ISUS	U	U	INSUS	
ITCHNG		U	DRIVTT	
ITESTT		U	DRIVTT	
ITIR	U	U	TIRIN	
IUVB		U	COMP4	
IUVS		U	COMP4	
IX	U	U	COMP	
IY	U	U	COMP	
I1	U		BARIER	
I2	U		BARIER	
I3	U		BARIER	
I4	U		BARIER	

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
JBHIT	U		BARIER	
JCBHIT	U	U	COMPN	
JDEND		U	COMP5	
KCOUNT		U	DRIVE	
LCB1	U	U	COMPN	
LCB2	U	U	COMPN	
LLL	U	U	COMP	
MODE	U	U	INPT	
NAPF	U	U	APTABL	
NAPR	U	U	APTABL	
NBTYP		U	COMP5	
NBX	U	U	INPT	
NBY	U	U	INPT	
NCAMF	U	U	INSUS	
NCAMR	U	U	INSUS	
NCRBSL	U	U	NEWCRB	
NCYC	U		BARIER	
NDEL	U	U	INPT	NDEL
NDTHF	U	U	INSUS	
NDTHR	U	U	INSUS	
NEN		U	DRIVI	
NEND	U	U	RUFNES	
NEQ	U	U	INTG	
NEQR		A	INTR	NOT USED
NLDCTR	U		BARIER	

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
NPAGE	U	U	HEAD	
NPD		U	DRIVE	
NRPM		U	INPT5	
NSEG		U	BARIER	
NTBL1	U	U	INPT	
NTBL2	U	U	INPT	
NTBL3	U	U	INPT	
NTLF		U	INPT5	
NTRAN		U	DRIVI	
NTTS		U	INPT5	
NTTI		U	INPT5	
NTT2		U	INPT5	
NTT3		U	INPT5	
NUNLD	U		BARIER	
NX	U	U	INPT	
NXFRCP		U	INPT4	
NXUGMU		U	INPT4	
NY	U	U	INPT	
NZTAB	U	U	INPT	
NZ5	U	U	INPT	
OMEGAO		U	DRIVI	
OMEGF	A	A	INPT	NOT USED
OMEGFC	U	U	INPT3	Ω_{FC}
OMEGFE	U	U	INPT3	Ω_{FE}
OMEGR	A	A	INPT	NOT USED
OMEGRC	U	U	INPT3	Ω_{RC}
OMEGRE	U	U	INPT3	Ω_{RE}
OMEGT	U	U	TIRIN	Ω_T
OMGPS	U	U	INPT1	Ω_ψ

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
OMT2A2	U	U	TIRIN	$\frac{\Omega_T A_2 A_3 (A_4 - A_2\Omega_T)}{A_4[\Omega_T A_1 A_2(\Omega_1 -1) -A_o]}$
OMT2M1	U	U	TIRIN	$\Omega_T A_1 A_2 (\Omega_T -1)$
P	U	U		P
PC		U	COMP5	P_c
PCAB	U		BARIER	$(\cos\alpha_B)_{t-1}$
PCBB	U		BARIER	$(\cos\beta_B)_{t-1}$
PCGB	U		BARIER	$(\cos\gamma_B)_{t-1}$
PHFP	U	U	SUSCMP	NOT USED
PHGI	U	U	DIMV	ϕ_{G_i}
PHG1	A	A	COMP	NOT USED
PHG2	A	A	COMP	NOT USED
PHIC	U	U	INPT	ϕ_C
PHICI	U	U	DIMV	ϕ_{CGi}
PHICLR	U	U	NEWCRB	
PHICM	U	U	NEWCRB	
PHIC1	U	U	INPT1	ϕ_{C1} (deg)
PHIC1R	U	U	COMPN	ϕ_{C1} (rad)
PHIC2	U	U	INPT1	ϕ_{C2} (deg)
PHIC2R	U	U	COMPN	ϕ_{C2} (rad)
PHIC3	U	U	NEWCRB	ϕ_{c3} (deg)
PHIC3R	U	U	NEWCRB	ϕ_{c3} (rad)
PHIC4	U	U	NEWCRB	ϕ_{c4} (deg)
PHIC4R	U	U	NEWCRB	ϕ_{c4} (rad)
PHIC5	U	U	NEWCRB	ϕ_{c5} (deg)
PHIC5R	U	U	NEWCRB	ϕ_{c5} (rad)
PHIC6	U	U	NEWCRB	ϕ_{c6} (deg)
PHIC6R	U	U	NEWCRB	ϕ_{c6} (rad)
PHIF	U	U		ϕ_F

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
PHIFD	U	U		$\dot{\phi}_F$
PHIFD2	U	U	SUSCMP	$\dot{\phi}_F^2$
PHIFO	U	U	INSUS	ϕ_{FO}
PHIFDO	U	U	INSUS	$\dot{\phi}_{FO}$
PHIF2	U	U	SUSCMP	ϕ_F^2
PHII	U	U		ϕ_i
PHIN	U	U	COMP	ϕ'_n
PHIR	U	U		ϕ_R
PHIRC	U	U	INSUS	ϕ_{CR}
PHIRD	U	U		ϕ_R
PHIRD2	U	U	COMP	ϕ^2_R
PHIRO	U	U	INPT	ϕ_{R_o}
PHIROD	U	U	INPT	$\dot{\phi}_{R_o}$
PHIR2	U	U	COMP	ϕ^2_R
PHIT	U	U	COMP	ϕ_t or ϕ
PHITL	U	U	EINDEX	ϕ_{t-1}
PHITP	U	U		ϕ'_t
PHIO	U	U	INPT	ϕ_o
PHI1	U	U	DIMV	ϕ_1
PHI1D	U	U	COMPN	$\frac{d\phi_1}{d\delta_1}\dot{\delta}_1$
PHI2	U	U	DIMV	ϕ_2
PHI2D	U	U	COMPN	$\frac{d\phi_2}{d\delta_2}\dot{\delta}_2$
PHI3	U	U	DIMV	ϕ_3
PHI3D	U	U	SUSCMP	$\dot{\phi}_3$
PHI4	U	U	DIMV	ϕ_4
PHI4D	U	U	SUSCMP	$\dot{\phi}_4$
PHRP	A	A	COMP	NOT USED

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
PI	U	U	COMP	π
PIO15R		U	COMP5	$15/\pi$
PIO2	U	U	EINDEX	$\pi/2$
PIO4	U	U	EINDEX	$\pi/4$
PONE		U	INPT5	P_1
PP		U	COMP5	P_j
PPD		U	DRIVE	
PPRB	U		BARIER	$(R_B)_{t-1}$
PQ	U	U	COMP	PQ
PQRMIN	U	U	INPT	
PR	U	U	COMP	PR
PSBDRY	U	U	INPT	Ψ_{BDRY}(rad)
PSBDRO	U	U	INPT	Ψ_{BDRY}(deg)
PSIF	U	U	INPT	$\dot{\Psi}_F$
PSIFDO	U	U	INPT1	Ψ_{Fio}
PSIFFH		U	DRIVE	
PSIFHO		U	DRIVI	
PSIFI	U	U		$\dot{\Psi}_{Fi}$
PSIFID	U	U		Ψ_{Fi}
PSIFIO	U	U	INPT1	Ψ_{Fio}
PSII	U	U		Ψ_i
PSIIP	U	U	DIMV	Ψ'_i
PSIJ		U	DRIVE	
PSIM		U	DRIVE	$(\Psi_F)_{IDEAL}$
PSIN	U	U	COMP	Ψ'_n
PSISKD		U	DRIVE	$\Delta\psi_{sj}$
PSIT	U	U	COMP	Ψ_t or Ψ
PSITEM		U	COMP4	Ψ'_i sgn U_{Gi}
PSITL	U	U	EINDEX	Ψ_{t-1}
PSITP	U	U		Ψ'_t
PSIO	U	U	INPT	Ψ_o

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
PSI1	U	U	DIMV	Ψ_1
PSI2	U	U	DIMV	Ψ_2
PSI3	U	U	DIMV	Ψ_3
PSI4	U	U	DIMV	Ψ_4
PSZR	U		BARIER	$(Z_R)_{t-1}$
PTWO		U	INPT5	P_2
PVDEF	U		BARIER	$(y'_{cpm})_t - (y'_{cpm})_{t-1}$
PZERO		U	INPT5	P_{Fo}, P_{Ro}
PO	U	U	INPT	P_o
P1	U	U	COMP	$\cos\beta_{yw_i} \cos\gamma_{GZ'_i}$
P2	U	U	COMP	p^2
P3	U	U	COMP	$\cos\gamma_{yw_i} \cos\alpha_{GZ'_i}$
P4	U	U	COMP	$\cos\gamma_{GZ'_i} \cos\alpha_{yw_i}$
P5	U	U	COMP	$\cos\alpha_{yw_i} \cos\beta_{GZ'_i}$
P6	U	U	COMP	$\cos\alpha_{GZ'_i} \cos\beta_{yw_i}$
P7	U	U	COMP	$\cos\beta_{GZ'_i} \cos\gamma_{yw_i}$
QAY		U	DRIVE	a_y
QR	U	U	COMP	QR
QO	U	U	INPT	Q_O
Q2	U	U	COMP	Q^2
R	U	U		R
RAD	U	U	COMP	$180/_{\pi}$
RB	U		BARIER	$(R_B)_t$
RB1	U		BARIER	R_{B1}
RF	U	U	INPT	R_F

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
RFPF	U	U	SUSCMP	$\rho_F Ø_F$
RFTF	U	U	COMP	R_F/T_F^2
RHFMUF	U	U	SUSCMP	$\rho_F M_{UF}$
RHF2MF	U	U	SUSCMP	$\rho_F^2 M_{UF}$
RF2MFI	U	U	SUSCMP	$I_F+\rho_F^2 M_{UF}$
RHMU2	U	U	COMP	$\rho^2 M_{UR}$
RHMR2I	U	U	COMP	$\rho^2 M_{UR} + I_R$
RHO	U	U	INPT	ρ
RHØF	U	U	INSUS	ρ_F
RHOF2	U	U	SUSCMP	ρ_F^2
RHOMAX		U	COMP5	$(\rho_{si})_{max}$
RHOMUR	U	U	COMP	ρM_{UR}
RHOS		U	COMP4	ρ_{S_i}
RHOSAV		U	COMP5	$(\Sigma\rho_{S_i}(\Delta t_n)/\Delta t$
RHOSMX		U	COMP5	
RHO2	U	U	COMP	ρ^2
RPF2M	U	U	SUSCMP	$\rho_F^2 M_{UF} Ø_F^2$
RPHFD	U	U	SUSCMP	$R\dot{Ø}_F$
RPHRD	U	U	COMP	$RØ_R$
RPME		U	COMP5	
RPR	U	U	COMP	$\rho Ø_R$
RPSFA		U	COMP4	$\dfrac{I_{Wj}+1/4I_{Dj}AR_j^2}{(I_{Wj}+1/4I_{Dj}AR_j^2)^2-(1/4I_{Dj}AR_j)^2}$
RPSFB		U	COMP4	$\dfrac{I_{Dj}AR_j^2}{(4I_{Wj}+I_{Dj}AR_j^2)-(1/2I_{Dj}AR_j^2)^2}$
RPSFC		U	COMP4	$1/I_{Wj}+1/4I_{Dj}AR_j^2$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
RPSFD		U	COMP4	$\frac{I_{Dj} AR_j^2}{4I_{Wj} + I_{Dj} AR_j^2}$
RPSFE		U	COMP5	$12/(I_{wj} + 1/4\ I_{Dj} \overline{AR}_2^2)$
RPSI		U		$(RPS)_i$
RPSSM		U	COMP4	
RR	U	U	INPT	R_R
RRM		U	INPT4	R_{RMi}
RRMC		U	INPT4	C_{RRMi_2}
RRTR	U	U	SUSCMP	R_R/T_R
RRTS	U	U	COMP	$R_R T_S$
RR1	U		BARIER	RR_1
RR2	U		BARIER	RR_2
RR2P	U		BARIER	$(RR_2)_{t-1}$
RTF	U	U	SUSCMP	R_F/T_{SF}
RTR	U	U	COMP	R_R/T_S
RW	U	U	TIRIN	R_W
RWDRIV		U	COMP5	
RWHJB	U	U	INPT1	RWHJB
RWHJE	U	U	INPT1	RWHJE
RO	U	U	INPT	R_o
R2	U	U	COMP	R^2
S		U	DRIVI	
SDEN	U		BARIER	$\Sigma\ (A_{INT})_i$
SECTP	U	U	COMP	$\sec \Theta_t$
SET	U		INPT2	$\overline{SET}$
SFCDTR		U	COMP4	$\Sigma F_{C_i} \Delta t_n$
SFRCPR		U	COMP4	$\Sigma F'_{R_i} \Delta t_n$
SFRX	U	U	COMPN	$\Sigma F_{Rx'_i}$
SFRY	U	U	COMPN	$\Sigma F_{Ry'_i}$
SFRZ	U	U	COMPN	$\Sigma F_{Rz'_i}$
SFSDTY		U	COMP4	$\Sigma F_{S_i} \Delta t_n$
SFXS	U	U	COMP	$\Sigma\ F_{XS}$
SFXU	U	U	COMP	$\Sigma\ F_{XU}$
SFYS	U	A	COMP	$\Sigma\ F_{YS}$
SFYU	U	U	COMP	$\Sigma\ F_{YU}$
SFYUF	A	A	COMP	NOT USED
SFYUR	A	A	COMP	NOT USED
SFZS	U	A	COMP	$\Sigma\ F_{ZS}$
SFZU	A	A	COMP	NOT USED
SFZ1	U	U	COMP	$\Sigma\ F_{Z1}$
SHED	U	U	HEAD	INITIAL CONDITION TITLE
SI	U	U	DIMV	S_i
SIGR	U		INPT2	σR_j
SIGT	U	U	TIRIN	σ_T
SINPH	U	U	COMP	$\sin \emptyset$
SINPHN	U	U	EINDEX	$\sin \emptyset'_n$
SINPS	U	U	COMP	$\sin \Psi$
SINPSN	U	U	EINDEX	$\sin \Psi'_n$
SINTH	U	U	COMP	$\sin \Theta$
SINTHN	U	U	EINDEX	$\sin \Theta'_n$
SLIP		U	COMP4	$(SLIP)_i$
SLIPAV		U	COMP4	$[\Sigma (SLIP)_i \Delta t_n]/\Delta t$
SLIPMT		U	INPT4	
SLIPMX		U	COMP5	
SLIPP		U	COMP5	$SLIP_P$
SLIPT		U	COMP4	$/(SLIP)_i/$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
SLOPE		U	DRIVE	
SLOPER		U	DRIVE	
SLOPE1	U	U	ADTNL	$\frac{dØ_1}{d\delta_1}$
SLOPE2	U	U	ADTNL	$\frac{dØ_2}{d\delta_2}$
SLOPE3	U	U	SUSCMP	$dØ/d\delta_3$
SLOPE4	U	U	SUSCMP	$dØ/d\delta_4$
SLPFAC		U	COMP4	h_i/U_{GWi}
SNPF	U	U	SUSCMP	$\Sigma N_{ØF}$
SNPR	U	U	COMP	$\Sigma N_{ØR}$
SNPS	U	A	COMP	$\Sigma N_{ØS}$
SNPSS	U	A	COMP	$\Sigma N_{\Psi S}$
SNPSU	U	U	COMP	$\Sigma N_{\Psi U}$
SNPU	U	U	COMP	$\Sigma N_{ØU}$
SNTS	U	A	COMP	$\Sigma N_{\Theta S}$
SNTU	U	U	COMP	$\Sigma N_{\Theta U}$
SPENGY	U		BARIER	
SPG	U	U	DIMV	$\sin Ø_{Gi}$
SPHI	A	A	COMP	NOT USED
SPHIC	U	A	ADTNL	$\sin Ø_{C_i}$
SPHICI		U	COMP4	$\sin Ø_{C_i}$
SPHTP	U	U	COMP	$\sin Ø'_t$
SPSI	A	A	COMP	NOT USED
SPSTP	U	U	EINDEX	$\sin \Psi'_t$
SPYG	U	U	DIMV	$\sin Ø_{yGi}$
SRHOS		U	COMP5	$\Sigma \rho s_i \Delta t_n$
SSLIP		U	COMP4	$\Sigma (SLIP)_i \Delta t_n$
ST		U	DRIVE	$(\Delta S.i/U_T)$
STEPD		U	COMP4	

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
STG	U	U	DIMV	$\sin\Theta_{Gi}$
STHETP	U	U	EINDEX	$\sin\Theta'_t$
STS02		U	DRIVE	$(\Delta S.i/U_T)^2/2$
STXG	U	U	DIMV	$\sin\Theta_{XGi}$
SUMM	U	U	COMP	ΣM
SWORK	U		BARIER	
SXR	U		BARIER	$(\Sigma X_R)_t$
SYR	U		BARIER	$(\Sigma Y_R)_t$
SZR	U		BARIER	$(\Sigma Z_R)_t$
T	U	U	INTG	t
TANPCL	U	U	NEWCRB	
TANPC1	U	U	COMPN	$\tan Ø_{c_1}$
TANPC2	U	U	COMPN	$\tan Ø_{c_2}$
TANPC3	U	U	NEWCRB	$\tan Ø_{c_3}$
TANPC4	U	U	NEWCRB	$\tan Ø_{c_4}$
TANPC5	U	U	NEWCRB	$\tan Ø_{c_5}$
TANPC6	U	U	NEWCRB	$\tan Ø_{c_6}$
TANTP	U	U	COMP	$\tan\Theta'_t$
TAU		U	COMP5	τ_i
TAUA		U	INPT5	τ_A
TAUF		U	DRIVI	τ
TAUO		U	INPT5	$(\tau_i)_o$
TB	U	U	INPT	TB
TCT		U	INPT5	CT
TCTEST		U	DRIVTT	
TE	U	U	INPT	TE
TEMPOR		U	DRIVE	

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
TERM		U	COMP4	$\arctan \frac{\gamma_{Gi}}{/U_{Gi}/}$
TERMB		U	COMP4	$\emptyset_{C_i} - .6366\emptyset_{C_i}/\emptyset_{C_i}/$
TERMP		U	COMP4	$[\frac{V_{Gi}}{/U_{Gi}/} - \tan(\psi'_i \operatorname{sgn} U_{Gi}]^2$
TERMX		U	DRIVE	
TERMY		U	DRIVE	
TERM1	U	U	COMP	$Z_f + \delta_1 + h_1 \cos\gamma_{h_1}$
TERM2	U	U	COMP	$Z_f + \delta_2 + h_2 \cos\gamma_{h_2}$
TESTB		U	DRIVE	T_b
TESTBO		U	DRIVI	T_b
TESTR1		U	DRIVE	T_{R_1}
TESTR2		U	DRIVE	T_{R_2}
TESTS1		U	DRIVE	T_{S_1}
TESTS2		U	DRIVE	T_{S_2}
TESTT		U	DRIVI	
TF	U	U	INPT	T_F
TF02	U	U	COMP	$T_F/2$
TG61	U	U	COMP	$M_{UR}(\dot{\delta}_3 - \emptyset_R\dot{\emptyset}_R)$
THED	U	U	HEAD	TIRE TITLE
THESKD		U	DRIVE	Θ_c
THETAO	U	U	INPT	Θ_o
THETN	U	U	COMP	Θ'_n
THETT	U	U	COMP	Θ_t or Θ
THETTL	U	U	EINDEX	Θ_{t-1}
THETTP	U	U		Θ'_t
THGI	U	U	DIMV	Θ_{Gi}
THG1	U	U	COMP	
THG2	A	A	COMP	NOT USED
THMAX	U	U	INPT	Θ_{max}
TI	U	A	DIMV	T_i
TIHI		A	COMP4	NOT USED
TIL		U	DRIVI	T_I
TIMR		A	INTR	NOT USED
TINCR	U	U	INPT	
TITE		U	DRIVE	$t-t_j-\tau$
TIZ	U	U	COMP	$M_{UF}[a^2 + (\frac{T_F^2}{2})] + M_{UR}b^2$
TIZ2	U	U	COMP	$M_{UR}\rho^2\dot{\emptyset}_R$
TJ		U	DRIVE	
TL		U	DRIVI	T_L
TLAMB		U	COMP5	$I_{D_j}\overline{AR}^2/(41_{W_j} + I_{D_j}\overline{AR}^2)$
TLF		U	INPT5	LF
TMT		U	DRIVE	$(T_I-T_L)/T_L$
TM4	U	U	COMP	$T_F M_{UF}/4$
TPATH		U	DRIVTT	
TPC		U	INPT5	P_C
TPD		U	DRIVE	
TPF	U	U	SUSCMP	$T_F\emptyset_F/2$
TPR	U	U	COMP	$T_R\emptyset_R/2$
TPRINT				
TQB		U	COMP5	$(TQ)_{Bi}$
TQD		U	COMP5	$(TQ)_{Di}$
TQE		U	COMP5	$(TQ)_E$
TQF	U	A	INPT	$\overline{TQ}_F$
TQFAC		A	COMP4	NOT USED
TQR	U	A	INPT	$\overline{TQ}_R$
TR	U	U	INPT	T_R
TRH	U	U	COMP	$R_W - h_i$

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
TRO2	U	U	COMP	$T_R/2$
TRKIN		U	DRIVE	
TRPME		U	INPT5	RPME
TS	U	U	INPT	T_S
TSF	U	U	INSUS	T_{SF}
TSF02	U	U	SUSCMP	$T_{SF}/2$
TS02	U	U	COMP	$T_S/2$
TSTR10		U	DRIVI	T_{R_1}
TSTR20		U	DRIVI	T_{R_1}
TSTS10		U	DRIVI	T_{S_I}
TSTS20		U	DRIVI	T_{S_I}
TT		U	INPT5	
TTAU		U	INPT5	
TTEM		U	DRIVE	
TTPSIT		U	DRIVE	
TTR		U	INPT5	(TR)
TTS		U	INPT5	(TS)
TWOPI	U	U	EINDEX	2π
TWOPIR		U	COMP4	$I/(2\pi)$
TWOT		U	INPT5	WOT
TX	U	U	COMP	$X'_{GPi} - X'_i$
TY	U	U	COMP	$Y'_{GPi} - Y'_i$
TZ	U	U	COMP	$Z'_{GPi} - Z'_i$
TO	U	U	INPT	
T1	U	U	INPT	
T1PSI	U	U	COMPN	$T_{1\psi}$
T2PSI	U	U	COMPN	$T_{2\psi}$
U	U	U		u
UG	U	U	DIMV	u_{Gi}

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
UGW		U	COMP5	u_{GW_i}
UI	U	U		u_i
UNP	U		BARIER	u'_n
UP		A	DRIVE	NOT USED
UPT	U		HARDPT	U'_{Ri}
UQ	U	U	COMP	uQ
UR	U	U	COMP	uR
URP	U		BARIER	u'_r
UT		U	DRIVE	u_T
UTMPH		U	DRIVE	U_T
UVWMIN	U	U	INPT	
UO	U	U	INPT	u_o
UI	U	U	ADTNL	u_I
U2	U	U	ADTNL	u_2
U3	U	U	ADTNL	u_3
U4	U	U	ADTNL	u_4
V	U	U		v
VAR	U	U	INTG	$[y]$
VARR		A	INTR	NOT USED
VDEF	U		BARIER	$Y'_{CPm} - (Y'_{BP})_t$
VECS		U	COMP5	$\sqrt{U_{G_I}^2 + \gamma_{G_i}^2}$
VG	U	U	DIMV	v_{Gi}
VGR12		U	DRIVI	VGR_{12}
VGR2I		U	DRIVI	VGR_{2I}
VGR23		U	DRIVI	VGR_{23}
VGR32		U	DRIVI	VGR_{32}
VGR34		U	DRIVI	VGR_{34}

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
VGR43		U	DRIVI	VGR_{43}
VHED		U	HEAD	VEHICLE TITLE
VI	U	U		v_i
VL	U		BARIER	$\delta_B - \epsilon_{n-1}$
VMAX	U		BARIER	δ_B
VNP	U		BARIER	v'_n
VP	U	U	COMP	vP
VPT	U		HARDPT	v'_{Ri}
VR	U	U	COMP	vR
VRP	U		BARIER	v'_r
VTAN	U		BARIER	$\overline{VTAN}$
VO	U	U	INPT	v_o
V1	U	U	ADTNL	v_1
V2	U	U	ADTNL	v_2
V3	U	U	ADTNL	v_3
V4	U	U	ADTNL	v_4
W	U	U		w
WI	U	U		w_i
WNP	U		BARIER	w'_n
WP	U	U	COMP	wP
WPT	U		HARDPT	w'_{Ri}
WQ	U	U	COMP	wQ
WRP	U		BARIER	w'_r
WO	U	U	INPT	w_o
W1	U	U	ADTNL	w_1
W2	U	U	ADTNL	w_2
W3	U	U	ADTNL	w_3
W4	U	U	ADTNL	w_4

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
X		U	DRIVE	
XB	U	U	INPT	X_B
XBB	U		BARIER	X_{BB}
XBT	U		BARIER	X_{BI}
XBDRY	U	U	INPT	X_{BDRY}
XBRAK		A	COMP4	NOT USED
XCP	U	U		X'_C
XCPBP	U		BARIER	X'_{CPB}
XCPN	U		BARIER	X_{CPn}
XCPNP	U		BARIER	X'_{CPn}
XCPTP	U		BARIER	X'_{CPT}
XCOP	U	U	INPT	X'_{CO}
XE	U	U	INPT	X_E
XF	U		BARIER	$(F_B)_{t-1}$
XGPP	U	U	DIMV	X'_{GPi}
XIF	U	U	INSUS	I_F
XIMPOR		U	DRIVI	WI_i
XINCR	U	U	INPT	X_{INCR}
XINDL	U	U	EINDEX	
XINDN	U	U	EINDEX	
XINPT	A		INPT2	NOT USED
XINPT5		A	INPT5	NOT USED
XINT		U	DRIVE	
XIPS	U	U	INPT1	I_ψ
XIR	U	U	INPT	I_R
XIX	U	U	INPT	I_X
XIXP	U	U	COMP	$(I'_X)_t$
XIXZ	U	U	INPT	I_{XZ}
XIXZP	U	U	COMP	$(I'_{XZ})_t$
XIY	U	U	INPT	I_Y

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
XIYP	U	U	ADTNL	$(I'_Y)_t$
XIYZP	U	U	COMP	$(I'_{YZ})_t$
XIZ	U	U	INPT	I_Z
XIZP	U	U	COMP	$(I'_Z)_t$
XIZR	U	U	COMP	$I_Z + I_R$
XLAMF	U	U	INPT	λ_F
XLAMR	U	U	INPT	λ_R
XLAMT	U	U	TIRIN	λ_T
XLDP	A		BARIER	NOT USED
XLM1	U	U	DIMV	λ_{1i}
XLM2	U	U	DIMV	λ_{2i}
XLM3	U	U	DIMV	λ_{3i}
XM	A		INPT2	NOT USED
XMS	U	U	INPT	M_S
XMTF04	U	U	COMP	$T_F M_{UF}/4$
XMTR04	U	U	SUSCMP	$M_{UR} T_R/4$
XMTX	U		BARIER	
XMUR	U	U	INPT	M_{UF}
XMUF02	U	U	COMP	$M_{UF}/2$
XMUGI	U	U	COMPN	$AMUG_i$, AMU
XMUI	U	U	COMP4	μ_i
XMUM		U	INPT4	μ_{mi}
XMUMAT		U	INPT4	
XMUR	U	U	INPT	M_{UR}
XMUR02	U	U	SUSCMP	$M_{UR}/2$
XMUXP		U	INPT4	μ_{XP}
XMUXS		U	INPT4	μ_{XS}
XMXPMT		U	INPT4	
XMXSMT		U	INPT4	
XNN	U		BARIER	x_N

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
XP	U	U		x'_i
XPS	U	U	INPT1	$\overline{PT}$
XRI	U		BARIER	$(x_R)_i$
XSTI	U		BARSTR	X_{ST_i}
XSTI0	U		BARSTR	X_{STi_0}
XSTIP	U		BARSTR	X'_{ST_i}
XTRA	A	A	ADTNL	NOT USED
XVF	U		INPT2	x_{VF}
XVP		U	DRIVE	X'_{VP_i}
XVR	U		INPT2	x_{VR}
XXFRCP		U	INPT4	
XXUGMU		U	INPT4	
XXX	U	U	COMP	
XXZGP5	U	U	INPT	
XX1	U	U	COMP	
XX2	U	U	COMP	
X1	U	U	INPT	x_1
X1P	U	U	DIMV	x'_1
X2	U	U	INPT	x_2
X2P	U	U	DIMV	x'_2
X3P	U	U	DIMV	x'_3
X4P	U	U	DIMV	x'_4
Y		U	DRIVE	
YB	U	U	INPT	Y_B
YBB	U		BARIER	y_{BB}
YBPT	U		BARIER	y'_{BT}
YBDRY	U	U	INPT	Y_{BDRY}
YBPTP	U		BARIER	y'_{BPT}
YBPO	U		INPT2	y'_{Bo}
YBT	U		BARIER	y_{BT}

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
YCIP	U	U		y'_{Ci}
YCLP	U	U	NEWCRB	
YCMP	U	U	NEWCRB	
YCP	U	U		y'_{C}
YCPBP	U		BARIER	y'_{CPB}
YCPMP	U		BARIER	y'_{CPm}
YCPN	U		BARIER	y_{CPn}
YCPNP	U		BARIER	y'_{CPn}
YCPTP	U		BARIER	y'_{CPT}
YCOP	U	U	INPT	y'_{Co}
YC1P	U	U	INPT1	y'_{C1}
YC2P	U	U	INPT1	y'_{C2}
YC3P	U	U	NEWCRB	y'_{c3}
YC4P	U	U	NEWCRB	y'_{c4}
YC5P	U	U	NEWCRB	y'_{c5}
YC6P	U	U	NEWCRB	y'_{c6}
YE	U	U	INPT	Y_{E}
YGPPP	U	U	DIVM	y'_{GPi}
YINCR	U	U	INPT	Y_{INCR}
YNN	U		BARIER	y_{n}
YP	U	U		y'_{i}
YRI	U		BARIER	$(y_R)_i$
YSTI	U		BARSTR	y_{STi}
YSTI0	U		BARSTR	y_{STi0}
YSTIP	U		BARSTR	y'_{STi}
YSTIP0	U		BARSTR	y'_{STi0}
YTRANS		U	DRIVI	
YV	U		INPT2	y_{V}
YVP		U	DRIVE	y'_{VPi}
YYY	U	U	COMP	

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
YYZGP5	U	U	INPT	
YY1	U	U	COMP	
YY2	U	U	COMP	
Y1	U	U	INPT	y_1
Y1P	U	U	DIMV	y'_1
Y2	U	U	INPT	y_2
Y2P	U	U	DIMV	y'_2
Y3P	U	U	DIMV	y'_3
Y4P	U	U	DIMV	y'_4
ZBB	U		BARIER	Z_{BB}
ZBBP	U		INPT2	z'_{BB}
ZBT	U		BARIER	z_{BT}
ZBTP	U		INPT2	z'_{BT}
ZCLP	U	U	NEWCRB	
ZCMP	U	U	NEWCRB	
ZCP	U	U		z'_{C}
ZCPBP	U		BARIER	z_{CPB}
ZCPN	U		BARIER	z_{CPn}
ZCPNP	U		BARIER	z'_{CPn}
ZCPTP	U		BARIER	z'_{CPT}
ZCOP	U	U	INPT	z'_{CO}
ZC2P	U	U	INPT1	z'_{C2}
ZC3P	U	U	NEWCRB	Z'_{C3}
ZC4P	U	U	NEWCRB	Z'_{C4}
ZC5P	U	U	NEWCRB	Z'_{C5}
ZC6P	U	U	NEWCRB	Z'_{C6}
ZETAB		U	INPT5	ζ_B
ZETA3	A	A	COMP	NOT USED
ZETA3D	A	A	COMP	NOT USED

PROGRAM VARIABLE	R D	V D	COMMON BLOCK	ANALYTICAL VARIABLE OR EXPRESSION
ZETA4	A	A	COMP	NOT USED
ZETA4D	A	A	COMP	NOT USED
ZF	U	U	INPT	Z_F
ZFD1	U	U	SUSCMP	$Z_F+\delta_1$
ZFD1RF	U	U	SUSCMP	$Z_F+\delta_1+\rho_F$
ZFD12	U	U	COMP	$Z_F + (\delta_1 + \delta_2)/2$
ZFD2	U	U	SUSCMP	$Z_F+\delta_2$
ZFD3R	U	U	COMP	$Z_F + \rho + \delta_3$
ZF0	U	U	SUSCMP	$Z_F+\rho_F$
ZGP	U	U	INPT	Z'_G
ZGPP	U	U	DIMV	Z'_{GPi}
ZNN	U	U	BARIER	z_n
ZP	U	U		z'_i
ZPGI	U	U	DIMV	z'_{Gi}
ZPR	U	U	COMP	$z_F + \rho$
ZR	U	U	INPT	z_R
ZRD3	U	U	COMP	$z_R + \delta_3$
ZRD3R	U	U	COMP	$z_R + \delta_3 + \rho$
ZRD34	U	U	SUSCMP	$Z_R+(\delta_3+\delta_4)/2$
ZRD4	U	U	SUSCMP	$Z_R+\delta_4$
ZRI	U		BARIER	$(z_R)_i$
ZRO	U	U	COMP	$z_R + \rho$
ZSTI	U		BARSTR	Z_{STi}
ZSTI0	U		BARSTR	Z_{STi_0}
ZSTIP	U		BARSTR	Z'_{STi}
ZVB	U		INPT2	z_{VB}
ZVT	U		INPT2	z_{VT}
ZZ1	U	U	COMP	
ZZZ	U	U	COMP	
Z1	U	U	INPT	z_1
Z1P	U	U	DIMV	z'_1
Z2	U	U	INPT	z_2
Z2P	U	U	DIMV	z'_2
Z3P	U	U	DIMV	z'_3
Z4P	U	U	DIMV	z'_4

3. HVOSM PROGRAM DESCRIPTION

3.1 Nature of the Problem Solved

The development of the Highway-Vehicle-Object-Simulation-Model (HVOSM) was undertaken to provide an analytical means of studying the energy conservation characteristics of roadside terrain and obstacles. The ultimate objective of the development was to reduce both the incidence of injury-producing accidents and the economic losses due to property damage that occur on existing rural highways.

To that end, the two versions of the HVOSM simulate the interaction between an automobile and it's environment with each version having a specialized capability.

The HVOSM-RD2 version was developed for evaluating roadside barriers, either of a rigid or deformable nature, and for detailed evaluations of roadway and roadside terrain geometrics such as those associated with railroad grade crossings, median earth berms and cut/fill slopes. The second program version, the HVOSM-VD2, was developed for the purpose of studying the effects of braking systems and the effects of driver control inputs in emergency and precollision situations as they relate to the performance of roadside elements.

3.2 HVOSM Program Capabilities

The HVOSM program versions provide the capability of simulating the rigid body dynamics of an automobile undergoing arbitrary maneuvers in an extensive environment.

The versions of the HVOSM computer simulation provide the user with the overall capability of simulating the following:

1. Simultaneous vehicle ride and handling motions of vehicles with either independent suspension or solid axle suspension or combinations thereof.

2. Impacts between the vehicle body and roadside structures.

3. The effects of variable terrain on vehicle response.

4. The effects of contact between tires and curbs on vehicle response.

5. The effects of the dynamics of wheel spin on vehicle response.

6. The detailed torque producing capability of various braking systems.

An overall comparison of the HVOSM models with regard to their specific capabilities is shown in Table 3.2-1.

3.3 HVOSM Program Limitations

3.3.1 Vehicle Model

The analytical model of the vehicle is limited to four wheels with either a rigid axle or independent suspension. Suspension compliance effects on steer and camber angles are neglected.

The steering system per se is not modeled, rather, steer inputs and the steer degree of freedom relate directly to the average steer angle of the two front wheels.

Table 3.2-1 SUMMARY OF HVOSM CAPABILITIES

		Roadside Design Version	Vehicle Dynamics Version
Degrees of Freedom	Sprung Mass	6	6
	Unsprung Masses	4	4
	Steer	1	1
	Wheel Spin	-	4
External Forces	Tire Forces	Friction Circle	Friction Ellipse
	Impact Forces	Yes	-
	Aerodynamic Forces	-	Yes
	Rolling Resistance	-	Yes
	Road Roughness	Yes	Yes
Terrain		Rigid-Five Tables	Rigid-Five Tables
Curbs		Yes	Yes
Suspension Stops		Asymmetric-energy absorbing	Asymmetric-energy absorbing
Control Inputs	Steer Table	Yes	Yes
	Wheel Torque Table	Yes	-
	Brake System Pressure	-	Yes
	Throttle Setting and Transmission Ratio	-	Yes
	Closed Loop Driver	-	Yes

The tires are treated as thin discs and therefore in cases of sharp terrain slope discontinuities where the wheel is nearly parallel to the discontinuity, the lack of consideration of lateral enveloping power of the tire may result in minor response discrepancies.

Shock absorber characteristics are assumed to be symmetric in compression and extension.

3.3.2 Tire Models

The point of application of the tire side forces is assumed to be a constant distance ($\overline{PT}$, the pneumatic trail) from the intersection of the front wheel steering axis and the ground.

The radial load-deflection properties are modeled as a bi-linear, perfectly elastic spring without damping.

Tire side force characteristics at extreme normal loads are not known. While the cornering stiffness is varied as an empirical function of tire loading in the load range where measurements are available, it is held constant under extremely high loading conditions.

3.3.3 Terrain

The terrain in all program versions is assumed to be rigid.

In each program version, use of the terrain boundary feature to model sharp slope discontinuities may result in significant momentary errors occurring in the calculation of the ground elevation and consequently the tire radial force. Such errors occur when the wheel center is on one side of a terrain boundary and the actual ground contact point is on the other side, and result from the assumption that the local ground directly under a wheel center is planar containing the ground contact point. When the wheel center and actual ground contact point are on opposite sides of a terrain boundary, this assumption is violated. Sharp slope discontinuities should be modeled with the curb option.

Road roughness input is assumed to be single-track data that varies only along the space-fixed X' axis. Data, in the form of elevation variation from the datum, must be at constant X' spacing.

3.3.4 Sprung Mass Impacts

Consideration of impact forces applied directly to the sprung mass is limited to the case of vertical faced barriers. Contact between the vehicle body and ground is not simulated.

Deformable barriers simulated by the HVOSM-RD2 are assumed to be massless.

Development effort on the sprung mass impact routine was quite limited and therefore the routine was not fully refined. Computational difficulties may arise in the sprung mass impact algorithms in some cases where a large amount of vheicle roll occurs due to a remaining difficulty in determining the boundary between newly crushed and previously crushed vehicle structure.

3.4 Mathematical Model Description

3.4.1 Coordinate Systems

Two primary coordinate systems, both orthogonal, are employed in the mathematical description of the vehicle. The first is a right handed coordinate system fixed in space (the inertial system). The second is a coordinate system fixed in the body of the vehicle. The inertial coordinate system first provides a valid system for the application of Newton's Laws, and secondly relates the vehicle to the terrain. The second (vehicle fixed) coordinate system affords convenience of analysis. That is, many parameters needed to describe the vehicle are most meaningfully related to the vehicle. In fact, some parameters are unchanging with respect to the vehicle but constantly changing with respect to space as the vehicle moves. For example, the steer angles of the front wheels may be constant with respect to the vehicle but vary with respect to space as the vehicle turns. Similarly, the moments and products of inertia are constant with respect to the vehicle but vary with respect to space as the vehicle moves.

Consequently, it is desirable to write the equations of motion of the vehicle with respect to vehicle fixed axes, and keep track of the vehicle with respect to a set of space fixed axes.

The space fixed axes are right handed with Z' pointing down (in the direction of gravitational attraction). The X' and Y' axes are located arbitrarily. Similarly, the vehicle Z axis is down (toward the bottom of the car), the X axis points forward toward the front of the car and the Y axis points toward the right side of the car. The origin of the vehicle coordinate system is the center of gravity of the vehicle sprung mass.

3.4.2 Degrees of Freedom

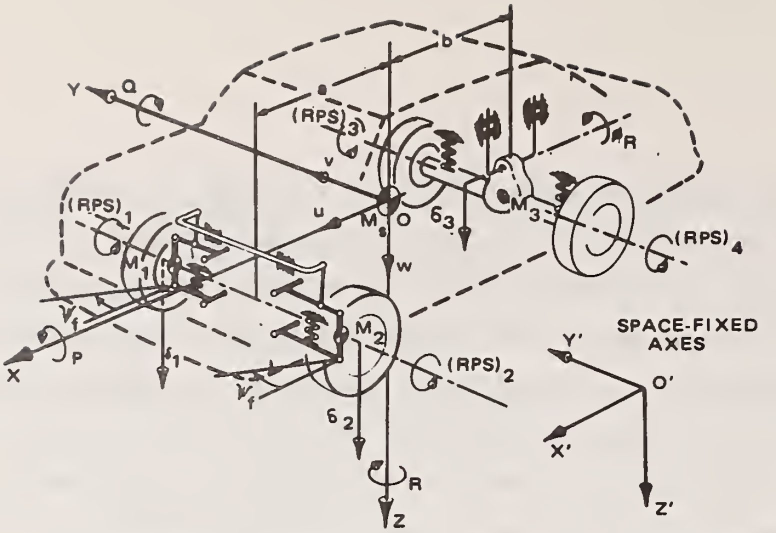
3.4.2.1 Roadside Design Version

The number of degrees of freedom of a dynamic system is equal to the number of generalized coordinates required to describe the position of all elements of the system with respect to inertial space. Description of the general motion of a rigid body in three-dimensional space requires six coordinates with respect to the space axes. These are three linear coordinates of a point on the body (X', Y', Z') and three Euler angles (ϕ, θ, ψ) that define the rotation of the body about that point.

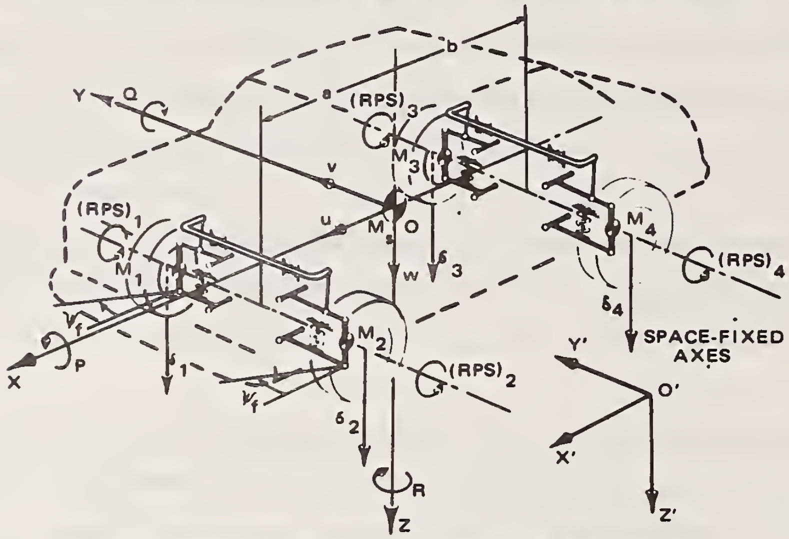
The analytical representation of the vehicle (Figure 3.4-1) is an assembly of three, four, or five rigid bodies consisting of the sprung mass (chassis and body) and unsprung masses (the wheels and/or axles) which move relative to the sprung mass. Since the sprung mass (M_s in the figure) is assumed to behave as a rigid body it requires six degrees of freedom (X_c', Y_c', Z_c', ϕ, θ, ψ). If the independent front suspension is in use, the two front wheels (M_1, M_2) are assumed to move vertically with respect to the vehicle body and thus require one degree of freedom each (δ_1, δ_2). For a solid front axle (M_1), a vertical degree-of-freedom (δ_1) and a rotational degree of freedom (ϕ_F) are required to describe its position and orientation. Similarly, for an independent rear suspension the wheels (M_3, M_4) have a degree of freedom each (δ_3, δ_4) and the solid rear axle (M_3) has a vertical (δ_3) and rotational (ϕ_R) degree of freedom. The steer angle of the front wheels (ψ_f) is an optional degree of freedom which may be specified. Thus, the total number of degrees of freedom in the analytical representation of the vehicle is eleven.

The steer mode degree of freedom, for which any inertial coupling effects are neglected, is introduced at the front wheels when rigid obstacles (e.g., curbs) are encountered by the wheels, or at the request of the user. When specified, the steer angle at the front wheels, ψ_f, is treated as an arbitrary tabular function of time until the wheel contacts a rigid obstacle. The tabular values at the time of contact and immediately before that time are used to provide starting values of angular displacement and velocity for the steer degree of freedom.

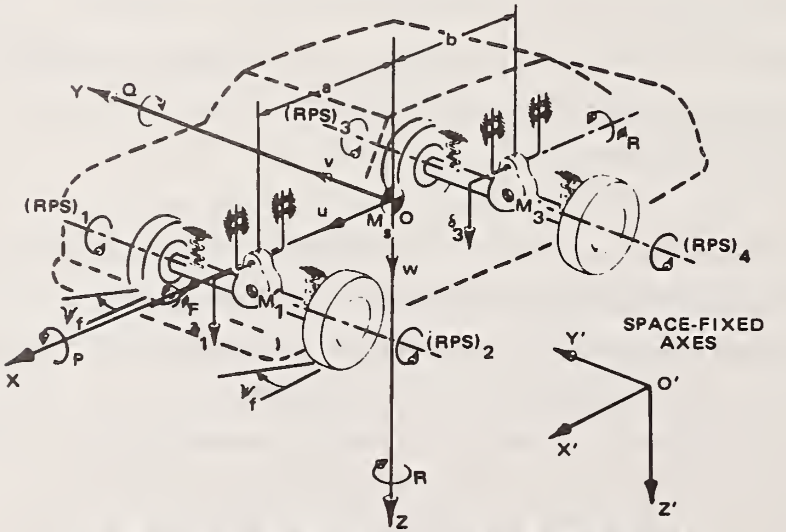
The centers of gravity of independently suspended wheels are assumed to be constrained to move along straight-line paths parallel to the sprung mass Z axis. Solid axle centers of gravity are assumed to be constrained to motions in a plane perpendicular to the sprung mass X axis. They are also assumed to be constrained to remain a fixed distance from the axle "roll center" (i.e., the virtual center about which axle motions take place in roll). This axle roll center is assumed to move along a straight-line path parallel to the sprung mass Z axis.



(a) INDEPENDENT FRONT - SOLID AXLE REAR SUSPENSION



(b) INDEPENDENT FRONT AND REAR SUSPENSION



(c) SOLID AXLE FRONT AND REAR SUSPENSIONS

Figure 3.4-1 ANALYTICAL REPRESENTATION OF VEHICLES

It is recognized that the actual paths in the vehicle coordinate system of the unsprung mass centers of gravity are curvilinear. However, the errors in inertial interaction effects produced by the straight-line assumptions are considered to be negligible. The corresponding errors in suspension geometry are corrected for the independent suspension case by inclusion of a tabular representation of track change as a function of wheel position.

3.4.2.2 Vehicle Dynamics Version

In addition to the degrees of freedom described in Section 3.4.2.1, the Vehicle Dynamics Version includes rotational degrees of freedom for the four wheels. Thus, the effects on tire forces of rotational wheel slip due to traction or braking can be approximated. The wheel rotational degrees of freedom are assumed to be isolated from the coupled differential equations of the sprung and unsprung masses but inertial coupling between the pair of drive wheels is included.

3.4.3 Inertial Properties

3.4.3.1 Roadside Design Version

Plane OXZ in Figure 3.4-1 is assumed to be a plane of mirror symmetry for the sprung mass.

The centers of gravity of independently suspended unsprung masses are assumed to coincide with the wheel centers. The wheels are treated as point masses, i.e., the fractional contribution of the suspension parts is approximated by a simple addition to the wheel mass.

The centers of gravity of solid axle unsprung mass are assumed to coincide with the geometric center of the axle. In the treatment of inertial coupling between the sprung mass and solid axle unsprung masses the axle is approximated by a thin rod.

Gyroscopic effects of the rotating wheels, drive train and engine assembles are neglected.

3.4.3.2 Vehicle Dynamics Version

Treatment of inertial properties in this version duplicates the foregoing with one addition. Gyroscopic precession of the front wheel steer degree of freedom due to wheel spin is included. However, precession torques acting on the sprung mass are neglected.

3.4.4 Suspension Geometry

Camber angles and half track change of independently suspended wheels relative to the vehicle are determined by interpolation of a tabular input of camber angle and track change as a function of suspension deflection.

The steer angles of the front wheels relative to the vehicle are assumed to be equal. Roll steer effects in the front suspension are neglected.

Rear axle roll steer is treated as a linear function of the angular degree of freedom of the rear axle, ϕ_R (see Figure 3.4-1). Inertial effects are neglected in the steer mode of rear axle motion. Independent rear suspension ride-steer is treated as a third order polynomial function of suspension position.

Anti-pitch effects of suspension geometry are simulated with tabular coefficients as a function of suspension deflection for the front and rear suspensions.

3.4.5 External Forces

External forces applied to the simulated vehicle arise from the interaction between the vehicle and its environment. They are applied directly to system components (sprung mass or unsprung masses) and do not act between system masses. Such forces include tire forces, rolling resistance, aerodynamic forces, and impact forces.

Tire forces calculated and applied to the vehicle include the radial force in the plane of the wheel arising from in-plane tire deformations, the side force arising from slip and camber angles, and tractive (circumferential) force arising from applied torques. These forces are interdependent for a given tire and the general method used in their computation is discussed in the next section.

Impact forces are considered in the Roadside Design version only. Rolling resistance and aerodynamic forces are accounted for in the Vehicle Dynamics version only.

3.4.5.1 Tire Forces

The tire simulation is designed to handle the complete range of loading, from a loss of ground contact to extreme overload. The empirical relationships used to generate the side, braking and traction forces are aimed primarily at accuracy within the normal ranges of operating conditions. It is assumed that excursions beyond the normal ranges of operating conditions will be of limited duration and that the tire forces under those conditions can be treated in a more approximate manner.

Provision has been made for up to four different sets of tire data; therefore, each tire on the vehicle may have different characteristics.

3.4.5.1.1 Radial Loading

As a starting point in the tire force calculations, the radial loading of each tire, F_{R_i}, is first calculated from the position and orientation of the individual wheel in relation to the local terrain. The radial loading is calculated in two different modes, depending on the nature and the current tire-terrain contact patch (see Figure 3.4-2).

In the first mode, terrain undulations are assumed to be sufficiently gradual to produce essentially planar tire-terrain contact patches at the individual tires. Within this mode, a "point-contact" representation of the tire is used to generate the radial loading. At each point in time, the terrain elevations and slopes, at points directly under each wheel center, are obtained by interpolation of tabular input data for the terrain profile. Determination of the "ground contact point" is accomplished by passing a plane through the wheel center perpendicular to both the wheel and the local ground planes at the individual wheels. The point that lies in this plane, the wheel plane, and the ground plane is designated the "ground contact point". The distances between the individual wheel centers and the corresponding "ground contact points" are then calculated to determine the existence and the extent of radial tire deflections. A "hardening" spring characteristic, depicted in Figure 3.4-3, is applied to generate corresponding radial loading for the individual tires.

The second mode of radial load calculation is used in the case of terrain irregularities for which the tire-terrain contact patch is not planar (e.g., curbs and road roughness). In this mode, the individual wheels in contact with such a terrain irregularities are treated as discs composed of nonlinear radial springs. The radial springs are identical and are arbitrarily spaced at 4° intervals in the assumed wheel disc. The nonlinear load-deflection characteristics are automatically generated by an input subroutine to match the specified flat-terrain properties (input data) in the point-contact mode (Figure 3.4-2). At each point in time, the lower half of

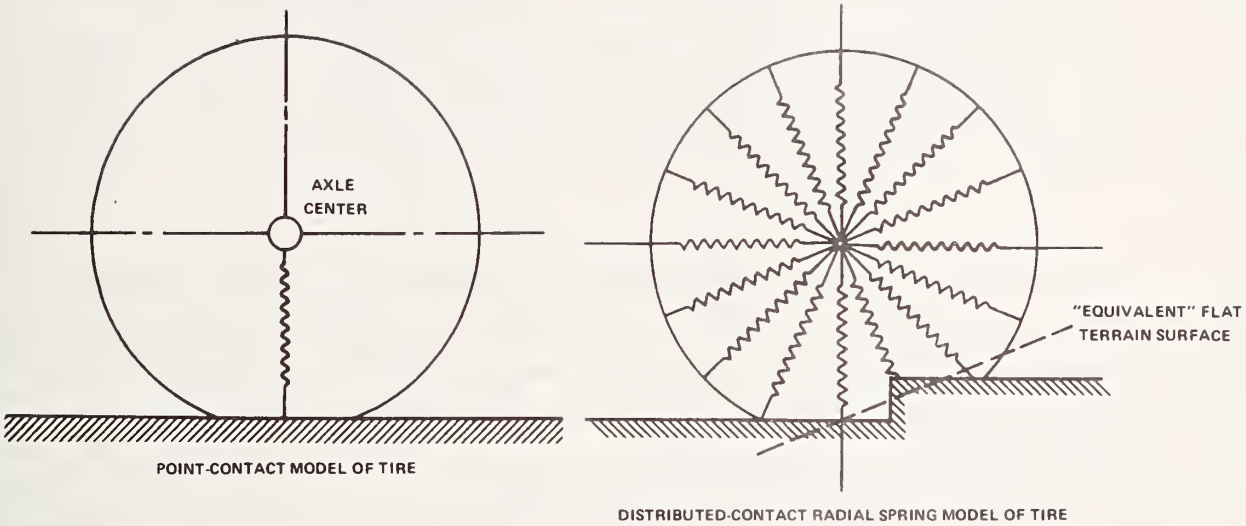


Figure 3.4-2 TWO MODES OF SIMULATION OF THE RADIAL CHARACTERISTICS OF TIRES

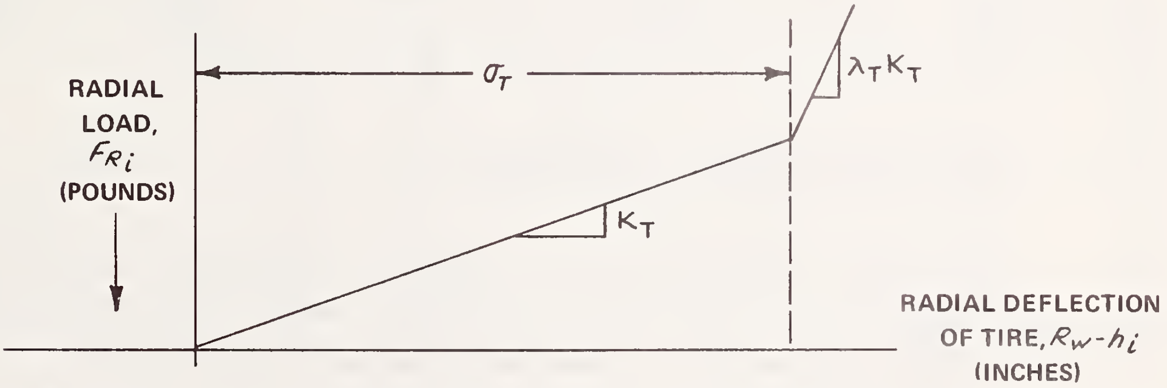


Figure 3.4-3 ASSUMED RADIAL LOAD-DEFLECTION CHARACTERISTIC OF TIRES (FLAT TERRAIN)

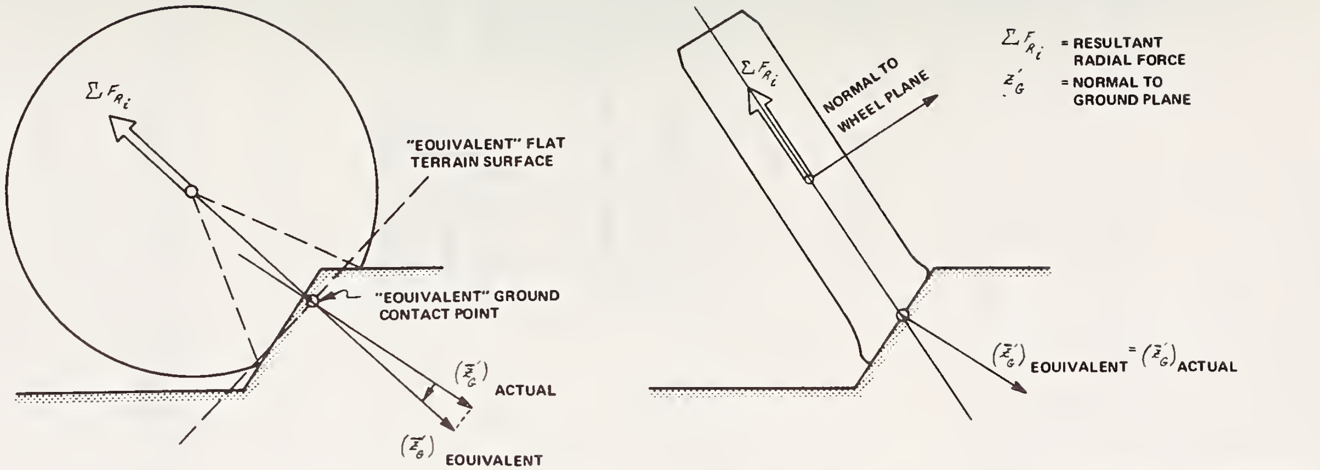
the wheel plane is swept by a vector, with origin at the wheel center and length equal to the undeflected wheel radius, to determine the tire-terrain interface profile at the locations of the individual radial springs. The vector sum of radial forces, corresponding to the deflections and orientations of the individual springs, is used to generate an "equivalent" ground contact point and an "equivalent" flat terrain surface at each wheel, thereby permitting a continuous calculation of approximate side, tractive and braking forces.

The equivalent ground contact point is defined in terms of the wheel geometry (location and orientation) and the orientation and magnitude of the radial tire loading. The equivalent ground contact point (C in Figure 3.4-4, Case 3) lies on the line coinciding with one radial tire load vector (ΣF_{R_i}). Its location along that line corresponds to the tire surface as deflected according to the Point Contact Model under a load equal to the radial tire load found above.

Next the plane formed by the radial tire loading vector and the normal to the wheel at the wheel center (or the equivalent ground contact point) is found (CAN in Case 3a, see Figure 3.4-4). The vector ($\overrightarrow{CP}$ in Case 3b) normal to the actual terrain nearest point C which also passes through point C is found and projected into plane CAN. The projected vector ($\overrightarrow{CQ}$) is finally used to find the equivalent terrain surface, which is defined to pass through point C and be perpendicular to CQ (Case 3c).

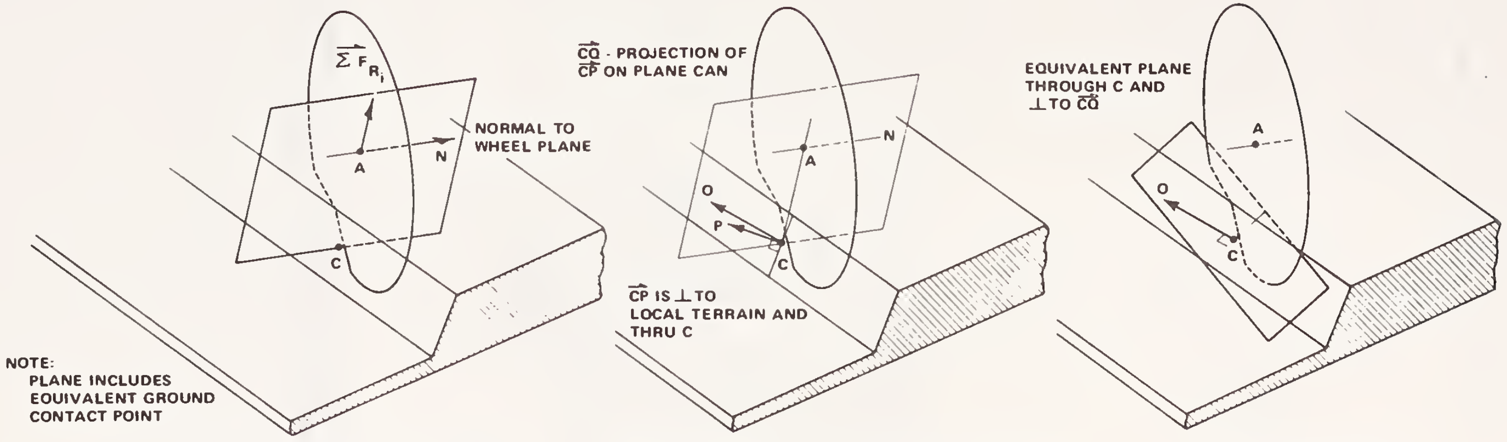
3.4.5.1.2 Tire Loading Normal to the Ground

The side, braking and traction forces are, of course, related to the tire load normal to the plane of the tire-terrain contact patch, F'_{R_i}, rather than the radial tire load, F_{R_i}. Therefore it is necessary to find the value of F'_{R_i} corresponding to the radial load, F_{R_i}, and the side force, F_{s_i}. The components of the external applied forces, F'_{R_i} and F_{s_i}, along



CASE 1 WHEEL PLANE PERPENDICULAR TO OBSTACLE PROFILE

CASE 2 WHEEL PLANE PARALLEL TO OBSTACLE PROFILE



a) FIND PLANE DEFINED BY $\overrightarrow{\Sigma F_{R_i}}$ AND WHEEL NORMAL

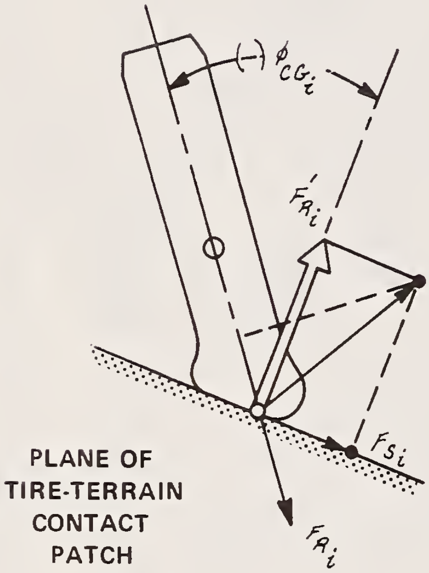
b) PROJECT NORMAL TO LOCAL TERRAIN (AT C) ONTO THE PLANE (CAN)

c) FIND EQUIVALENT PLANE

CASE 3 GENERAL

Figure 3.4-4 "EQUIVALENT" FLAT TERRAIN SURFACE FOR NONPLANAR TIRE-TERRAIN CONTACT the line of action of the radial tire force, F_{R_i}, are depicted in Figure 3.4-5. These force components must be in equilibrium with F_{R_i}, such that

$$F'_{R_i} \cos \phi_{CG_i} + F_{s_i} \sin \phi_{CG_i} = F_{R_i} . \tag{1}$$



ϕ_{CG_i} = CAMBER ANGLE RELATIVE TO TERRAIN (SHOWN NEGATIVE)

F_{s_i} = SIDE FORCE PRODUCED BY COMBINATION OF SLIP ANGLE AND CAMBER ANGLE

i = 1, 2, 3, 4

Figure 3.4-5 VECTOR SUMMATION OF FORCES WITH COMPONENTS ALONG THE LINE OF ACTION OF THE RADIAL TIRE FORCE (VIEWED FROM REAR)

Solution of (1) for F'_{R_i} yields

$$F'_{R_i} = F_{R_i} \sec \emptyset_{CG_i} - F_{s_i} \tan \emptyset_{CG_i} . \tag{2}$$

Since F'_{R_i} is required for the determination of F_{s_i}, an initial approximation of F_{s_i} is obtained by extrapolation from the previous time increment. Following the calculation of F_{s_i} in the current time increment, an iterative procedure is employed to correct both F'_{R_i} and F_{s_i}.

3.4.5.1.3 Side Forces

The side force calculations are based on the small angle (slip and camber) properties of the tires which are "saturated" at large angles. Variations in the small-angle cornering and camber stiffnesses produced by changes in tire loading are approximated by parabolic curves fitted to experimental data (Figure 3.4-6). The small-angle cornering stiffness is taken to be the partial derivative of lateral force with respect to slip angle as measured at zero slip angle for various tire loads. The upper plot in Figure 3.4-6 depicts a parabola fitted to the small-angle cornering stiffness as a function of tire loading, in which the cornering stiffness varies as,

$$C_{s0} = A_0 + A_1 F'_{R_i} - \frac{A_1}{A_2} (F'_{R_i})^2 \tag{3}$$

The lower plot of Figure 3.4-6 depicts a similar fit to small-angle camber stiffness, the partial derivative of lateral force with respect to camber angle as measured at zero camber angle, in which the camber stiffness varies as,

$$C_{c0} = A_3 F'_{R_i} - \frac{A_3}{A_4} (F'_{R_i})^2 \tag{4}$$

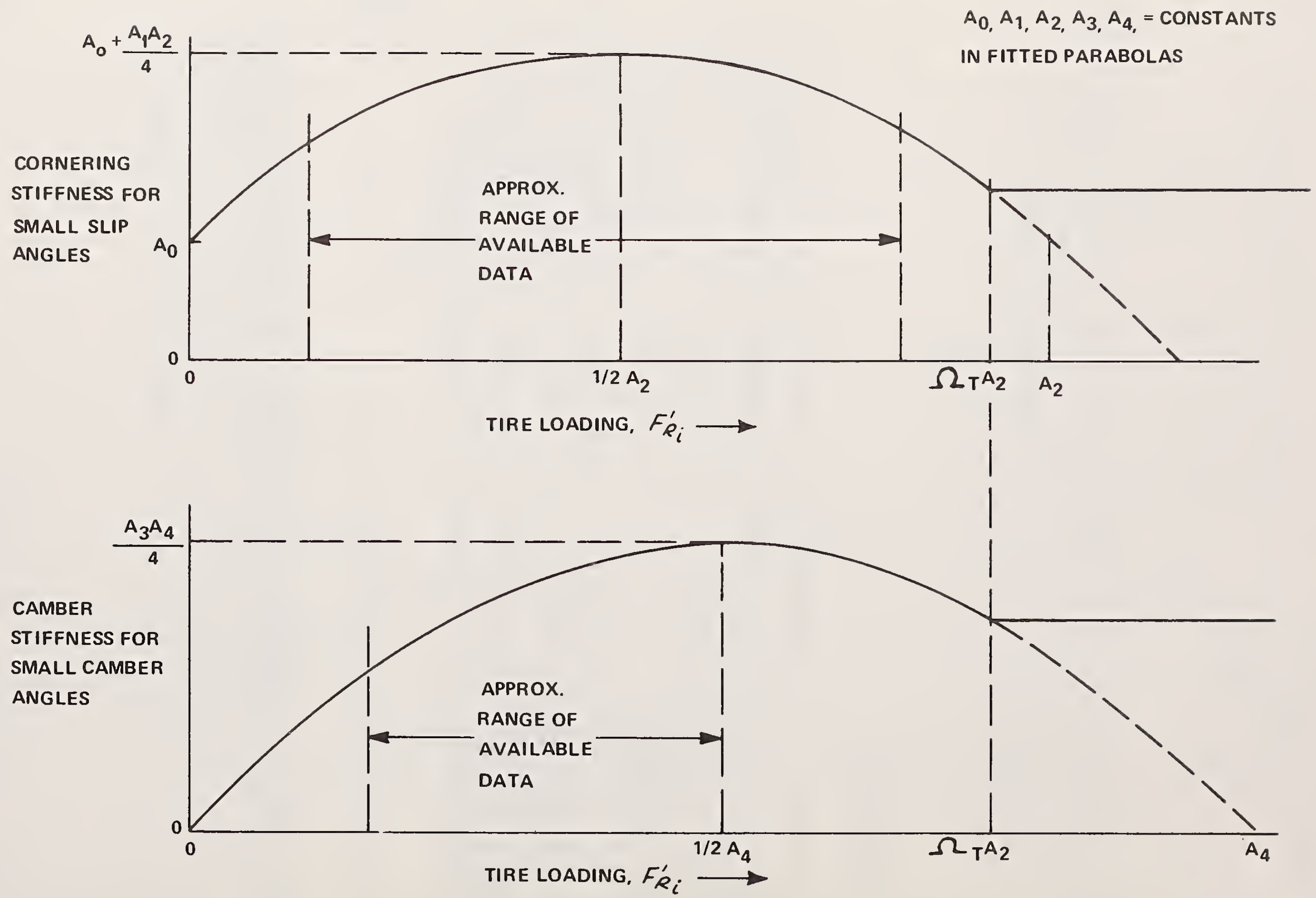


Figure 3.4-6 SIMULATED VARIATION OF SMALL-ANGLE CORNERING AND CAMBER STIFFNESS WITH LOADING NORMAL TO TIRE-TERRAIN CONTACT PATCH

The fitted parabolic curves are abandoned for tire loading in excess of $\Omega_T A_2$ (see Figure 3.4-6), where the approximate range of the coefficient is $0.80 < \Omega_T < 1.15$ (Ω_T is an adjustable item of input data). The side force properties are then treated as being independent of tire loading. The use of Ω_T is necessary to avoid artificial reversal of the slip angle forces under conditions of extreme loading (i.e., where $A_2 << F'_{R_i}$). Actual properties of tires in this range of loading (i.e., extreme overload) are not known.

For the case of zero traction and braking the side forces, for small slip and camber angles, can be expressed from (4) and (3) as

$$\left(F_{S_i}\right)_{CAMBER} = -\left[\frac{A_3 F'_{R_i}\left(F'_{R_i} - A_4\right)}{A_4}\right] \phi_{CG_i} , \tag{5}$$

$$\left(F_{S_i}\right)_{SLIP} = \left[\frac{A_1 F'_{R_i}\left(F'_{R_i} - A_2\right) - A_0 A_2}{A_2}\right]\left[\frac{v_{G_i}}{u_{G_i}} - \psi'_i\right] \tag{6}$$

where the sign convention corresponds to the right-hand rule applied to the system depicted in Figure 3.4-1.

The tire model must handle extremely large camber angles relative to the tire-terrain contact planes. Applicable tire data are not known to be available. Therefore the assumption has been made that the camber force, for a given normal load, will reach its maximum value at 45 degrees of camber. In accordance with this assumption, a parabolic variation of camber force with camber angle is simulated with the peak occurring at 45 degrees (see Figure 3,4-7). With the assumed large-angle camber characteristic depicted in Figure 3.4-7, Equation (5), for the complete range of possible camber angles, becomes

$$\left(F_{S_i}\right)_{CAMBER} = -\left[\frac{A_3 F'_{R_i}\left(F'_{R_i} - A_4\right)}{A_4}\right]\left[\phi_{CG_i} - \frac{2}{\pi}\phi_{CG_i}\left|\phi_{CG_i}\right|\right] \tag{7}$$

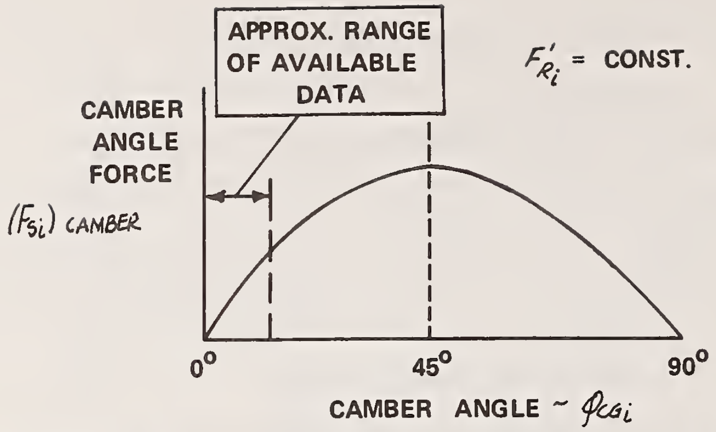


Figure 3.4-7 ASSUMED VARIATION OF CAMBER FORCE WITH CAMBER ANGLE

To permit the use of the nondimensional slip angle concept which "saturates" the side force at large slip angles, an "equivalent" slip angle (i.e., a slip angle which will produce the same value of side force as resulting from the camber angle) is defined to approximate camber effects

$$\beta'_i = \left\{ \frac{A_2 A_3 F'_{R_i}(A_4 - F'_{R_i})}{A_4\left[A_1 F'_{R_i}(F'_{R_i} - A_2) - A_0 A_2\right]} \right\} \left[\phi_{CG_i} - \frac{2}{\pi} \phi_{CG_i} \left| \phi_{CG_i} \right| \right]. \tag{8}$$

Note that the selected analytical treatment of camber angles subjects the camber force to the saturation effects of the slip angle, superimposed on the assumed behavior shown in Figure 3.4-7. While the assumption depicted in Figure 3.4-7 may be shown to be in error when appropriate tire data becomes available, it was found to be necessary to reduce the "equivalent" slip angle of large camber angles to avoid an unrealistic predominance of camber effects on steeply inclined terrain obstacles. On the basis of the comparisons of predicted and experimental responses that have been made to date, it must be concluded that the selected analytical representation of large-angle camber effects is at least adequate.

Using definition (8), the resultant side force for small angles and the entire range of camber angles can be expressed as

$$F'_{s_i} = \left[\frac{A_1 F'_{R_i} (F'_{R_i} - A_2) - A_0 A_2}{A_2} \right] \left[\frac{v_{G_i}}{u_{G_i}} - \psi'_i + \beta'_i \right] . \qquad (9)$$

Application of Equation (9) to the nondimensional side force relationship (see Figure 3.4-8) yields

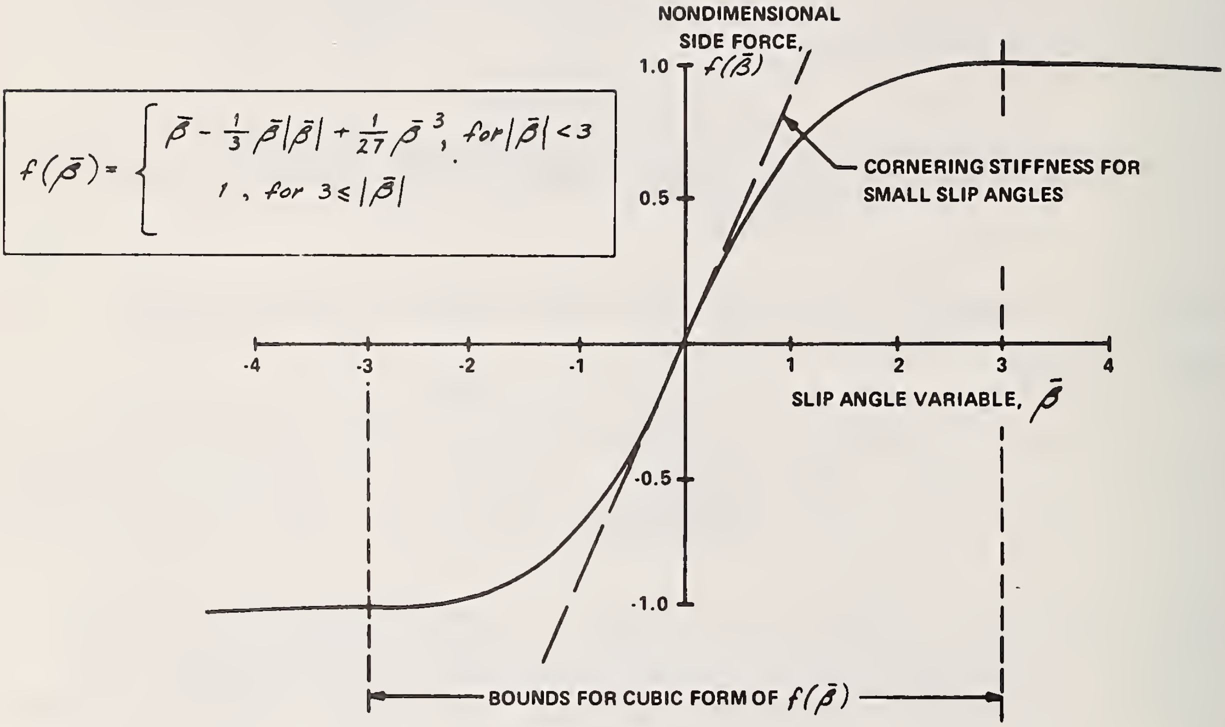
$$f(\bar{\beta}_i) = \frac{F_{s_i}}{(F_{s_i})_{max}} = \bar{\beta}_i - \frac{1}{3} \bar{\beta}_i \left| \bar{\beta}_i \right| + \frac{1}{27} \bar{\beta}_i^3 \qquad (10)$$

where F_{s_i} = resultant side force for entire range of slip and camber angles, and

$$\bar{\beta}_i = \frac{F'_{s_i}}{(F_{s_i})_{max}} \qquad (11)$$

Large values of the slip angle, particularly in skidding, make it necessary to use the arctan (v_{G_i} / u_{G_i}) rather than (v_{G_i} / u_{G_i}). Also, in cases where reversal of the vehicle velocity has occurred, it has been found to be necessary to control the algebraic signs of the slip and steer angles. Equation (11) requires that Equation (9) be modified as follows:

$$\bar{\beta}_i = \left[\frac{A_1 F'_{R_i} (F'_{R_i} - A_2) - A_0 A_2}{A_2 (F_{s_i})_{max}} \right] \left[\arctan \frac{v_{G_i}}{\left| u_{G_i} \right|} - (1 \operatorname{sgn} u_{G_i}) \psi'_i + \beta'_i \right] \qquad (12)$$



$$f(\bar{\beta}) = \begin{cases} \bar{\beta} - \frac{1}{3}\bar{\beta}|\bar{\beta}| + \frac{1}{27}\bar{\beta}^{3}, & \text{for } |\bar{\beta}| < 3 \\ 1, & \text{for } 3 \leq |\bar{\beta}| \end{cases}$$

Figure 3.4-8 NONDIMENSIONAL TIRE SIDE-FORCE CURVE

3.4.5.1.4 Circumferential Forces

3.4.5.1.4.1 Roadside Design Version

The "friction circle" concept is based on the assumption that the maximum force that can be generated by the tires in the plane of the tire-terrain contact patch is equal in all directions. With the use of the "friction circle" concept (see Figure 3.4-9), the maximum side force can be expressed as

$$\left(F_{S_i}\right)_{max} = \sqrt{\mu^2 \left(F'_{R_i}\right)^2 - F_{c_i}^2} \qquad (13)$$

where F_{c_i} = circumferential tire force (i.e., traction or braking) at wheel i, in pounds.

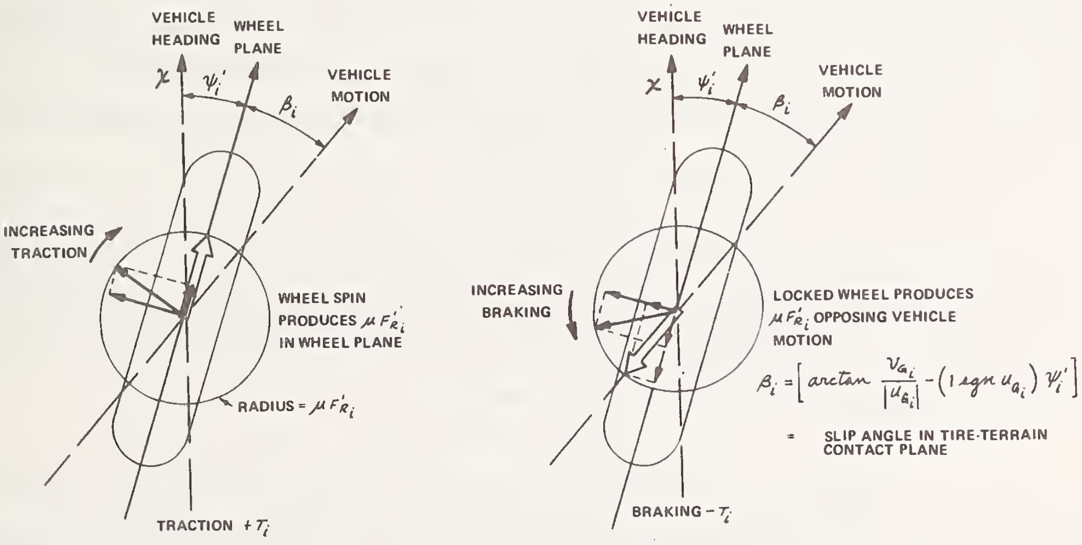


Figure 3.4-9 FRICTION CIRCLE CONCEPT

3.4.5.1.4.2 HVOSM Vehicle Dynamics Version

The calculation of the tire loading normal to the ground, F'_{R_i}, and the tire side force, F_{s_i}, follows the same assumptions and derivations[1] given in the previous section. However, the tire model employed in this program version makes use of the "friction ellipse" concept in establishing the relationship between side and circumferential forces. In addition, the inclusion of wheelspin as a degree-of-freedom necessitates the use of longitudinal tire characteristics in determining the instantaneous, circumferential force based on measured tire properties.

The "friction ellipse" is an extension of the widely used "friction circle" concept that permits a more realistic analytical treatment of interactions between the circumferential force (i.e., tractive or braking) and the side force of a tire. Experimental evidence that the maximum values of tire friction forces are dependent on direction relative to the wheel plane. General representation of frictional properties of pneumatic tires requires independent specification of lateral and circumferential friction coefficient and their variation with load and speed. Further, two characteristic coefficients are required to represent the circumferential friction, i.e., the peak (μ_{xp}) and sliding (μ_{xs}) coefficient.

In the "friction ellipse" form of treatment of interactions, the maximum value of the resultant tire friction force in the tire-terrain contact plane is assumed to be bounded by an ellipse with the minor axis equal to $2\mu_y F'_R$ and major axis equal to $2\mu_{xp} F'_R$, where

μ_y = effective tire-terrain friction coefficient for side forces, for the given conditions of vehicle speed and tire loading. Note that, in the absence of circumferential forces, the value $\mu_y F'_R$ constitutes the maximum achievable side force.

μ_{xp} = peak tire terrain friction coefficient for circumferential forces for the given conditions of vehicle speed and tire loading.

F'_{R_i} = tire loading perpendicular to the tire-terrain contact plane, lbs.

The bounding ellipse is depicted in Figure 3.4-10. Note that a value of $\mu_{xp} = \mu_y$ will reduce the "friction ellipse" to a "friction circle".

In the calculation procedure of the developed analytical treatment of interactions, the circumferential tire force, F_c, is given first priority in utilization of the available friction. The maximum value of side force, $(F_s)_{max}$, corresponds to a resultant force that constitutes a radius vector of the bounding ellipse, is then determined for use in the calculation of side forces.

Implementation of the friction ellipse tire model requires tabular inputs of μ_y, μ_{xp}, μ_{xs} and $SLIP_p$ (the value of SLIP at which μ_{xp} occurs) as functions of both speed and load. Note that these values of friction are obtained directly from tire test data and therefore reflect frictional properties of the test surface. Differences between nominal friction coefficients of the test surface and simulated terrain are accounted for by modifying the tabular input values by the ratio of the simulated surface friction (AMU) to the measurement surface friction (μ_m). For example:

$$\mu_{y\ \text{effective}} = \mu_{y\ \text{tabular}} \times \frac{AMU}{\mu_m}$$

The instantaneous circumferential friction coefficient is determined from input values and the instantaneous value of tire slip (SLIP) via the functional relationships given in Figure 3.4-11. Note that in addition to μ_{xp}, μ_{xs} and $SLIP_p$, the input value of C_T, the circumferential force stiffness, is required.

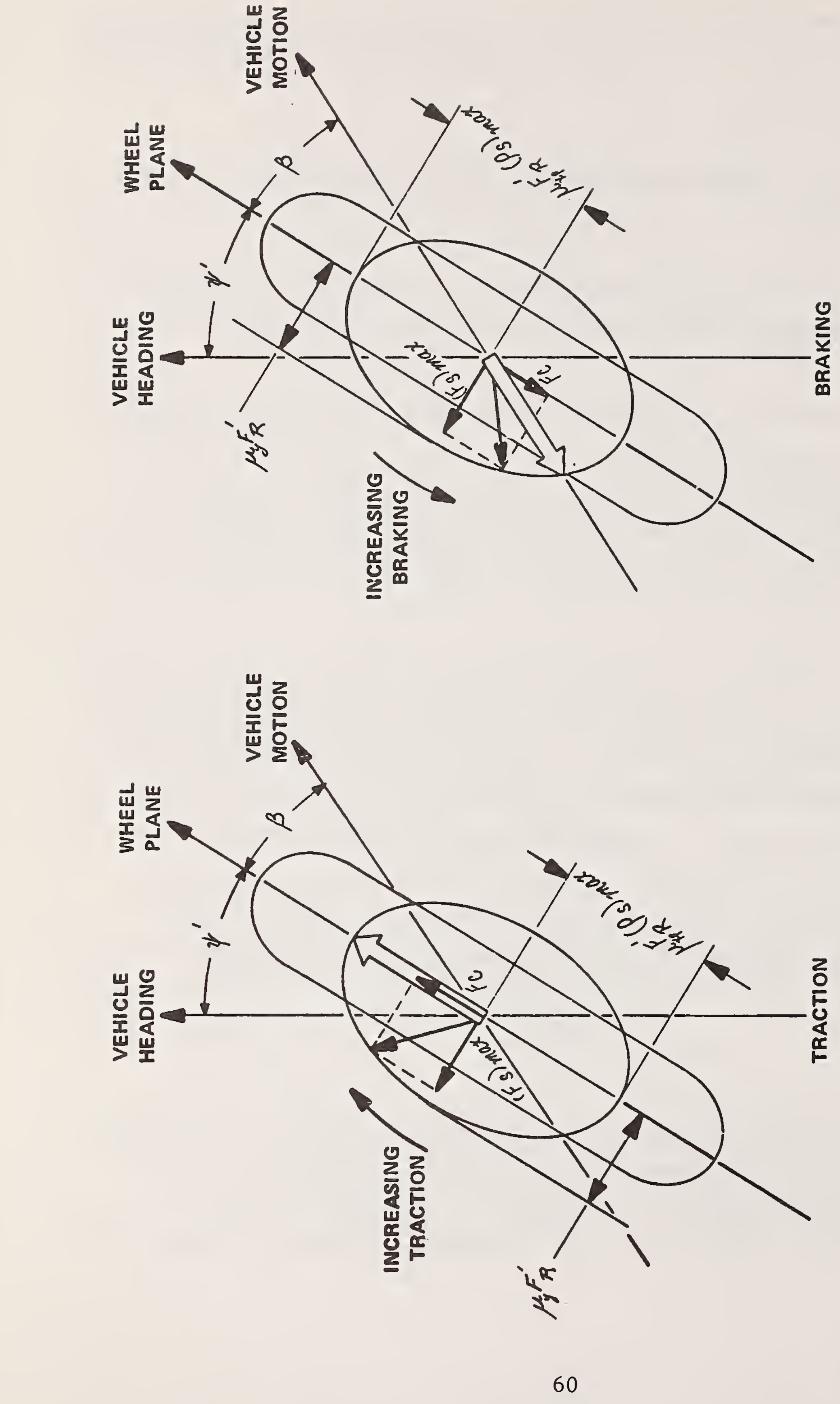
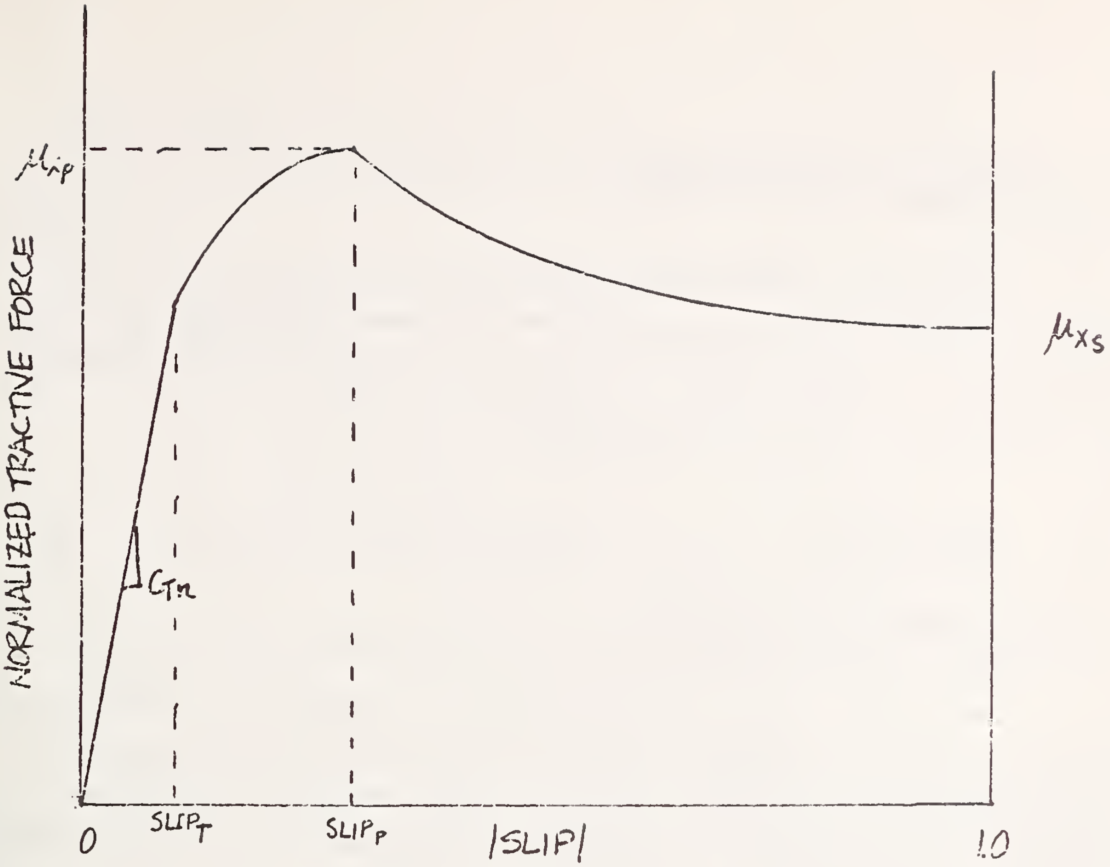


Figure 3.4-10 **FRICTION ELLIPSE CONCEPT**



$$\mu_x = C_{Tn}|SLIP| \quad \text{for} \quad 0 \leq |SLIP| \leq SLIP_T$$

$$\mu_x = C_0 + C_1|SLIP| + C_2|SLIP|^2 \quad \text{for} \quad SLIP_T < |SLIP| \leq SLIP_P$$

$$\mu_x = C_3 + C_4|SLIP| + C_5|SLIP|^2 \quad \text{for} \quad SLIP_P < |SLIP| < 1.0$$

$$C_{Tn} = \frac{C_T}{F_R'}$$

where:

$$SLIP_T = \frac{-.8\mu_{xp}}{C_{Tn}}$$

$$C_2 = \frac{-.2\,\mu_{xp}}{\left(SLIP_P - \frac{.8\mu_{xp}}{C_{Tn}}\right)^2} \qquad C_5 = \frac{\mu_{xp} - \mu_{xs}}{(SLIP_P - 1.0)^2}$$

$$C_1 = -2\,C_2\,(SLIP_P) \qquad C_4 = -2\,C_5$$

$$C_0 = \mu_{xp} + C_2\,(SLIP_P)^2 \qquad C_3 = \mu_{xs} + C_5$$

Figure 3.4-11 NORMALIZED TRACTIVE FORCE VS. SLIP MODEL

3.4.5.1.5 Wheel Aligning Troques

Aligning torques on the front wheels are simulated by means of a constant "pneumatic trail" dimension when the steer-mode degree of freedom is activated. The steer degree of freedom is activated either on contact with a curb or as a user exercised option.

3.4.5.2 Impact Forces

3.4.5.2.1 Roadside Design Version

The vehicle sprung mass is treated as a rigid body surrounded by a layer of isotropic, homogeneous material which exhibits linear perfectly inelastic behavior, as shown in Figure 3.4-12. The dynamic pressure in the peripheral layer of material is assumed to increase linearly with the depth of penetration (see Figure 3.4-12).

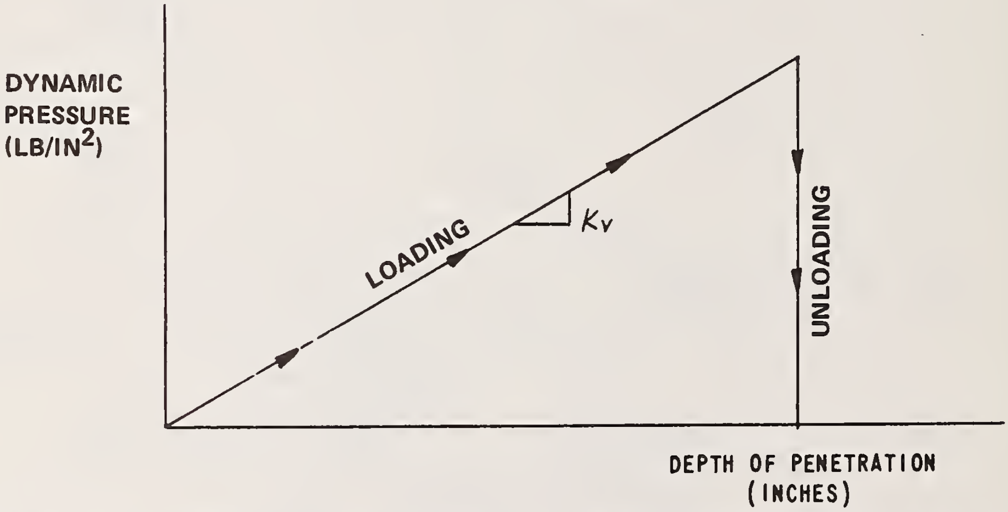


Figure 3.4-12 **FIRST-APPROXIMATION TREATMENT OF COLLISION PROPERTIES OF VEHICLE PERIPHERY**

With these first approximation assumptions, the force normal to the contact interface with an obstacle is determined from the dynamic pressure and contact area as:

$$F_N = K_V \int A d\delta \text{ lbs.}$$

where δ = depth of penetration, inches

A = area of contact, in.^2

K_V = property of vehicle structure, lb/in.^3

Inertial effects are neglected in the assumed peripheral layer of material.

This simplified representation of the vehicle structural properties is consistent both with the measurements and with the fragmentary data that are available in the literature for moderate depths of penetration. The occurrence of larger depths of penetration of vehicle structure is assumed to produce localized forces resulting from deformation of specific structural members (e.g., suspension components) that are computed based on deformations of those members. These localized "hardpoints" are defined relative to the vehicle and their deformation is determined by the distance between the undeformed hardpoint and the barrier. A structural force is computed as the product of this deformation and the hardpoint stiffness, K_{ST}.

3.4.5.3 Rolling Resistance and Aerodynamic Drag - Vehicle Dynamics Version

The effects of aerodynamic drag are approximated by a force applied directly to the sprung mass. An empirical relationship is used to approximate the magnitude of the applied force as a function of the first and second powers of the longitudinal component of vehicle velocity. It is assumed, for simplicity, that the motion-resisting force acts through the center of gravity of the sprung mass, and along the longitudinal axis of the vehicle (i.e., the X axis), in the direction opposite that of the longitudinal component of vehicle velocity. Rolling resistance is approximated as a motion-resisting moment applied to each wheel. This moment varies with tire radial force.

3.4.6 Terrain Profile

3.4.6.1 Terrain Table Representation

The method of simulation of uneven terrain for both program versions permits use of as many as five separate tables for specification of terrain elevations with each table limited to a maximum of 441 points (corresponding to a grid of 21 values each for X' and Y'). Four of the tables are constant increment tables for X' and Y'. The fifth is a variable increment table which requires specification of the X' and Y' values of the grid, in addition to the terrain elevations, as input data. Input tabular values of terrain slopes are not required. Rather, these quantities are computed in the program from the terrain elevation data.

The program provides for overlapping of the tables. Thus, for example, a "fine mesh" table may be used to provide extreme detail of a section of terrain that is located within the bounds of one or more "coarse mesh" tables. In addition, different friction coefficients for the ground surface defined in each table may be specified.

Each of the five tables may include interpolation boundaries which preclude rounding of abrupt profile changes. Boundaries may be oriented either perpendicular to the Y' axis or angled with respect to the X' axis as shown in Figure 3.4-13. Not more than four angled boundaries or two Y' boundaries may be specified for each terrain input table. Each of the angled boundaries is defined by specifying the X' intercept of the boundary (X_{BDRY}) at the beginning Y' value of the table and the angle (ψ_{BDRY}) of the boundary measured with respect to the X' axis (Figure 3.4-13). The friction coefficient between the tire and ground in a terrain table is the product of the terrain table friction multiplier (AMUG) and the nominal tire friction coefficient (i.e., AMUG$\times\mu$).

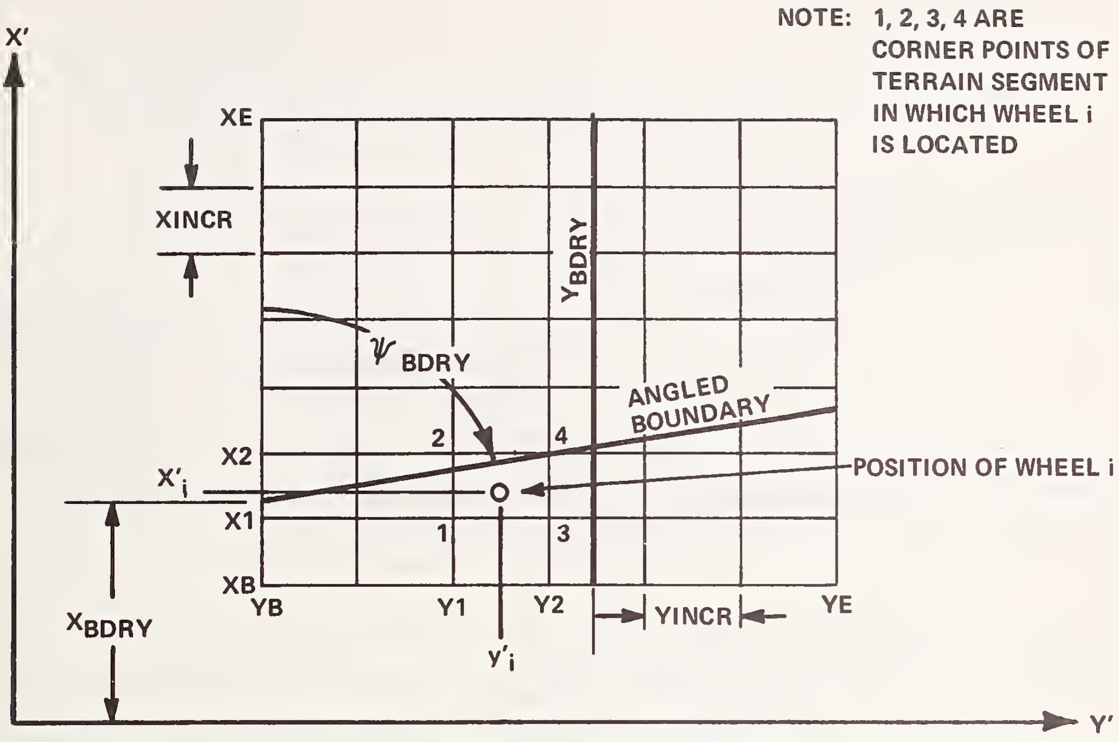


Figure 3.4-13 TERRAIN TABLE GRID

3.4.6.2 Curb Representation

The analytical representation of curb profiles is depicted in Figure 3.4-14. Up to six planes may be defined with lines of intersection parallel to the space-fixed X' axis. The wheels not in contact with the curb are assumed to be on a flat, horizontal plane with the specified ground friction coefficient, μ. When in contact with a curb, the friction coefficient used for the tire is the product of the curb friction multiplier (μ_c) and the normal ground friction coefficient (i.e., $\mu_c \times \mu$).

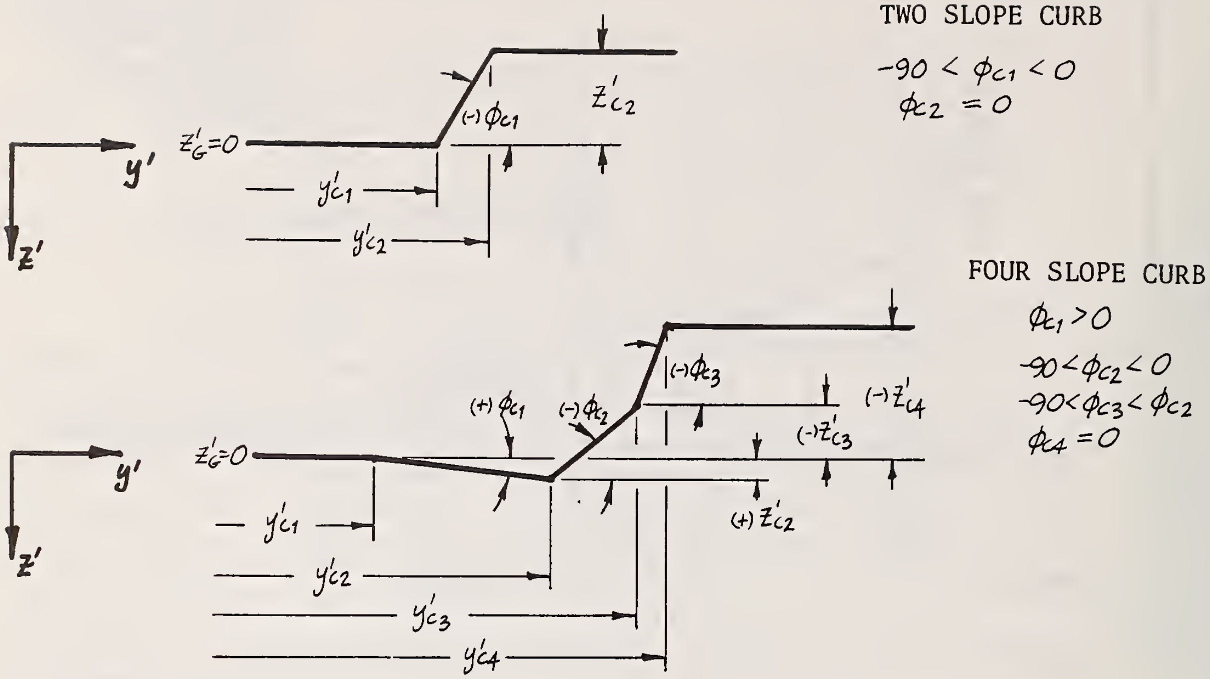


Figure 3.4-14 ANALYTICAL REPRESENTATION OF CURB PROFILES

3.4.6.3 Road Roughness

Excitation of the vehicle due to road roughness is included in both program versions. Roughness data is input as a change in road elevation from the datum plane at equally spaced intervals along the X' axis and is independent of Y' location. The tire radial spring model is used to obtain an equivalent ground contact point of the tire in a manner similar to that used for the curb representation. Linear interpolation is used to define the road profile between input data points. Note that the road roughness data points are input from a sequential data set (tape, disk). Side-to-side phasing of tire excitation can be obtained by directing the vehicle at an angle to the X' axis. Terrain tables cannot be used simultaneously with the road roughness option.

3.4.7 Control Inputs

3.4.7.1 Roadside Design Version

Open-loop control inputs in the form of steer angle of the front wheels and braking or tractive wheel torques can be entered as arbitrary tabular functions of time, which are interpolated in the calculation procedure. The braking and tractive torques are entered separately for the front and rear wheels, but they are applied equally to the left and right wheels at each end of the vehicle. The effects of differential drive gears are simulated for the case of traction (i.e., the torque applied to each of the two wheels of a given pair is limited to the value that spins either of the two wheels).

The input table for the front steer angle is abandoned when a curb is encountered by a wheel, at which time the front wheel steer degree of freedom is activated. A friction torque is applied in the steer-mode degree of freedom to approximate driver (or remote control) restraint of the steering system. A torque produced by steer angle limits stops is applied to the steering system when the steer angle limits are exceeded.

3.4.7.2 Vehicle Dynamics Version

Open-loop control inputs in the form of the steer angle at the front wheels (assumed to be equal at the two wheels), the throttle setting, the hydraulic pressure in the brake system master cylinder, and the transmission ratio are entered as arbitrary tabular functions of time, which are interpolated in the calculation procedure. Closed-loop control is provided by the preview-predictor driver model.

3.4.7.2.1 Steering Control

The input table table for the steered angle is abandoned when a curb is encountered by the wheels, at which time the steer-mode degree of freedom is activated. A friction torque is applied in the steer-mode degree of freedom to approximate driver (on remote control) restraint of the steering system as well as steering system friction. Mechanical limits of steer angle are simulated in the model.

3.4.7.2.2 Brake System Representation

In view of the many empirical aspects of the design of brake components and systems, the definitions of braking functional relationships for the present computer simulation have not been rigorously derived. Rather, existing idealized relationships have been adapted, where available, in forms that are aimed at providing approximations of system interactions and ease of adjustments. Where functional relationships have not been found to be defined, tabular functions have been used in the computer program.

The simulated brakes produce torques opposing wheel rotations in response to hydraulic pressure in the master cylinder. The master cylinder pressure is entered in "open-loop" form as an input tabular function of time. In each expression, the brake torque is a linear function of the excess of actuation pressure over "push out" pressure, at a given brake temperature (see Figure 3.4-15). Therefore, the provision of the ability to approximate fade effects is the only reason for the complexity in the expressions describing the braking process. In Figures 3.4-16 through 3.4-19, sketches of four different types of brakes and corresponding relationships between brake torque and pressure are presented.

The effects of elevated temperatures on brakes (i.e., fade), particularly on brakes with a large amount of self-actuation, are not known to be defined analytically. It is known, of course, that the "effective" friction coefficient of the lining material changes with temperature, but an established predictive technique is not known to exist. Similarly, the rate of heat dissipation by the brake assembly does not appear to be defined by

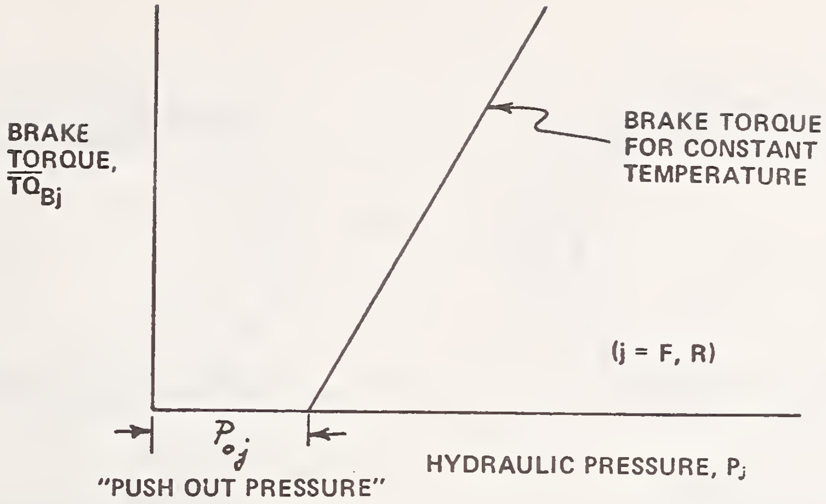
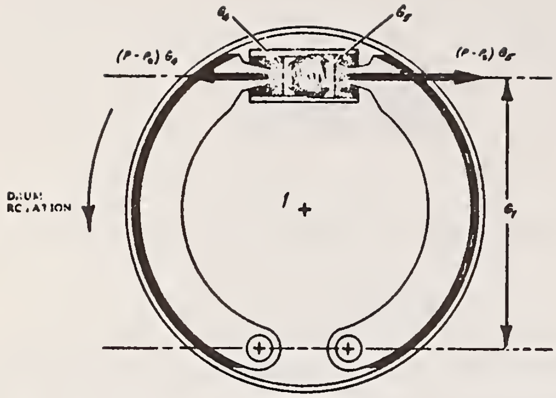


Figure 3.4-15 SIMULATED RELATIONSHIP BETWEEN BRAKE TORQUE AND HYDRAULIC PRESSURE

a general analytical treatment. Therefore, provisions have been made for the entry of coefficients of heat transfer, specific heats, effective masses of heated parts, and for the tabular entry of a fade coefficient for the brake lining as a function of brake temperature (Figure 3.4-20). If such data are available or can be estimated, the simulation provides an approximate treatment of dynamic fade effects based on time-history calculations of the energy dissipation at the individual brakes. Note that the availability of experimental data on the time history of brake temperature during brake tests will permit an empirical adjustment of these inputs, to produce a "realistic" variation of calculated temperatures in the simulation. The fade effects can be suppressed, if desired, by selection of appropriate input data.

A variety of control devices for varying the distribution of braking effort are becoming increasingly common on U. S. automobiles. The model includes provisions for simulation of pressure reducing devices.

Brake pressure reducing devices produce a ratio of rear/front hydraulic pressure of less than 1.00 when a preselected master cylinder pressure is exceeded. Some valves of this type include more than one such step change in rear/front pressure ratio. In Figure 3.4-21, a plot of rear versus front hydraulic pressure is presented for this type of device.



G_1 = Lever arm, inches

G_2 = Actuation constant, assumed to be equal for the two shoes. (Note that $G_2 \approx 1.42$ in Chrysler Products

(LF) = Coefficient to permit change of lining friction at elevated temperatures

G_3 = Effective lining-to-drum friction coefficient at design temp.

G_4 = Cylinder area - leading shoe, in.^{2}

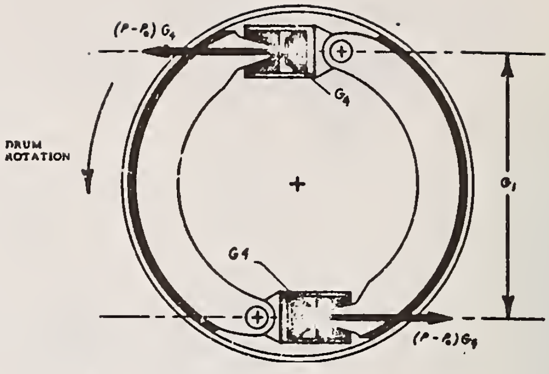
G_5 = Cylinder area - trailing shoe, in.^{2}

P = Hydraulic pressure, psig

P_0 = Push-out pressure, psig

$$(TQ)_B = \begin{cases} 0, \text{ for } (P-P_0) \leq 0 \\ \frac{1}{12}(P-P_0)\, G_1 G_2 G_3 (LF) \left\{ \frac{G_4\left[1+G_2G_3(LF)\right]+G_5\left[1-G_2G_3(LF)\right]}{\left[1-G_2G_3(LF)\right]^2} \right\} \text{ for } 0<(P-P_0) \end{cases}$$

Figure 3.4-16 TYPE 1 BRAKE-DRUM TYPE WITH LEADING AND TRAILING SHOES, UNIFORM OR STEPPED CYLINDER



G_1 = Lever arm, inches

G_2 = Actuation constant

(LF) = Coefficient to permit change of lining friction at elevated temperatures

G_3 = Effective lining-to-drum friction coefficient at design temp.

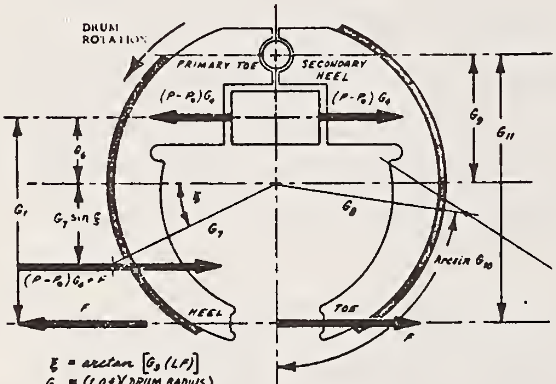
G_4 = Cylinder area, in.^{2}

P = Hydraulic pressure, psig

P_0 = Push-out pressure, psig

$$(TQ)_B = \begin{cases} 0, \text{ for } (P-P_0) \leq 0 \\ \frac{1}{6}(P-P_0)\, G_1 G_4 \left[\frac{G_2G_3(LF)}{1-G_2G_3(LF)}\right], \text{ for } 0<(P-P_0) \end{cases}$$

Figure 3.4-17 TYPE 2 BRAKE-DRUM TYPE WITH TWO LEADING SHOES, TWO CYLINDERS

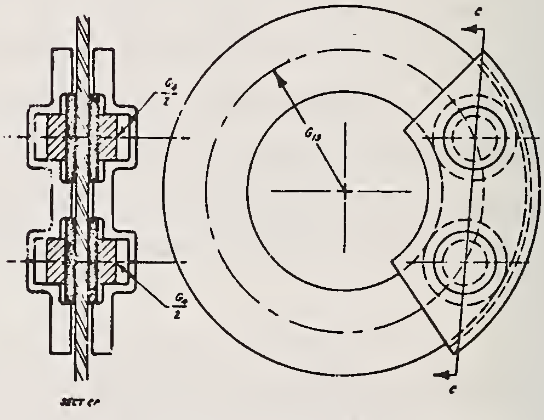


$\xi = \arctan\left[G_3(LF)\right]$

$G_9 = (1.04)(\text{DRUM RADIUS})$

$$(TQ)_B = \begin{cases} 0, \text{ for } (P-P_0) \leq 0 \\ \frac{1}{12}(P-P_0)\, G_4 \left\{ \left[1+\frac{G_6+G_7\sin\xi}{G_1-G_6-G_7\sin\xi}\right]\left[G_7\sin\xi+\frac{G_8G_{11}G_{12}(LF)}{G_9G_{10}\left[1-G_2G_{12}(LF)\right]}\right] - \frac{G_1G_8G_{12}(LF)}{G_9G_{10}\left[1-G_2G_{12}(LF)\right]} \right\}, \text{ for } 0<(P-P_0) \end{cases}$$

Figure 3.4-18 TYPE 3 BRAKE-BENDIX DUO SERVO



G_6 = Total cylinder area per side of disc, in.^{2}

G_{13} = Mean lining radius, inches

G_3 = Effective lining-to-disc friction coefficient

(LF) = Coefficient to permit change of lining friction at elevated temperatures

P = Hydraulic pressure, psig

P_0 = Push-out pressure, psig

$$(TQ)_R = \begin{cases} 0, \text{ for } (P-P_0) \leq 0 \\ \frac{1}{6}(P-P_0)\, G_3 G_6 G_{13} (LF), \text{ for } 0<(P-P_0) \end{cases}$$

Figure 3.4-19 TYPE 4 BRAKE-CALIPER DISC

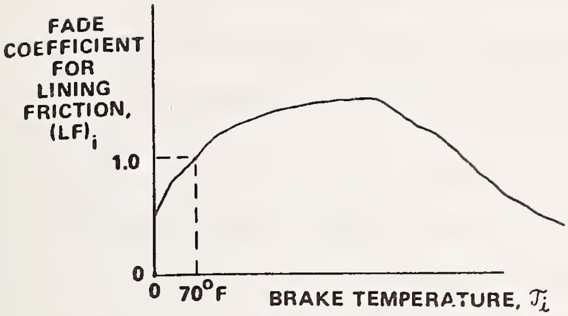


Figure 3.4-20 FADE COEFFICIENT VS TEMPERATURE

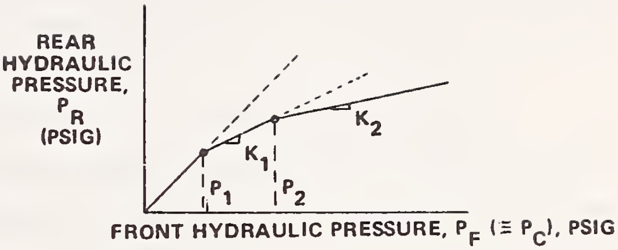


Figure 3.4-21 REAR VS FRONT HYDRAULIC PRESSURE WITH PRESSURE REDUCING DEVICE

The control device characteristic depicted in Figure 3.4-21 is represented by the following analytical relationships:

P_F = f(time), as interpolated from an input table.

$$P_R = \begin{cases} P_F, \text{ for } 0 \leq P_F \leq P_1 \\ P_1 + K_1 (P_F - P_1), \text{ for } P_1 < P_F \leq P_2 \\ P_1 + K_1 (P_2 - P_1) + K_2 (P_F - P_2), \text{ for } P_2 < P_F \end{cases}$$

where $K_1 \leq 1.00, \quad K_2 \leq K_1$

3.7.7.2.3 Tractive Effort Aspects

The primary objectives of the analytical selections related to the vehicle drive line have been to approximate the effects of engine braking and to limit the applied tractive torques to values compatible with the vehicle speed and engine power.

The violent manuevers and accident-related events expected to be studied with the present computer simulation are generally of short duration and the need for the ability to shift gears during a run is of secondary importance. However, in view of the relative ease of including a declutching and gear changing option, these items have nonetheless been incorporated.

The engine torque is interpolated, for engine speed and for throttle setting, from corresponding tabular inputs. The instantaneous engine speed is determined from the transmission ratio and the speed of the propeller shaft corresponding to the instantaneous values of rotational speeds of the driving wheels. For engine speeds thus determined, that are less than or equal to 500 revolutions per minute, the transmission ratio is set to zero, simulating a disengagement of the clutch. The throttle setting is entered as a tabular function of time. It is assumed that the engine torque increases linearly with throttle setting between the values entered for closed throttle and for wide open throttle, Figure 3.4-22. Driveline torque is the product of engine torque and overall transmission ratio.

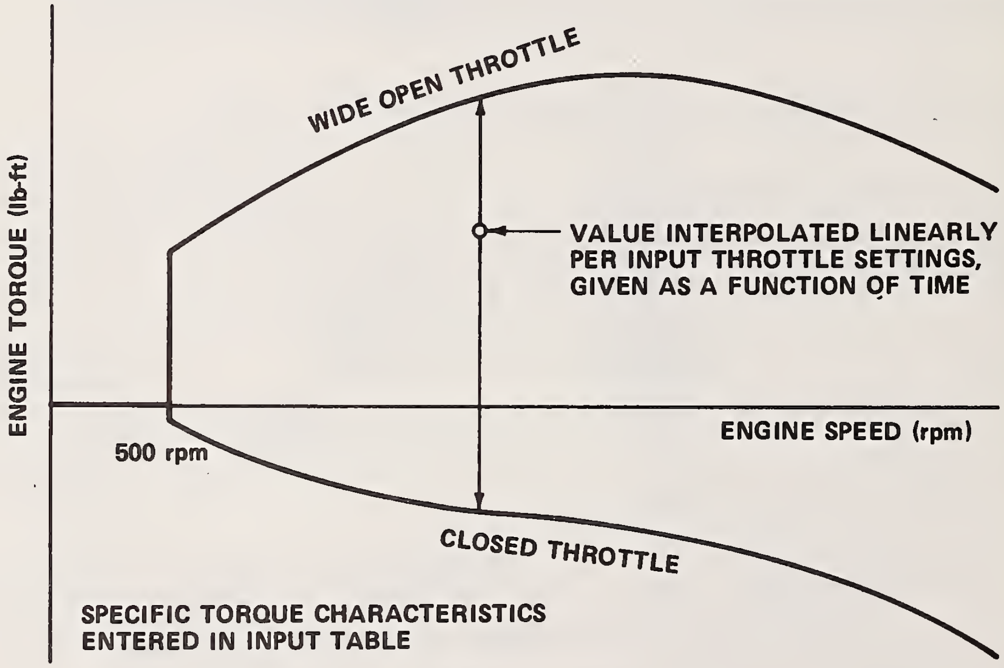


Figure 3.4-22 ENGINE TORQUE = f [ENGINE SPEED, THROTTLE SETTING]

3.4.7.3 Preview-Predictor Driver Model

The driver model includes several modes of operation: path-following, speed maintenance, speed change and skid recovery modes. The normal steering mode is path-following. The path-following mechanism predicts the future vehicle path based on the instantaneous velocity and an estimated lateral acceleration due to the instantaneous front wheel steer angle. In the calculation of the projected path, the model assumes that the vehicle will maintain its present velocity except for the continuous effect of the lateral acceleration. The estimated lateral acceleration is a function of the forward velocity, the front wheel steer angle and the stability and control characteristics of the vehicle. Error estimates are made between the predicted path and the desired path at evenly spaced points along the predicted path. These error estimates are weighted to account for the reduction in lateral acceleration required to null errors at further distances ahead of the vehicle. The error estimates are also weighted to emphasize the importance of errors at particular locations along the desired path. The change in the front wheel steer angle is proportional to the average of the weighted error estimates. This steer command is filtered to reflect human dynamic capabilities, specifically neuro-muscular dynamic characteristics.

Operating simultaneously with the path-following mode is either the speed change mode or the speed maintenance mode. The speed change mode uses input data values of the desired speeds, their initiation times and attainment distances to determine the required brake pedal forces and accelerator pedal deflections. In calculating the brake and throttle control commands, the model assumes linear relationships between deceleration and brake pedal force and acceleration and throttle position. Initialization of the path-following mode requires that the initial vehicle position and heading be consistent with the desired path. To initialize the speed control mode the initial vehicle speed is set equal to the first desired speed.

If, because of terrain features or cornering forces, the vehicle should gain or lose speed such that the difference between the desired speed and the actual speed exceeds the threshold values, the model will activate the speed maintenance mode and attempt to return the vehicle to its most recent desired speed. These threshold values are variable model inputs; further specificity requires experimental data relevant to these particular driving situations.

The skid recovery mode is activated if the vehicle slip angle, θ_c, the angle between the vehicle heading and its velocity vector, exceeds a pre-selected threshold value, T_{R_1}. The degree of severity of the skid is determined from comparison of the vehicle slip angle with a second (higher) threshold, T_{R_2}. For skids of low severity the brake pedal force (FBRK) and accelerator pedal deflection (APD) are set to zero; however, the steering control remains under the path-following mode. If the skid is of high severity, in which the higher vehicle slip angle threshold is exceeded, the steering commands are determined by the skid recovery routine. Thus, for more severe skids, brake pedal force and accelerometer pedal deflection are set to zero, path-following is discontinued and steer commands are generated strictly to recover the directional control of the vehicle. Under the skid recovery mode, the steer angle change is proportional to the average front wheel slip angle, ψ_F, and the sign of the steer correction is in the direction of reducing the average front wheel slip angle. Repetitive steer angle corrections are made until the wheel slip angle is equal to zero. Steer commands are filtered, as in the path-following mode, before being applied to the vehicle.

All of the model functions operate on their appropriate inputs at discrete time increments, as determined by the input value of EMDT, the time between driver samples in seconds. Significant changes in model output can be produced by this mechanism, including correlation with recorded nonlinear responses of human operators.

It should be noted that the threshold or indifference levels mentioned above are designed to be single parameters representing the minimum detection level for that particular control input or, if the driver chooses not to act until a higher value is reached, the minimum indifference level for that control input.

3.4.8 Suspension Properties

3.4.8.1 Deflection Limiting Stops

The simulated suspensions bumper properties include progressively stiffening load-deflection rates and an adjustable amount of energy dissipation. Provision has also been incorporated for unsymmetrical placement of the jounce (compression) and rebound (extension) bumpers with respect to the design positions of the wheels. The combined spring and bumper forces are calculated in the manner depicted in Figure 3.4-23.

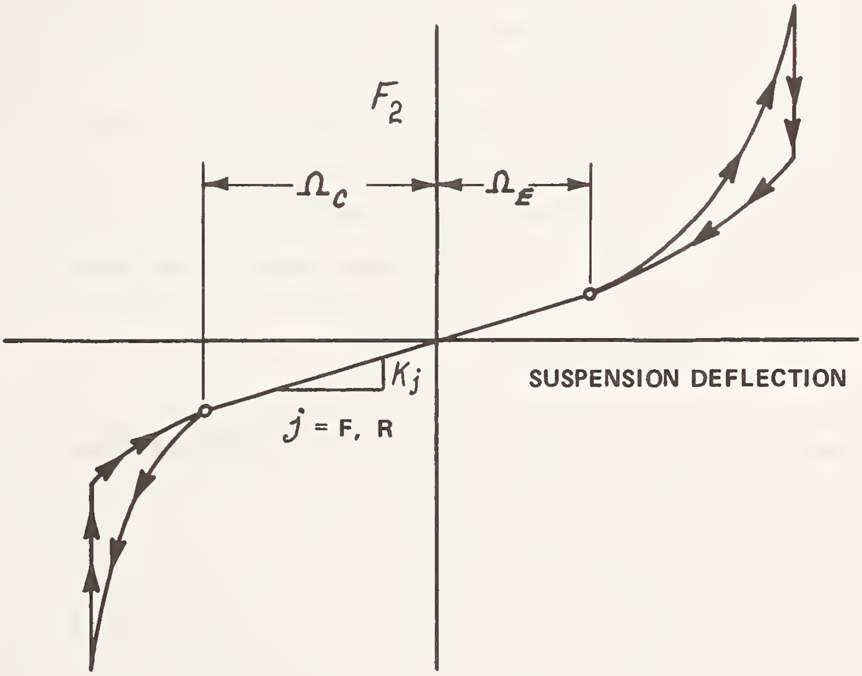


Figure 3.4-23 GENERAL FORM OF SIMULATED SUSPENSION BUMPER CHARACTERISTICS

3.4.8.2 Suspension Damping

The assumed form of damping is depicted in Figure 3.4-24. The coulomb friction, C'_i, is used to approximate the combination of "blow-off" type damping in the shock absorbers and actual friction in the suspension. Rate sensitive damping is simulated by a viscous coefficient, C_i, effective at the wheel.

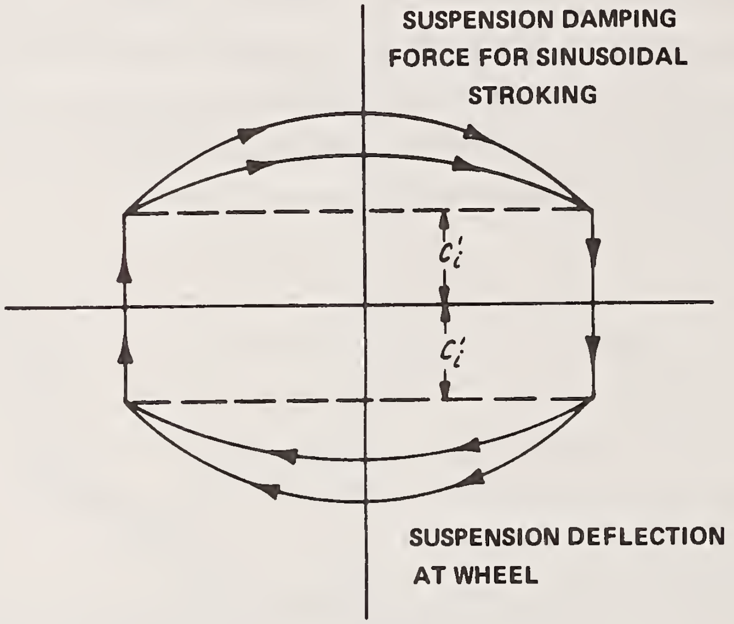


Figure 3.4-24 ASSUMED FORM OF SUSPENSION DAMPING

3.4.8.3 Auxiliary Roll Stiffness

Provision is made for the entry of auxiliary roll stiffness at both the front and the rear suspensions (i.e., roll stiffness in excess of that corresponding to the front suspension rates in ride and to the rear spring rates and spacing). While the anti-roll torsion bar which is frequently included in the independent front suspensions of conventional automobile designs constitutes an obvious form of auxiliary roll stiffness, it should be noted that torsional effects in the leaf springs of a conventional Hotchkiss rear suspension also produce a significant amount of auxiliary roll stiffness, as do increasingly common rear anti-roll torsion bars.

3.4.8.4 Anti-Pitch Suspension Linkages

Since 1957, the U. S. automobile industry has incorporated a variety of suspension linkage configurations that act to reduce the suspension deflections produced by dynamic weight transfer during braking or acceleration. In these "anti-pitch" suspensions, the geometric arrangement of linkages is selected such that the reaction to applied wheel torques (i.e., braking or acceleration) induces extra vertical loading of the wheel through the linkages. The linkage-supported portion of the vertical wheel loading can be either positive or negative, according to the direction of the applied wheel torque. It acts to support part of the suspension load change produced by weight transfer during braking or acceleration.

Of particular importance in relation to a study of braking dynamics are the facts that (1) anti-pitch effects produce rapid changes in tire loading, since they do not require suspension deflections to generate the load changes, and (2) the magnitudes of the anti-pitch effects, for given applied wheel torques, generally change with suspension deflections. Item (1) may have significant effects on the occurrence of wheel lockup in braking. Item (2) influences the side-to-side distribution of longitudinally transferred weight under conditions of braking or acceleration in a turn, where a vehicle roll deflection exists. It may, therefore, have significant effects on the upper limits of vehicle control.

In view of the above considerations, an approximation of anti-pitch effects was considered to be an essential part of the present analytical model. The selected form of approximation consists of tabular entries of anti-pitch coefficients as functions of the suspension positions for the front and rear suspensions.

Since definitions of anti-pitch terminology that are appropriate for the three-dimensional situation are not known to exist, the following definition has been created to fill the needs of the present research:

The Anti-Pitch Coefficient, $(AP)_j$, is the ratio of the positive or negative "jacking" force acting on the wheel to the corresponding moment of the applied circumferential tire force about a line parallel to the vehicle Y axis. The units of $(AP)_j$ are lbs/lb-ft. Tabular entires of $(AP)_j$ correspond to given displacements of the wheel centers from their design positions, as measured in the direction of the vehicle Z axis. Positive values of $(AP)_j$ are taken to correspond to positive anti-pitch effects at the front and rear suspensions for forward braking.

3.5 Solution Procedures

3.5.1 Dependent Variables

Application of Newton's Laws to a linear dynamical system results in a set of equations of the form:

$$[M]\{\ddot{X}\} \quad [C]\{\dot{X}\} + [K]\{X\} = \{f(t)\}.$$

The solution procedure required in solving this system is, in principle:

(a) Determine the coefficient matrices, [M], [C], and [K]

(b) Evaluate the time-dependent forcing function {f(t)}

(c) Knowing the values of {X} and {X} at a given time t, evaluate $\{\ddot{X}\}$

(d) Integrate $\{\ddot{X}\}$ to obtain $\{\dot{X}\}$ and {X} at time t + Δt.

In practice, however, this procedure is generally compressed by evaluating $\{\ddot{X}\}$ from $[D]\ \{\ddot{X}\} = \{E(X,\ \dot{X},\ t)\}$, where the "applied forces" include both external and internal system nonlinear forces as well as "effective" forces resulting from writing the equations of motion with respect to a non-Newtonian frame of reference.

Further, it is generally desirable to perform a transformation on the (n) second-order equations to produce (2n) first-order equations which are accepted by "standard" numerical integration algorithms for first order systems. The system of equation then take the form:

$$\left[\begin{array}{c:c} [D] & [0] \\ \hdashline [0] & [I] \end{array}\right] \{\dot{y}\} = \left\{\begin{array}{c} E(x,\dot{x},t) \\ \hdashline 0 \end{array}\right\}$$

where

$$\{\dot{y}\} = \left\{\begin{array}{c} \ddot{X} \\ \hdashline \dot{X} \end{array}\right\}$$

and [I] is the identity matrix.

In general, the numerical integrator is designed to receive {y} and return the integrated variables {y}, where $\{y\} = \left\{ \frac{\dot{x}}{x} \right\}$.

In the case of the HVOSM, a further transformation is necessary to relate vehicle position and orientation to space since the equations of motion are written with respect to the moving (vehicle) axis system. The velocity components of the vehicle sprung mass with respect to the vehicle axes must first be transformed to the space fixed axes, then integrated to obtain the sprung mass position with respect to space. This is accomplished with the following:

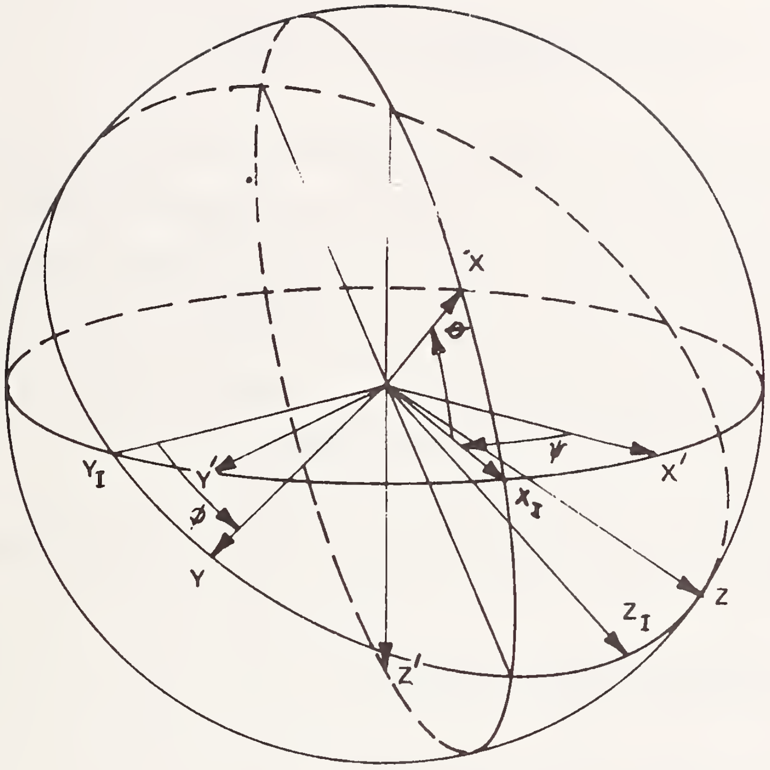
$$\begin{Bmatrix} u' \\ v' \\ w' \end{Bmatrix} = [A] \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$$

where [A] is the transformation matrix relating the orientation of the vehicle axes to the space axes.

$$\begin{aligned} u' &= \dot{x}'_c \\ v' &= \dot{y}'_c \\ w' &= \dot{z}'_c \end{aligned}$$

are the first derivatives with respect to time of the location of the origin of the vehicle axes with respect to the space fixed axes. Note that the sequence of rotation of the Euler angles used in the HVOSM to orient the vehicle with respect to the space axis system is ψ_t (yaw), θ_t (pitch) and ϕ_t (roll). The rotational sequence is illustrated in Figure 3.5-1.

Similarly, since the components of angular velocity along the vehicle axes are not generally collinear with the axes of rotation of the Euler angles, the components along these rotation axes are:



ψ ABOUT AXIS Z'
θ ABOUT AXIS Y_I (AN INTERMEDIATE AXIS)
ϕ ABOUT AXIS X

Figure 3.5-1 EULER ANGLES (AERONAUTICAL STANDARD) RELATING BODY AXES (X , Y , Z) WITH RESPECT TO FIXED AXES (X′, Y′, Z′)

$$\dot{\theta}_t = Q \cos \phi_t - R \sin \phi_t$$

$$\dot{\phi}_t = P + Q \sin \phi_t \tan \theta_t + R \cos \phi_t \tan \theta_t$$

$$\dot{\psi}_t = (Q \sin \phi_t + R \cos \phi_t) \sec \theta_t$$

The presence of the tangent and secant of the pitch angle results in singularities as θ_t approaches $^{\pi}/2$, therefore an indexing scheme is included in the program to reference the integration to an intermediate axis system should the need arise. When this occurs, an intermediate axis system is defined and the orientation of the vehicle with respect to this axis system is given by the Euler angles: ϕ_t, θ_t, and ψ_t. This procedure is described in detail in the HVOSM Engineering Manual - Analysis.

A tabulation of the derivatives {y} and the corresponding integrated dependent variables is shown in Table 3.5-1.

3.5.2 Overall Program Solution Procedure

3.5.2.1 Roadside Design Solution Procedure

The program structure of the HVOSM-RD2 version is shown in Figure 3.5-2. The program is organized on two functional levels with the MAIN routine controlling the upper level and subroutine DAUX controlling the lower level. The upper level performs functions associated with overall program control, including initialization, input, output, obtaining time invariant constants, and integration control including normal and abnormal program stops.

The lower level of functions are directly associated with evaluation of the time derivatives of the dependent variables for numerical integration. These functions require the performance of three tasks: (1) the evaluation of forces acting on the vehicle, (2) the evaluation of the elements of the inertial matrix and the forcing functions, and (3) evaluation of the derivatives of the dependent variables.

Table 3.5-1

Summary of HVOSM Dependent Variables and Derivatives

DERIVATIVE $\{\dot{Y}\}_t$	DEPENDENT VARIABLE $\{Y\}_{t+\Delta t}$
$\dot{u}$	u
$\dot{v}$	v
$\dot{w}$	w
$\dot{P}$	P
$\dot{Q}$	Q
$\dot{R}$	R
$\ddot{\delta}_1$	$\dot{\delta}_1$
$\dot{\delta}_1$	δ_1
$\ddot{\delta}_2$ or $\ddot{\phi}_F$	$\dot{\delta}_2$ or $\dot{\phi}_F$
$\dot{\delta}_2$ or $\dot{\phi}_F$	δ_2 or ϕ_F
$\ddot{\delta}_3$	$\dot{\delta}_3$
$\dot{\delta}_3$	δ_3
$\ddot{\phi}_R$ or $\ddot{\delta}_4$	$\dot{\phi}_R$ or $\dot{\delta}_4$
$\dot{\phi}_R$ or $\dot{\delta}_4$	ϕ_R or δ_4
$\dot{\theta}'_t$	θ'_t
$\dot{\phi}'_t$	ϕ'_t
$\dot{\psi}'_t$	ψ'_t
U'	X'_C
V'	Y'_C
W'	Z'_C
$\ddot{\psi}_f$	$\dot{\psi}_f$
$\dot{\psi}_f$	ψ_f

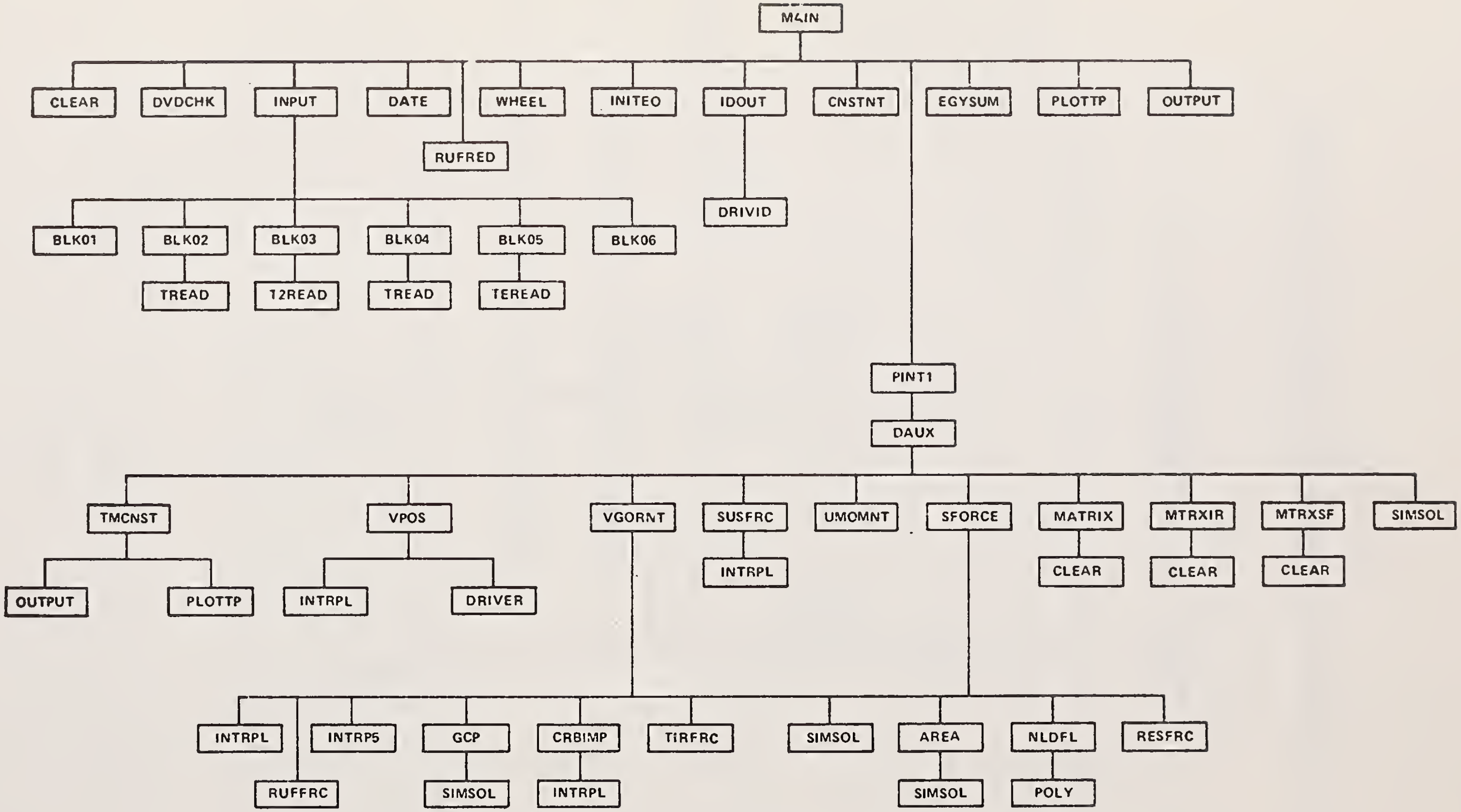


Figure 3.5-2 **HVOSM-RD2 OVERALL PROGRAM BLOCK DIAGRAM**

The first task is accomplished by calls from subroutine DAUX to subroutines TMCNST, VPOS, VGORNT, SUSFRC, UMOMNT and SFORCE as discussed later. These computational subroutines, along with subsequent calls, evaluate variables which are of general use at this level, geometrical relationships between the vehicle and its environment, forces acting at the interface between the vehicle tires and ground, forces acting between the vehicle sprung and unsprung masses, and impact forces acting between the vehicle body and barrier.

The second task is accomplished by subroutines MATRIX, MTRXIR or MTRXSF, which evaluate the elements of the mass matrix [D] and the forcing matrix [E] for the three suspension options. The third task is accomplished by subroutines SIMSOL and DAUX. SIMSOL performs a simultaneous solution for the second-order time derivatives of the dependent variables defined by [D] and [E] matrices ($\dot{u}$, $\dot{v}$, $\dot{w}$, $\dot{P}$, $\dot{Q}$, $\dot{R}$, $\ddot{\delta}_1$, $\ddot{\delta}_2$ or $\ddot{\phi}_F$, $\ddot{\delta}_3$, $\ddot{\phi}_R$ or $\ddot{\delta}_4$). DAUX then evaluates the first-order time derivatives of the dependent variables and the first- and second-order time derivatives of the front wheel steer angle, if this option is in effect. These variables are then numerically integrated by subroutine PINT1.

The subroutines DRIVID and DRIVER, shown on Figure 3.5-2, are dummy subroutines and have no function. The calls to these subroutines were included in the program to provide linkages, facilitating future program modifications for simulating closed-loop driver control of the vehicle.

A description of the functions performed by the control and computational routines conclude Section 3.5.1.

MAIN Routine

The MAIN routine performs these overall program control functions:

(1) Clears selected storage areas to zero by calling subroutine CLEAR

(2) Obtains required input for a run by calling subroutine INPUT

(3) Obtains current date from computer system by calling subroutine DATE

(4) If the road roughness option is being used, obtains roughness input by calling RUFRED

(5) If the distributed radial spring tire model is required, calls WHEEL to calculate data and sets up tire data arrays

(6) If ZF = 0 and ZR = 0, calls INITEQ to establish initial vertical equilibrium

(7) Prints run input by calling IDOUT

(8) Initializes program flags and indicators

(9) Sets up run constants for general use throughout program by calling CNSTNT

(10) Initiates forward integration of one-time step by calling PINT1

(11) Controls program output by calling subroutine OUTPUT as selected time intervals

(12) Tests for normal and abnormal stops

A normal program stop occurs when the cumulative integration time is equal to or greater than the run time limit specified by the input. Abnormal program stops can occur when the resultant linear and angular velocities of the vehicle sprung mass are less than specified input quantities, when the vehicle is near a rollover condition (that is, when the vehicle has rolled to 90 degrees), or when a terminal error has occurred. A list of terminal errors and corresponding messages is contained in the <u>HVOSM Programmers Manual.</u>

(13) Tests for necessity of coordinate system indexing to avoid possibility of undefined quantities in expression for time rate of change of the Euler angles

(14) Tests program indicators for occurrence of tire contact with a curb and/or sprung mass contact with a barrier, and changes integration time interval if necessary

(15) Controls output to vehicle graphics tape

Subroutine DAUX

Subroutine DAUX controls the lower level program functions by calling subroutines which evaluate forces acting on the vehicle, and evaluate the derivatives of the dependent variables to be integrated. This subroutine controls functions that:

(1) Call TMCNST to calculate time variables for general use throughout the program and index coordinate system if necessary

(2) Calculate time varying effective inertial terms: $(I'x)_t$, $(I'y)_t$, $(I'z)_t$, $(I'xz)_t$, $(I'yz)_t$. $(\gamma_2)_t$, $(\gamma_3)_t$, $(\gamma_4)_t$, $(\gamma_5)_t$, $(\gamma_6)_t$, $(\gamma_7)_t$, $(\gamma_8)_t$, $(\gamma_9)_t$

(3) Call subroutines VPOS, VGORNT, SUSFRC, UMOMNT and SFORCE to calculate geometrical relationships between the vehicle and its environment, and forces acting on the vehicle

(4) Call subroutine MATRIX, MTRXIR or MTRXSF to set up the mass matrix and forcing functions for equations of motion

(5) Call SIMSOL to solve equations of motion for second derivatives with respect to time

(6) Evaluate derivatives to be integrated: $\dot{u}$, $\dot{v}$, $\dot{w}$, $\dot{p}$, $\dot{q}$, $\dot{\gamma}$, $\ddot{\delta}_1$, $\ddot{\delta}_2$ or $\ddot{\phi}_F$, $\ddot{\delta}_3$, $\ddot{\phi}_R$ or $\ddot{\delta}_4$, $\dot{\delta}_1$, $\dot{\delta}_2$ or $\dot{\phi}_F$, $\dot{\delta}_3$, $\dot{\phi}_R$ or $\dot{\delta}_4$, $\dot{\theta}_t$, $\dot{\phi}_t$, $\dot{\psi}_t$, $\dot{X}'_c$, $\dot{Y}'_c$, $\dot{Z}'_c$

(7) Evaluates:

$\ddot{\psi}f$, $\dot{\psi}f$

if the steer degree-of-freedom is in use

Subroutine VPOS

This subroutine determines the position, orientation, and velocity of the wheels of the vehicle with respect to the vehicle fixed axes, or with respect to the space fixed axes, the torque acting on the front and rear wheels, and the direction of the vehicle x and y axis with respect to space. A listing of computational steps employed follows, and a variable flow diagram for the subroutine is shown in Figure 3.5-3.

(1) Interpolate input front and rear torque tables (TQ_F, TQ_R) with respect to time to determine torques (T_i) acting on wheels

(2) Calculate wheel center velocity components (u_i) with respect to space resolved along the vehicle x axis. Note that the longitudinal velocity of the ground contact point is assumed to be equal to that of the wheel center

(3) Calculate transformation matrix [A] from the vehicle axes to the space axes, from ϕ, θ, ψ

(4) Calculate direction cosines of the vehicle (x) and (y) axes ($\cos \alpha_x$, $\cos \beta_x$, $\cos \gamma_x$ and $\cos \alpha_y$, $\cos \beta_y$, $\cos \gamma_y$) with respect to the space axes

(5) Calculate positions of the wheel centers with respect to the space axes, X'_i, Y'_i, Z'_i

(6) Determine front and rear wheel camber angles (ϕ_1, ϕ_2, ϕ_3, ϕ_4) either from camber tables (ϕ_C, ϕ_{CR}) or axle roll angles (ϕ_F, ϕ_R) depending on suspension option.

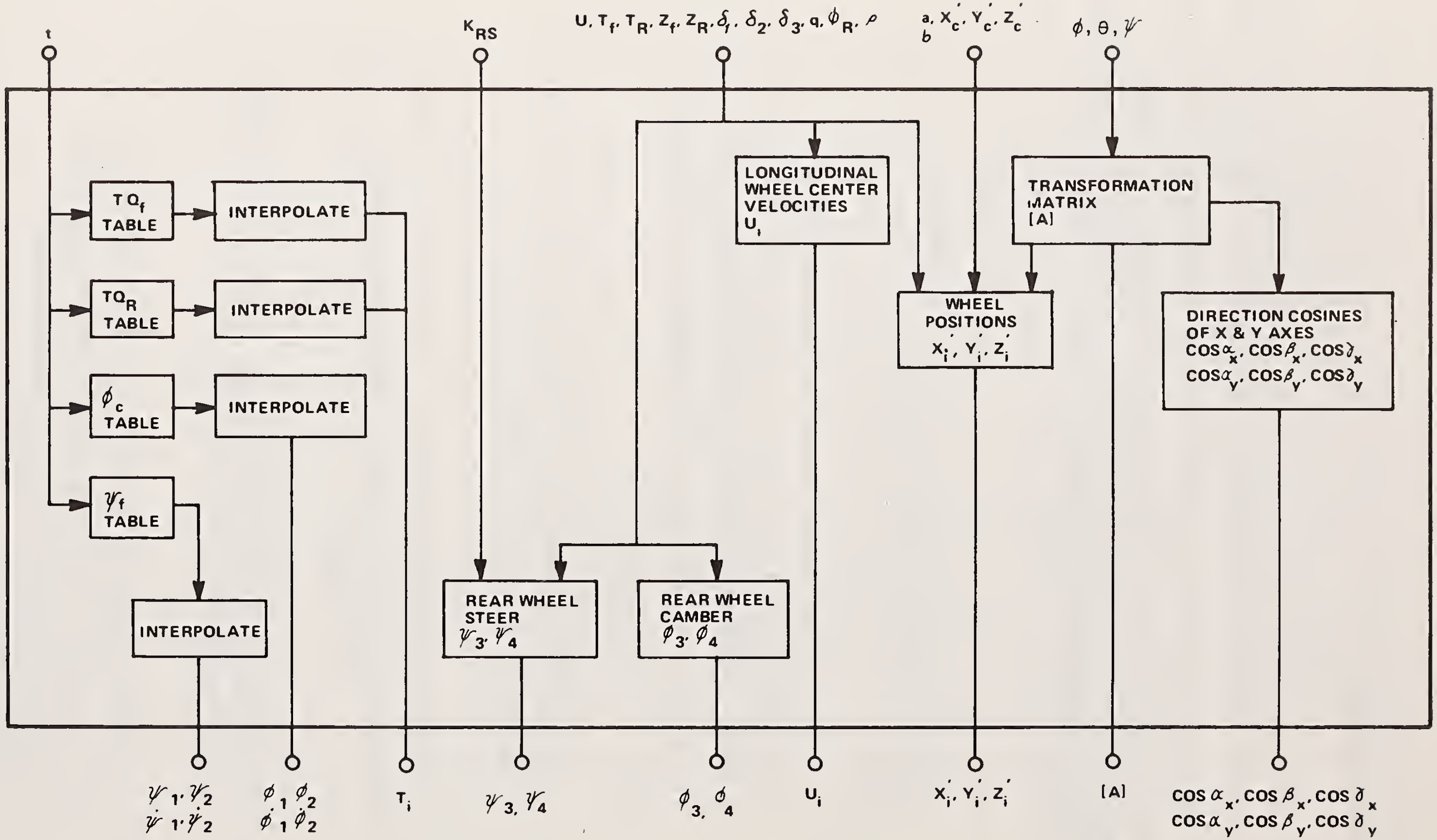


Figure 3.5-3 SUBROUTINE VPOS

(7) If the steer degree-of-freedom option is not in effect, interpolate input steer (ψ_f) table with respect to time to determine front wheel steer angles (ψ_1, ψ_2), and steer angular velocities ($\dot{\psi}_1$, $\dot{\psi}_2$)

(8) Determine rear wheel steer angles (ψ_3, ψ_4)

Subroutine VGORNT

This subroutine determines the orientation of the vehicle with respect to the local ground. This includes determining direction cosines of normals to various planes as well as lines of action of tire forces. The local terrain under each wheel is specified by an elevation and two Euler angles (specifying the ground slopes). The elevation and angles are determined from either the default option of flat horizontal terrain, terrain tables, road roughness data, or a curb face. The specific procedure follows and a variable flow diagram is provided in Figure 3.5-4.

(1) Calculate direction cosines of a normal to the ith wheel plane ($\cos \alpha_{ywi}$, $\cos \beta_{ywi}$, $\cos \gamma_{ywi}$)

(2) Determine whether wheel i is in a terrain table curb region, on flat, horizontal terrain or whether the road roughness option is being used. If the wheel is not in a curb region, subroutine INTRP5 is called to compute terrain elevations and slopes (note that, if the wheel is not within the terrain table bounds, the default of zero elevation and slopes is used). If the wheel is located on the last curb slope, the elevation and slopes are computed directly from curb impact data. Direction cosines of a normal to the ground plane ($\cos \alpha_{GZ'i}$, $\cos \beta_{GZ'i}$, $\cos \gamma_{GZ'i}$), and the direction components of a line perpendicular to the normal of both

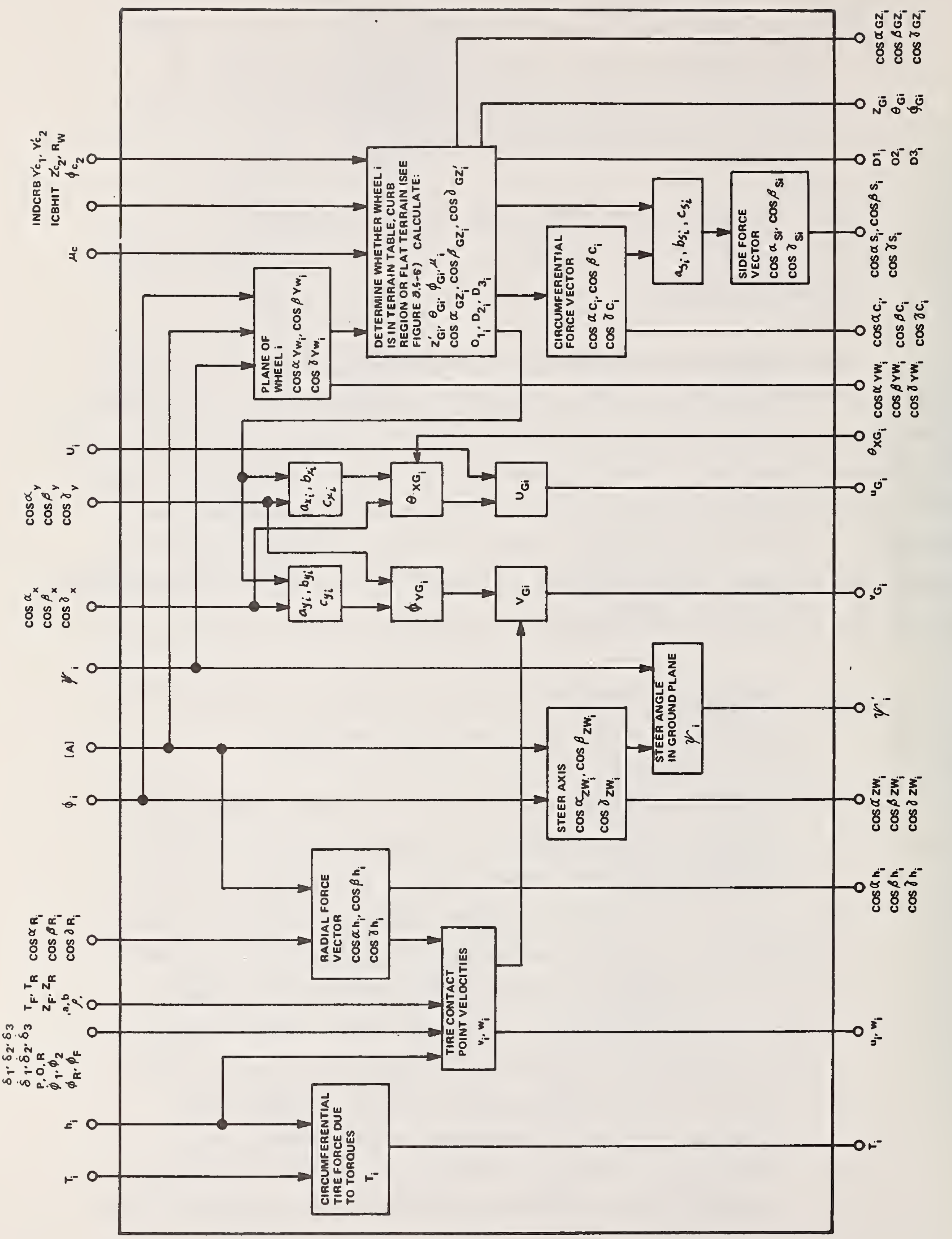


Figure 3.5-4 SUBROUTINE VGORNT

the wheel plane and ground plane are calculated. Subroutine GCP is then called to calculate the location of the ground contact point.

However, if the wheel is located within the region of the curb but not on the last slope, subroutine CRBIMP is called to calculate the "equivalent" ground elevation and slopes, and the contact point. The direction cosines of the ground plane and direction components of a line perpendicular to the normals to the ground and wheel planes are computed and the friction coefficient for the wheel is modified by the curb factor (μ_c).

If the road roughness option is being used, subroutine RUFFRC is called to calculate the equivalent ground elevation and slopes and the ground contact point in a manner similar to that used for curbs.

(3) Calculate direction cosines of the resultant radial tire force vector with respect to the space axes ($\cos \alpha_{hi}$, $\cos \beta_{hi}$, $\cos \gamma_{hi}$)

(4) Compute circumferential tire force due to applied torque (T_i). Note that this force is later subject to change in subroutine TIRFRC to that limiting value which can be sustained by the available tire-ground friction

(5) Compute lateral and vertical velocities of the tire contact point (v_i, w_i). Note that these velocities are measured with respect to the space axes, but are resolved along the vehicle axis directions

(6) Determine direction components of a line perpendicular to both the normal to the ground and vehicle (y) axis (a_{xi}, b_{xi}, c_{xi})

(7) Calculate sine and cosine of the angle between the vehicle (X) axis and the ground plane ($\sin \theta_{XGi}$, $\cos \theta_{XGi}$)

(8) Calculate longitudinal velocity of tire contact point parallel to ground plane (u_{G_i})

(9) Calculate direction components of a line perpendicular to both a normal to the ground plane and the vehicle (X) axis (a_{yi}, b_{yi}. c_{yi})

(10) Calculate angle between the (y) axis and the ground plane ($\sin \alpha_{yGi}$, $\cos \alpha_{yGi}$)

(11) Calculate lateral velocity of the tire contact point in the ground plane (v_{Gi})

(12) Calculate direction cosines of the wheel steer axis ($\cos \alpha_{zw_i}$, $\cos \beta_{zw_i}$, γ_{zw_i})

(13) Calculate steer angle in the ground plane (ψ'_i)

(14) Calculate direction cosines of the line of action of the circumferential tire force and the tire side force ($\cos \alpha_{ci}$, $\cos \beta_{ci}$, $\cos \gamma_{ci}$ and $\cos \alpha_{si}$, $\cos \beta_{si}$, and $\cos \gamma_{si}$)

(15) Call subroutine TIRFRC to calculate tire side and circumferential forces.

Subroutine INTRP5

This subroutine determines the elevation and slope of the terrain under the vehicle wheels by interpolation of the input terrain data. INTRP5 performs these functions:

(1) The highest numbered terrain table (1 through 5) applicable to the wheel is determined by sequentially testing if the wheel is located within the X' and Y' bounds of each table

(2) The grid segment within which the wheel is located is determined and the corner points are labeled as shown in Figure 3.4-13.

(3) Testing is performed to determine if an interpolation boundary cuts through the segment

(4) If no boundaries cut through the grid segment within which the wheel lies, the elevation under the wheel (Z_{Gi}) is interpolated from the input elevation at the corner points, and the slopes are calculated (θ_{Gi}, ϕ_{Gi})

(5) If a y' boundary cuts through the segment, the elevation is extrapolated from either one grid segment less than or one grid segment greater than the one in which the wheel is located in the y' direction, and the slopes are calculated

(6) If an angled boundary cuts through the grid segment in which the wheel is located, a test is first made to determine if the wheel has crossed the boundary and the grid points are logically renumbered to extrapolate the elevation and slopes under the wheel

Subroutine GCP

Given the position of the ith wheel center in space, and the ground and wheel orientations, subroutine GCP computes the location of the ground contact point and the direction and magnitude of the tire radial force. The solution steps are described in the following text, and a variable flow diagram is shown in Figure 3.5-5.

(1) Calculate coordinates (relative to the space fixed axes) of the ground contact point (X'_{GPi}, Y'_{GPi}, Z'_{GPi}) by simultaneous solution of the intersection of three planes; the wheel plane, the ground plane, and a plane perpendicular to both, and the distance between the wheel center and ground contact point (Δ_i)

(2) Calculate direction cosines of the line of action of the tire radial force ($\cos \alpha_{Ri}$, $\cos \beta_{Ri}$, $\cos \gamma_{Ri}$). This is the direction of the ground contact point from the wheel center in the space fixed axes

(3) Calculate rolling radius of the tire (h_i) with logical testing to ensure that the rolling radius never exceeds the undeformed tire radius (R_w)

(4) Calculate radial tire force (F_{R_i}) from the tire deflection ($R_w - h_i$)

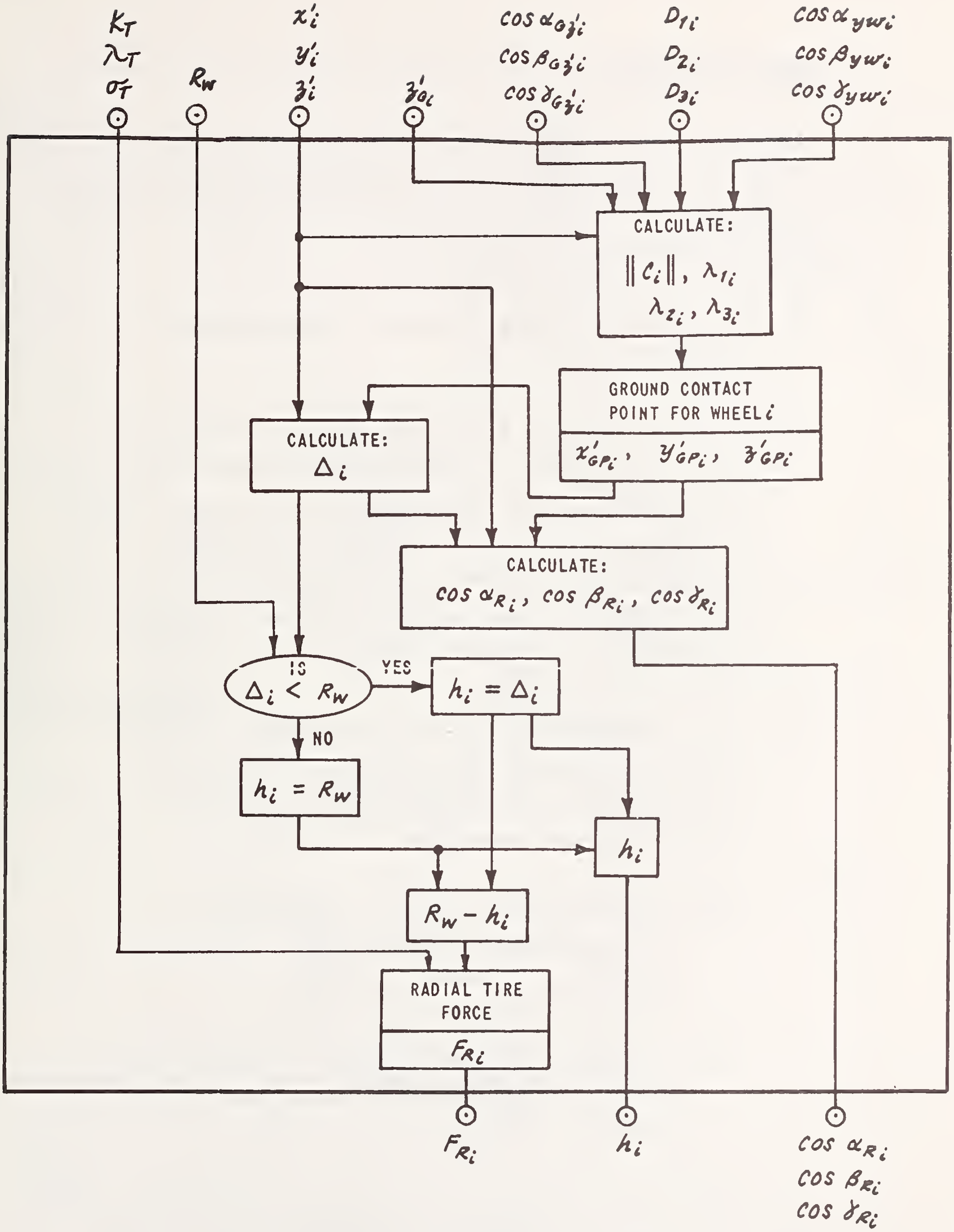


Figure 3.5-5 Subroutine GCP

Subroutine TIRFRC

This subroutine calculates the circumferential and side tire forces from applied torques, contact point velocity components in the ground plane, steer and camber angles. The computational steps are listed below and a variable flow diagram is shown in Figure 3.5-6.

(1) Calculate camber angle relative to the ground plane (ϕ_{CGi})

(2) Calculate the tire force perpendicular to the ground (F'_{Ri}). Note that, as shown in Figure 3.5-6, this calculation requires knowledge of the side force before it is known. A two step iteration is performed involving steps 2 through 6 using the previously calculated side force initially, and the recomputed side force in the second iteration

(3) Test circumferential force due to applied torques calculated in subroutine VPOS (T_i), and calculate the applied circumferential force (F_{c_i}), subject to the following conditions:

   (a) Ensure that ratio of the circumferential to normal forces do not exceed the available friction (μ)

   (b) Ensure that if braking occurs the applied torque does not change the direction of motion of the vehicle

   (c) Ensure that for tractive torque, the applied torque is limited to the minimum value that can be sustained by either of a pair of wheels (front or rear) simulating differential action

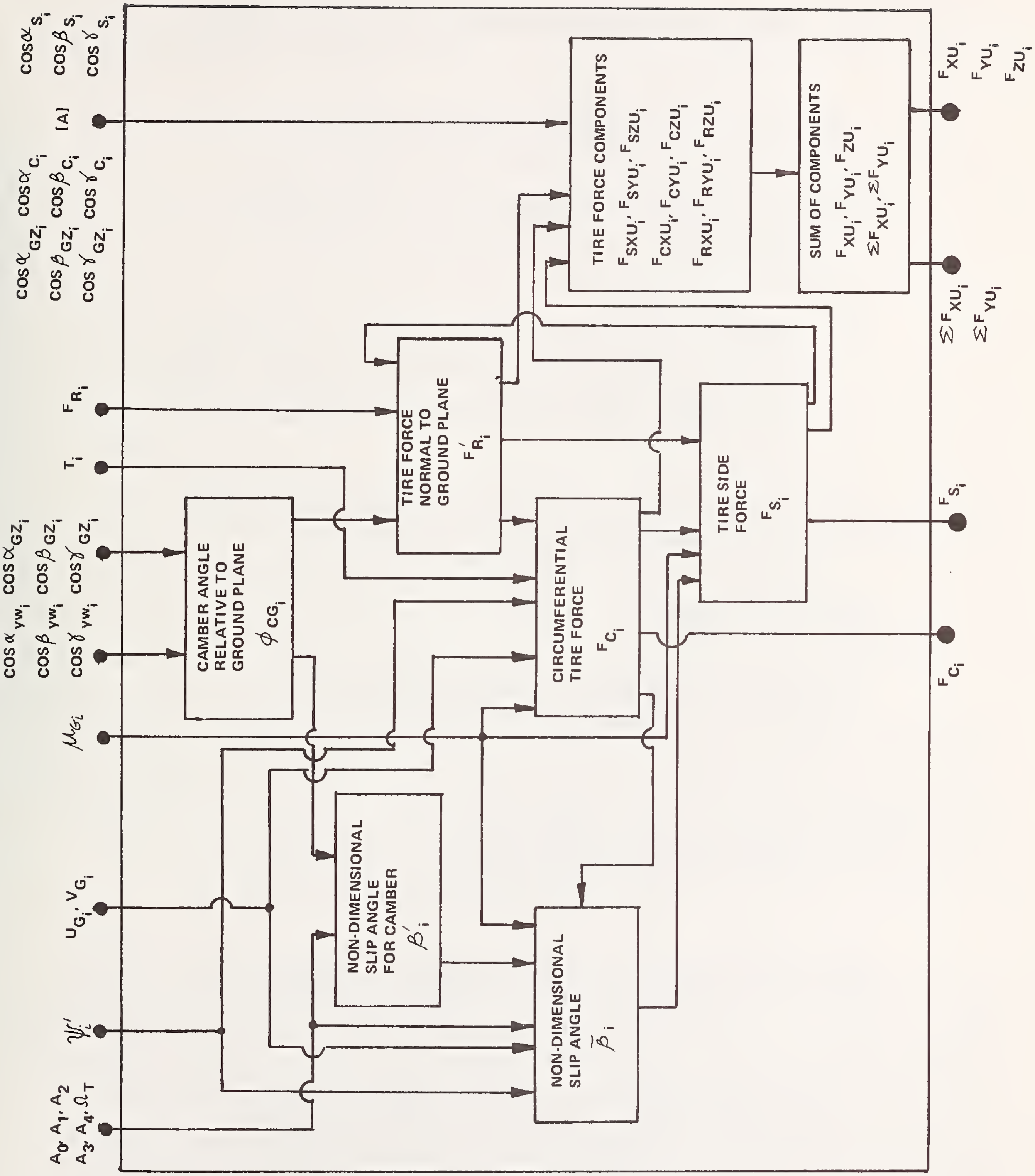


Figure 3.5-6 SUBROUTINE TIRFRC

(4) Calculate non-dimensional slip angle equivalent for camber (β'_i)

(5) Calculate non-dimensional slip angle ($\overline{\beta}_i$)

(6) Calculate tire side force (F_{s_i}) and repeat once from Step 2

(7) Calculate components of the individual tire forces (normal, side and circumferential) along the vehicle axes (F_{Rxui}, F_{Ryui}, F_{Rzui}, F_{sxui}, F_{syui}, F_{szui}, F_{cyui}, F_{czui})

(8) Calculate sum of the tire force components acting along the vehicle axes (F_{xui}, F_{yui}, F_{zui})

Subroutine CRBIMP

The algorithm designed to simulate tire contact with curbs is executed only when both the curb impact option is indicated by the number 1.0 in field 2 of input card 102 and when a given tire (or tires) is in close proximity to the lateral position of the curb. Proximity testing is carried out in subroutine VGORNT and when indicated, the integration step size is decreased to Δ_{tc} to maintain stability during the curb traversal in the main routine.

When the above conditions are indicated, the single point contact model of the tire is abandoned in favor of the distributed radial spring mode and a resultant in plane radial force is computed based on the tire deformation resulting from the true curb profile. Once this resultant force is known, an equivalent ground contact point and ground slopes are computed assuming the force resulted from deformation of the tire in the single-point contact mode. Transfer back to an equivalent ground plane is necessary because of the need to link existing side force computational procedures to the distributed radial force mode.

The computational procedure is outlined below and a variable flow diagram is shown in Figure 3.5-7.

(1) Calculate transformation matrix from a coordinate system fixed in the wheel plane with the (X) axis along the jth radial spring according to the sequence ϕ_i (camber), ψ_i (steer) and θ_j (radial spring) angle relative to the Z axis) to the vehicle axes $[A_j]$

(2) Calculate transformation matrix from the wheel coordinate system to the space system [B]

(3) Calculate distance between the wheel center and terrain along the jth radial spring (h'_j). Note that since there are six possible planes that define the terrain in the region of a curb the logical test procedure shown in Figure 3.5-8 is employed to ensure compatibility between h'_j and the lateral position (y_j) of the ground contact point of the jth radial spring

(4) Calculate longitudinal and vertical coordinates of the ground contact point of the jth radial spring in the space coordinate system (X'_j, Z'_j)

(5) Calculate direction cosines of the jth radial spring force in space ($\cos \alpha_j$, $\cos \beta_j$, $\cos \gamma_j$)

(6) Calculate magnitude of the jth radial force by interpolation of the radial spring force-deflection characteristics as determined in subroutine WHEEL (F'_J)

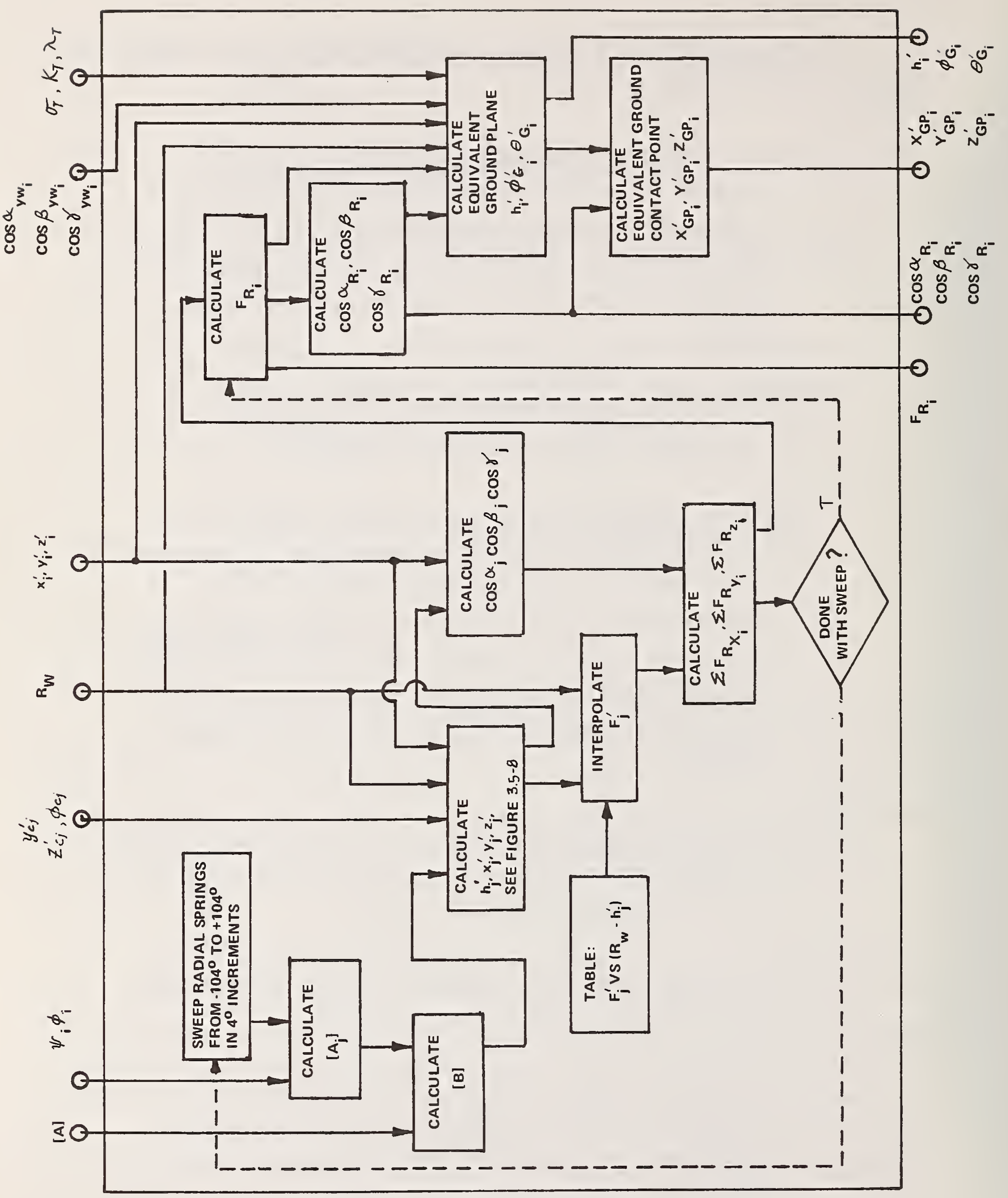


Figure 3.5-7 SUBROUTINE CRBIMP

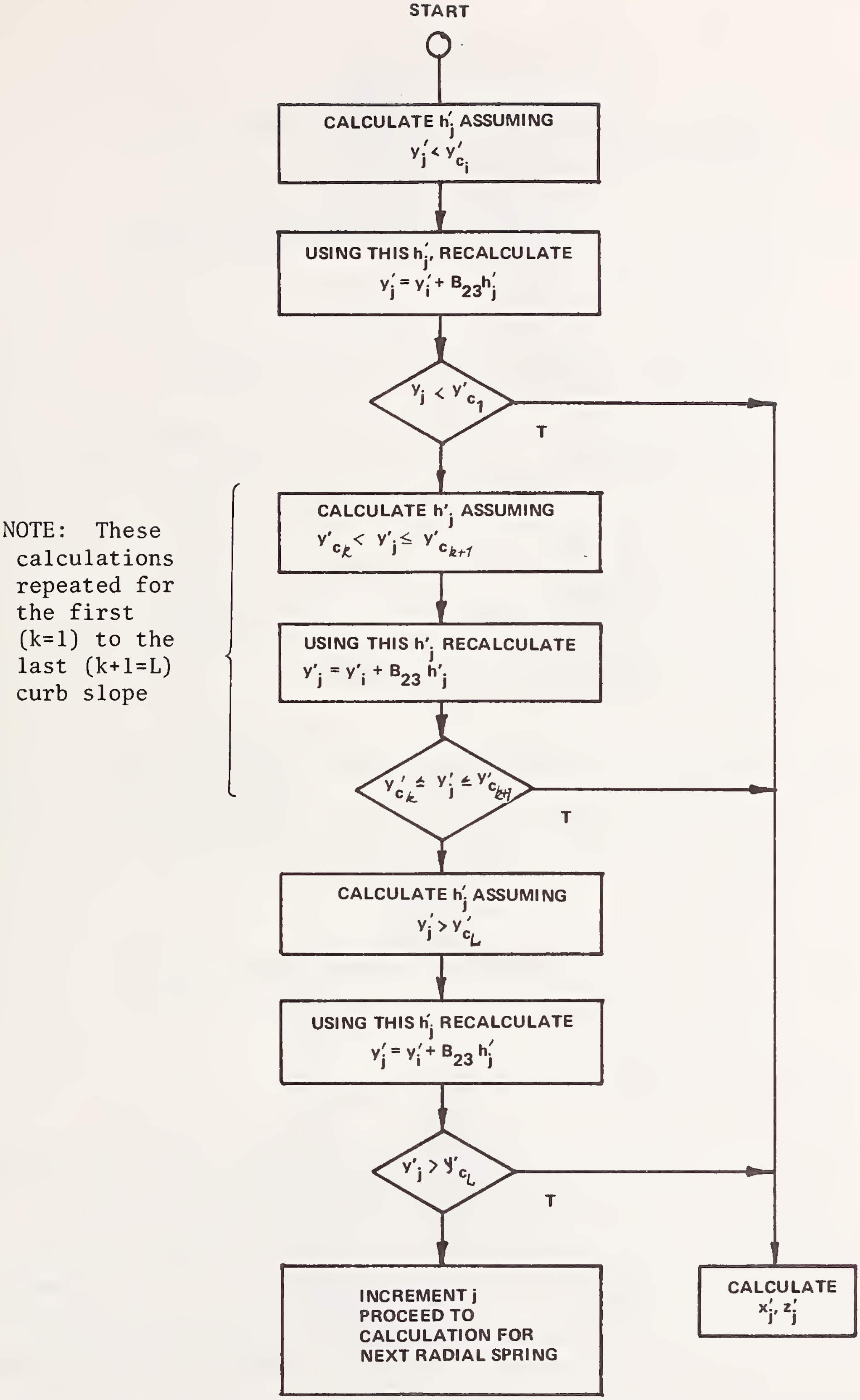


Figure 3.5-8 LOGIC TO INSURE COMPATIBILITY BETWEEN RADIAL SPRING AND CURB ZONE

(7) Calculate and accumulate jth radial spring force components ($\Sigma F_{RX'i}$, $\Sigma F_{RY'i}$, $\Sigma F_{RZ'i}$)

(8) Repeat Steps 1 through 7 until all radial springs have been used

(9) Compute the resultant radial tire force (F_{R_i})

(10) Calculate direction cosines of this force with respect to the vehicle axes ($\cos \alpha_{Ri}$, $\cos \beta_{Ri}$, $\cos \gamma_{Ri}$)

(11) Calculate distance from the wheel center to the equivalent ground contact point that would have produced the same force magnitude if the single point tire model were used (h_i)

(12) Calculate equivalent ground slopes that would have produced the same direction of the radial force if the single contact point tire model were used (ϕ_{Gi}, θ_{Gi})

(13) Calculate equivalent ground contact point (X'_{GPi}, Y'_{GPi}, Z'_{GPi})

Subroutine SFORCE

Given the position and orientation of the vehicle and the barrier, this subroutine calculates the geometrical interface between the two through an iterative process of changing the barrier displacement until a force balance between the barrier and vehicle is achieved if the deformable barrier option is employed; or by returning the barrier to its undeformed position if the rigid barrier option is used. This subroutine is described in the following text and shown in Figure 3.5-9.

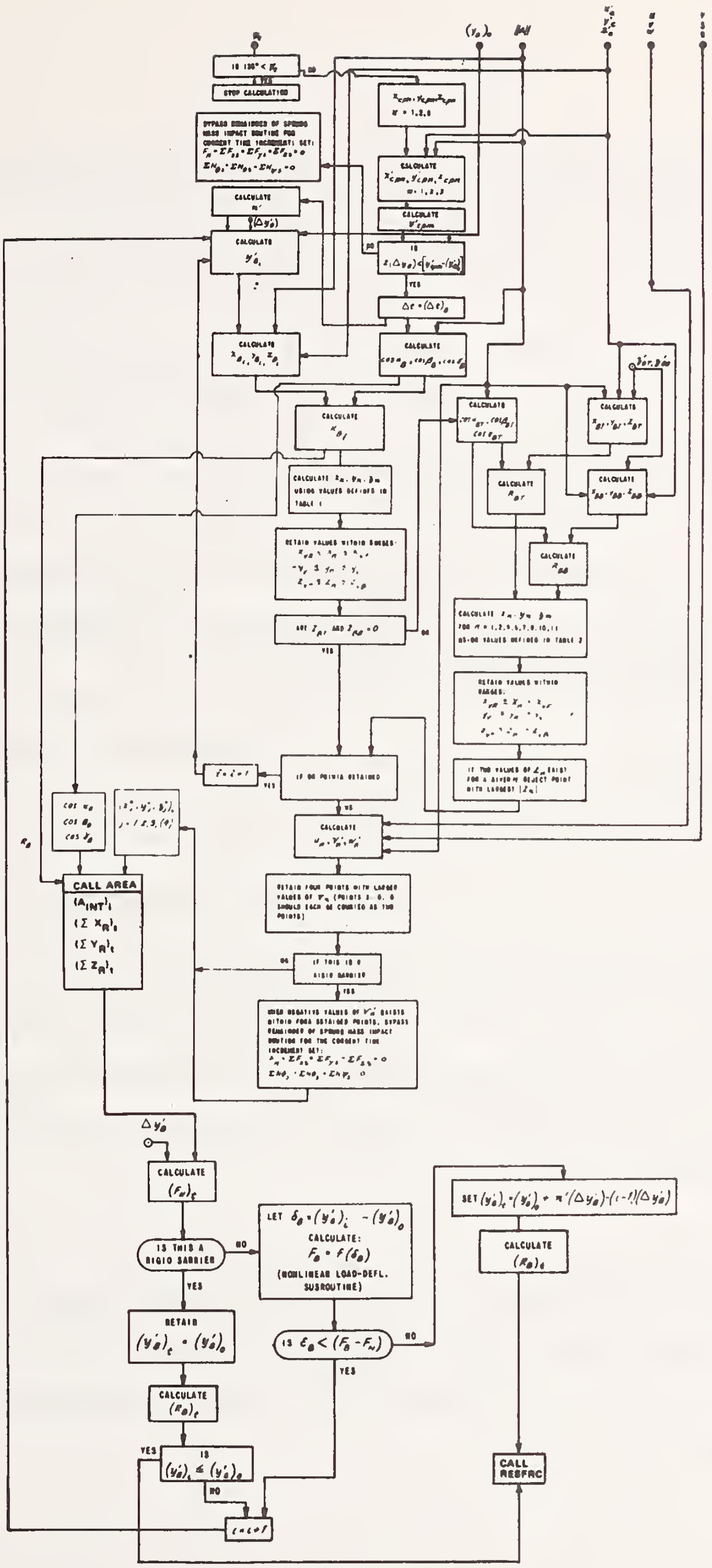


Figure 3.5-9 SUBROUTINE SFORCE

(1) Calculate location of the vehicle corner points at the c.g. height in space (X'_{cpn}, Y'_{cpn}, Z'_{cpn}) and determine which corner is closest to the barrier

(2) Calculate location of the top and bottom points on the vehicle corner closest to the barrier (X'_{cpt}, Y'_{cpt}, Z'_{cpt} and X'_{cpb}, Y'_{cpb}, Z'_{cpb}) and let Y'_{cpm} by the maximum of Y'_{cpt}, Y'_{cpb}

(3) Test for proxmity to the barrier and if Y'_{cpm} is not greater than $(Y'_B)_0 + 2(\Delta Y'_B)$, bypass the remainder of the sprung mass force computation

(4) Calculate direction cosines of a normal to the barrier face (vertical) plane ($\cos \alpha_B$, $\cos \beta_B$, $\cos \gamma_B$)

(5) If the finite vertical barrier face plane option is in use, calculate direction cosines of a normal to the planes defining the top and bottom limits of the barrier ($\cos \alpha_{BT}$, $\cos \beta_{BT}$, $\cos \gamma_{BT}$), the positions of points on the top and bottom planes in the vehicle axis system (X_{BT}, Y_{BT}, Z_{BT} and X_{BB}, Y_{BB}, Z_{BB}) and plane constants (R_{BT} and R_{RB})

(6) Calculate position of the intersection of the Y' axis with the previous barrier face plane with respect to the vehicle axes ($X_{B'}$, $Y_{B'}$, $Z_{B'}$) and the plane constant for the previous barrier equilibrium face plane ($R_{B'}$)

(7) Calculate approximate location of the axis of rotation of the vehicle in the vehicle plane $Z = 0$ relative to the barrier (X_{B1}, Y_{B1}, Z_{B1}) by intersection of the previous time increment barrier vehicle interface plane and the present barrier plane with an assumed deflection of δ_{Bt-1}

(8) Calculate direction cosines of a normal to the plane which is perpendicular to the present barrier face plane and passes through the axis of rotation ($\cos \alpha_{B1}$, $\cos \beta_{B1}$, $\cos \gamma_{B1}$) and the plane constant (R_{B1}). This plane defines the approximate boundary of compression of the vehicle structure if within the vehicle boundaries

(9) Calculate the current position of the hardpoints (X'_{STi}, Y'_{STi}, Z'_{STi})

(10) Begin iteration of the barrier deflection starting with the barrier deflected to the limit of contact with the vehicle and incrementally decreasing the barrier deflection while increasing the vehicle deformation until a force balance between the barrier and vehicle is achieved by Steps 10 through 19

(11) Calculate location of a point on the current barrier cutting plane (X_{Bi}, Y_{Bi}, Z_{Bi}) and the plane constant (R_{Bi})

(12) Determine possible intercepts of the barrier cutting plane with the vehicle periphery depending on whether the finite or infinite vertical barrier option is used (x_n, y_n, z_n)

(13) Logically determine which of the possible intercepts are to be retained based on the vehicle boundaries and the location of the axis of rotation

(14) Calculate velocity components of the retained points (u'_n, v'_n, w'_n)

(15) Call subroutine AREA to calculate area of intersection, $(A_{INT})_i$, for this cutting plane

(16) Calculate impact forces due to hard point deflection (F_{NSTi})

(17) Calculate summation of the incremental forces produced by deformation of the vehicle over the i cutting planes

(18) If the rigid barrier option is in use, continue decreasing the barrier deflection until the initial position is reached (i.e., repeat from Step (11)

(19) If the deformable barrier option is in use call NLDFL to obtain the barrier force based on the current position (F_B)

(20) Test for equilibrium between the vehicle and barrier. If the barrier force (F_B) has decreased and the vehicle force (F_N) has increased to the point where $F_B < F_N + E_B$ equilibrium is assumed. If $F_B > F_N + E_B$, equilibrium has not yet been reached, therefore the barrier position is decreased by $\Delta y'_B$ and repetition from Step 11 occurs

(21) Once equilibrium has been reached for the deformable barrier option or the original barrier position has been reached for the rigid barrier option, subroutine RESFRC is called to determine the resultant forces and moments applied to the vehicle sprung mass

Subroutine AREA

This subroutine calculates the interface area between the vehicle and barrier and the coordinates of the point of application of the impact forces.

Subroutine AREA is shown in Figure 3.5-10.

(1) Logically order and identify the retained intercept points (x''_j, y''_j, z''_j)

(2) Calculate characteristic lengths of the intersection area (S_{1i}, S_{2i}, S_{3i})

(3) Calculate intersection area $(A_{INT})_i$

(4) Calculate point of application of the impact forces $(\Sigma X_R)_t$, $(\Sigma Y_R)_t$, $(\Sigma Z_R)_t$

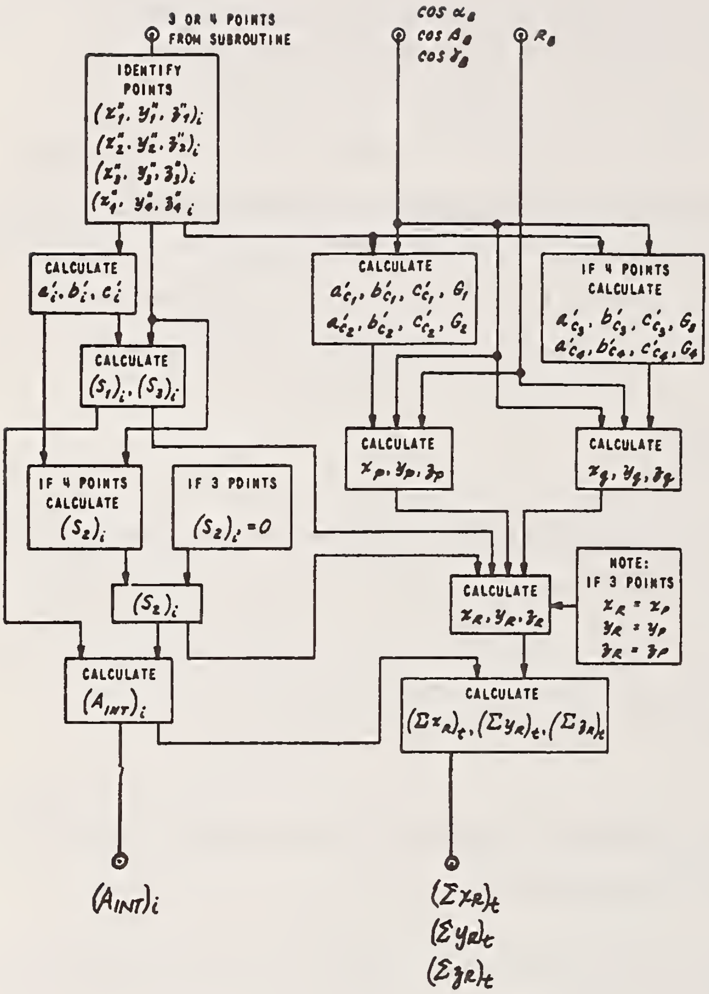


Figure 3.5-10 Subroutine AREA

Subroutine RESFRC

Given the vehicle crush force (F_N) and the hard point forces (F_{NSTi}), application of the forces (ΣX_R, ΣY_R, ΣZ_R) and X_{STi}, Y_{STi}, Z_{STi} and the vehicle-barrier friction coefficient, this subroutine claculates the resultant forces and moments due to the impact force acting on the sprung mass. A flow diagram is shown in 3.5-11. Subroutine RESFRC performs these functions.

(1) Calculate velocity components of the point of application of the impact force with respect to space (u'_R, v'_R, w'_R)

(2) Calculate velocity of this point tangent of barrier ($\overline{VTAN}$)

(3) Calculate friction force acting between the vehicle and barrier ($\overline{FRICT}$)

(4) Calculate resultant force components in the vehicle areas (ΣF_{xs}, ΣF_{ys}, ΣF_{zs})

(5) Calculate resultant moments of force acting on the sprung mass ($\Sigma N\phi_s$, $\Sigma N\theta_s$, $\Sigma N\psi_s$)

Subroutine INITEQ

This subroutine establishes initial vertical equilibrium of the vehicle on flat, level terrain, if Z_F and Z_R are input as 0.0.

(1) Calculate front and rear suspension forces for equilibrium

(2) Calculate front and rear tire forces for equilibrium

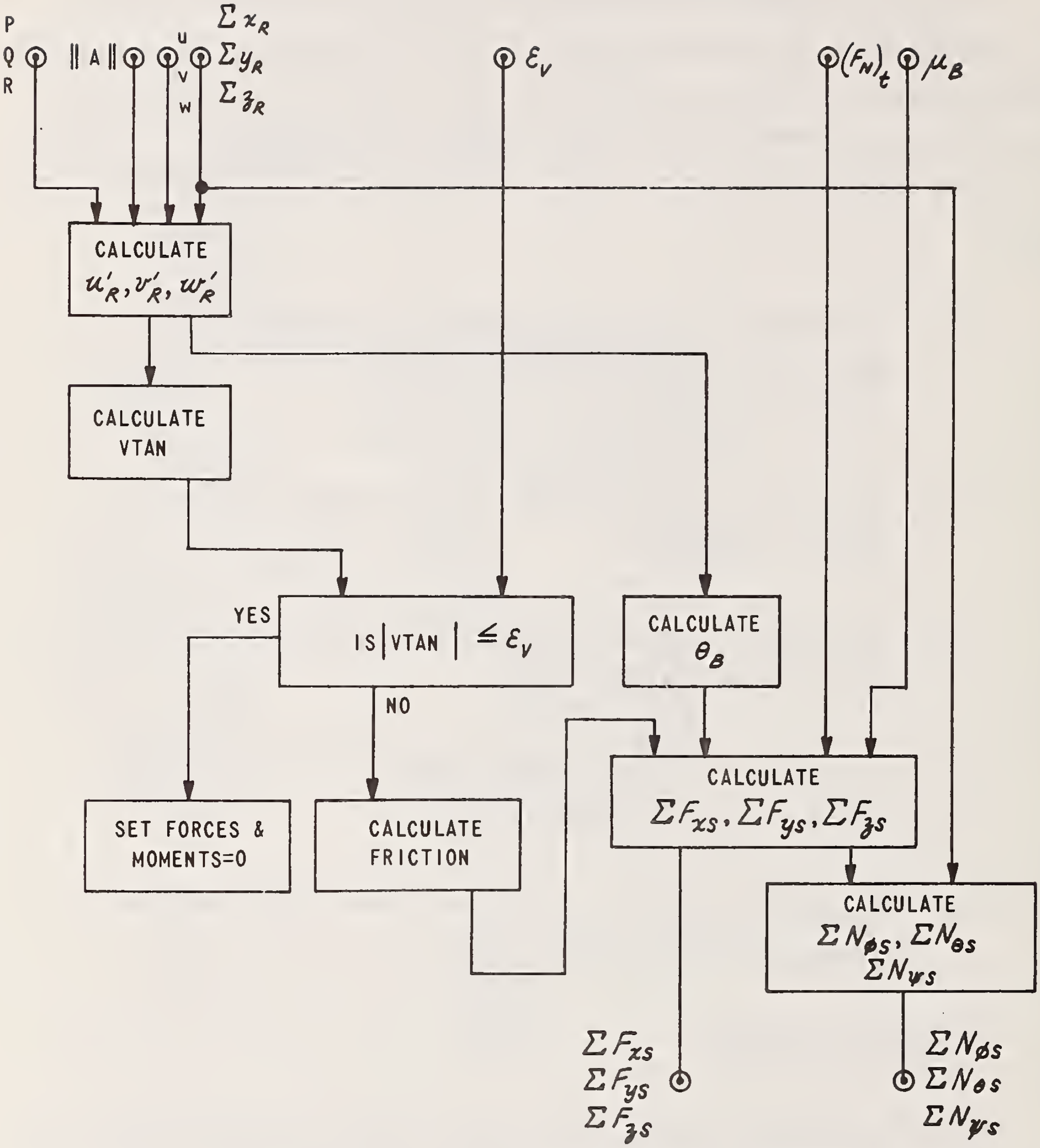


Figure 3.5-11 **SUBROUTINE RESFRC**

(3) Calculate Z_F and Z_R

(4) Calculate tire rolling radius (h_i)

Subroutine MATRIX

This subroutine calculates the elements of the inertial matrix [D] and the forcing matrix [E] for the independent front suspension, rigid axle rear suspension option.

Subroutine MTRXIR

This subroutine calculates the elements of the inertial matrix [D] and the forcing matrix [E] for the independent front and rear suspension option.

Subroutine MTRXSF

This subroutine calculates the elements of the inertial matrix [D] and the forcing matrix [E] for the solid axle front and rear suspension option.

Subroutine RUFFRC

This subroutine makes use of the distributed radial spring tire model to approximate tire enveloping power for use with road roughness data. It is used only when roughness data is supplied. The computational procedure employed is similar to that used in subroutine CRBIMP except that the road roughness profile is substituted for the curb profile.

(1) Calculate transformation matrix from a coordinate system fixed in thw wheel plane with the (X) axis along the jth radial spring according to the sequence ϕ_i (camber), ψ_i (steer) and θ_j (radial spring angle relative to the Z axis) to the vehicle axes [Aj]

(2) Calculate transformation matrix from the wheel coordinate system to the space system [B]

(3) Calculate the distance between the wheel center and terrain along the jth radial spring. Note that, for each radial spring, a loop is employed to vary the road profile segment until the radial spring intersects the correct road segment. This is determined by the intersection falling within the road segment limits

(4) Calculate longitudinal and vertical coordinates of the ground contact point of the jth radial spring in the space coordinate system (y'_j, z'_j)

(5) Calculate direction cosines of the jth radial spring force in space $(\cos \alpha_j, \cos \beta_j, \cos \gamma_j)$

(6) Calculate magnitude of the jth radial spring force by interpolation of the radial spring force-deflection characteristic as determined in subroutine WHEEL (F'_j)

(7) Calculate and accumulate jth radial spring force components $(\Sigma F_{RX'i}, \Sigma F_{RY'i}, \Sigma F_{RZ'i})$

(8) Repeat Steps 1 through 7 until all radial springs have been used

(9) Compute the resultant radial tire force (F_{Ri})

(10) Calculate direction cosines of this force with respect to the vehicle axes $(\cos \alpha_{Ri}, \cos \beta_{Ri}, \cos \gamma_{Ri})$

(11) Calculate distance from the wheel center to the equivalent ground contact point that would have produced the same force magnitude if the single point tire model were used (h_i)

(12) Calculate equivalent ground slopes that would have produced the same direction of the radial force if the single contact point tire model were used (ϕ_{Gi}, θ_{Gi})

(13) Calculate equivalent ground contact point (x'_{GPi}, y'_{GPi}, z'_{GPi})

Subroutine SUSFRC

This subroutine computes the suspension forces acting between the sprung and unsprung masses.

(1) Calculate front and rear friction damping force (F_{1Fi}, F_{1Ri})

(2) Calculate elastic spring force and jounce or rebound stop force (F_{2Fi}, F_{2Ri})

(3) Calculate suspension anti-pitch force (F_{ZPFi}, F_{APRi})

(4) Calculate suspension jacking force (F_{JFi})

(5) Calculate total suspension force (S_i)

(6) Calculate sum of the vertical forces acting on sprung mass (Σ_{Fz1})

Subroutine UMOMNT

Given the suspension forces and tire forces, this subroutine computes the moments acting on the sprung mass for the suspension option being used (ΣN_{ϕ}, ΣN_{θ}, ΣN_{ψ}, ΣN_{ϕ_F}, ΣN_{ϕ_R})

Subroutine WHEEL

This subroutine calculates the individual radial spring force-deflection characteristic for use in the radial spring mode of the tire radial force calculation. Compatibility is maintained between the single-point contact mode and the radial spring mode under conditions of flat terrain. The procedure used incrementally deflects the tire and calculates the change in the radial spring rate required for the current incremental deflection to produce a compatible resultant vertical force with that produced by the single point contact mode.

Subroutine SIMSOL

The function of this subroutine is to solve a set of real simultaneous linear algebraic equations of the form $[A]\{x\} = \{B\}$.

Subroutine PINT1 (Numerical Integration)

The numerical integration routine used provides the user with an Runge-Kutta classical fourth-order method as modified by E. K. Blum or the Adams-Moulton predictor-corrector method using the Runge-Kutta method for starting the process.

Let the system of equations to be solved be given in the form:

$$y_i = f_i\ (x, y_1, y_2, \ldots., y_N)$$
$$y_i(x_o) = y_{io} \quad i = 1, 2, \ldots N$$

Let y_{in} be the value of y_i at $x = x_n$ and f_{in} the derivative of y_i at $x = x_n$. If h is the increment (step-size) of the independent variable x, the classical Runge-Kutta fourth-order method uses the formulas:

$$K_{i1} = hf_i\ (x_n, y_{in})$$

$$K_{i2} = hf_i\ (x_n + 1/2\ h, y_{in} + 1/2\ K_{i1})$$

$$K_{i3} = hf_i\ (x_n + 1/2\ h, y_{in} + 1/2\ K_{i2})$$

$$K_{i4} = hf_i\ (x_n + h, y_{in} + K_{i3})$$

$$y_i, n + 1 = y_{i,n} + 1/6\ (K_{i1} + 2K_{i2} + 2K_{i3} + K_{i4})$$

where i = 1, 2, ... N

E. K. Blum Modification

The following recursive form of the E. K. Blum's exact modification of the Runge-Kutta is used in this routine:

$$z_0 = y_n$$

$$q_0 = y_n \quad \text{at } x = x_0 \tag{2.1}$$

$$P_0 = hf(Z_0)$$

$$Z_1 = Z_0 + P_{0/2} \quad \text{at } x = x_0 + h/2 \tag{2.2}$$

$$q_1 = P_0$$

$$P_1 = hf(Z_1)$$

$$Z_2 = Z_1 + P_{1/2} - q_{1/2}$$

$$q_2 = q_{1/6} \quad \text{at } x = x_0 + h/2 \tag{2.3}$$

$$P_2 = hf(Z_2) - P_{1/2}$$

$$Z_3 = Z_2 + P_2 \quad \text{at } x = x_0 + h \tag{2.4}$$

$$P_3 = hf(Z_3) + 2P_2$$

$$y_i, n + 1 \equiv Z_4 = Z_3 + q_3 + P_{3/6} \tag{2.5}$$

(we omit the subscript i from each of the vectors Z_j, q_j and P_j for reasons of economy)

The main advantage of the modified Runge-Kutta formulas is that they reduce considerably the rounding error arising from the unavoidable use of digital numbers and pseudo-operations.

Adams-Moulton Predictor-Corrector Method:

The routine uses the following formulas for the system (1.1):

$$\overset{[P]}{y}_{i,n+1} = y_{i,n} + h/24(55f_{i,n} - 59f_{i,n-1} + 37f_{i,n-2} - 9f_{i,n-3}) \tag{3.1}$$

$$y_{i,n+1} = \overset{[C]}{y}_{i,n+1} = y_{in} + h/24(9\overset{[P]}{f}_{i,n+1} + 19f_{in} - 5f_{i,n-1} + f_{i,n-2})$$

The starting values needed in the predictor formula are obtained using the Runge-Kutta-Blum (RKB) method. In the evaluation of y_i at $x = x_{n+1}$ the predictor and corrector formulas are applied only once so that only two derivative evaluations ($\overset{[P]}{f}_{i,n+1}$ and f_{in}) are needed for each Adams-Moulton (variable or fixed step-size) integration step.

Variable Adams-Moulton

The step-size h to be used in the variable mode is determined mainly by:

$$E_{n+1} = \underset{i}{MAX} \frac{\left| y^{[p]}_{i,n+1} - y^{[c]}_{i,n+1} \right|}{14 D_i}.$$

$$D_i = \underset{i}{MAX} \left\{ \left| y^{[c]}_{i,n+1} \right|, \alpha \right\}, i \; 1,2, \ldots N$$

where

E_{n+1} is the local truncation error estimate in the actual evaluation of yn+1; α (>0) is a constant used to prevent unnecessary reductions in /h/ whenever /y, n+1/ is small (normally the routine will set α = 1 unless otherwise specified by the user).

Let:

$\bar{E}$	Is the upper bound on the truncation error estimate (specified by the user), that is, the number of significant digits which the user desires to preserve locally throughout the integration. Normally $\bar{E}$ should be in the range $10^{-8} \leq \bar{E} \leq 10^{-3}$ and in double precision $\bar{E}$ should be in the range $10^{-16} \leq \bar{E} \leq 15^{-12}$
M	Is a constant, M > 0, (specified by the user), from which a lower bound $\bar{E} M^{-1} \bar{E}$ is obtained (normally M ranges from 50 to 150 and in double precision from 1000 to 1500)
β	Is a constant between 0 and 1, used to increase or decrease the step-size. The routine will take β = 1/2 unless β is otherwise specified by the user

α	Is a positive number used to prevent unnecessary reduction in the variable step-size when the dependent variables are sufficiently small. When A(3) is zero the routine uses the normal value of one
h_{max}	Is a positive upper bound for the magnitude of the variable step-size. If A(4) is zero the routine assumes there is no upper bound
h_{min}	Is a positive lower bound for the magnitude of the variable step-size. The routine assumes there is no lower bound when A(5) is zero

The step-size h will be then increased or decreased according to the following inequalities:

$\overline{E}_{n+1} > \overline{E}$	The step size is reduced to β_h, where $0 < \beta < 1$
$\overline{E} \geq \overline{E}_{n+1} \geq \overline{E}^{-1}$	The step-size remains unchanged
$\overline{E}_{n+1} < \overline{E}^{-1}$	For 3 successive integration steps, the step-size is increased to h/β.

Increasing and Decreasing the Step-Size

The starting values, the first three successive points after the initial point P_0, for the Adams-Moulton formulas are always obtained using the RKB method whenever the interval size is changed, just as at the beginning of an integration.

In the variable mode, if the starting values have been obtained using the RKB method, then the next point is computed using the Adams-Moulton predictor-corrector formulas. Whenever the truncation error at this point calls for a decrease in h, the routine returns to the initial point P_0 and computes new starting values with the decreased value of h. However, if the step-size is to be decreased at a point P_i, where the preceeding point P_{i-1} was computed in the variable mode and the inequality held at P_{i-1}, then a new start is initiated at P_{i-1} with a decreased value of /h/.

If for three successive variable integration steps P_{i-1}, P_i and P_{i+1} inequality holds, then a new start is initiated at P_{i+1} with the increased value of /h/. After an interval is increased, the routine prevents increasing again until six more points have been complete. However, the routine may decrease the interval as often as necessary. The truncation error test will guarantee that the local error does not exceed $\bar{E}$, however the cumulative error will usually exceed $\bar{E}$. Hence, $\bar{E}$ should be chosen sufficiently small to allow for an accumulation of trancation error.

The user must always provide a starting value for h and he may, if desired, specify a maximum value of /h/, h_{max} beyond which the routine will not increase /h/ and a minimum of /h/, h_{min}, below which it will not decrease h. If no value is specified for h_{max} and h_{min} the routine will set the values at 10^3 and 10^{-7}, respectively. Negative values of h may be used for backward integration.

Control and DAUX

There are two entries to this routine. The first (control word = 1) must be used once at the beginning to set up the routine for integration of a given set of N differential equations. The second entry (control word = 2) may be used any number of times after the first to integrate all y_i from x to x + h.

Whenever the control word is 1 the routine uses the auxiliary subroutine DAUX to evaluate the derivatives at the initial point $x = x_0$ and returns with all y_i unchanged. The routine also checks and sets up the six parameter words $\overline{E}$, M_i, α, h_{max}, h_{min} and β needed in the variable mode of operation. Before executing the initialization entry, the user must have already set up the appropriate values for x, h and y_i, i = 1, 2 ... N. Ordinarily, after an execution of the second entry all y_i assume new values, x will have been advanced to the value x + h, and h will be unchanged, unless in the variable mode. On exit the values y_i are always those which correspond to the point x + h and y_i.

Whenever an integration step involves RKB integration, four derivative evaluations are needed:

$$f_i\ (x_n + 1/2h,\ y_{in} + 1/2K_{i\ell})$$

$$f_i\ (x_n + 1/2h,\ y_{in} + 1/2K_{i2})$$

$$f_i\ (x_n + h,\ y_{in} + K_{i3})$$

$$y'_{i,\ n+\ell} = f_i\ (x_n + h,\ y_{n+\ell})$$

where K_{ij} are given and modified. In the fixed h predictor-corrector mode, the first three integration entries involve RKB integration and subsequent ones involve AM integration. Each AM integration step requires two derivative evaluations:

$$f_{i\ n+\ell}^{[p]} = f_i\ (x_n + h,\ y_i,\ {}^{[p]}_{n+\ell})$$

$$y'_i{}_{\ n+\ell} = f_i\ (x_n + h,\ y_n + \ell)$$

A particular integration setup, in the variable mode, may involve either AM or RKB or both.

3.5.2.2 Vehicle Dynamics Version Solution Procedure

The program structure of the HVOSM-VD1 version is shown in Figure 3.5-12. Differing from the RD2 versions, this program is organized on three fundamental levels. The upper level is controlled by the MAIN routine and performs functions associated with overall program control including initialization, input, output, obtaining time invariant constants, and integration control including normal and abnormal program stops.

The inclusion of wheel spin degrees-of-freedom may lead to rapidly changing derivatives that requires an integration interval orders of magnitude smaller than that necessary for the other derivatives in the simulation to maintain stability. To maximize computational efficiency, only those derivatives and variables that require a reduced step size are computed as the frequency required for stability, while the remainder of the program derivatives are updated at the normal vehicle integration step size. Therefore, variables that change relatively slowly with time, such as the vehicle position and orientation, applied driving and braking torques, suspension forces and the derivatives of the sprung mass and unsprung masses in the vertical direction, are evaluated on the second functional level in a manner similar to that of RD2 version.

The lowest level evaluates variables that may be changing more rapidly with time, such as the spin derivatives and velocities, as well as the tire-ground forces which are dependent on the instantaneous value of wheel spin velocity. This level utilizes an independently controlled integration step-size to ensure that stability is maintained. An inner integration loop is employed which integrates the spin derivatives within the normal vehicle integration time step.

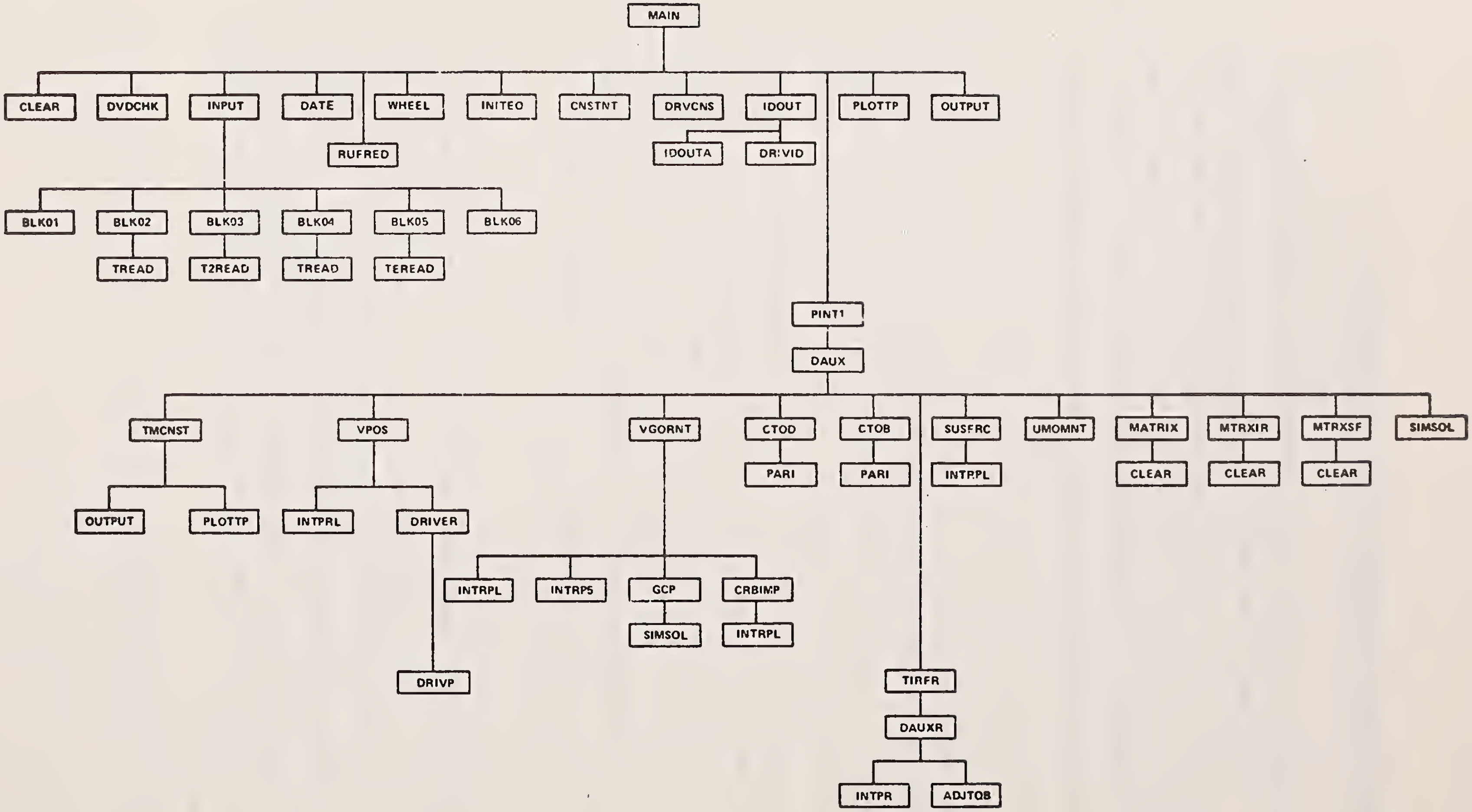


Figure 3.5-12 **HVOSM-VD2 OVERALL PROGRAM BLOCK DIAGRAM**

The general procedure employed is to (1) determine the step-size required for stability in subroutine TIRFC, (2) evaluate the derivatives of the wheel spin velocity in subroutine DAUXR by computing the forces acting between the tire and ground, (3) return to TIRFC in order to integrate these derivatives, and (4) continue this "inner integration loop" until the cumulative integration time reaches the next update time for the second-level integration.

The forces acting on the tires are then averaged over the cumulative small integration intervals for subsequent calculation of the other program derivatives in subroutine DAUX.

3.5.2.2.1 Differences Between the Vehicle Dynamics and Roadside Design Versions

The major difference between these two program versions is the detail in which the interface between the tire and ground is modeled. While under many conditions of vehicle operation, the rotational inertia of the wheels can be neglected with adequate results, the detailed simulation of braking/driving dynamics requires that wheel spin dynamics be treated. With the inclusion of wheel spin inertia, the circumferential tire forces can no longer be calculated directly from the applied torque. Therefore the computation of tire forces was changed to derive circumferential forces from the rotational slip of the tire and further modified to make use of best available tire-ground experimental information (the friction ellipse concept).

Determination of braking and driving torques applied to the wheels was also modified to reflect the details of various braking systems and engine torque output capabilities. The braking and driving torques are calculated in subroutines CTQB and CTQD, respectively, replacing interpolation of input torque tables that formerly took place in subroutine VPOS. Integration of the wheel spin derivatives takes place in the new subroutine TIRFC and calculation of the tire forces occurs in subroutine DAUXR (which replaces TIRFRC from the RD2 version). Subroutine ADJTQB has been added to control braking torques at small values of wheel spin velocity, and driveline torque reaction has been included in the calculation of the moments acting on the vehicle sprung mass and rear axle in subroutine UMOMNT.

Another difference is the addition of a preview-predictor driver model in the VD2 version. This model employs computational subroutines DRIVER and DRIVP which determine the front wheel steer angle for path following or skid recovery and control vehicle speed and speed changes, respectively.

A description of the functions performed by the changed or added subroutines is now presented. Subroutines which are not described here perform the same functions as discussed in Section 3.5.2.1.

Subroutine VPOS

This subroutine determines the position, orientation, and velocity of the wheels of the vehicle either with respect to the vehicle-fixed axes or in some cases with respect to the space-fixed axes, the torques acting on the front and rear wheels, and the direction of the vehicle x and y axis with respect to space. A variable flow diagram for the subroutine is shown in Figure 3.5-13. The subroutine performs these computational steps:

(1) Calculate wheel center velocity components (μ_i) with respect to space resolved along the vehicle x axis. Note that the longitudinal velocity of the ground contact point is assumed to be equal to that of the wheel center

(2) Calculate transformation matrix [A] from the vehicle axes to the space axes, from ϕ, θ, ψ

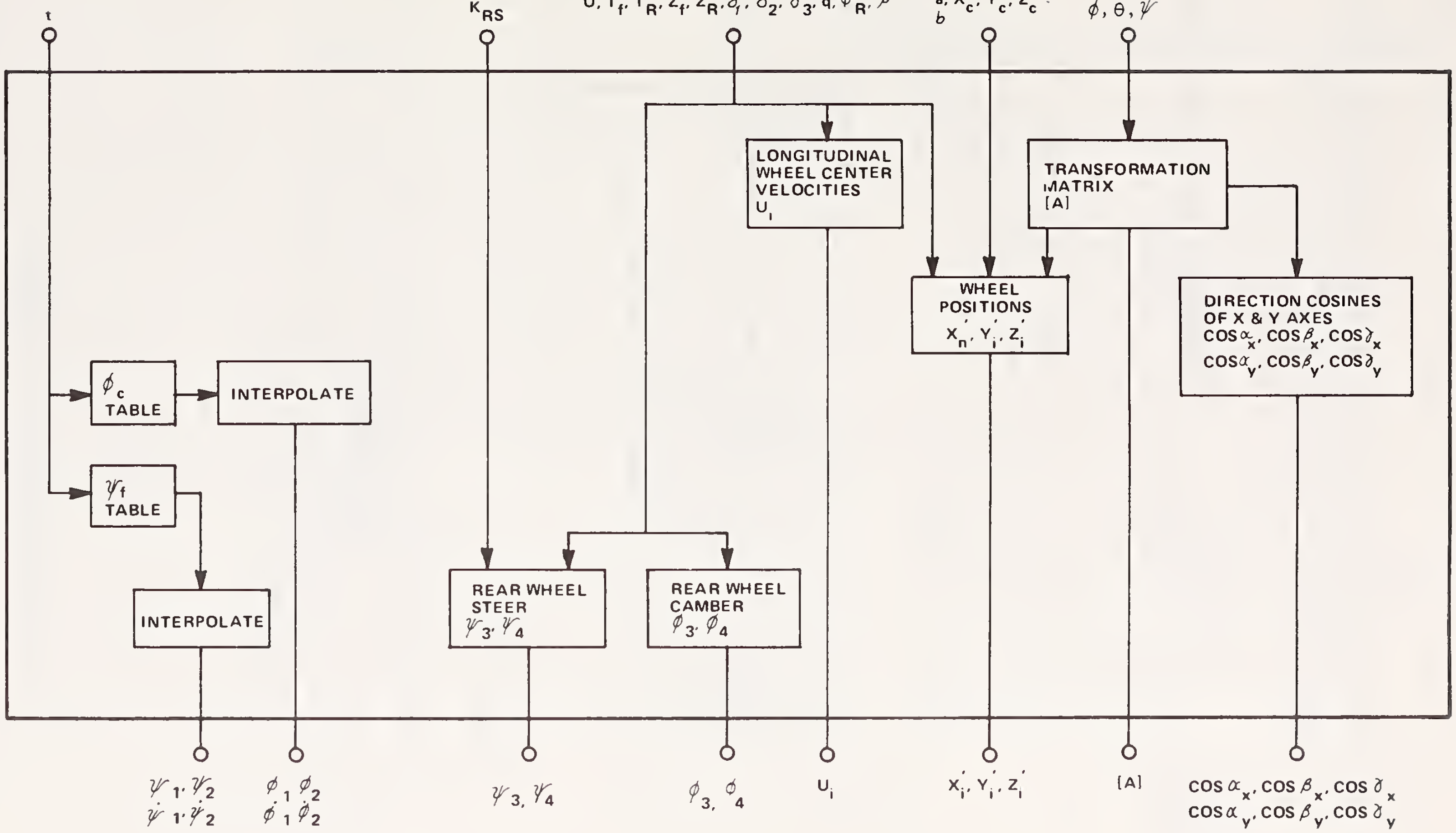


Figure 3.5-13 **SUBROUTINE VPOS**

(3) Calculate direction cosines of the vehicle (x) and (y) axes (cos α_x, cos β_x, cos γ_x and cos α_y, cos β_y, cos γ_y) with respect to the space axes

(4) Calculate positions of the wheel centers with respect to the space axes, X'_i, Y'_i, Z'_i

(5) Determine front and rear wheel camber angles (ϕ_1, ϕ_2, ϕ_3, ϕ_4) either from camber tables (ϕ_C, ϕ_{CR}) or axle roll angles (ϕ_F, ϕ_R) depending on suspension option

(6) If the steer degree-of-freedom option is not in effect, interpolate input steer (ψ_f) table with respect to time to determine front wheel steer angles (ψ_1, ψ_2), and steer angular velocities ($\dot{\psi}_1$, $\dot{\psi}_2$)

(7) Determine rear wheel steer angles (ψ_3, ψ_2)

Subroutine CTQD

This subroutine computes the driveline torque at the driving end of the vehicle based on the engine speed, throttle setting, engine troque characteristics, and transmission ratio. This procedure is shown in Figure 3.5-14. CTQD performs these functions:

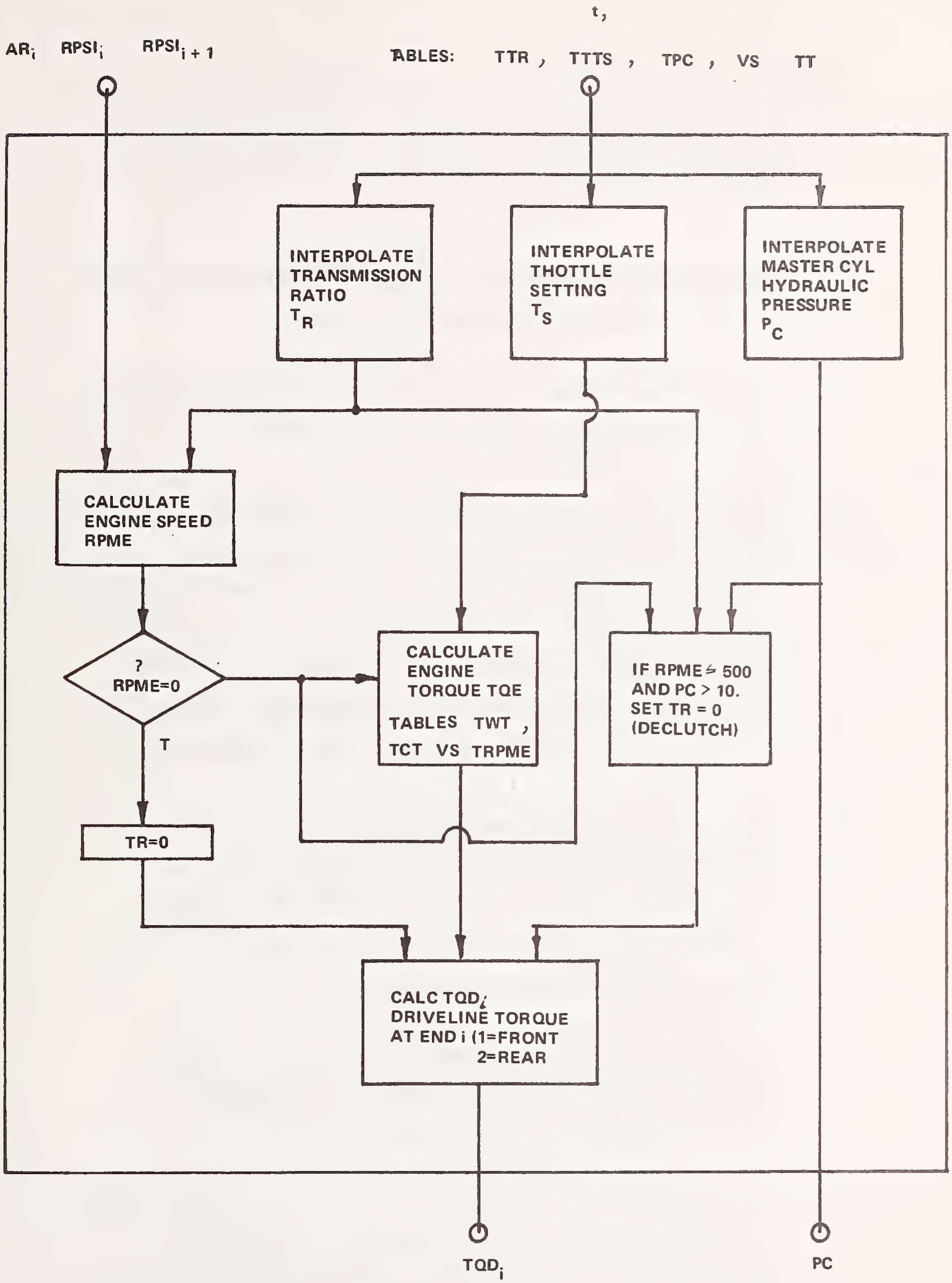


Figure 3.5-14 SUBROUTINE CTQD

(1) Obtain master cylinder hydraulic pressure (Pc) by interpolation of the hydraulic pressure versus time table

(2) Obtain throttle setting (TS) by interpolation of the throttle setting versus time table

(3) Obtain transmission ratio (TR) by interpolation of the transmission ratio versus time table

(4) If the driver model is being used, steps 1, 2 and 3 are omitted. The brake pedal force (F_{BRK}) and accelerator pedal deflection (APD) are used to obtain master cylinder hydraulic pressure (Pc) and throttle setting (TS). The transmission ratio is obtained from a simplified automatic transmission model which selects the transmission gear based on engine speed

(5) Calculate engine speed (RPME) from the average rotational velocity of the two driving wheels $1/2\ (RPS_i + RPS_{i+1})$, the axle ratio (AR_j), and transmission ratio. Note that a conversion is made from radians/second to revolutions/minute

(6) If engine speed is computed to be zero by either the transmission ratio or axle ratio being zero, the driving torque (TQ_{D_i}) is set to zero

(7) If engine speed is non-zero, the engine output torque is interpolated from the wide-open throttle and closed-throttle torque characteristics as a function of engine speed

(8) If engine speed is less than 500 rpm and the master cylinder hydraulic pressure is greater than 10 psig, the transmission ratio is set to zero, simulating declutching

(9) The driveline torque is then calculated based on the engine torque and transmission ratio

Subroutine CTQB

The function of this subroutine is to calculate the braking torques at each wheel as a function of brake system hydraulic pressure and brake characteristics. A flow diagram is shown in Figure 3.5-15. CTQB performs these functions:

(1) Set front brake wheel cylinder pressure (P_F) to master cylinder pressure (P_c) calculated in subroutine CTQD

(2) Adjust rear brake wheel cylinder pressure (P_R) to reflect proportioning value characteristics (K_1, K_2, P_1, P_2)

(3) Check front and rear brake wheel cylinder pressure to see if they are greater than or less than the "push-out" pressures (P_{FO}, P_{RO}). If less than, the brake is not actuated and the braking torque for that set of wheels is set to zero

(4) If cylinder pressure is greater than "push-out" pressure, the brake fade coefficient $(LF)_i$ is interpolated as a function of the current brake temperature (τ_i)

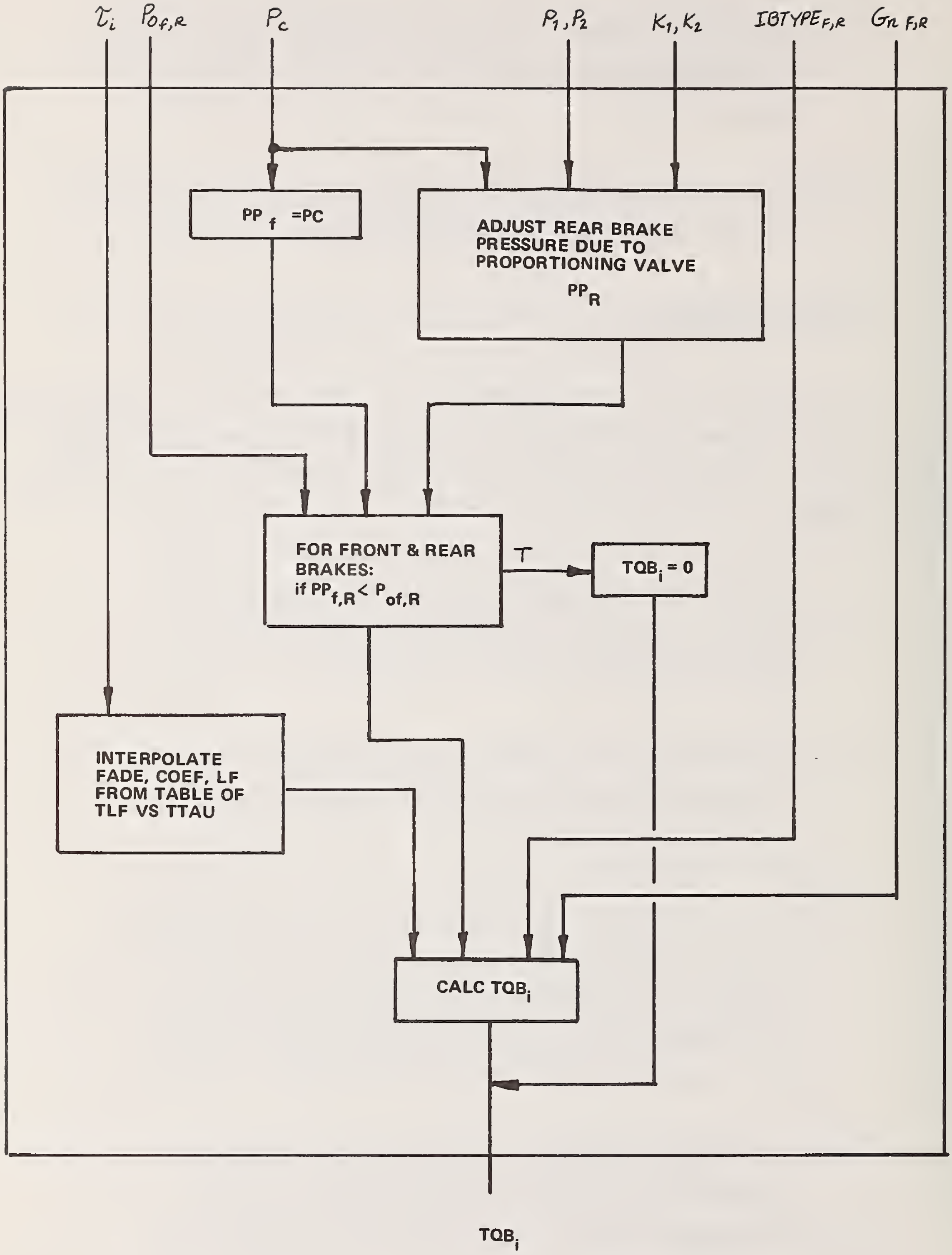


Figure 3.5-15 SUBROUTINE CTQB

(5) The braking torque ($(TQ)_{Bi}$) is calculated knowing the brake type (TYPE), the cylinder, pressure, the lining fade coefficient and the brake characteristics (G_{nj})

Subroutine TIRFC

Subroutine TIRFC provides control of the integration of the wheel spin velocities at the reduced step-size of the internal integration loop and the required linkages to the remainder of the program. Since the wheel spin derivatives may require a significantly smaller solution step-size than the sprung and unsprung masses, the solution of the uncoupled wheel spin equations of motion and subsequent integration occurs at a step-size which is independently controlled within this subroutine to ensure solution stability. Linkages to the solution of the sprung and unsprung mass equations of motion are provided in the form of time averages of tire forces over the number of small step intervals required to accumulate the vehicle integration interval. A flow diagram for this subroutine is shown in Figure 3.5-16. The subroutine performs these functions:

(1) Calculate wheel camber angle relative to the ground plane (ϕ_{ci})

(2) Calculate longitudinal velocity of the wheel center in the plane of the wheel and parallel to the ground plane (U_{GWi})

(3) The first time this routine is entered, initialize the rotational velocity of each wheel by assuming a pure rolling constraint, then call DAUXR to evaluate the rotational acceleration

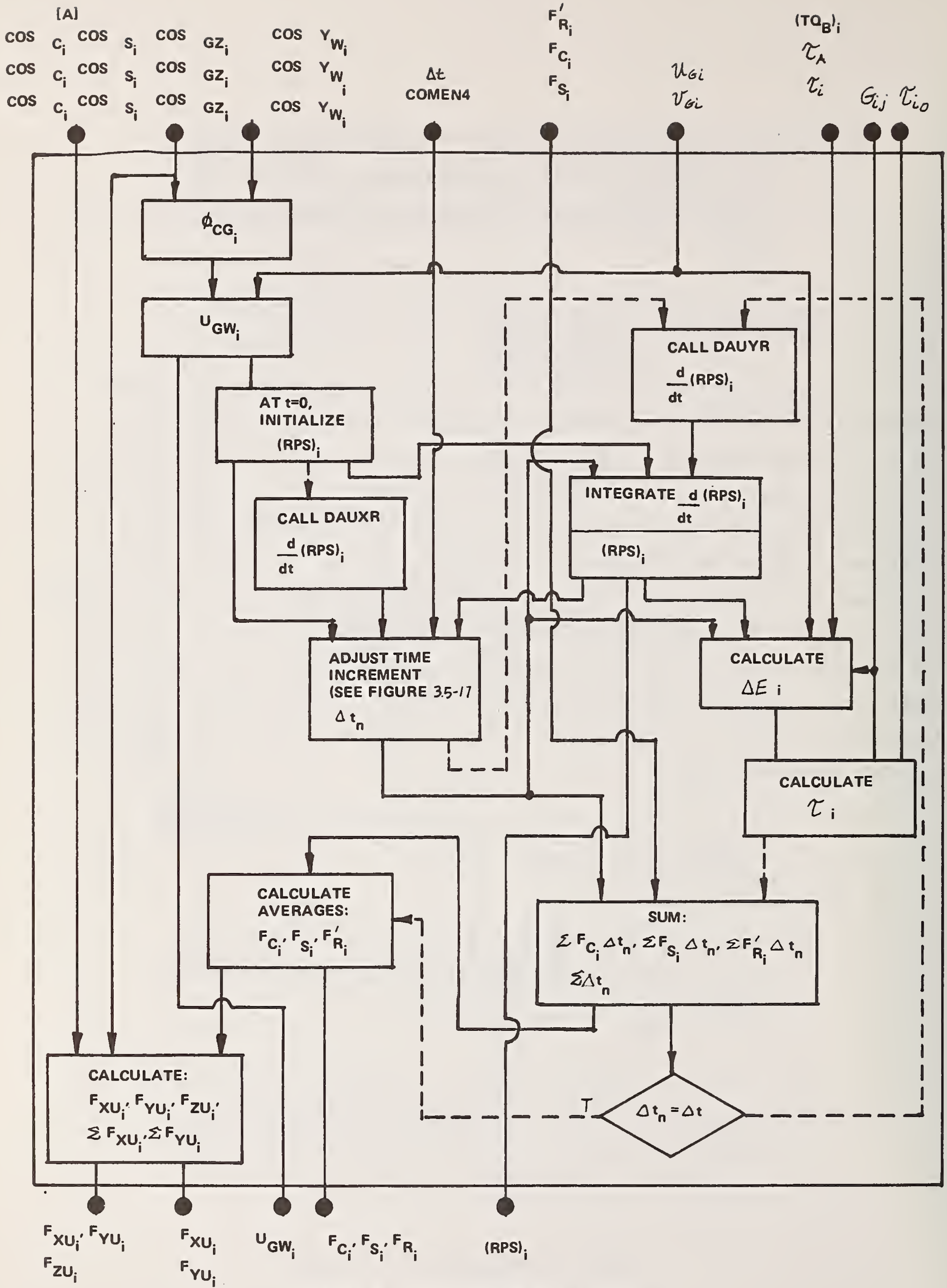


Figure 3.5-16 SUBROUTINE TIRFR

(4) Using previously computed values of the wheel spin velocity and acceleration (from either step 3 or the previous integration step), determine integration step-size for integration of the wheel spin accelerations (Δt_n) as shown in Figure 3.5-17

(5) Call subroutine DAUXR to evaluate wheel spin acceleration

(6) Integrate wheel spin equations of motion assuming constant acceleration over the interval Δt_n

(7) Calculate incremental change in energy absorbed by the brake assembly (ΔE_i)

(8) Calculate updated temperature of the brake (τ_i)

(9) Compute sums of tire normal, circumferential, and side forces multiplied by the step-size (Δt_n) ($\Sigma F_{c_i} \Delta t_n$, $\Sigma F_{s_i} \Delta t_n$, $\Sigma F'_{R_i} \Delta t_n$)

(10) Repeat from Step 5 until sum of wheel spin integration ($\Sigma \Delta t_n$) is equal to the vehicle solution step-size (Δt)

(11) Calculate average tire normal, side, and circumferential forces acting over time since last update of the vehicle equations of motion (Δt)

(12) Calculate components of tire forces acting along vehicle axes

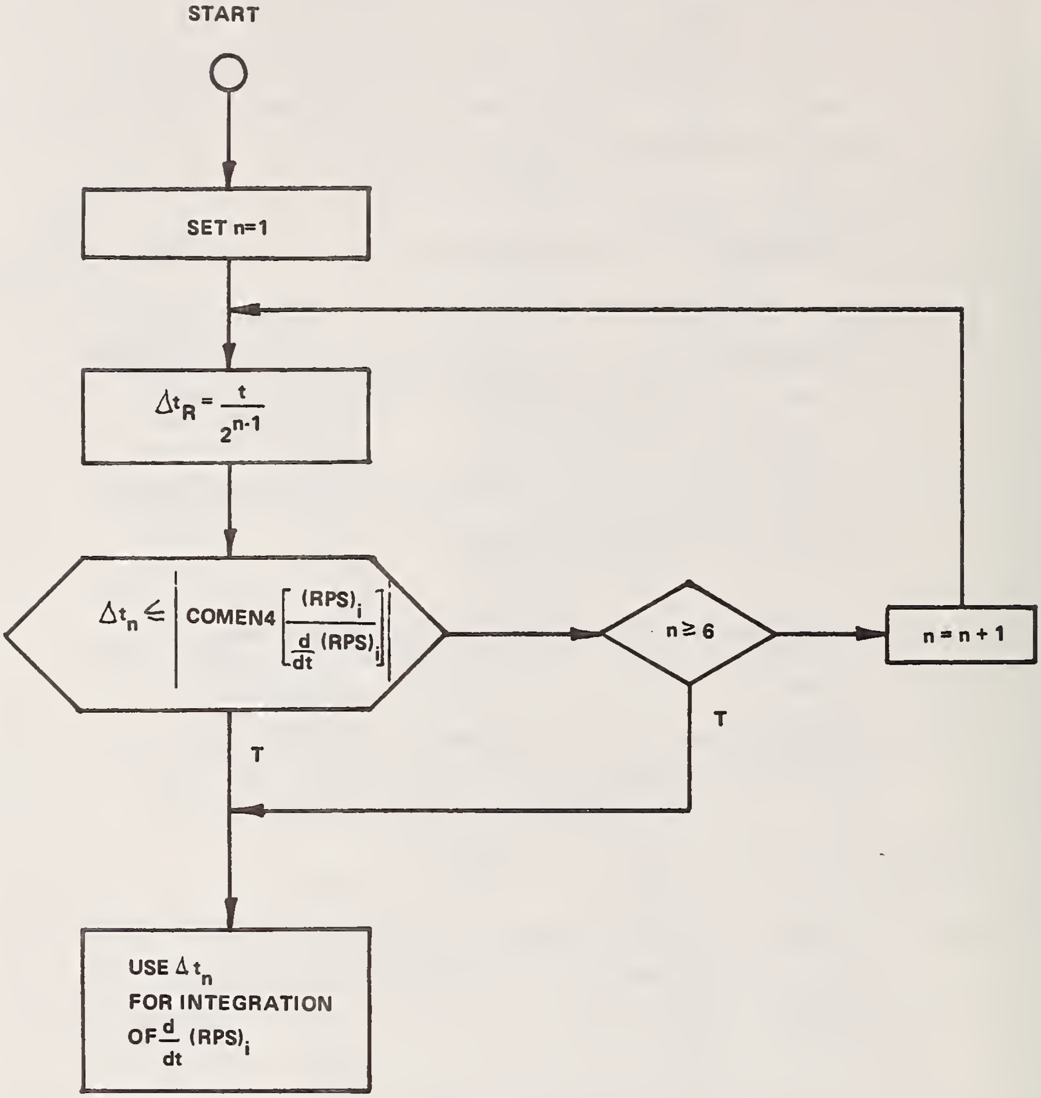


Figure 3.5-17 ADJUSTMENT OF WHEEL SPIN INTEGRATION INCREMENT

Subroutine DAUXR

The function of subroutine DAUXR is to evaluate the wheel spin accelerations ($\frac{d}{dt}$ (RPS_i)). To accomplish this, it is necessary to determine or have available, the forces and torques acting on the wheels. Since the braking and driving torques acting on the wheels have relatively small rates of change with respect to time, these variables can be considered constant during the evaluation of the wheel spin accelerations and updated only at the vehicle integration interval. An exception occurs when the wheel spin velocity is small and braking torques are non-zero. This case is discussed in subroutine ADJTQB.

However, the circumferential tire force (and consequently the side and normal forces) is a function of the longitudinal slip, $(SLIP)_i$, which itself is a function of the wheel spin velocity. These forces may change rapidly with time, and thus must be updated within the wheel spin integration loop. A block flow diagram for DAUXR is shown in Figure 3.5-18. DAUXR performs these functions:

(1) If radial tire force (F_{R_i}) is non-zero, calculate tire force normal to the ground (F'_{R_i})

(2) Interpolate input tables to find maximum available side force friction (μ_i) and peak and sliding circumferential force friction (μ_{p_i}, μ_{s_i}) as functions of wheel velocity (μ_{GW_i}) and load (F'_{R_i})

(3) Calculate rotational slip from wheel center velocity in the tire plane and parallel to the ground (U_{GWi}), the rolling radius (h_i), and the current spin velocity (RPS_i)

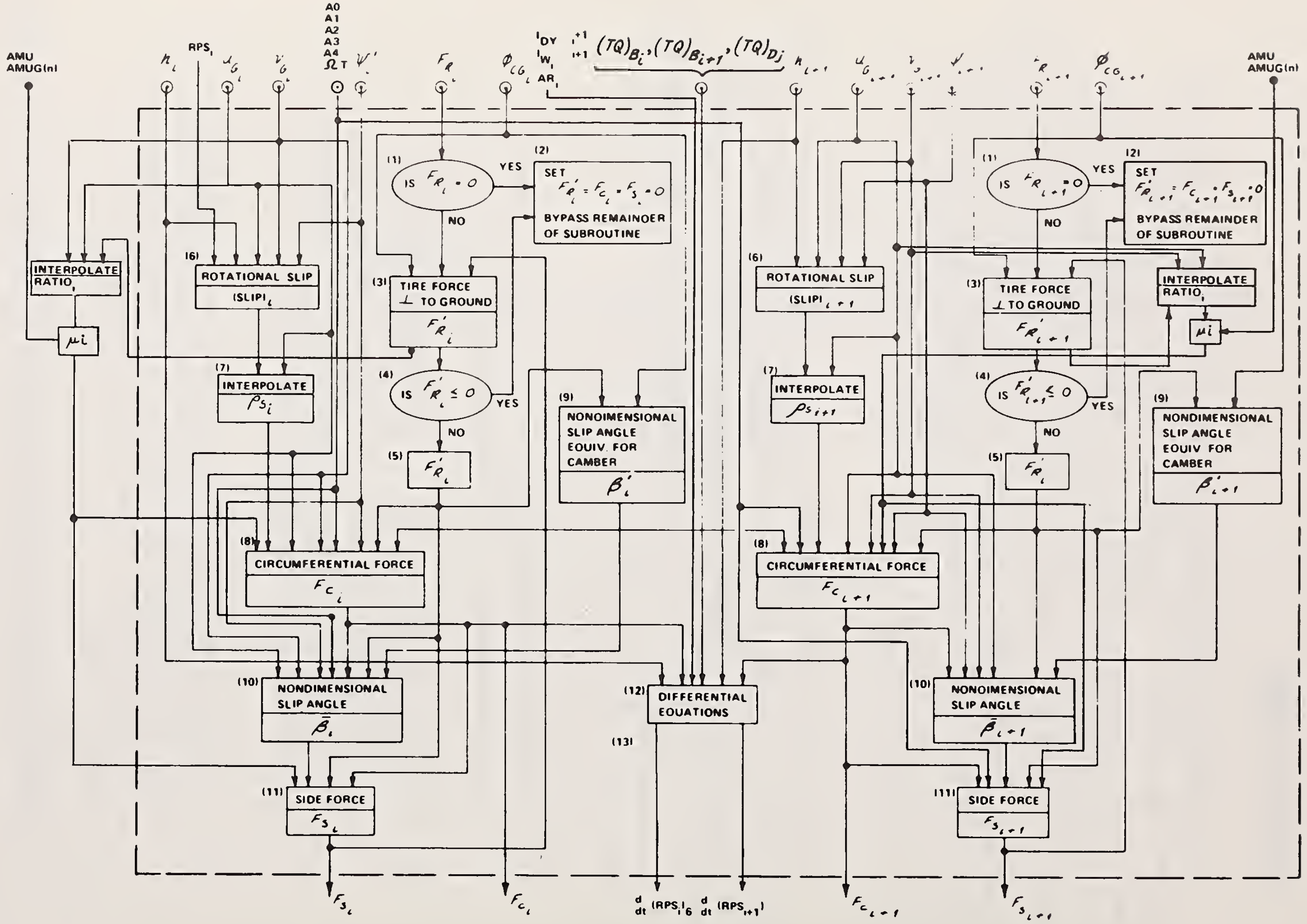


Figure 3.5-18 **SUBROUTINE DAUXR**

(4) Calculate the normalized circumferential force (μ_{x_i}) based on the wheel rotational slip ($SLIP_i$), the circumferential force stiffness (C_{Ti}) and the peak and sliding friction coefficients (μ_{P_i}, μ_{s_i})

(5) Calculate circumferential tire force (F_{c_i})

(6) Calculate non-dimensional slip angle equivalent for camber (β'_i)

(7) Calculate non-dimensional slip angle ($\bar{\beta}_i$)

(8) Calculate tire side force (F_{s_i})

(9) Call subroutine ADJTQB to adjust applied brake torque for small rotational velocities

(10) Calculate wheel spin accelerations ($\frac{d}{dt}$ $(RPS)_i$)

Subroutine ADJTQB

The function of this subroutine is to adjust braking torques at small values of spin velocity to ensure that solution stability is maintained. With a digital integration procedure, the simulation of coulomb friction (braking torques) can cause an overshoot of zero velocity when the velocity at the beginning of the interval is small and thereby add energy to the system is held constant during the interval. To avoid this problem, limiting values are applied to braking torques at small velocities, which approximately produces a zero acceleration (thus maintaining the current, small spin velocity). Inclusion of inertial coupling between drive wheels results in three combinations of spin velocity and applied torque to consider.

Case 1 The spin velocities of both sides of the front or rear (RPS_i, RPS_{i+1}) are less than the limiting threshold for which the logic is applied (ξ_B), and the braking torques of both sides are greater than the torque due to the circumferential tire force ($F_{c_i} h_i$, $F_{c_{i+1}} h_{i+1}$). In practice, this implies that the brake torque could accelerate the wheel in the opposite direction since it overpowers the circumferential force. Note also, that for both side spin velocities less than ξ_B, side-to-side inertial coupling is neglected.
For this case, the braking torques at both sides are set equal in magnitude to the torque produced by the circumferential force and rolling radius and opposing the direction of rotation, as shown in Figure 3.5-19.

Case 2 The spin velocity at both sides of the front or rear (RPS_i, RPS_{i+1}) are less than the limiting threshold (ξ_B). The applied brake torque at one side is less than circumferential force moment, while at the other side, it is greater than the circumferential force moment.

Since the wheel at which the brake torque is less than the circumferential force moment cannot change the sign of its spin velocity, the applied value of brake torque is retained as long as the circumferential moment is opposite in sign velocity. If they have the same sign, the braking torque is set to zero since it would otherwise accelerate the wheel. The brake torque at the other side is checked for sign and magnitude of the circumferential force moment and the side-to-side coupling moment, and reset to the limit value if necessary.

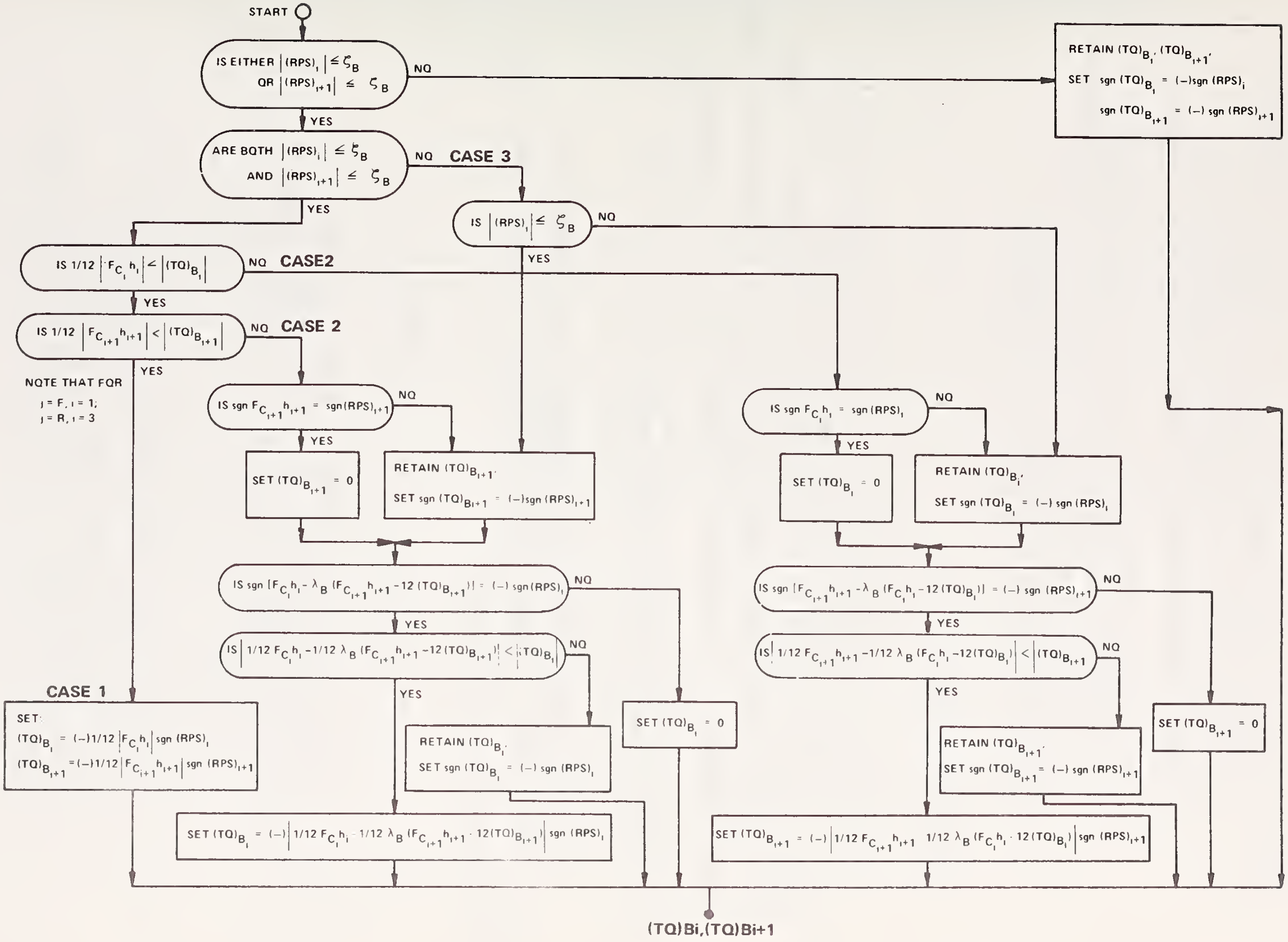


Figure 3.5-19 **SUBROUTINE ADJTQB**

Case 3 The spin velocity at one side is less than the threshold value (ξ_B) and greater than ξ_B at the other side. In this case, the braking torque at the fast side (spin velocity greater than ξ_B), is retained and the torque at the slow side is checked for sign and magnitude of the circumferential moment, with side-to-side coupling moment, and reset to the limit value if the brake torque is capable of slowing the wheel spin down further.

Subroutine DRIVER

The function of subroutine DRIVER is to provide automatic vehicle control in both the path following and speed maintenance modes. In the path following mode, the driver predicts the vehicle position at a number of times in the future based on the current lateral acceleration and estimates positional errors. These errors are then weighted and used to produce a new command steer angle to minimize future errors. A filter is then used to approximate driver lead and lag times and neuro-muscular delays.

In the speed maintenance mode, the driver may be commanded to accelerate or decelerate at given times or to maintain a constant speed. The subroutine procedure is outlined below.

(1) Calculate the vehicle side slip angle (θ_c)

(2) Check for vehicle skidding. If the lower skid threshold (T_{R1}) is reached, set both brake pedal force (F_{BRK}) and accelerator pedal deflection (APD) to zero and continue with the path following calculations. If the upper skid threshold (T_{R2}) is reached, abandon the path following mode and enter the skid recovery mode. In this mode the command steer angle is proportional to the difference between the vehicle sideslip and front wheel steer angle.

(3) If the skid recovery mode is not in effect, subroutine DRIVP is called to determine the required accelerator pedal deflection (APD) or brake pedal force (F_{BRK}).

(4) For the path following mode, the vehicle position corresponding to a time i in the future (X'_{vPi}, Y'_{vPi}) is obtained by integration of the driver's estimate of lateral acceleration (a_y) due to front wheel steer angle. This position is then compared with the corresponding point on the desired path (X'_{Pi}, Y'_{Pi}) and an error obtained. This sequence is repeated for each time in the future at which samples are made and a total weighted error obtained (WE_i, WI_i, e_i). The total error is then multiplied by the control gain (K_P) and the command steer angle ($\Delta\psi_{Fi}$) obtained.

(5) The command steer angles for eacy time j are then filtered to account for neurological and muscular systems of a human driver and the filter output, $\Delta\psi_F(t)$, is summed to obtain the front wheel steer angle, $\psi_F(t)$.

Subroutine DRIVP

This subroutine supplies driver inputs to the vehicle for speed control. The interface between the driver and vehicle consists of accelerator pedal deflection and brake pedal force. The computational procedure is given below.

(1) For a change of speed task, if the time of the desired change (t_{C_R}) is equal to the current time (t), the new desired speed (DS_R) and the distance to null the speed difference ($DISTI_R$) are set to DS and DIST.

At each time increment after t_{C_R}, DIST is reduced by U_TEMDT. The speed difference (ΔV) is calculated as the difference between the desired speed (DS) and current speed (U_T).

(2) If the speed differential is within the speed response threshold and indifference levels (T_{S_1}, T_{S_2}), the acceleration required to null the difference within DIST is computed (D_{ax}). If it is not within the levels, no change in APD or F_{BRK} is made.

(3) If D_{ax} is positive, a new accelerator pedal deflection is computed (APD)

(4) If D_{ax} is negative and greater than the braking indifference level, the brake pedal force is computed

4. HVOSM INPUT/OUTPUT

4.1 HVOSM Input

4.1.1 Roadside Design Version

Input to the HVOSM-RD2 is supplied primarily in the form of punched cards. All data cards must contain a three-digit number in columns 78-80. The first of these represent the data block number and the remaining two numbers represent the card number within the data block. Data blocks are catagorized and numbered as follows:

Block Number	Data Content
1	Simulation Control data
2	Vehicle data
3	Tire data
4	Vehicle Control data
5	Terrain/Environmental data
6	Initial Conditions

Each data block may contain a title card with the last two digits of the card number being 00 (e.g., vehicle data title card would be numbered 200). Title cards may contain alphanumeric information which is printed on each output page.

Data is entered on individual data cards and on table cards in 9 fields of 8 columns each (9F8.0 format). Any data not supplied defaults to 0.0. The format for table entry consists of a table information card containing information on the number of entries, beginning and end values, the number of tables, etc., depending on the particular table being read. Immediately following this card are the table data cards, each containing the same card number in columns 78-80 as the table information card. Table data cards must also contain a table sequence number in column 76 (or 75-76 if a two digit number) which must always be larger than the sequence number on the previous table data card. The last card in the input data deck must be numbered 9999 in columns 77-80.

Input decks may be stacked so that multiple runs can be made in a single job. Only cards which are changed from the previous deck must be supplied. Each data deck must contain card number 9999 as the last card in the deck.

In addition to card input, Fortran unit 4 is used to supply road roughness data if this option is being used. This data is read from subroutine RUFRED and is assumed to be unformatted in sequential form.

A description of the data required on each input card follows.

HED(I)	I=1,18								100
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
HED	-	RUN TITLE CARD This card may contain up to 72 characters of alphanumeric information describing a run and is printed on each output page.	-

T0	T1	DTCOMP	DTPRNT	THMAX	UVWMIN	PQRMIN			101
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
T0		INITIAL SIMULATION TIME	sec
T1		FINAL SIMULATION TIME	sec
DTCOMP		NORMAL VEHICLE INTEGRATION TIME STEP	sec
DTPRNT		OUTPUT PRINT TIME INTERVAL (MULTIPLE OF DTCOMP)	sec
THMAX		VALUE OF PITCH ANGLE (θ'_t) AT WHICH THE SPACE FIXED AXES ARE INDEXED, USUALLY 70°	deg
UVMIN		VALUES OF RESULTANT LINEAR AND ANGULAR VELOCITIES FOR SIMULATION STOP TEST. IF BOTH VEHICLE VELOCITIES ARE LESS THAN INPUT VALUES, RUN IS TERMINATED.	in/sec
PQRMIN			rad/sec

ISUS	INDCRB	NCRBSL	DELTC	INDB	DELTB				102
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
ISUS		SUSPENSION OPTION INDICATOR = 0, INDEPENDENT FRONT, SOLID REAR AXLE = 1, INDEPENDENT FRONT AND REAR = 2, SOLID FRONT AND REAR AXLES	-
INDCRB		CURB IMPACT INDICATOR = 0, NO CURB INPUT = 1, CURB INPUT SUPPLIED (PROVIDES STEER DEGREE OF FREEDOM AND RADIAL SPRINGS TIRE MODEL) = -1, NO CURB INPUT SUPPLIED (PROVIDES STEER DEGREE OF FREEDOM WITH POINT CONTACT TIRE MODEL)	-
NCRBSL		NUMBER OF CURB SLOPES SUPPLIED IF INDCRB = 1 $2 \leq NCRBSL \leq 6$	-
DELTC	Δt_c	INTEGRATION TIME STEP FOR CURB IMPACTS	sec
INDB		INDICATOR FOR BARRIER TYPE OPTION: = 1, RIGID BARRIER, FINITE VERTICAL DIMENSIONS = 2, RIGID BARRIER, INFINITE VERTICAL DIMENSIONS = 3, DEFORMABLE BARRIER, FINITE VERTICAL DIMENSIONS = 4, DEFORMABLE BARRIER, INFINITE VERTICAL DIMENSIONS	-
DELTB	$(\Delta t)_B$	VEHICLE INTEGRATION TIME STEP FOR USE DURING BARRIER IMPACTS	sec
		NOTE: If INDCRB = -1, initial conditions for the front wheel steer angle (PSIFIO, PSIFD) must be supplied on card 601.	

MODE	EBAR	EM	AAA	HMAX	HMIN	BET			103
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
MODE		NUMERICAL INTEGRATION MODE INDICATOR = 0, VARIABLE ADAMS-MOULTON = 1, RUNGE-KUTTA = 2, FIXED ADAMS-MOULTON NOTE: The following variables are required only when MODE = 0, See Section 3.5.	
EBAR	$\overline{E}$	UPPER BOUND ON THE TRUNCATION ERROR ESTIMATE	
EM	M	CONSTANT FROM WHICH THE LOWER BOUND ON THE TRUNCATION ERROR ESTIMATE IS COMPUTED	
AAA	α	POSITIVE NUMBER USED TO PREVENT UNNECESSARY REDUCTION IN THE VARIABLE STEP SIZE	
HMAX	h_{max}	POSITIVE UPPER BOUND ON THE MAGNITUDE OF THE VARIABLE STEP SIZE	
HMIN	h_{min}	POSITIVE LOWER BOUND ON THE MAGNITUDE OF THE VARIABLE STEP SIZE	
BETA	β	POSITIVE NUMBER BETWEEN ZERO AND ONE USED TO INCREASE OR DECREASE THE STEP SIZE	

NPAGE(4)	NPAGE(6)	NPAGE(7)	NPAGE(8)	NPAGE(9)	NPAGE(10)	NPAGE(14)			104
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		NOTE: THE NPAGE ARRAY IS USED TO CONTROL OUTPUT PRINTED FROM A RUN. IF AN ARRAY ELEMENT IS NON-ZERO THE GROUP OF OUTPUT DATA CORRESPONDING TO THAT ELEMENT IS PRINTED. THE OUTPUT CORRESPONDING TO THE ELEMENTS READ ON CARD 104 ARE USER CONTROLLED. IF THE OUTPUT IS DESIRED A NON-ZERO NUMBER MUST BE READ IN THE APPROPRIATE FIELD. THE OUTPUT GROUPS CORRESPONDING TO THESE ELEMENTS ARE:	
NPAGE(4)		ANGULAR ACCELERATIONS; SUSPENSION ACCELERATIONS FOR INDEPENDENT SUSPENSIONS OR DISPLACEMENTS, VELOCITIES AND ACCELERATIONS OF THE ROLL CENTER AND AXLE ANGLE FOR SOLID AXLES	
NPAGE(6)		INCLINATION (CAMBER) ANGLE OF THE WHEELS WITH RESPECT TO THE GROUND; STEER ANGLE OF THE WHEELS; AND CAMBER ANGLE OF THE WHEELS WITH RESPECT TO THE VEHICLE	
NPAGE(7)		LONGITUDINAL AND LATERAL VELOCITIES OF THE TIRE CONTACT POINT WITH RESPECT TO THE VEHICLE	
NPAGE(8)		ELEVATION OF THE GROUND CONTACT POINT OF THE TIRES	
NPAGE(9)		TOTAL SUSPENSION FORCES AND SUSPENSION ANTI-PITCH FORCES	
NPAGE(10)		SUSPENSION DAMPING FORCES AND CHANGE IN SUSPENSION SPRING FORCES FROM EQUILIBRIUM	
NPAGE(14)		COMPONENTS OF TIRE FORCES ALONG THE INERTIAL AXES	

VHED(I),	I=1,18								200
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
VHED	-	VEHICLE DESCRIPTION TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING THE SIMULATED VEHICLE. NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	

XMS	XMUF	XMUR	XIX	XIY	XIZ	XIXZ	XIR	XIF	201
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
XMS	M_S	SPRUNG MASS	lb-sec^2/in
XMUF	M_{uF}	TOTAL FRONT UNSPRUNG MASS	lb-sec^2/in
XMUR	M_{uR}	TOTAL REAR UNSPRUNG MASS	lb-sec^2/in
XIX	I_X	MASS MOMENT OF INERTIA OF THE SPRUNG MASS ABOUT THE VEHICLE X AXIS	lb-sec^2-in
XIY	I_Y	MASS MOMENT OF INERTIA OF THE SPRUNG MASS ABOUT THE VEHICLE Y AXIS	lb-sec^2-in
XIZ	I_Z	MASS MOMENT OF INERTIA OF THE SPRUNG MASS ABOUT THE VEHICLE Z AXIS	lb-sec^2-in
XIXZ	I_{XZ}	MASS PRODUCT OF INERTIA OF THE SPRUNG MASS IN THE VEHICLE X-Z PLANE	lb-sec^2-in
XIR	I_R	MASS MOMENT OF INERTIA OF THE SOLID AXLE REAR UNSPRUNG MASS ABOUT A LINE PARALLEL TO THE VEHICLE X-AXIS AND THROUGH THE REAR UNSPRUNG MASS CENTER OF GRAVITY. REQUIRED ONLY IF ISUS = 0 OR 2	lb-sec^2-in
XIF	I_F	MASS MOMENT OF INERTIA OF THE SOLID AXLE FRONT UNSPRUNG MASS ABOUT A LINE PARALLEL TO THE VEHICLE X-AXIS AND THROUGH THE FRONT UNSPURNG MASS CENTER OF GRAVITY. REQUIRED ONLY IF ISUS = 2.	lb-sec^2-in

A	B	TF	TR	RHO	TS	RHOF	TSF	G	202
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

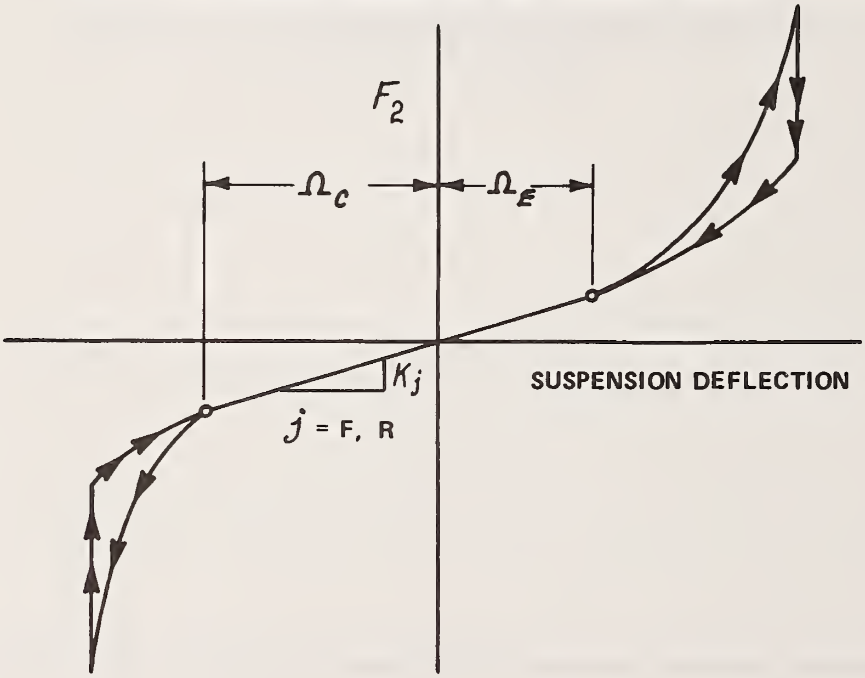
Program Variable	**Analytical Variable**	**Description**	**Input Units**
A	a	HORIZONTAL DISTANCE FROM SPRUNG MASS C.G. TO CENTERLINE OF FRONT WHEELS	in
B	b	HORIZONTAL DISTANCE FROM SPRUNG MASS C.G. TO CENTERLINE OF REAR WHEELS	in
TF	T_F	FRONT WHEEL TRACK	in
TR	T_R	REAR WHEEL TRACK	in
RHO	ρ	VERTICAL DISTANCE BETWEEN REAR AXLE C.G. AND REAR AXLE ROLL CENTER, POSITIVE FOR ROLL CENTER ABOVE C.G.	in
TS	T_S	DISTANCE BETWEEN REAR SPRING MOMENTS FOR SOLID REAR AXLE	in
		NOTE: RHO AND TS REQUIRED ONLY IF ISUS = 0 or 2	
RHOF	ρ_F	VERTICAL DISTANCE BETWEEN FRONT AXLE C.G. AND FRONT AXLE ROLL CENTER, POSITIVE FOR ROLL CENTER ABOVE C.G.	in
TSF	T_{SF}	DISTANCE BETWEEN FRONT SPRING MOUNTS FOR SOLID FRONT AXLE	in
		NOTE: RHOF AND TSF REQUIRED ONLY IF ISUS = 2	
G	g	GRAVITATIONAL ACCELERATION	in/sec^2
		NOTE: IF G IS NOT SUPPLIED A DEFAULT VALUE OF 386.4 in/sec^2 IS ASSUMED.	

X1	Y1	Z1	X2	Y2	Z2	ZF	ZR		203
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
X1	X_1	COORDINATES OF FIRST ACCELEROMETER POSITION WITH RESPECT TO THE VEHICLE	in
Y1	Y_1		
Z1	Z_1		
X2	X_2	COORDINATES OF SECOND ACCELEROMETER POSITION WITH RESPECT TO THE VEHICLE	in
Y2	Y_2		
Z2	Z_2		
ZF	Z_F	STATIC VERTICAL DISTANCE BETWEEN FRONT WHEEL C.G. (OR FRONT AXLE ROLL CENTER IF ISUS = 2) AND SPRUNG MASS C.G.	in
ZR	Z_R	STATIC VERTICAL DISTANCE BETWEEN REAR AXLE ROLL CENTER (OR REAR WHEEL C.G.) AND SPRUNG MASS C.G.	in
		NOTE: IF ZF AND ZR ARE NOT SUPPLIED, THEY WILL AUTOMATICALLY BE CALCULATED WITHIN THE PROGRAM TO INSURE INITIAL VERTICAL EQUILIBRIUM OF THE VEHICLE ON FLAT, LEVEL TERRAIN AT 0.0 ELEVATION	

AKF	AKFC	AKFCP	AKFE	AKFEP	XLAMF	OMEGFC	OMEGFE		204
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 87 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
AKF	K_F	LINEAR FRONT SUSPENSION LOAD DEFLECTION RATE	lb/in
AKFC	K_{FC}	LINEAR COEFFICIENT OF THE FRONT SUSPENSION COMPRESSION (JOUNCE) BUMPER TERM	lb/in
AKFCP	K'_{FC}	CUBIC COEFFICIENT OF THE FRONT SUSPENSION COMPRESSION (JOUNCE) BUMPER TERM	lb/in^3
AKFE	K_{FE}	LINEAR COEFFICIENT OF THE FRONT SUSPENSION EXTENSION (REBOUND) BUMPER TERM	lb/in
AKFEP	K_{FE}	CUBIC COEFFICIENT OF THE FRONT SUSPENSION EXTENSION (REBOUND) BUMPER TERM	lb/in^3
XLAMF	λ_F	RATIO OF CONSERVED TO TOTAL ABSORBED ENERGY IN THE FRONT SUSPENSION BUMPERS	-
OMEGFC	Ω_{FC}	FRONT SUSPENSION DEFLECTION AT WHICH THE COMPRESSION BUMPER IS CONTACTED (Note: should be negative)	in
OMEGFE	Ω_{FE}	FRONT SUSPENSION DEFLECTION WHICH THE EXTENSION BUMPER IS CONTACTED (Note: should be positive)	in.
		NOTE: ALL SUSPENSION PARAMETERS ARE EFFECTIVE AT THE WHEEL FOR INDEPENDENT FRONT SUSPENSION OR AT THE SPRING POSITION FOR SOLID FRONT AXLE.	



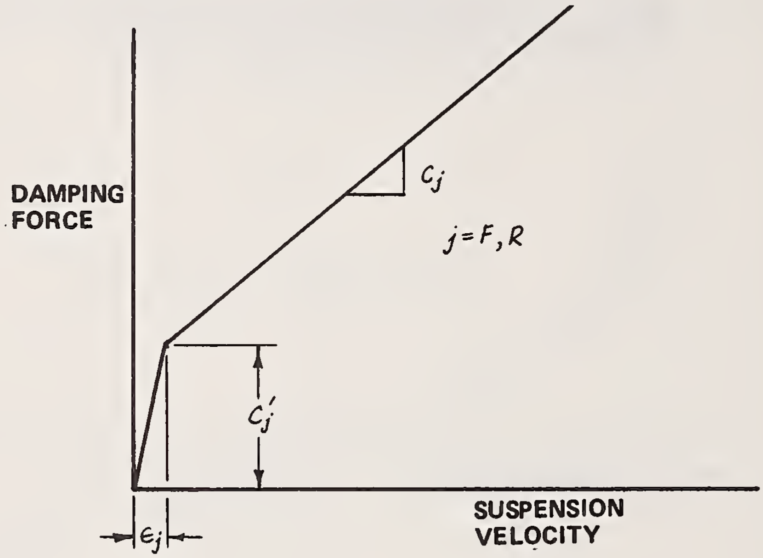
GENERAL FORM OF SIMULATED SUSPENSION BUMPER CHARACTERISTICS

AKR	AKRC	AKRCP	AKRE	AKREP	XLAMR	OMEGRC	OMEGRE		205
1 2 3 4 5 6 7 8	8 10 11 12 13 14 15 16	17 18 18 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 38 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
AKR	K_R	LINEAR REAR SUSPENSION LOAD DEFLECTION RATE	lb/in
AKRC	K_{RC}	LINEAR COEFFICIENT OF THE REAR SUSPENSION COMPRESSION (JOUNCE) BUMPER TERM	lb/in
AKRCP	K'_{RC}	CUBIC COEFFICIENT OF THE REAR SUSPENSION COMPRESSION (JOUNCE) BUMPER TERM	lb/in^3
AKRE	K_{RE}	LINEAR COEFFICIENT OF THE REAR SUSPENSION EXTENSION (REBOUND) BUMPER TERM	lb/in
AKREP	K'_{RE}	CUBIC COEFFICIENT OF THE REAR SUSPENSION EXTENSION (REBOUND) BUMPER TERM	lb/in^3
XLAMR	λ_R	RATIO OF CONSERVED TO TOTAL ABSORBED ENERGY IN THE REAR SUSPENSION BUMPERS	-
OMEGRC	Ω_{RC}	REAR SUSPENSION DEFLECTION AT WHICH THE COMPRESSION BUMPER IS CONTACTED (Note: should be negative)	in
OMEGRE	Ω_{RE}	REAR SUSPENSION DEFLECTION AT WHICH THE EXTENSION BUMPER IS CONTACTED (Note: should be positive)	in
		NOTE: ALL SUSPENSION PARAMETERS ARE EFFECTIVE AT THE WHEEL FOR INDEPENDENT REAR SUSPENSION OR AT THE SPRING FOR SOLID REAR AXLE	

CF	CFP	EPSF	CR	CRP	EPSR				206
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
CF	C_F	FRONT VISCOUS DAMPING COEFFICIENT PER SIDE	lb sec/in
CFP	C_F	FRONT SUSPENSION COULOMB FRICTION PER SIDE	lb
EPSF	ε_F	FRONT SUSPENSION FRICTION NULL BAND	in/sec
CR	C_R	REAR SUSPENSION VISCOUS DAMPING COEFFICIENT PER SIDE	lb sec/in
CRP	C'_R	REAR SUSPENSION COULOMB FRICTION PER SIDE	lb
EPSR	ε_R	REAR SUSPENSION FRICTION NULL BAND	in/sec
		NOTE: ALL SUSPENSION PARAMETERS ARE EFFECTIVE AT THE WHEEL FOR INDEPENDENT SUSPENSION OR AT THE SPRING FOR SOLID AXLE	

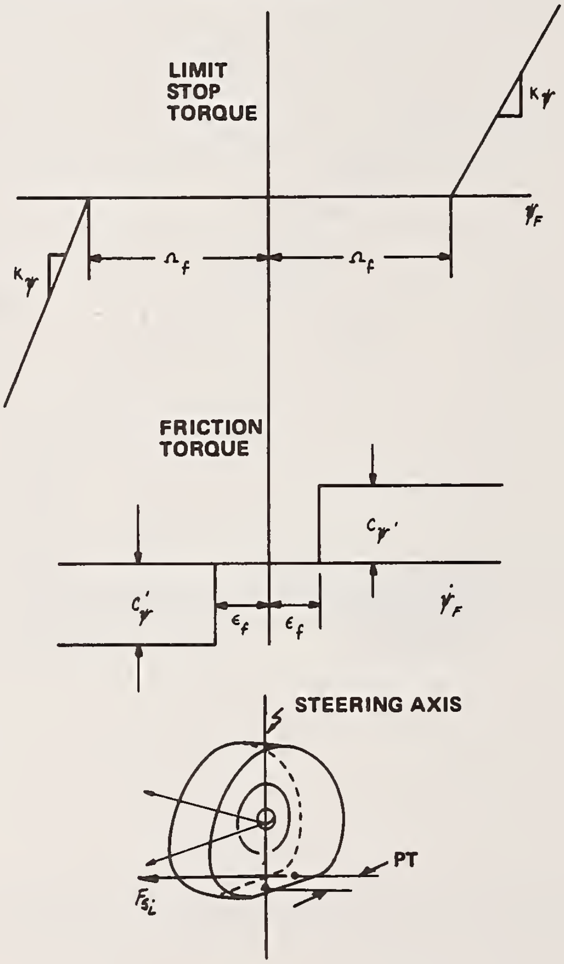


RF	RR	AKRS	AKDS	AKDS1	AKDS2	AKDS3			207
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
RF	R_F	AUXILIARY ROLL STIFFNESS OF THE FRONT SUSPENSION	lb-in/ rad
RR	R_R	REAR SUSPENSION AUXILIARY ROLL STIFFNESS	lb in/ rad
AKRS	K_{RS}	REAR AXLE ROLL-STEER COEFFICIENT	deg/deg
		NOTE: AKRS IS REQUIRED ONLY IS ISUS = 0 OR 2	
AKDS	$K_{\delta s}$	COEFFICIENTS FOR CUBIC REPRESENTATION OF REAR WHEEL STEER ANGLE AS A FUNCTION OF WHEEL DISPLACEMENT. THESE COEFFICIENTS ARE REQUIRED ONLY WHEN ISUS = 1	rad
AKDS1	$K_{\delta s1}$		rad/in
AKDS2	$K_{\delta s2}$		rad/in^2
AKDS3	$K_{\delta s3}$		rad/in^3

XIPS	CPSP	OMGPS	AKPS	EPSPS	XPS				208
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
XIPS	I_ψ	STEERING SYSTEM STEER MOMENT OF INERTIA ABOUT THE WHEEL STEERING AXES	lb-sec^2-in
CPSP	C'_ψ	STEERING SYSTEM COULOMB FRICTION TORQUE, EFFECTIVE AT THE WHEEL STEERING AXES	lb-in
OMGPS	Ω_ψ	FRONT WHEEL STEER ANGLE AT WHICH STEERING LIMIT STOPS ARE ENGAGED	rad
AKPS	K_ψ	STIFFNESS OF THE STEERING LIMIT STOPS, EFFECTIVE AT THE FRONT WHEEL STEERING AXES	lb-in/rad
EPSPS	ϵ_ψ	FRICTION LAG IN THE STEERING SYSTEM	rad/sec
XPS	$\overline{PT}$	FRONT WHEEL PNEUMATIC TRAIL	in
		NOTE: THIS CARD MUST BE FURNISHED IF INDCRB (CARD 101 IS EITHER 1.0 OR -1.0	



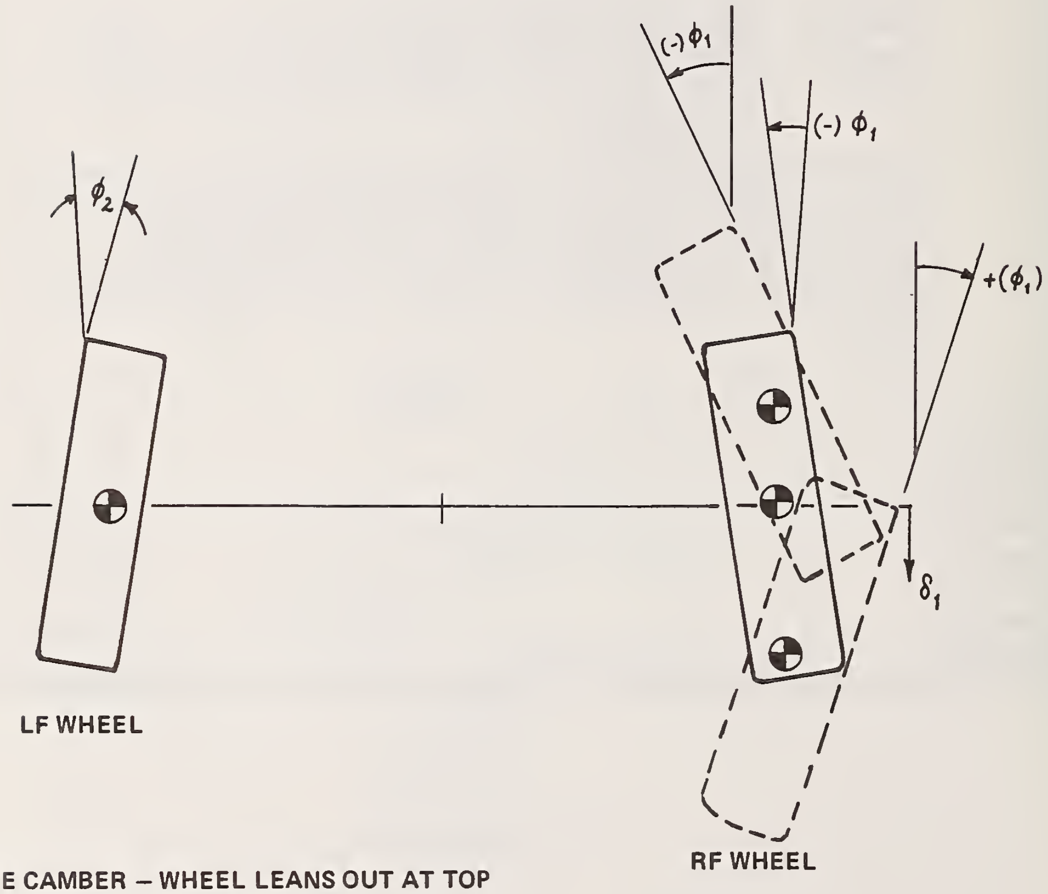
DELB	DELE	DDEL	NDTHF	NDTHR					209
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		NOTE: THE PARAMETERS ON CARD 209 APPLY TO FOUR TABLES DEFINING CAMBER AND HALF-TRACK CHANGES AS A FUNCTION OF WHEEL DISPLACEMENT. CARD 209 AND SUBSEQUENT TABLE CARDS ARE NOT REQUIRED IF ISUS = 2	
DELB		BEGINNING VALUE OF WHEEL DISPLACEMENT FOR TABLES	in
DELE		END VALUE OF WHEEL DISPLACEMENT FOR TABLES	in
DDEL		INCREMENT VALUE OF WHEEL DISPLACEMENT FOR TABLES	in
NDTHF		INDICATOR FOR FRONT HALF-TRACK CHANGE TABLE. TABLE IS SUPPLIED IF NDTHF ≠ 0	
NDTHR		INDICATOR FOR REAR HALF-TRACK CHANGE TABLE. TABLE IS SUPPLIED IF NDTHR ≠ 0	
		FOLLOWING CARD 209 ARE UP TO 4 TABLES CONTAINING [(DELE-DELB)/DDEL]+1 ENTRIES IN THE ORDER:	
		PHIC(I) FRONT WHEEL CAMBER TABLE PHIRC(I) REAR WHEEL CAMBER TABLE (REQUIRED IF ISUS=1) DTHF(I) FRONT HALF-TRACK CHANGE (REQUIRED IF NDTHF≠0) DTHR(I) REAR HALF-TRACK CHANGE (REQUIRED IF ISUS=1 AND NDTHR≠0)	deg deg in in
		TABLE ENTRIES ARE READ IN FIELDS OF 8 AND MUST CONTAIN 209 IN COLUMNS 78-80. A TABLE SEQUENCE NUMBER MUST ALSO BE SUPPLIED IN COLUMN 76 AND SEQUENCE NUMBER MUST INCREASE WITH EACH CARD. EACH NEW TABLE MUST START ON A NEW CARD. A MAXIMUM OF 50 ENTRIES IS ALLOWED FOR EACH TABLE.	

-5.0	-5.0	1.0	1.0	1.0					209
PHIC(1)	PHIC(2)	...				...		PHIC(9)	1 209
PHIC(10)	PHIC(11)								2 209
PHIRC(1)	PHIRC(2)	...				...		PHIRC(9)	3 209
PHIRC(10)	PHIRC(11)								4 209
DTHF(1)	DTHF(2)	...				...		DTHF(9)	5 209
DTHF(10)	DTHF(11)								6 209
DTHR(1)	DTHR(2)	...				...		DTHR(9)	7 209
DTHR(10)	DTHR(12)								8 209
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

CAMBER TABLE

δ	ϕ_c
DELB	PHIC(1)
DELB+DDEL	PHIC(2)
⋮	⋮
DELB+nDDEL	PHIC(n+1)
⋮	⋮
DELE	$\text{PHIC}\left(\frac{\text{DELE-DELB}}{\text{DDEL}}+1\right)$



POSITIVE CAMBER – WHEEL LEANS OUT AT TOP
NEGATIVE CAMBER – WHEEL LEANS IN AT TOP

DAPFB	DAPFE	DAPF							210
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DAPFB		BEGINNING SUSPENSION DEFLECTION FOR FRONT ANTI-PITCH COEFFICIENT TABLE	in
DAPFE		ENDING SUSPENSION DEFLECTION FOR FRONT ANTI-PITCH COEFFICIENT TABLE	in
DDAPF		INCREMENTAL DEFLECTION FOR FRONT ANTI-PITCH COEFFICIENT TABLE	in
		FOLLOWING CARD 210 IS A TABLE CONTAINING	
APF	AP_F	[(DAPFE-DAPFB)/DDAPF]+1 ENTRIES OF FRONT ANTI-PITCH COEFFICIENT, APF(I) TABLE ENTRIES ARE READ IN 9 FIELDS OF 8 COLUMNS. A MONOTONICALLY INCREASING TABLE SEQUENCE NUMBER MUST BE IN COLUMN 76 AND 210 MUST BE IN COLUMNS 78-80. A MAXIMUM OF 21 ENTRIES IS ALLOWED. EXAMPLE:	lb/lb-ft

-5.0	5.0	1.0							210
APF(1)	APF(2)	(APF(3)	...				APF(8)	APF(9)	1 210
APF(10)	APF(11)								2 210
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

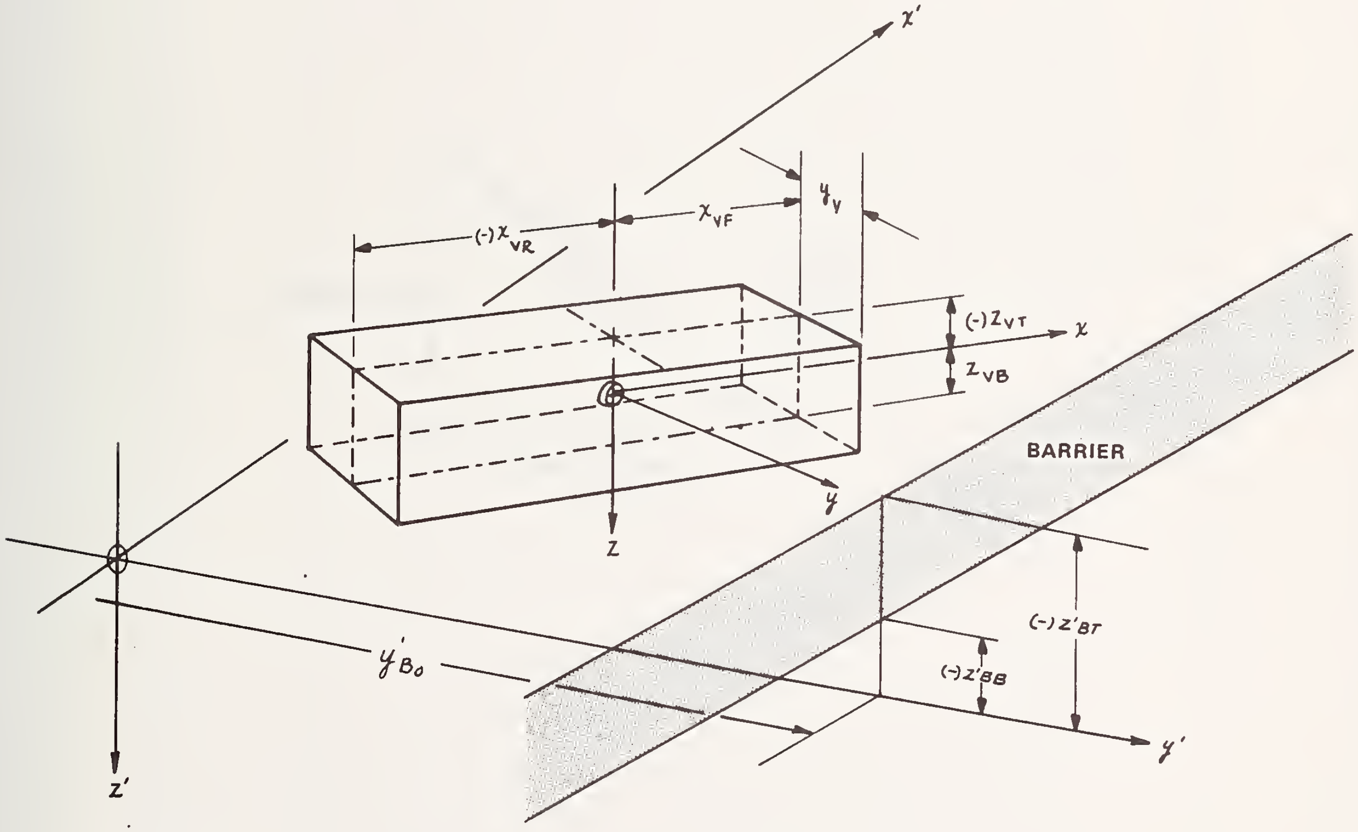
DAPRB	DAPRE	DDAPR							211
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DAPRB		BEGINNING SUSPENSION DEFLECTION FOR REAR ANTI-PITCH COEFFICIENT TABLE	in
DAPRE		ENDING SUSPENSION DEFLECTION FOR REAR ANTI-PITCH COEFFICIENT TABLE	in
DDAPR		INCREMENTAL DEFLECTION FOR REAR ANTI-PITCH COEFFICIENT TABLE	in
APR	AP_R	FOLLOWING CARD 211 IS A TABLE CONTAINING [(DAPRE-DAPRB)/DDAPR]+1 ENTRIES OF REAR ANTI-PITCH COEFFICIENT, APR(I) TABLE ENTRIES ARE READ IN 9 FIELDS OF 8 COLUMNS. A MONOTONICALLY INCREASING TABLE SEQUENCE NUMBER MUST BE IN COLUMN 76 AND CARD NUMBER 211 MUST BE IN COLUMNS 78-80. A MAXIMUM OF 21 ENTRIES IS ALLOWED. EXAMPLE:	lb/lb-ft

-5.0 APR(1)	5.0 APR(2)	5.0 APR(3)							211 1 211
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

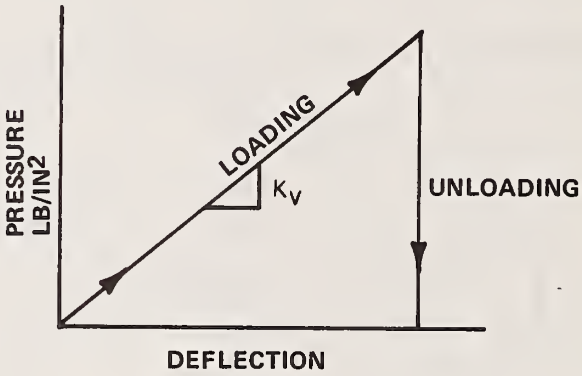
XVF	XVR	YV	ZVT	ZVB	AKV				212
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
XVF	X_{VF}	X COORDINATE OF FRONT OF VEHICLE	in
XVR	X_{VR}	X COORDINATE OF REAR OF VEHICLE	in
YV	Y_V	HALF-WIDTH OF VEHICLE	in
ZVT	Z_{VT}	Z COORDINATE OF PLANE DEFINING TOP OF VEHICLE	in
ZVB	Z_{VB}	Z COORDINATE OF PLANE DEFINING BOTTOM OF VEHICLE	in
AKV	K_V	LOAD-DEFLECTION CHARACTERISTIC FOR VEHICLE STRUCTURE	lb/in^3



XSTIO(1)	XSTIO(2)	XSTIO(3)	YSTIO(1)	YSTIO(2)	YSTIO(3)				213
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
XSTIO(1)	X_{ST10}	X AND Y POSITIONS OF THE VEHICLE	in
XSTIO(2)	X_{ST20}	STRUCTURAL HARD POINTS WITH RESPECT TO THE VEHICLE AXIS SYSTEM	in
XSTIO(3)	X_{ST30}		in
YSTIO(1)	Y_{ST10}		in
YSTIO(2)	Y_{ST20}		in
YSTIO(3)	Y_{ST30}		in



ZSTIO(1)	ZSTIO(2)	ZSTIO(3)	AKST(1)	AKST(2)	AKST(3)				214
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

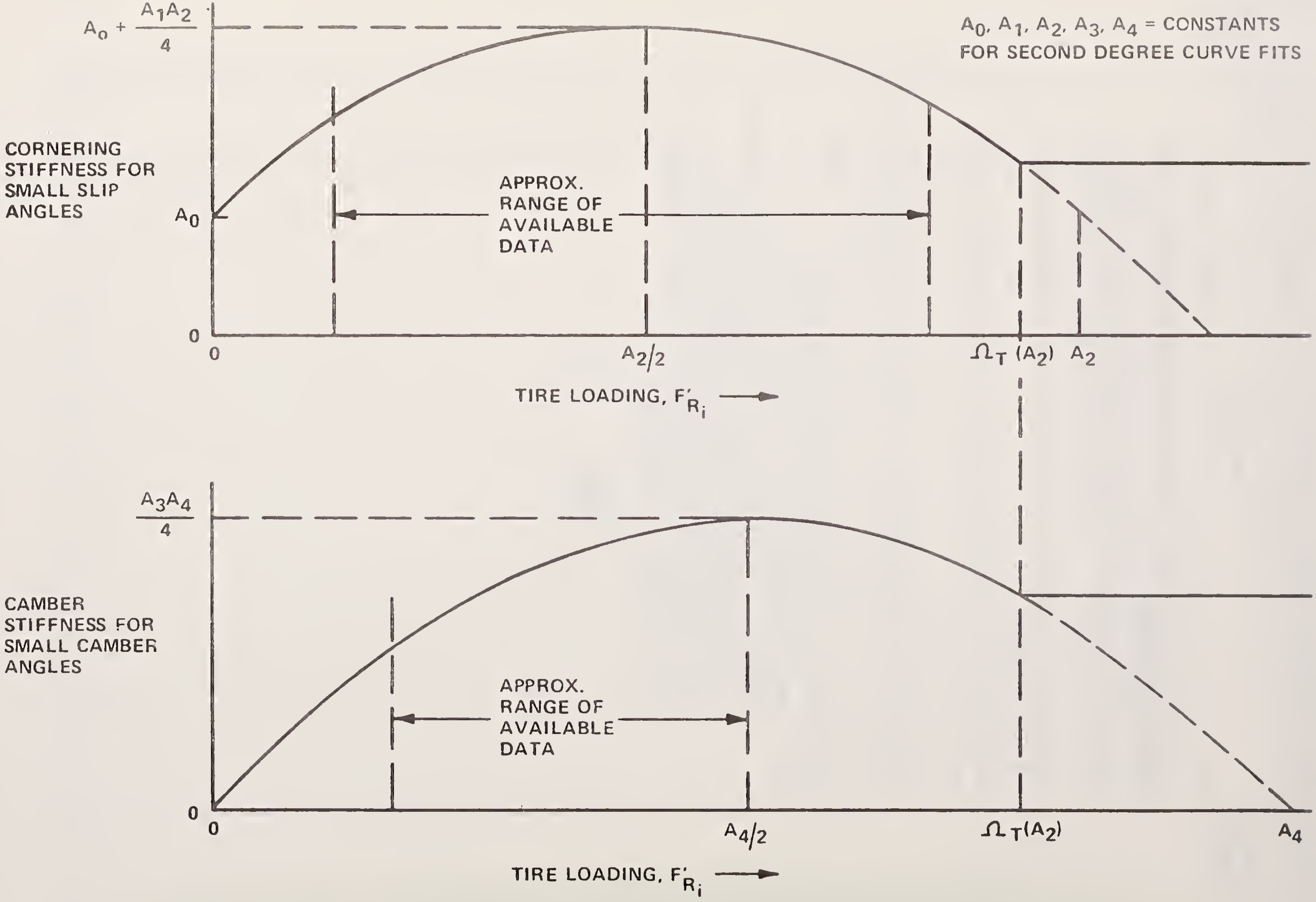
Program Variable	Analytical Variable	Description	Input Units
ZSTIO(1)	Z_{ST10}	Z POSITION OF THE VEHICLE STRUCTURAL HARDPOINTS WITH RESPECT TO THE VEHICLE AXIS SYSTEM	in
ZSTIO(2)	Z_{ST20}		in
ZSTIO(3)	Z_{ST30}		in
AKST(1)	K_{ST1}	OMNI-DIRECTIONAL STIFFNESS OF THE VEHICLE STRUCTURAL HARD POINTS	lb/in
AKST(2)	K_{ST2}		lb/in
AKST(3)	K_{ST3}		lb/in

THED(I),	I=1,18								300
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
THED	-	TIRE TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING THE SIMULATED VEHICLE TIRES. NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	-

ITIR(1)	ITIR(2)	ITIR(3)	ITIR(4)	RWHJE	DRWHJ				301
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
ITIR(1)		INDICATOR TO IDENTIFY THE SET OF TIRE DATA TO BE USED FOR THE RF TIRE	-
ITIR(2)		INDICATOR TO IDENTIFY THE SET OF TIRE DATA TO BE USED FOR THE LF TIRE	-
ITIR(3)		INDICATOR TO IDENTIFY THE SET OF TIRE DATA TO BE USED FOR THE RR TIRE	-
ITIR(4)		INDICATOR TO IDENTIFY THE SET OF TIRE DATA TO BE USED FOR THE LR TIRE	-
RWHJE		FINAL DEFLECTION $(R_W-h'j)$ OF THE FORCE $(F'j)$ VERSUS DEFLECTION CHARACTERISTIC OF THE RADIAL SPRING TIRE MODEL	in
DRWHJ		INCREMENT OF DEFLECTION OF THE FORCE-DEFLECTION CHARACTERISTICS OF THE RADIAL SPRING TIRE MODEL. NOTE: RWHJE AND DRWHJ MUST BE SUPPLIED ONLY IF INDCRB = 1 OR IRUF $\neq$ 0. THE FORCE CORRESPONDING TO THE DEFLECTION VALUES IS COMPUTED AUTOMATICALLY IN SUBROUTINE WHEEL FOR EACH SET OF TIRE PROPERTIES. THE NUMBER OF FORCE ENTRIES IS LIMITED TO 35. THEREFORE, $\frac{RWHJE}{DRWHJ} + 1 \le 35$	in



SIMULATED VARIATION OF SMALL-ANGLE CORNERING AND CAMBER STIFFNESS WITH VERTICAL TIRE LOAD

AKT(1)	SIGT(1)	XLAMT(1)	A0(1)	A2(1)	A3(1)	A4(1)	OMEGT(1)		1 301
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 18 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 87 68 69 70 71 72	73 74 75 76 77 78 79 80

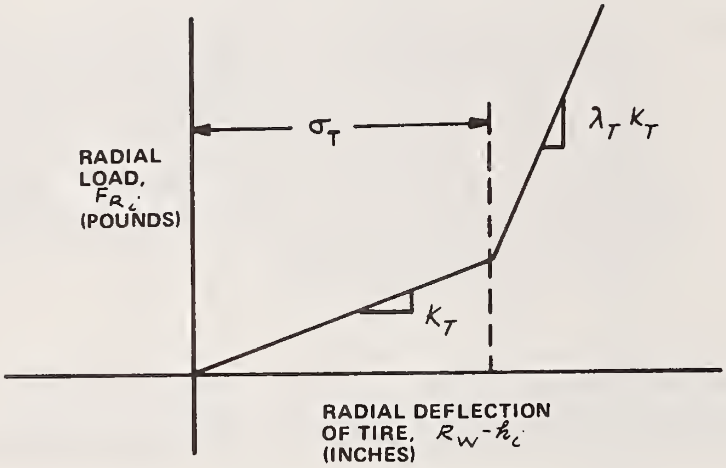
Program Variable	Analytical Variable	Description	Input Units
AKT(1)	K_{T_1}	TIRE LOAD-DEFLECTION RATE IN THE QUASI-LINEAR RANGE	lb/in
SIGT(1)	σ_{T_1}	TIRE DEFLECTION AT WHICH THE LOAD DEFLECTION RATE INCREASES	in
XLAMT(1)	λ_{T_1}	MULTIPLIER OF K_T USED TO OBTAIN TIRE STIFFNESS AT LARGE DEFLECTIONS	-
A0(1)	A_{0_1}	CONSTANT FOR TIRE SIDE FORCE VS SLIP ANGLE CHARACTERISTICS	
A1(1)	A_{1_1}	CONSTANT FOR TIRE SIDE FORCE CHARACTERISTICS DUE TO SLIP ANGLE	
A2(1)	A_{2_1}	CONSTANT FOR TIRE SIDE FORCE CHARACTERISTICS DUE TO SLIP ANGLE	
A3(1)	A_{3_1}	CONSTANT FOR TIRE SIDE FORCE CHARACTERISTICS DUE TO CAMBER ANGLE	
A4(1)	A_{4_1}	CONSTANT FOR TIRE SIDE FORCE CHARACTERISTICS DUE TO CAMBER ANGLE	
OMEGT(1)	Ω_{T_1}	MULTIPLIER OF A_2 AT WHICH TIRE SIDE FORCE CHARACTERISTIC VARIATION WITH LOAD IS ABANDONED	
		NOTE: THIS CARD REPRESENTS THE FIRST PARTIAL SET OF TIRE DATA AND IS REQUIRED. IF MORE THAN ONE TIRE DATA SET IS INDICATED BY TWO OR MORE DIFFERENT ENTRIES FOR ITIR ON CARD 301 THEN SUBSEQUENT DATA FOLLOWS THIS CARD WITH THE SAME FORMAT AND THE TIRE DATA SET NUMBER REPLACING 1 IN COLUMN 76. FOR EXAMPLE, 301 REPRESENTS TWO DIFFERENT TIRE DATA SETS, ONE USED FOR THE FRONT TIRES, THE SECOND USED FOR THE REAR TIRES OF THE VEHICLE.	

1.0	1.0	2.0	2.0						301
AKT(1)	SIGT(1)	XLAMT(1)	A0(1)	A1(1)	A2(1)	A3(1)	A4(1)	OMEGT(1)	1 301
AKT(2)	SIGT(2)	XLAMT(2)	A0(2)	A1(2)	A2(2)	A3(2)	A4(2)	OMEGT(2)	2 301
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 18 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

AMU(1)	AMU(2)	AMU(3)	AMU(4)	RW(1)	RW(2)	RW(3)	RW(4)		302
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	**Analytical Variable**	**Description**	**Input Units**
AMU(1) AMU(2) AMU(3) AMU(4)	μ_1 μ_2 μ_3 μ_4	NOMINAL FRICTION COEFFICIENT BETWEEN THE AND GROUND. THE FOUR VALUES CORRESPOND TO THE FOUR TIRE DATA SETS. AT LEAST ONE AND AT MOST THE SAME NUMBER AS THE NUMBER OF DATA SETS BEING USED ARE REQUIRED.	
RW(1) RW(2) RW(3) RW(4)	R_{W_1} R_{W2} R_{W_3} R_{W_4}	UNDEFLECTED TIRE RADIUS. THE FOUR VALUES CORRESPOND TO THE FOUR TIRE DATA SETS. AT LEAST ONE AND AT MOST THE SAME NUMBER AS THE NUMBER OF DATA SETS BEING USED ARE REQUIRED. FOR EXAMPLE IF, AS IN THE EXAMPLE ON CARD 301, TWO TIRE DATA SETS ARE BEING USED.	

AMU(1)	AMU(2)			RW(1)	RW(2)				302
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80



CHED(I)	, I=1,18								400
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
CHED	-	VEHICLE CONTROL TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING VEHICLE CONTROL INPUTS. NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	-

TB	TE	TINCR	NTBL1	NTBL2	NTBL3				401
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

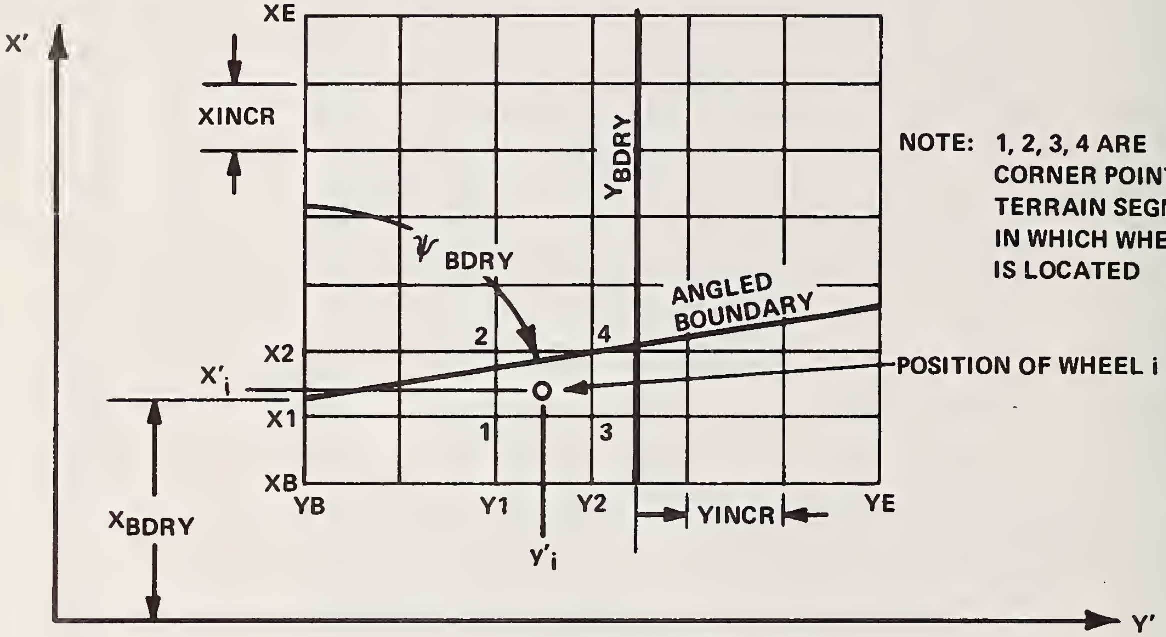
Program Variable	Analytical Variable	Description	Input Units
TB		INITIAL TIME FOR DRIVER CONTROL INPUT TABLES	sec
TE		FINAL TIME FOR DRIVER CONTROL INPUT TABLES	
TINCR		INCREMENT OF TIME FOR DRIVER CONTROL INPUT TABLES	sec
NTBL1		INDICATOR FOR STEER ANGLE (ψ_f) TABLE; READ ψ_F TABLE ONLY IF NTBL1 $\neq$ 0.0	
NTBL2		INDICATOR FOR FRONT WHEEL TORQUE ($\overline{TQ}_F$) TABLE; READ $\overline{TQ}_F$ TABLE ONLY IF NTBL2 $\neq$ 0.0	
NTBL3		INDICATOR FOR REAR WHEEL TORQUE ($\overline{TQ}_R$) TABLE; READ $\overline{TQ}_R$ TABLE ONLY IF NTBL3 $\neq$ 0.0	
		NOTE: TE MUST BE > TB AND THE NUMBER OF ENTRIES IN EACH TABLE [(TE-TB)/TINCR]+1 MUST BE $\leq$ 50. IF TB $\neq$ T0 (CONTROL INPUTS STARTING IN THE MIDDLE OF A RUN), THE FIRST THREE VALUES IN THE INPUT TABLES MUST BE ZERO CONTROL INPUTS BETWEEN T0 AND TB. ALSO IF TE < T1 (CONTROL INPUTS ENDING IN THE MIDDLE OF A RUN), THE CONTROL INPUTS BETWEEN TE AND T1 ARE DETERMINED BY QUADRATIC INTERPOLATION OF THE LAST THREE VALUES IN THE CONTROL TABLE. HENCE, IF ZERO CONTROL INPUTS ARE DESIRED BETWEEN TE AND T1, THE LAST THREE ENTRIES IN THE TABLES MUST BE ZERO. ANY (OR ALL) OF THE THREE TABLES THAT ARE TO BE INPUT MUST APPEAR IN THE ORDER:	
PSIF	ψ_F	PSIF - front wheel steer table	deg
TQF	TQ_F	TQF - front wheel torque table (each wheel)	lb-ft
TQR	TQ_R	TQR - rear wheel torque table (each wheel)	lb-ft
		EACH TABLE CARD MUST CONTAIN 401 IN COLUMNS 78-80 AND MUST ALSO CONTAIN AN INCREASING TABLE SEQUENCE NUMBER IN COLUMN 76. FOR EXAMPLE, IF PSIF AND TQR ARE TO BE READ FROM t = 0.0 TO t = 1.0 sec IN INCREMENTS OF 0.1 sec:	

0.0	1.0	0.1	1.0	0.0	1.0				401
PSIF(1)	PSIF(2)	...				...	PSIF(8)	PSIF(9)	1 401
PSIF(10)	PSIF(11)								2 401
TQR(1)	TQR(2)	...				...	TQR(8)	TQR(9)	3 401
TQR(10)	TQR(11)								4 401
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

GHED(I),	I=1,18								500
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
GHED	-	TERRAIN TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING THE SIMULATED VEHICLE'S ENVIRONMENT (CURBS, TERRAIN TABLES, BARRIER). NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	-

Cards 501 through 505 are employed for input of terrain tables. These tables include a maximum of four constant increment tables and one variable increment table which must be the highest numbered table in use. The constant increment tables are all read under the same format, table 1 being read on cards 501, etc. The variable increment table is read with a slightly different format on cards numbered one greater than the highest numbered constant increment table.



TERRAIN TABLE GRID

XB(I)	XE(I)	XINCR(I)	YB(I)	YE(I)	YINCR(I)	NBX(I)	NBY(I)		50I
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		CONSTANT INCREMENT TERRAIN TABLE	
		NOTE: THE CONSTANT INCREMENT TERRAIN TABLE NUMBER REPLACES THE LETTER I IN THE CARD NUMBER. THUS, CONSTANT INCREMENT TABLE 1 BECOMES CARD 501, ETC.	
XB(I)		INITIAL X' VALUE OF TERRAIN TABLE I	in
XE(I)		FINAL X' VALUE OF TERRAIN TABLE I	in
XINCR(I)		INCREMENT OF X' BETWEEN TERRAIN TABLE ENTRIES	
YB(I)		INITIAL Y' VALUE OF TERRAIN TABLE I	in
YE(I)		FINAL Y' VALUE OF TERRAIN TABLE I	in
YINCR(I)		INCREMENT OF Y' BETWEEN TERRAIN TABLE ENTRIES	
NBX(I)		NUMBER OF ANGLED BOUNDARIES FOR TABLE I ($0 \le NBX \le 4$)	
NBY(I)		NUMBER OF Y' BOUNDARIES FOR TABLE I ($0 \le NBY \le 2$)	
		CARD 50I CONTAINS THE CONTROL INFORMATION FOR TERRAIN TABLE I. THE REMAINDER OF THE DATA IS CONTAINED ON CARDS NUMBERED 50I WITH AN INCREASING TABLE SEQUENCE NUMBER CONTAINED IN COLUMN 76.	
		IF NBX(I) ≠ 0 THE FOLLOWING TWO CARDS ARE REQUIRED CONTAINING	
XBDRY PSBDRO		XBDRY - THE XB INTERCEPT OF THE ANGLED BOUNDARIES PSBDRO - THE ANGLED BOUNDARIES ANGLE FROM THE X' AXIS	in deg
XBDRY(J,I) PSBDRO(J,I)		J = 1, NBX(I) J = 1, NBX(I)	1 50I 2 50I
		IF NBY(I) ≠ 0 THE FOLLOWING CARD IS REQUIRED CONTAINING	
YBDRY		YBDRY - THE LOCATION OF THE Y' BOUNDARIES	in
YBDRY(J,I)		J = 1, NBY(I)	n 50I
		WHERE n IS THE LARGEST SEQUENCE NUMBER YET SUPPLIED.	
		NOTE: $0 \le NBX(I) \le 4$ $0 \le NBY(I) \le 2$	
		NO BOUNDARY CARDS NEED BE SUPPLIED IF BOUNDARIES ARE NOT REQUIRED FOR TABLE I.	

Following the boundary cards, or card 50I if no boundary cards are used, are the terrain elevation cards. These cards contain the elevation of the terrain (Z'_G) at each grid point within table I. NX x NY entries must be supplied where:

$$NX = [(XE(I)-XB(I))/XINCR(I)]+1$$
$$NY = [(YE(I)-YB(I))/YINCR(I)]+1$$

and $NX \leq 21$, $NY \leq 21$. Entries are made with the Y' coordinate varying most rapidly and must contain card number 50I in columns 78-80 and an increasing sequence number in column 76.

ZGP(1,J)	J = 1,NY	Elevation for y' values at XB(I)	s	50I
ZGP(2,J)	J = 1,NY	Elevation for y' values at XB(I)+ XINCR(I)	s	50I
:			:	:
:			:	:
ZGP(NX,J)	J = 1,NY	Elevation for y' grid points at XE(I)	s	50I
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72			73 74 75 76	77 78 79 80

where s in column 76 represents the table sequence number which must increase with each card.

XY(I)	XE(I)	NX(I)	YB(I)	YE(I)	NY(I)	NBX(I)	NBY(I)	1.0	50I
1 2 3 4 5 6 7 8	8 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 38 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		VARIABLE INCREMENT TERRAIN TABLE	
		NOTE: THE VARIABLE INCREMENT TERRAIN TABLE NUMBER REPLACES THE LETTER I IN THE CARD NUMBER. THUS, IF THE VARIABLE INCREMENT TABLE IS TABLE NUMBER 3, IT IS READ ON CARDS 503.	
XB(I)		INITIAL X' VALUE OF TERRAIN TABLE I	in
XE(I)		FINAL X' VALUE OF TERRAIN TABLE I	in
NX(I)		NUMBER OF X' GRID POINTS TO BE SUPPLIED	
YB(I)		INITIAL Y' VALUE OF TERRAIN TABLE I	in
YE(I)		FINAL Y' VALUE OF TERRAIN TABLE I	in
NY(I)		NUMBER OF Y' GRID POINTS TO BE SUPPLIED	
NBX(I)		NUMBER OF ANGLED BOUNDARIES FOR TABLE I ($0 \le NBX \le 4$)	
NBY(I)		NUMBER OF Y' BOUNDARIES FOR TABLE I ($0 \le NBY \le 2$)	
		NOTE: 1.0 MUST APPEAR IN COLUMNS 65-72.	
		CARD 50I CONTAINS THE CONTROL INFORMATION FOR TERRAIN TABLE I. THE REMAINDER OF THE DATA IS CONTAINED ON CARDS NUMBERED 50I WITH AN INCREASING TABLE SEQUENCE NUMBER CONTAINED IN COLUMN 76.	
		IF NBX(I) ≠ 0 THE FOLLOWING TWO CARDS ARE REQUIRED CONTAINING	
XBDRY PSBDRO		XBDRY - THE XB INTERCEPT OF THE ANGLED BOUNDARIES PSBDRO - THE ANGLED BOUNDARIES ANGLE FROM THE X' AXIS	in deg
XBDRY(J,I) PSBDRO(J,I)		J = 1, NBX(I) J = 1, NBX(I)	1 50I 2 50I
		IF NBY(I) ≠ 0 THE FOLLOWING CARD IS REQUIRED CONTAINING	
YBDRY		YBDRY - THE LOCATION OF THE Y' BOUNDARIES	in
YBDRY(J,I)		J = 1, NBY(I)	n 50I
		WHERE n IS THE LARGEST SEQUENCE NUMBER YET SUPPLIED.	
		NOTE: $0 \le NBX(I) \le 4$ $0 \le NBY(I) \le 2$ NO BOUNDARY CARDS NEED TO SUPPLIED IF BOUNDARIES ARE NOT REQUIRED FOR TABLE I.	

Following the boundary cards, or card 50I, if no boundary cards are used, are the terrain elevation cards. These cards contain the elevation of the terrain (Z'_G) at each grid point within table I. NX x NY entries must be supplied where NX and NY are read in fields 3 and 6 on card 50I and $NY \leq 21$, $NY \leq 21$. Entries are made with the Y' coordinate varying most rapidly and must contain card number 50I in columns 78-80 and an increasing sequence number in column 76.

ZGP(1,J)	J = 1,NY	Elevation for y' values at XB(I)	s	50I
ZGP(2,J)	J = 1,NY	Elevation for y' values at XXZGP5(2)	s	50I
:			:	:
:			:	:
ZGP(NX,J)	J = 1,NY	Elevation for y' grid points at XE(I)	s	50I

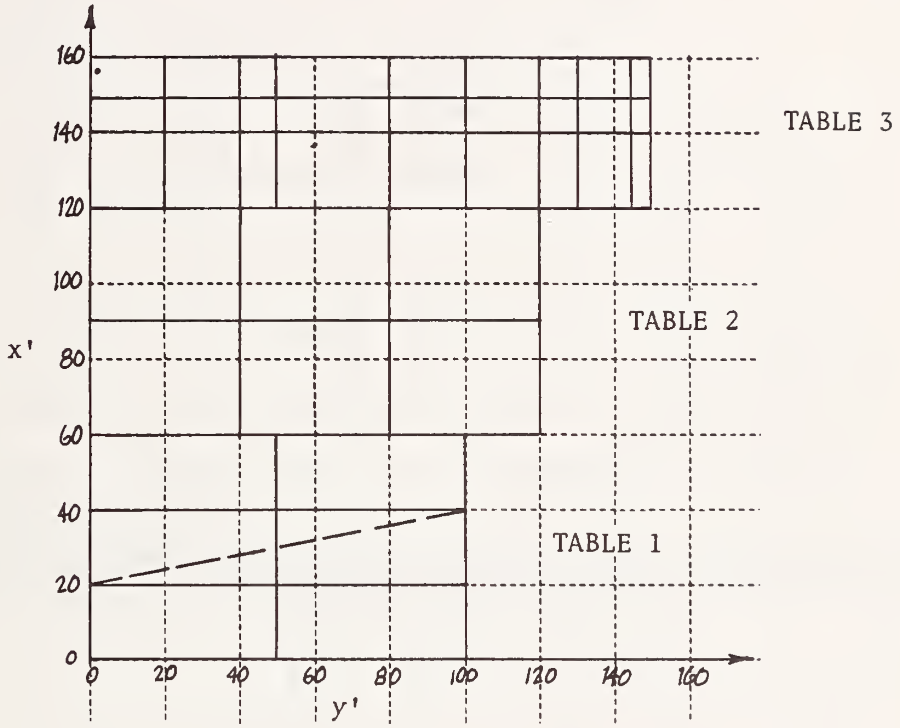
where s in column 76 represents the table sequence number which must increase with each card.

Following the elevation entries are two tables containing the Y' and X' grid locations for the variable increment table.

YYZGP5(N)	N = 1,NY(I)	s	50I
XXZGP5(N)	N = 1,NX(I)	s	50I

TERRAIN TABLE EXAMPLE

Consider three terrain tables as shown in the sketch:



Let table 1 have an x' increment of 20" and a y' increment of 50"; table 2 have an x' increment of 30" and a y' increment of 40". Table 3 is a variable increment table containing elevations at y' = 0, 20, 40, 50, 80, 100, 120, 130, 145 and 150 inches and x' = 120, 140, 150 and 160 inches. Also, let table 1 contain an angled boundary with an x' intercept of 20" and $\psi'_{BDRY} = \arctan\left(\frac{100}{20}\right) = 78.7°$.

Let the elevations for each grid point be determined from the following tables:

TABLE 1

		Y'		
		0.0	50.0	100.0
X'	0.0	0.0	0.0	0.0
	20.0	1.0	2.0	1.0
	40.0	2.0	3.0	2.0
	60.0	4.0	4.0	4.0

TABLE 2

		Y'			
		0.0	40.0	80.0	120.0
X'	60.0	4.0	4.0	4.0	4.0
	90.0	4.0	5.0	6.0	4.0
	120.0	3.0	4.0	5.0	5.0

TABLE 3

		Y'									
		0.0	20.	40.	60.	80.	100.	120.	130.	145.	150.
X'	120.0	3.0	3.5	4.0	4.5	5.0	5.0	5.0	6.0	3.0	3.5
	140.0	3.0	3.0	3.5	4.0	4.0	4.5	4.0	3.5	2.5	2.0
	150.0	1.0	2.0	2.0	2.5	2.5	2.5	2.5	2.0	1.0	0.5
	160.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

0.0	60.0	20.0	0.0	100.0	50.0	1.0	0.0		501
20.0									1 501
78.7									2 501
0.0	0.0	0.0							3 501
1.0	2.0	1.0							4 501
2.0	3.0	2.0							5 501
4.0	4.0	4.0							6 501
60.0	120.0	30.0	0.0	120.0	40.0	0.0	0.0		502
4.0	4.0	4.0	4.0						1 502
4.0	5.0	6.0	4.0						2 502
3.0	4.0	5.0	5.0						3 502
120.0	160.0	4.0	0.0	150.0	10.0	0.0	0.0	0.0	503
3.0	3.5	4.0	4.5	5.0	5.0	5.0	6.0	3.0	1 503
3.5									2 503
3.0	3.0	3.5	4.0	4.0	4.5	4.0	3.5	2.5	3 503
2.0									4 503
1.0	2.0	2.0	2.5	2.5	2.5	2.5	2.0	1.0	5 503
0.5									6 503
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7 503
0.0									8 503
0.0	20.0	40.0	60.0	80.0	100.0	120.0	130.0	145.0	9 503
150.0									10 503
120.0	140.0	150.0	160.0						11 503
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

AMUG(1)	AMUG(2)	AMUG(3)	AMUG(4)	AMUG(5)					506
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

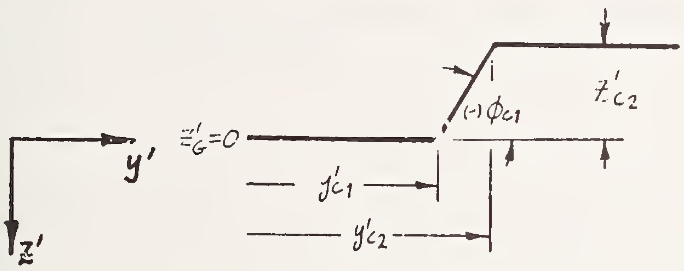
Program Variable	Analytical Variable	Description	Input Units
AMUG(1) AMUG(2) AMUG(3) AMUG(4) AMUG(5)		TERRAIN TABLE FRICTION MULTIPLIERS. THESE FACTORS ARE A MULTIPLE OF THE NOMINAL TIRE-GROUND FRICTION COEFFICIENT THAT CHANGE THAT VALUE WHEN A TIRE IS WITHIN A GIVEN TERRAIN TABLE	

YC1P	YC2P	YC3P	YC4P	YC5P	YC6P	AMUC			507
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
YC1P	y'_{c_1}	LATERAL POSITIONS OF THE FIRST THROUGH THE SIXTH SLOPE CHANGES DEFINING A CURB	in
YC2P	y'_{c_2}		in
YC3P	y'_{c_3}		in
YC4P	y'_{c_4}		in
YC5P	y'_{c_5}		in
YC6P	y'_{c_6}		in
		NOTE: ONLY AS MANY SLOPE CHANGE POSITIONS AS IS INDICATED BY NCRBSL, CARD 101, NEED BE SUPPLIED	
AMUC	μ_c	CURB FRICTION MULTIPLIER. THIS FACTOR IS A MULTIPLE OF THE NOMINAL TIRE-GROUND FRICTION COEFFICIENT THAT CHANGES THAT VALUE WHEN IN CONTACT WITH A CURB.	

ZC2P	ZC3P	ZC4P	ZC5P	ZC6P					508
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

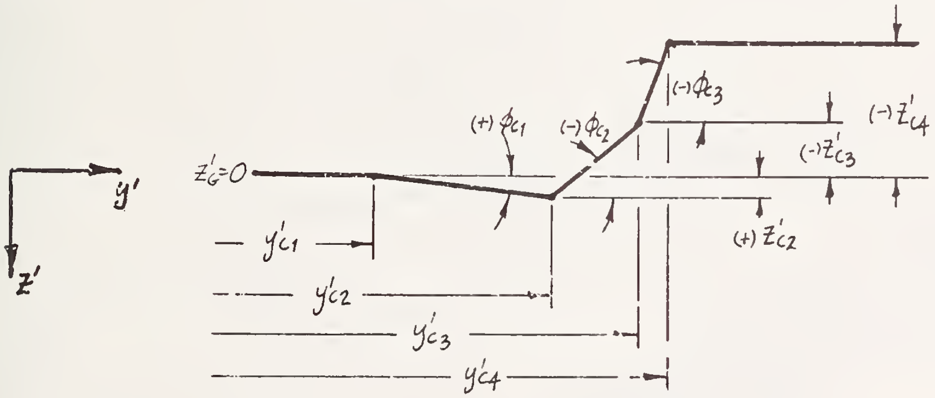
Program Variable	Analytical Variable	Description	Input Units
ZC2P	Z'_{c_2}	CURB ELEVATION AT y'_{c_2} THROUGH y'_{c_6}, RESPECTIVELY	in
ZC3P	Z'_{c_3}		in
ZC4P	Z'_{c_4}		in
ZC5P	Z'_{c_5}		in
ZC6P	Z'_{c_6}		in



TWO SLOPE CURB

$-90 < \phi_{c1} < 0$

$\phi_{c2} = 0$



FOUR SLOPE CURB

$\phi_{c1} > 0$

$-90 < \phi_{c2} < 0$

$-90 < \phi_{c3} < \phi_{c2}$

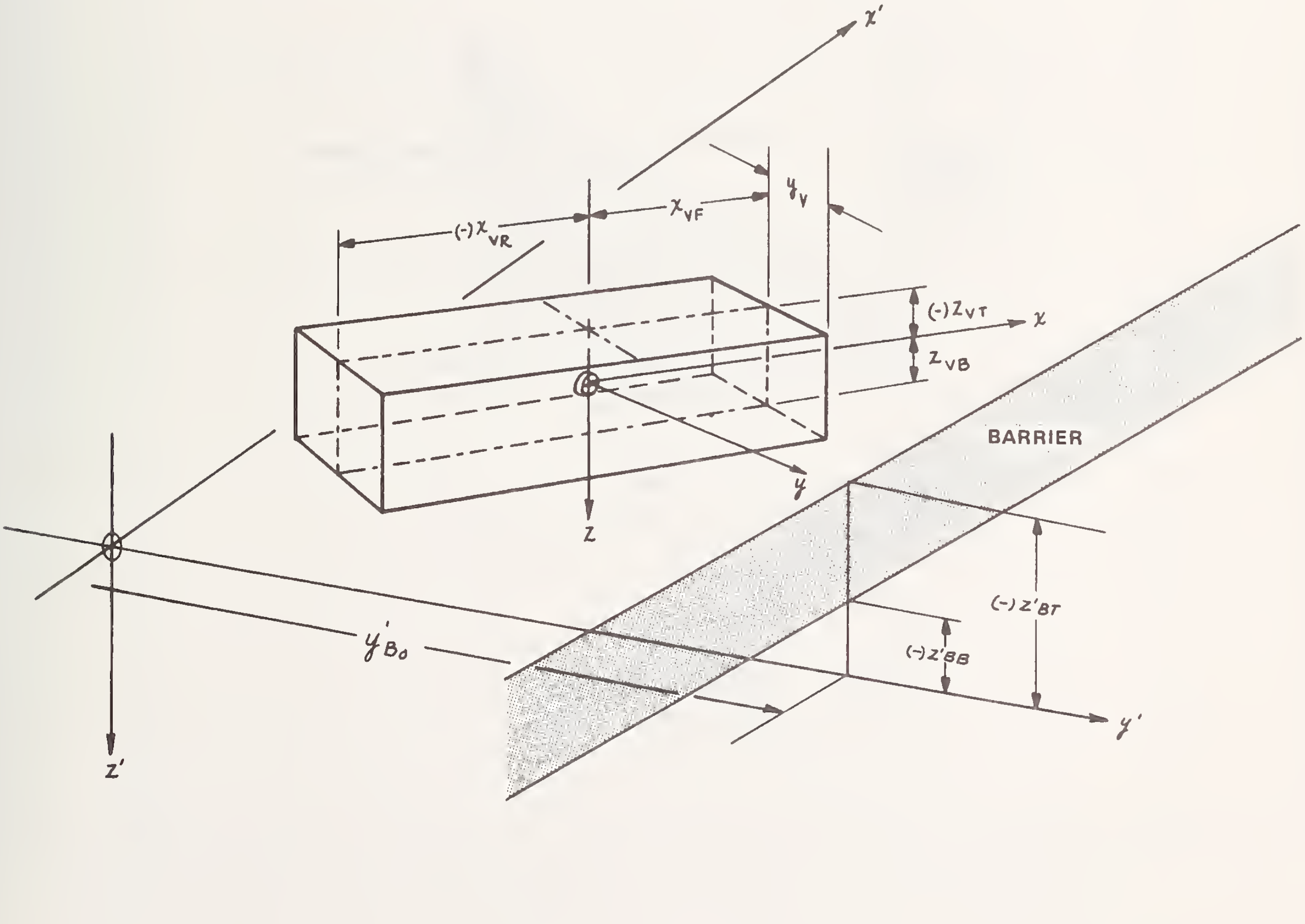
$\phi_{c4} = 0$

PHIC1	PHIC2	PHIC3	PHIC4	PHIC5	PHIC6				509
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
PHIC1	ϕ_{c_1}	FIRST THROUGH SIXTH CURB SLOPE ANGLE	deg
PHIC2	ϕ_{c_2}		deg
PHIC3	ϕ_{c_3}		deg
PHIC4	ϕ_{c_4}		deg
PHIC5	ϕ_{c_5}		deg
PHIC6	ϕ_{c_6}		deg

YBPO	ZBTP	ZBBP	DELYBP	AMUB	EPSV	EPSB	SET	CONS	510
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

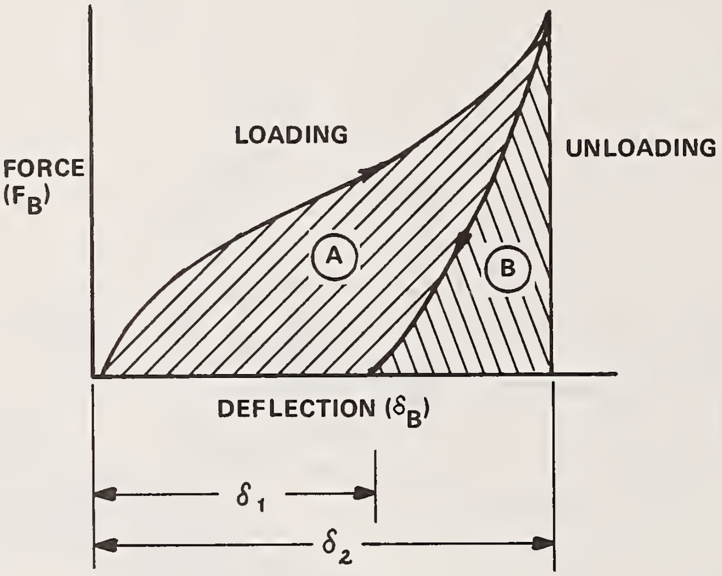
Program Variable	Analytical Variable	Description	Input Units
YBPO	$(y'_B)_O$	INITIAL LATERAL POSITION OF THE BARRIER FACE PLANE	in
ZBTP	Z'_{BT}	ELEVATION OF TOP OF FINITE VERTICAL BARRIER	in
ZBBP	Z'_{BB}	ELEVATION OF BOTTOM OF FINITE VERTICAL BARRIER	in
DELYBP	$\Delta y'_B$	INCREMENTAL DISPLACEMENT OF DEFORMABLE BARRIER	in
AMUB	μ_B	COEFFICIENT OF FRICTION ACTING BETWEEN VEHICLE SPRUNG MASS AND BARRIER	-
EPSV	ε_V	FRICTION LAG FOR VEHICLE-BARRIER FRICTION FORCE	in/sec
EPSB	ε_B	ERROR LIMIT IN FORCE BALANCE BETWEEN VEHICLE AND BARRIER	lbs
SET	$\overline{SET}$	RATIO OF PERMANENT DEFLECTION TO MAXIMUM DEFLECTION OF BARRIER	-
CONS	$\overline{CONS}$	RATIO OF CONSERVED ENERGY TO MAXIMUM ENERGY ABSORGED BY BARRIER	-



SIGR(1)	SIGR(2)	SIGR(3)	SIGR(4)	SIGR(5)	SIGR(6)	SIGR(7)	SIGR(8)	SIGR(9)	511
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
SIRG	σ_R	POLYNOMIAL COEFFICIENTS FOR LOAD-DEFLECTION CHARACTERISTIC FOR BARRIER OF THE FORM: $F_B = \sigma_1 + \sum_{i=2}^{5} \sigma_i \delta_B^{(i-1)} + \sum_{i=7}^{11} \sigma_i \dot{\delta}_B^{(i-6)}$ NOTE THAT THE REMAINING TWO COEFFICIENTS, IF USED, MUST BE SUPPLIED ON THE FOLLOWING CARD	

SIGR(10)	SIGR(11)								512
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80



$$\overline{SET} = \frac{\delta_1}{\delta_2}$$

$$\overline{CONS} = \frac{\text{AREA A}}{\text{AREA}(A+B)}$$

DELG	NEND								513
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	**Analytical Variable**	**Description**	**Input Units**
DELG	Δ_G	CONSTANT DISTANCE INCREMENT BETWEEN ROAD ROUGHNESS INPUT POINTS	in
NEND		NUMBER OF ROAD ROUGHNESS POINTS TO BE READ ($NEND \leq 2200$)	
		NOTE: ROAD ROUGHNESS DATA IN THE FORM OF ELEVATION CHANGE FROM THE DATUM ARE READ WITHIN SUBROUTINE RUFRED FROM FORTRAN DEVICE 4 VIA AN UNFORMATTED READ. IF THESE DATA ARE READ, THE ROAD ROUGHNESS INDICATOR IS SET TO 1 (IRUF=1). THE USE OF THE ROAD ROUGHNESS OPTION AND TERRAIN TABLES IS MUTUALLY EXCLUSIVE.	

SHED(I),	I=1,18								600
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
SHED	-	INITIAL CONDITION TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING THE INITIAL CONDITIONS FOR THE RUN. NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE	-

PHIO	THETAO	PSIO	PO	QO	RO	PSIFIO	PHIFDO		601
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
PHIO	ϕ_0	INITIAL VEHICLE VEHICLE ROLL ANGEL EULER ANGLES, SEE FIGURE 3.5-1	deg
THETAO	θ_0	INITIAL VEHICLE PITCH ANGLE	deg
PSIO	ψ_0	INITIAL VEHICLE YAW ANGLE	deg
PO	P_0	INITIAL VEHICLE ANGULAR VELOCITY ABOUT THE x AXIS	deg/sec
QO	Q_0	INITIAL VEHICLE ANGULAR VELOCITY ABOUT THE y AXIS	deg/sec
RO	R_0	INITIAL VEHICLE ANGULAR VELOCITY ABOUT THE z AXIS	deg/sec
PSIFIO	ψ_{f0}	INITIAL FRONT WHEEL STEER ANGLE	deg
PSIFDO	$\dot{\psi}_{f0}$	INITIAL FRONT WHEEL STEER ANGULAR VELOCITY	deg/sec

XCOP	YCOP	ZCOP	UO	VO	WO				602
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
XCOP	X'_{co}	INITIAL x' COORDINATE OF THE SPRUNG MASS C.G. FROM THE SPACE AXES	in
YCOP	Y'_{co}	INITIAL y' COORDINATE OF THE SPRUNG MASS C.G. FROM THE SPACE AXES	in
ZCOP	z'_{co}	INITIAL z' COORDINATE OF THE SPRUNG MASS C.G. FROM THE SPACE AXES	in
UO	U_o	INITIAL LONGITUDINAL VELOCITY OF THE VEHICLE C.G. ALONG THE VEHICLE AXES	in/sec
VO	V_o	INITIAL LATERAL VELOCITY OF THE VEHICLE C.G. ALONG THE VEHICLE AXES	in/sec
WO	W_o	INITIAL LONGITUDINAL VELOCITY OF THE VEHICLE C.G. ALONG THE VEHICLE AXES	in/sec

DEL10	DEL20	DEL30	PHIRO	DEL10D	DEL20D	DEL30D	PHIROD		603
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DEL10	δ_{10}	INITIAL RF WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL20	δ_{20}	INITIAL RF WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL30	δ_{30}	INITIAL REAR ROLL CENTER DISPLACEMENT FROM EQUILIBRIUM	in
PHIRO	ϕ_{R_o}	INIITAL REAR AXLE ROLL ANGLE WITH RESPECT TO THE VEHICLE	deg
DEL10D	$\dot{\delta}_{10}$	INITIAL RF WHEEL DEFLECTION VELOCITY	in/sec
DEL20D	$\dot{\delta}_{20}$	INITIAL LF WHEEL DEFLECTION VELOCITY	in/sec
DEL30D	$\dot{\delta}_{30}$	INITIAL REAR ROLL CENTER DISPLACEMENT VELOCITY	in/sec
PHIROD	$\dot{\phi}_{R_o}$	INITIAL REAR AXLE ROLL ANGULAR VELOCITY	deg/sec
		NOTE: THIS FORM OF CARD 603 IS USED ONLY FOR ISUS = 0.	

DEL10	DEL20	DLE30	DEL40	DEL20D	DEL30D	DEL40D			603
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DEL10	$\delta10$	INITIAL RF WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL20	δ_{20}	INITIAL LF WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL30	δ_{30}	INITIAL RR WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL40	δ_{40}	INITIAL LR WHEEL DISPLACMENET FROM EQUILIBRIUM	in
DEL40D	$\dot{\delta}_{10}$	INITIAL RF WHEEL DEFLECTION VELOCITY	in/sec
DEL20D	$\dot{\delta}_{20}$	INITIAL LF WHEEL DEFLECTION VELOCITY	in/sec
DEL30D	$\dot{\delta}_{30}$	INITIAL RR WHEEL DEFLECTION VELOCITY	in/sec
DEL40D	$\dot{\delta}_{40}$	INITIAL LR WHEEL DEFLECTION VELOCITY	in/sec
		NOTE: THIS FORM OF CARD 603 USED ONLY WHEN ISUS = 1.	

DEL10	PHIF0	DEL30	PHIR0	DEL10D	PHIF0D	DEL30D	PHIR0D		603
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DEL10		INITIAL FRONT ROLL CENTER DISPLACEMENT FROM EQUILIBRIUM	in
PHIF0		INITIAL FRONT AXLE ROLL ANGLE RELATIVE TO THE VEHICLE	deg
DEL30		INITIAL REAR ROLL CENTER DISPLACEMENT FROM EQUILIBRIUM	in
PHIR0		INITIAL REAR AXLE ROLL ANGLE RELATIVE TO THE VEHICLE	deg
DEL10R		INITIAL FRONT ROLL CENTER DEFLECTION VELOCITY	in/sec
PHIF0D		INITIAL FRONT AXLE ANGULAR VELOCITY	deg/sec
DEL30D		INITIAL REAR ROLL CENTER DEFLECTION VELOCITY	in/sec
PHIR0D		INITIAL REAR AXLE ANGULAR VELOCITY	deg/sec
		NOTE: THIS FORM OF CARD 603 USED ONLY WHEN ISUS = 2.	

									9999
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		THIS CARD SIGNIFIES THE END OF A DATA SET AND MUST BE SUPPLIED	

4.1.2 Vehicle Dynamics Version

Input to the HVOSM-VD2 is supplied primarily in the form of punched cards. All data cards must contain a three-digit number in columns 78-80. The first of these represent the data block number and the remaining two numbers represent the card number within the data block. Data blocks are categorized and numbered as follows:

Block Number	Data Content
1	Simulation Control data
2	Vehicle data
3	Tire data
4	Vehicle Control data
5	Terrain/environmental data
6	Initial conditions

Each data block may contain a title card with the last two digits of the card number being 00 (e.g., vehicle data title card would be numbered 200). Title cards may contain alphanumeric information which is printed on each page.

Data is entered on individual data cards and on table cards in 9 fields of 8 columns each (9F8.0 format). Any data not supplied defaults to 0.0. The format for table entry consists of a table information card containing information on the number of entries, beginning and end values, the number of tables, etc. depending on the particular table being read. Immediately following this card are the table data cards, each containing the same card number in columns 78-80 as the table information card. Table data cards must also contain a table sequence number in column 76 (or 75-76 if a two digit number) which must always be larger than the sequence number on the previous table data card. The last card in the input data deck must be numbered 9999 in columns 77-80.

Input decks may be stacked so that multiple runs can be made in a single job. Only cards which are changed from the previous deck must be supplied. Each data deck must contain card number 9999 as the last card in the deck.

In addition to card input, Fortran unit 4 is used to supply road roughness data if this option is being used. This data is read from subroutine RUFRED and is assumed to be unformatted in sequential form.

A description of the data required on each input card follows.

HED(I),	I=1,18								100
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 18 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
HED	-	RUN TITLE CARD THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHA-NUMERIC INFORMATION DESCRIBING A RUN AND IS PRINTED ON EACH OUTPUT PAGE	-

T0	T1	DTCOMP	DTPRNT	THMAX	UVWMIN	PQRMIN	COMEN4		101
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
T0		INITIAL SIMULATION TIME	sec
T1		FINAL SIMULATION TIME	sec
DTCOMP		NORMAL VEHICLE INTEGRATION TIME STEP	sec
DTPRNT		OUTPUT PRINT TIME INTERVAL (MULTIPLE OF DTCOMP)	
THMAX		VALUE OF PITCH ANGLE (θ'_t) AT WHICH THE SPACE FIXED AXES ARE INDEXED, USUALLY 70°	deg
UVWMIN		VALUES OF RESULTANT LINEAR AND ANGULAR VELOCITIES FOR SIMULATION STOP TEST. IF BOTH VEHICLE VELOCITIES ARE LESS THAN INPUT VALUES, RUN IS TERMINATED	in/sec
PQRMIN			rad/sec
COMEN4		MULTIPLIER CONSTANT USED IN TEST TO DETERMINE REQUIRED TIME STEP SIZE FOR INTEGRATION STABILITY OF THE WHEEL SPIN EQUATIONS OF MOTION. RECOMMENDED VALUE IS 0.001	-

ISUS	INDCRB	NCRBSL	DELTC	IDRVER	IBUG				102
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
ISUS		SUSPENSION OPTION INDICATOR = 0, INDEPENDENT FRONT, SOLID REAR AXLE = 1, INDEPENDENT FRONT AND REAR = 2, SOLID FRONT AND REAR AXLES	-
INDCRB		CURB IMPACT INDICATOR = 0, NO CURB INPUT = 1, CURB INPUT SUPPLIED (PROVIDES STEER DEGREE OF FREEDOM AND RADIAL SPRINGS TIRE MODEL) = -1, NO CURB INPUT SUPPLIED (PROVIDES STEER DEGREE OF FREEDOM WITH POINT CONTACT TIRE MODEL)	-
NCRBSL		NUMBER OF CURB SLOPES SUPPLIED IF INDCRB = 1 $2 \le NCRBSL \le 6$	-
DELTC	Δt_c	INTEGRATION TIME STEP FOR CURB IMPACTS	sec
IDRVER		INDICATOR FOR PREVIEW-PREDICTOR DRIVER OPTION DRIVER OPTION USED IF IDRVER $\neq$ 0	-
IBUG		INDICATOR FOR ADDITIONAL DRIVER OUTPUT IBUG = 0, NO ADDITIONAL OUTPUT IBUG = 1, MINIMUM ADDITIONAL OUTPUT IBUG = 2, MAXIMUM ADDITIONAL OUTPUT NOTE: IF INDCRB = -1, INITIAL CONDITION FOR THE FRONT WHEEL STEER ANGLE (PSIFIC, PSIFDO) MUST BE SUPPLIED ON CARD 601	

MODE	EBAR	EM	AAA	HMAX	HMIN	BET			103
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	**Analytical Variable**	**Description**	**Input Units**
MODE		NUMERICAL INTEGRATION MODE INDICATOR = 0, VARIABLE ADAMS-MOULTON = 1, RUNGE-KUTTA = 2, FIXED ADAMS-MOULTON NOTE: THE FOLLOWING VARIABLES ARE REQUIRED WHEN MODE=0, SEE SECTION 3.5.	
EBAR	$\overline{E}$	UPPER BOUND ON THE TRUNCATION ERROR ESTIMATE	
EM	M	CONSTANT FROM WHICH THE LOWER BOUND ON THE TRUNCATION ERROR ESTIMATE IS COMPUTED	
AAA	α	POSITIVE NUMBER USED TO PREVENT UNNECESSARY REDUCTION IN THE VARIABLE STEP SIZE	
HMAX	h_{max}	POSITIVE UPPER BOUND ON THE MAGNITUDE OF THE VARIABLE STEP SIZE	
HMIN	h_{min}	POSITIVE LOWER BOUND ON THE MAGNITUDE OF THE VARIABLE STEP SIZE	
BETA	β	POSITIVE NUMBER BETWEEN ZERO AND ONE USED TO INCREASE OR DECREASE THE STEP SIZE	

NPAGE(4)	NPAGE(6)	NPAGE(7)	NPAGE(8)	NPAGE(9)	NPAGE(10)	NPAGE(14)	NPAGE(19)		104
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		NOTE: THE NPAGE ARRAY IS USED TO CONTROL OUTPUT PRINTED FROM A RUN. IF AN ARRAY ELEMENT IS NON-ZERO THE GROUP OF OUTPUT DATA CORRESPONDING TO THAT ELEMENT IS PRINTED. THE OUTPUT CORRESPONDING TO THE ELEMENTS READ ON CARD 104 ARE USER CONTROLLED. IF THE OUTPUT IS DESIRED A NON-ZERO NUMBER MUST BE READ IN THE APPROPRIATE FIELD. THE OUTPUT GROUPS CORRESPONDING TO THESE ELEMENTS ARE:	
NPAGE(4)		ANGULAR ACCELERATIONS; SUSPENSION ACCELERATIONS FOR INDEPENDENT SUSPENSIONS OR DISPLACEMENTS, VELOCITIES AND ACCELERATIONS OF THE ROLL CENTER AND AXLE ANGLE FOR SOLID AXLES	
NPAGE(6)		INCLINATION (CAMBER) ANGLE OF THE WHEELS WITH RESPECT TO THE GROUND; STEER ANGLE OF THE WHEELS; AND CAMBER ANGLE OF THE WHEELS WITH RESPECT TO THE VEHICLE	
NPAGE(7)		LONGITUDINAL AND LATERAL VELOCITIES OF THE TIRE CONTACT POINT WITH RESPECT TO THE VEHICLE	
NPAGE(8)		ELEVATION OF THE GROUND CONTACT POINT OF THE TIRES	
NPAGE(9)		TOTAL SUSPENSION FORCES AND SUSPENSION ANTI-PITCH FORCES	
NPAGE(10)		SUSPENSION DAMPING FORCES AND CHANGE IN SUSPENSION SPRING FORCES FROM EQUILIBRIUM	
NPAGE(14)		COMPONENTS OF TIRE FORCES ALONG THE INERTIAL AXES	
NPAGE(19)		ENERGY DISSIPATED BY BRAKES AND TIRES	

VHED(I),	I=1,18								200
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
VHED	-	VEHICLE DESCRIPTION TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING THE SIMULATED VEHICLE. NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	-

XMS	XMUF	XMUR	XIX	XIY	XIZ	XIXZ	XIR	XIF	201
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
XMS	M_S	SPRUNG MASS	lb-sec^2/in
XMUF	M_{uF}	TOTAL FRONT UNSPRUNG MASS	lb-sec^2/in
XMUR	M_{uR}	TOTAL REAR UNSPRUNG MASS	lb-sec^2/in
XIX	I_X	MASS MOMENT OF INERTIA OF THE SPRUNG MASS ABOUT THE VEHICLE x AXIS	lb-sec^2-in
XIY	I_Y	MASS MOMENT OF INERTIA OF THE SPRUNG MASS ABOUT THE VEHICLE y AXIS	lb-sec^2-in
XIZ	I_Z	MASS MOMENT OF INERTIA OF THE SPRUNG MASS ABOUT THE VEHICLE z AXIS	lb-sec^2-in
XIXZ	I_{XZ}	MASS PRODUCT OF INERTIA OF THE SPRUNG MASS IN THE VEHICLE x-z PLANE	lb-sec^2-in
XIR	I_R	MASS MOMENT OF INERTIA OF THE SOLID AXLE REAR UNSPRUNG MASS ABOUT A LINE PARALLEL TO THE VEHICLE x-AXIS AND THROUGH THE REAR UNSPRUNG MASS CENTER OF GRAVITY. REQUIRED ONLY IF ISUS = 0 OR 2	lb-sec^2-in
XIF	I_F	MASS MOMENT OF INERTIA OF THE SOLID AXLE FRONT UNSPRUNG MASS ABOUT A LINE PARALLEL TO THE VEHICLE x-AXIS AND THROUGH THE FRONT UNSPRUNG MASS CENTER OF GRAVITY. REQUIRED ONLY IS ISUS = 2	lb-sec^2-in

A	B	TF	TR	RHO	TS	RHOF	TSF	G	202
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

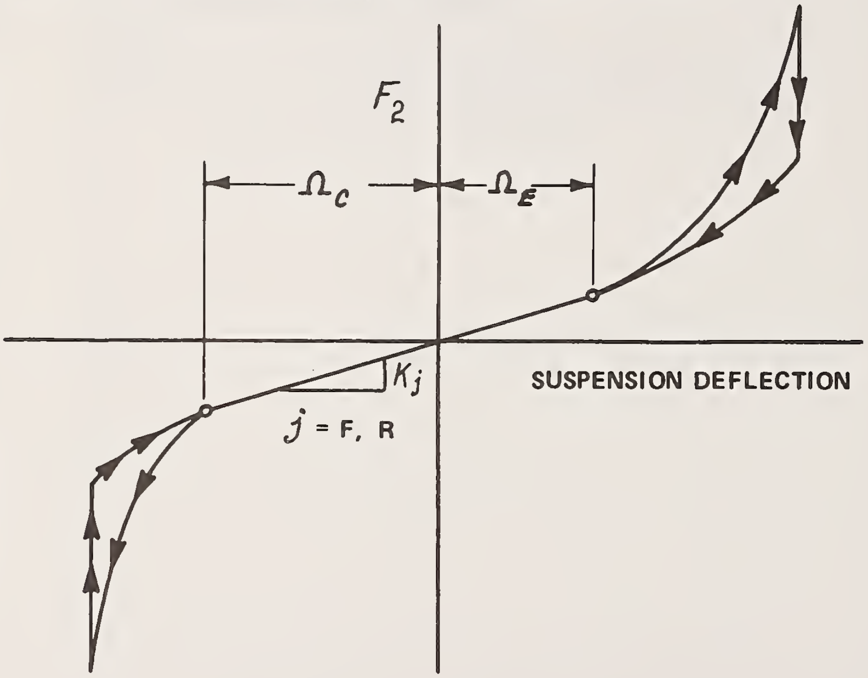
Program Variable	Analytical Variable	Description	Input Units
A	a	HORIZONTAL DISTANCE FROM SPRUNG MASS C.G. TO CENTERLINE OF FRONT WHEELS	in
B	b	HORIZONTAL DISTANCE FROM SPRUNG MASS C.G. TO CENTERLINE OF REAR WHEELS	in
TF	T_F	FRONT WHEEL TRACK	in
TR	T_R	REAR WHEEL TRACK	in
RHO	ρ	VERTICAL DISTANCE BETWEEN REAR AXLE C.G. AND REAR AXLE ROLL CENTER, POSITIVE FOR ROLL CENTER ABOVE C.G.	in
TS	T_S	DISTANCE BETWEEN REAR SPRING MOMENTS FOR SOLID REAR AXLE	in
		NOTE: RHO AND TS REQUIRED ONLY IF ISUS = 0 OR 2	
RHOF	ρ_F	VERTICAL DISTANCE BETWEEN FRONT AXLE C.G. AND FRONT AXLE ROLL CENTER, POSITIVE FOR ROLL CENTER ABOVE C.G.	in
TSF	T_{SF}	DISTANCE BETWEEN FRONT SPRING MOUNTS FOR SOLID FRONT AXLE	in
		NOTE: RHOF AND TSF REQUIRED ONLY IF ISUS = 2	
G	g	GRAVITATIONAL ACCELERATION	$\mathrm{in/sec}^2$
		NOTE: IF G IS NOT SUPPLIED A DEFAULT VALUE OF 386.4 $\mathrm{in/sec}^2$ IS ASSUMED	

X1	Y1	Z1	X2	Y2	Z2	ZF	ZR		203
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
X1	X_1	COORDINATES OF FIRST ACCELEROMETER POSITION WITH RESPECT TO THE VEHICLE	in
Y1	Y_1		
Z1	Z_1		
X2	X_2	COORDINATES OF SECOND ACCELEROMETER POSITION WITH RESPECT TO THE VEHICLE	in
Y2	Y_2		
Z2	Z_2		
ZF	Z_F	STATIC VERTICAL DISTANCE BETWEEN FRONT WHEEL C.G. (OR FRONT AXLE ROLL CENTER IF ISUS = 2) AND SPRUNG MASS C.G.	in
ZR	Z_R	STATIC VERTICAL DISTANCE BETWEEN REAR AXLE ROLL CENTER (OR REAR WHEEL C.G.) AND SPRUNG MASS C.G.	in
		NOTE: IF ZF AND ZR ARE NOT SUPPLIED, THEY WILL AUTOMATICALLY BE CALCULATED WITHIN THE PROGRAM TO INSURE INITIAL VERTICAL EQUILIBRIUM OF THE VEHICLE ON FLAT, LEVEL TERRAIN AT 0.0 ELEVATION	

AKF	AFFC	AKFCP	AKFE	AKFEP	XLAMF	OMEGFC	OMEGFE		204
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
AKF	K_F	LINEAR FRONT SUSPENSION LOAD DEFLECTION RATE	lb/in
AKFC	K_{FC}	LINEAR COEFFICIENT OF THE FRONT SUSPENSION COMPRESSION (JOUNCE) BUMPER TERM	lb/in
AKFCP	K'_{FC}	CUBIC COEFFICIENT OF THE FRONT SUSPENSION COMPRESSION (JOUNCE) BUMPER TERM	lb/in^3
AKFE	K_{FE}	LINEAR COEFFICIENT OF THE FRONT SUSPENSION EXTENSION (REBOUND) BUMPER TERM	lb/in
AKFEP	K'_{FE}	CUBIC COEFFICIENT OF THE FRONT SUSPENSION EXTENSION (REBOUND) BUMPER TERM	lb/in^3
XLAMF	λ_F	RATIO OF CONSERVED TO TOTAL ABSORBED ENERGY IN THE FRONT SUSPENSION BUMPERS	-
OMEGFC	Ω_{FC}	FRONT SUSPENSION DEFLECTION AT WHICH THE COMPRESSION BUMPER IS CONTACTED (Note: should be negative)	in
OMEGFE	Ω_{FE}	FRONT SUSPENSION DEFLECTION WHICH THE EXTENSION BUMPER IS CONTACTED (Note: should be positive)	in
		NOTE: ALL SUSPENSION PARAMETERS ARE EFFECTIVE AT THE WHEEL FOR INDEPENDENT FRONT SUSPENSION OR AT THE SPRING POSITION FOR SOLID FRONT AXLE	



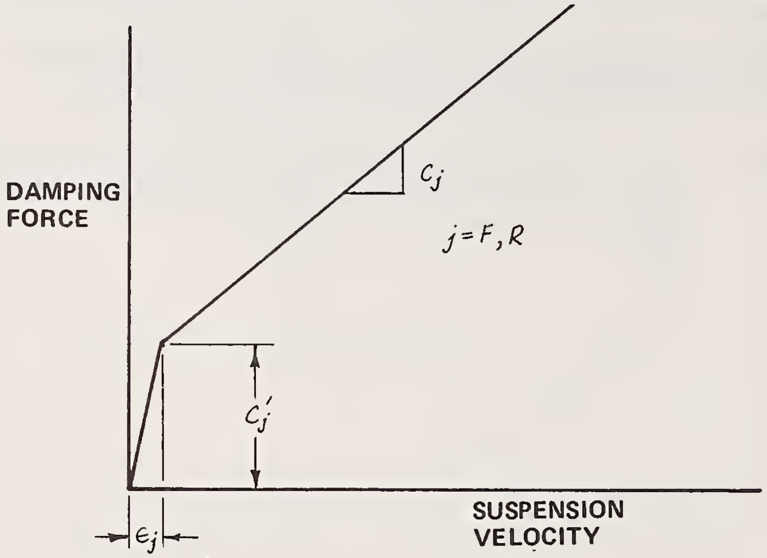
GENERAL FORM OF SIMULATED SUSPENSION BUMPER CHARACTERISTICS

AKR	AKRC	AKRCP	AKRE	AKREP	XLAMR	OMEGRC	OMEGRE		205
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
AKR	K_R	LINEAR REAR SUSPENSION LOAD DEFLECTION RATE	lb/in
AKRC	K_{RC}	LINEAR COEFFICIENT OF THE REAR SUSPENSION COMPRESSION (JOUNCE) BUMPER TERM	lb/in
AKRCP	K'_{RC}	CUBIC COEFFICIENT OF THE REAR SUSPENSION COMPRESSION (JOUNCE) BUMPER TERM	lb/in^3
AKRE	K_{RE}	LINEAR COEFFICIENT OF THE REAR SUSPENSION EXTENSION (REBOUND) BUMPER TERM	lb/in
AKREP	K'_{RE}	CUBIC COEFFICIENT OF THE REAR SUSPENSION EXTENSION (REBOUND) BUMPER TERM	lb/in^3
XLAMR	λ_R	RATIO OF CONSERVED TO TOTAL ABSORBED ENERGY IN THE REAR SUSPENSION BUMPERS	-
OMEGRC	Ω_{RC}	REAR SUSPENSION DEFLECTION AT WHICH THE COMPRESSION BUMPER IS CONTACTED (Note: should be negative)	in
OMEGRE	Ω_{RE}	REAR SUSPENSION DEFLECTION AT WHICH THE EXTENSION BUMPER IS CONTACTED (Note: should be positive)	in
		NOTE: ALL SUSPENSION PARAMETERS ARE EFFECTIVE AT THE WHEEL FOR INDEPENDENT REAR SUSPENSION OR AT THE SPRING FOR SOLID REAR AXLE.	

CF	CFP	EPSF	CR	CRP	EPSR				206
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
CF	C_F	FRONT VISCOUS DAMPING COEFFICIENT PER SIDE	lb sec/ in
CFP	C_F	FRONT SUSPENSION COULOMB FRICTION PER SIDE	lb
EPSF	ε_F	FRONT SUSPENSION FRICTION NULL BAND	in/sec
CR	C_R	REAR SUSPENSION VISCOUS DAMPING COEFFICIENT PER SIDE	lb sec/ in
CRP	C'_R	REAR SUSPENSION COULOMB FRICTION PER SIDE	lb
EPSR	ε_R	REAR SUSPENSION FRICTION NULL BAND	in/sec
		NOTE: ALL SUSPENSION PARAMETERS ARE EFFECTIVE AT THE WHEEL FOR INDEPENDENT SUSPENSION OR AT THE SPRING FOR SOLID AXLE	

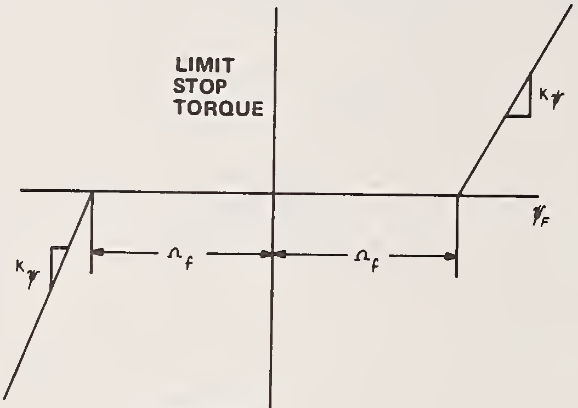


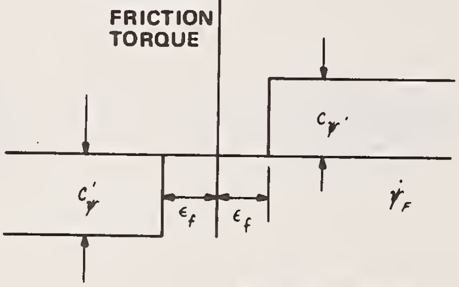
RF	RR	AKRS	AKDS	AKDS1	AKDS2	AKDS3			207
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

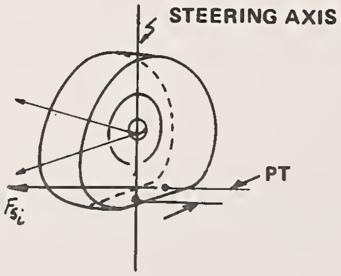
Program Variable	Analytical Variable	Description	Input Units
RF	R_F	AUXILIARY ROLL STIFFNESS OF THE FRONT SUSPENSION	lb-in/ rad
RR	R_R	REAR SUSPENSION AUXILIARY ROLL STIFFNESS	lb in/ rad
AKRS	K_{RS}	REAR AXLE ROLL-STEER COEFFICIENT NOTE: AKRS IS REQUIRED ONLY IF ISUS = 0 OR 2	deg/deg
AKDS	$K_{\delta s}$	COEFFICIENTS FOR CUBIC REPRESENTATION OF REAR WHEEL STEER ANGLE AS A FUNCTION OF WHEEL DISPLACEMENT. THESE COEFFICIENTS ARE REQUIRED ONLY WHEN ISUS = 1	rad
AKDS1	$K_{\delta s1}$		rad/in
AKDS2	$K_{\delta s2}$		$\mathrm{rad/in}^2$
AKDS3	$K_{\delta s3}$		$\mathrm{rad/in}^3$

XIPS	CPSP	OMGPS	AKPS	EPSPS	XPS				208
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
XIPS	I_ψ	STEERING SYSTEM STEER MOMENT OF INERTIA ABOUT THE WHEEL STEERING AXES	lb-sec^2-in
CPSP	C'_ψ	STEERING SYSTEM COULOMB FRICTION TORQUE, EFFECTIVE AT THE WHEEL STEERING AXES	lb-in
OMGPS	Ω_ψ	FRONT WHEEL STEER ANGLE AT WHICH STEERING LIMIT STOPS ARE ENGAGED	rad
AKPS	K_ψ	STIFFNESS OF THE STEERING LIMIT STOPS, EFFECTIVE AT THE FRONT WHEEL STEERING AXES	lb-in/rad
EPSPS	ε_ψ	FRICTION LAG IN THE STEERING SYSTEM	rad/sec
XPS	$\overline{PT}$	FRONT WHEEL PNEUMATIC TRAIL	in
		NOTE: THIS CARD MUST BE FURNISHED IF INDCRB (CARD 101) IS EITHER 1.0 OR -1.0	







DELB	DELE	DDEL	NDTHF	NDTHR					209
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		NOTE: THE PARAMETERS ON CARD 209 APPLY TO FOUR TABLES DEFINING CAMBER AND HALF-TRACK CHANGES AS A FUNCTION OF WHEEL DISPLACEMENT. CARD 209 AND SUBSEQUENT TABLE CARDS ARE NOT REQUIRED IF ISUS = 2.	
DELB		BEGINNING VALUE OF WHEEL DISPLACEMENT FOR TABLES	in
DELE		ENDING VALUE OF WHEEL DISPLACEMENT FOR TABLES	in
DDEL		INCREMENT VALUE OF WHEEL DISPLACEMENT FOR TABLES	in
NDTHF		INDICATOR FOR FRONT HALF-TRACK CHANGE TABLE. TABLE IS SUPPLIED IF NDTHF ≠ 0	
NDTHR		INDICATOR FOR REAR HALF-TRACK CHANGE TABLE. TABLE IS SUPPLIED IF NDTHR ≠ 0 AND ISUS = 1	
		FOLLOWING CARD 209 ARE UP TO 4 TABLES CONTAINING [(DELE-DELB)/DDEL]+1 ENTRIES IN THE ORDER:	
		PHIC(I) FRONT WHEEL CAMBER TABLE	deg
		PHIRC(I) REAR WHEEL CAMBER TABLE (REQUIRED IF ISUS=1)	deg
		DTHF(I) FRONT HALF-TRACK CHANGE (REQUIRED IF NDTHF≠0)	in
		DTHR(I) REAR HALF-TRACK CHANGE (REQUIRED IF ISUS=1 AND NDTHR ≠ 0)	in
		TABLE ENTRIES ARE READ IN FIELDS OF 8 AND MUST CONTAIN 209 IN COLUMNS 78-80. A TABLE SEQUENCE NUMBER MUST ALSO BE SUPPLIED IN COLUMN 76 AND SEQUENCE NUMBER MUST INCREASE WITH EACH CARD. EACH NEW TABLE MUST START ON A NEW CARD. A MAXIMUM OF 50 ENTRIES IS ALLOWED FOR EACH TABLE. EXAMPLE (ASSUMING ISUS = 1):	

-5,0	5.0	1.0	1.0	1.0					209
PHIC(1)	PHIC(2)	...					...	PHIC(9)	1 209
PHIC(10)	PHIC(11)								2 209
PHIR(1)	PHIRC(2)	...					...	PHIC(9)	3 209
PHIRC(10)	PHIRC(11)								4 209
DTHF(1)	DTHF(2)	...					...	DTHF(9)	5 209
DTHF(10)	DTHF(11)								6 209
DTHR(1)	DTHR(2)	...					...	DTHR(9)	7 209
DTHR(10)	DTHR(12)								8 209
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

DAPFB	DAPFE	DDAPF							210
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DAPFB		BEGINNING SUSPENSION DEFLECTION FOR FRONT ANTI-PITCH COEFFICIENT TABLE	in
DAPFE		ENDING SUSPENSION DEFLECTION FOR FRONT ANTI-PITCH COEFFICIENT TABLE	in
DDAPF		INCREMENTAL DEFLECTION FOR FRONT ANTI-PITCH COEFFICIENT TABLE	in
APF	AP_F	FOLLOWING CARD 210 IS A TABLE CONTAINING [(DAPFE-DAPFB)/ DDAPF]+1 ENTRIES OF FRONT ANTI-PITCH COEFFICIENT, APF(I) TABLE ENTRIES ARE READ IN 9 FIELDS OF 8 COLUMNS. A MONOTONICALLY INCREASING TABLE SEQUENCE NUMBER MUST BE IN COLUMN 76 AND 210 MUST BE IN COLUMNS 78-80. A MAXIMUM OF 21 ENTRIES IS ALLOWED. EXAMPLE:	lb/lb-ft

-5.0	5.0	1.0							210
APF(1)	APF(2)	APF(3)	...				APF(8)	APF(9)	1 210
APF(10)	APF(11)								2 210
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

DAPRB	DAPRE	DDAPR							211
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 38 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DAPRB		BEGINNING SUSPENSION DEFLECTION FOR REAR ANTI-PITCH COEFFICIENT TABLE	in
DAPRE		ENDING SUSPENSION DEFLECTION FOR REAR ANTI-PITCH COEFFICIENT TABLE	in
DDAPR		INCREMENTAL DEFLECTION FOR REAR ANTI-PITCH COEFFICIENT TABLE	in
APR	AP_R	FOLLOWING CARD 211 IS A TABLE CONTAINING [(DAPRE-DAPRB)/ DDAPR]+1 ENTRIES OF REAR ANTI-PITCH COEFFICIENT, APR(I) TABLE ENTRIES ARE READ IN 9 FIELDS OF 8 COLUMNS. A MONOTONICALLY INCREASING TABLE SEQUENCE NUMBER MUST BE IN COLUMN 76 AND CARD NUMBER 211 MUST BE IN COLUMNS 78-80. A MAXIMUM OF 21 ENTRIES IS ALLOWED. EXAMPLE:	lb/lb-ft

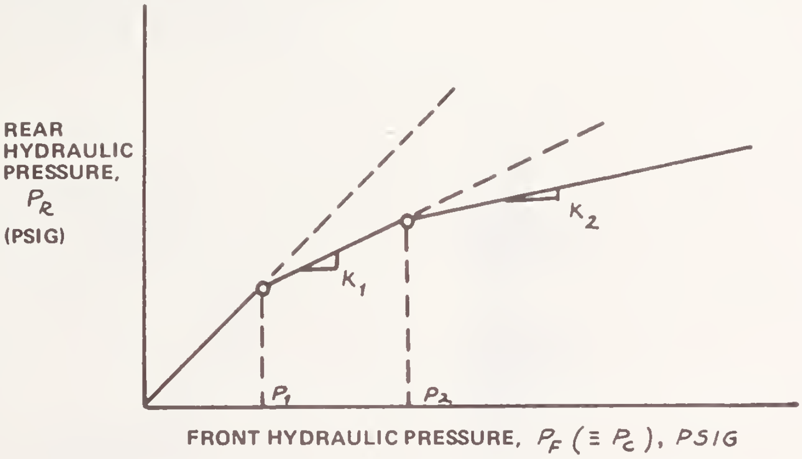
-5.0	5.0	5.0							211
APR(1)	APR(2)	APR(3)							1 211
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

FIDJF	FIWJF	FIDJR	FIWJR	ARBRF	ARBRR				212
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
FIDJF	I_{DF}	FRONT DRIVE LINE INERTIA (Note: if rear wheel drive vehicle, I_{DF} should be entered as 0.0)	$lb\text{-}sec^2\text{-}in$
FIWJF	I_{WF}	ROTATIONAL (SPIN) INERTIA OF AN INDIVIDUAL FRONT WHEEL	$lb\text{-}sec^2\text{-}in$
FIDJR	I_{DR}	REAR DRIVE LINE INERTIA (Note: if front wheel drive vehicle I_{DR} should be entered as 0.0)	$lb\text{-}sec^2\text{-}in$
FIWJR	I_{WR}	ROTATIONAL (SPIN) INERTIA OF AN INDIVIDUAL REAR WHEEL	$lb\text{-}sec^2\text{-}in$
ARBRF	$(AR)_F$	DRIVING AXLE RATIO FOR FRONT WHEEL DRIVE; RATIO OF PROP-SHAFT SPEED TO WHEEL SPEED. (Note: In general $(AR)_F$ will be greater than 1.0; default is 1.0)	-
ARBRR	$(AR)_R$	DRIVING AXLE RATIO FOR REAR WHEEL DRIVE; RATIO OF PROP-SHAFT SPEED TO WHEEL SPEED. (Note: In general $(AR)_R$ will be greater than 1.0, default is 1.0)	-

AK1	AK2	PONE	PTWO	PZERO(1)	PZERO(2)	ZETAB			213
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
AK1	K_1	SLOPE OF P_R VS P_F (REAR TO FRONT BRAKE SYSTEM PRESSURE PROPORTIONING) FOR $P_1 < P_F < P_2$.	
AK2	K_2	SLOPE OF P_R VS P_F (REAR TO FRONT BRAKE SYSTEM PRESSURE PROPORTIONING) FOR $P_F > P_2$	-
PONE	P_1	FIRST PRESSURE AT WHICH REAR TO FRONT BRAKE SYSTEM PRESSURE PROPORTIONING OCCURS	lb/in^2
PTWO	P_2	SECOND PRESSURE AT WHICH REAR TO FRONT BRAKE SYSTEM PRESSURE PROPORTIONING OCCURS	lb/in^2
PZERO(1)	P_{FO}	PUSH-OUT PRESSURE OF FRONT BRAKES, REQUIRED TO PRODUCE CONTACT BETWEEN THE LINING MATERIAL AND DRUM OR DISK	psig
PZERO(2)	P_{R_O}	PUSH-OUT PRESSURE OF REAR BRAKES, REQUIRED TO PRODUCE CONTACT BETWEEN THE LINING MATERIAL AND DRUM OR DISK	psig
ZETAB	ζ_B	THRESHOLD VALUE OF WHEEL ROTATIONAL VELOCITY, BELOW WHICH LOGIC IS APPLIED TO LIMIT BRAKING TORQUE	rad/sec

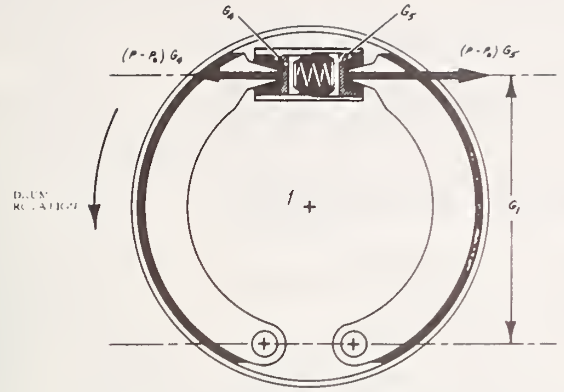


REAR VS FRONT HYDRAULIC PRESSURE WITH PRESSURE REDUCING DEVICE

IBTYP(1)	IBTYP(2)								214

Program Variable	Analytical Variable	Description	Input Units
IBTYP(1)	TYPE	FRONT WHEEL BRAKE TYPE INDICATOR. $1 \le \text{IBTYP} \le 4$	
IBTYP(2)	TYPE	REAR WHEEL BRAKE TYPE INDICATOR. $1 \le \text{IBTYPE} \le 4$	
		FOLLOWING THIS CARD ARE 4 TABLE CARDS CONTAINING:	
GN	$G_{1F,R}$ THROUGH $G_{16F,R}$	BRAKE PARAMETERS. THE SECOND SUBSCRIPT OF GN(I,J) REFERS TO FRONT BRAKES IF 1 AND REAR BRAKES IF 2. THE FIRST SUBSCRIPT REFERS TO THE BRAKE PARAMETER DESCRIPTIVE OF THE TYPE OF BRAKE AS INDICATED BY IBTYP(1) AND IBTYP(2) ON CARD 214.	
		THE BRAKE PARAMETERS ARE READ IN THE FOLLOWING FORMAT.	

GN(1,1)	GN(2,1)	GN(3,1)	GN(4,1)	GN(5,1)	GN(6,1)	GN(7,1)	GN(8,1)	GN(9,1)	1 214
GN(0,1)	GN(11,1)	GN(12,1)	GN(13,1)	GN(14,1)					2 214
GN(1,2)	GN(2,2)	GN(3,2)	GN(4,2)	GN(5,2)	GN(6,2)	GN(7,2)	GN(8,2)	GN(9,2)	3 214
GN(10,2)	GN(11,2)	GN(12,2)	GN(13,2)	GN(14,2)					4 214



G_1 = Lever arm, inches

G_2 = Actuation constant, assumed to be equal for the two shoes. (Note that $G_2 \approx 1.42$ in Chrysler Products

(LF) = Coefficient to permit change of lining friction at elevated temperatures

G_3 = Effective lining-to-drum friction coefficient at design temp.

G_4 = Cylinder area - leading shoe, in.^{2}

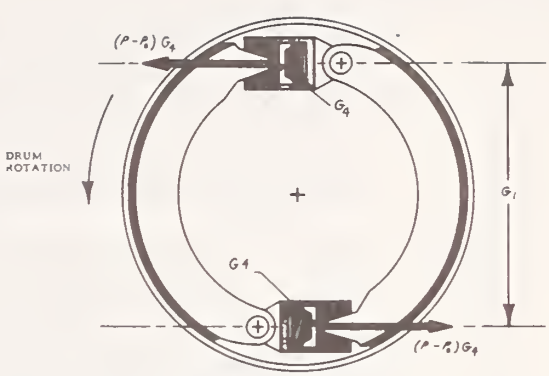
G_5 = Cylinder area - trailing shoe, in.^{2}

P = Hydraulic pressure, psig

P_0 = Push-out pressure, psig

$$(TQ)_B = \begin{cases} 0, \text{ for } (P-P_0) \le 0 \\ \frac{1}{12}(P-P_0)\, G_1 G_2 G_3 (LF) \left\{ \frac{G_4 [1 + G_2 G_3 (LF)] + G_5 [1 - G_2 G_3 (LF)]}{[1 - G_2 G_3 (LF)]^2} \right\} \text{ for } 0 < (P-P_0) \end{cases}$$

TYPE 1 BRAKE-DRUM TYPE WITH LEADING AND TRAILING SHOES, UNIFORM OR STEPPED CYLINDER



G_1 : Lever arm, inches

G_2 : Actuation constant

(LF) : Coefficient to permit change of lining friction at elevated temperatures

G_3 : Effective lining-to-drum friction coefficient at design temp.

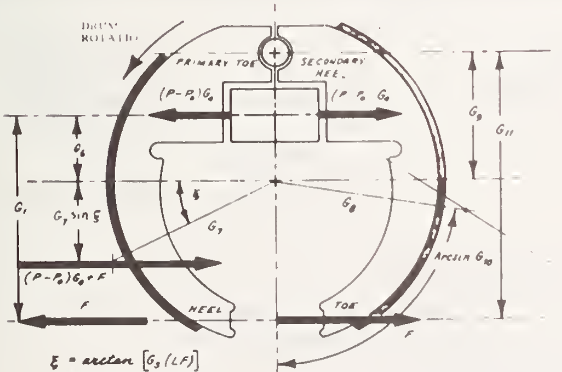
G_4 Cylinder area, in.^{2}

P Hydraulic pressure, psig

P_0 Push-out pressure, psig

$$(TQ)_B = \begin{cases} 0, \text{ for } (P-P_0) \le 0 \\ \frac{1}{6}(P-P_0)\, G_1 G_4 \left[\frac{G_2 G_3 (LF)}{1 - G_2 G_3 (LF)} \right], \text{ for } 0 < (P-P_0) \end{cases}$$

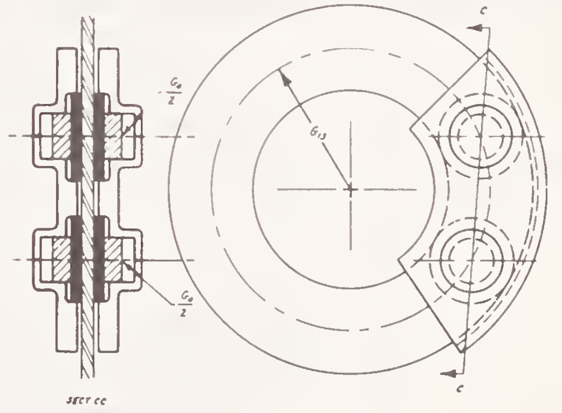
TYPE 2 BRAKE-DRUM TYPE WITH TWO LEADING SHOES, TWO CYLINDERS



$\xi = \arctan [G_3 (LF)]$
$G_7 \approx (1.04)(\text{DRUM RADIUS})$

$$(TQ)_B = \begin{cases} 0, \text{ for } (P-P_0) \le 0 \\ \frac{1}{12}(P-P_0)\, G_4 \left\{ \left[1 + \frac{G_6 + G_7 \sin\xi}{G_1 - G_6 - G_7 \sin\xi} \right] \left[G_7 \sin\xi + \frac{G_8 G_{11} G_{12} (LF)}{G_9 G_{10} [1 - G_2 G_{12} (LF)]} \right] - \frac{G_1 G_8 G_{12} (LF)}{G_9 G_{10} [1 - G_2 G_{12} (LF)]} \right\}, \text{ for } 0 < (P-P_0) \end{cases}$$

TYPE 3 BRAKE-BENDIX DUO SERVO



G_4 : Total cylinder area per side of disc, in.^{2}

G_{13} : Mean lining radius, inches

G_3 = Effective lining-to-disc friction coefficient

(LF) = Coefficient to permit change of lining friction at elevated temperatures

P = Hydraulic pressure, psig

P_0 = Push-out pressure, psig

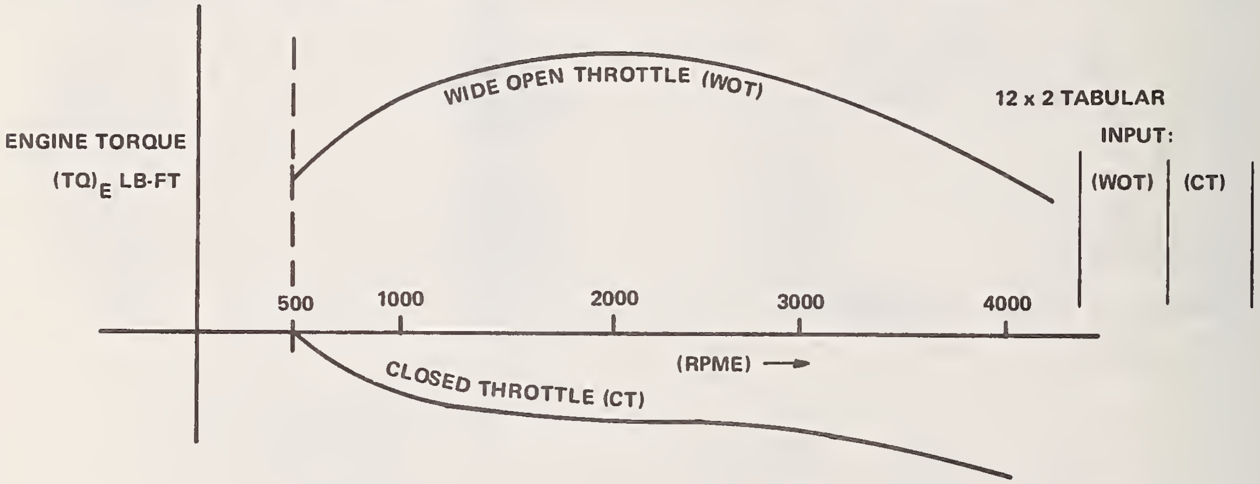
$$(TQ)_B = \begin{cases} 0, \text{ for } (P-P_0) \le 0 \\ \frac{1}{6}(P-P_0)\, G_3 G_4 G_{13} (LF), \text{ for } 0 < (P-P_0) \end{cases}$$

TYPE 4 BRAKE-CALIPER DISC

BRPM	ERPM	DRPM							215
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
BRPM		LOWEST ENGINE RPM FOR ENGINE TORQUE TABLES VS RPM	RPM
ERPM		HIGHEST ENGINE RPM FOR ENGINE TORQUE TABLES VS RPM	RPM
DRPM		INCREMENT OF ENGINE RPM FOR ENGINE TORQUE TABLES VS RPM	RPM
		FOLLOWING THIS CARD ARE TWO ENGINE TORQUE TABLES:	
TWOT	WOT	TWOT - ENGINE TORQUE FOR WIDE-OPEN THROTTLE	lb-ft
TCT	CT	TCT - ENGINE TORQUE FOR CLOSED THROTTLE	lb-ft
		A MAXIMUM OF 12 ENTRIES IS ALLOWED FOR EACH TABLE. EACH TABLE CARD MUST CONTAIN 215 IN COLUMNS 78-80 AND AN INCREASING SEQUENCE NUMBER IN COLUMN 76. THE NUMBER OF ENTRIES SUPPLIED MUST BE N = [(ERPM-BRPM)/DRPM]+1	
TWOT(I)	I=1,N		
TCT(I)	I=1,N		
		FOR EXAMPLE:	

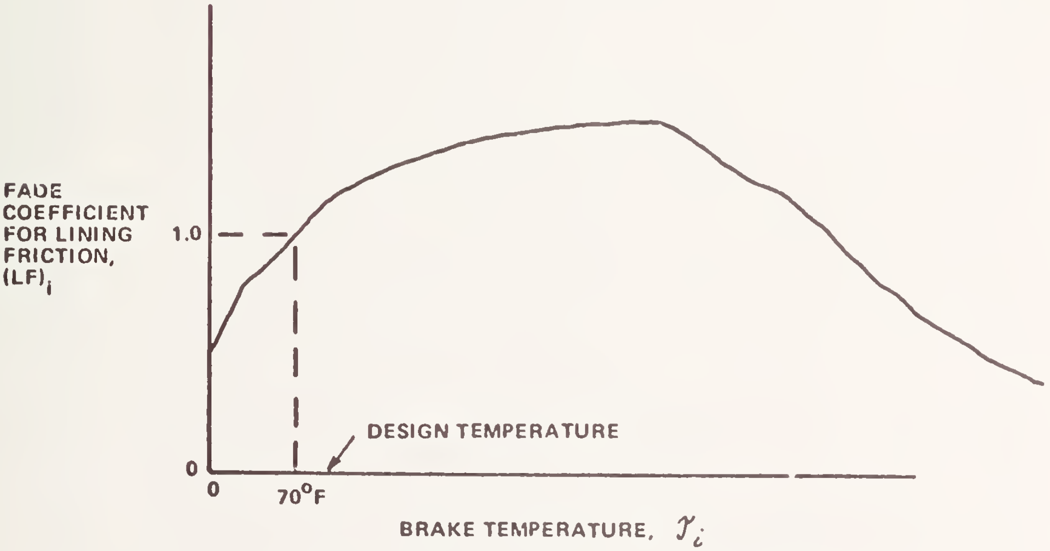
500.	500.	500.							215
TWOT(1)	TWOT(2)	TWOT(3)	TWOT(4)	TWOT(5)	TWOT(6)	TWOT(7)	TWOT(8)	TWOT(9)	1 215
TWOT(10)									2 215
TCT(1)	TCT(2)	TCT(3)	TCT(4)	TCT(5)	TCT(6)	TCT(7)	TCT(8)	TCT(9)	3 215
TCT(10)									4 215
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80



INPUTS TO DEFINE ENGINE PROPERTIES

BTLF	ETLF	DTLF							216
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
BTLF		LOWEST TEMPERATURE FOR BRAKE LINING FACE COEFFICIENT VS TEMPERATURE	°F
ETLF		HIGHEST TEMPERATURE FOR BRAKE LINING FACE COEFFICIENT VS TEMPERATURE	°F
DTLF		INCREMENT OF TEMPERATURE FOR BRAKE LINING FADE COEFFICIENT VS TEMPERATURE FOLLOWING THIS CARD IS A TABLE:	°F
TLF	LF	BRAKE LINING FADE COEFFICIENT TABLE AS A FUNCTION OF TEMPERATURE. LINING COEFFICIENT TABLE CORRESPONDS TO TEMPERATURES FROM BTLF TO ETLF IN INCREMENTS OF DTLF. THE NUMBER OF ENTRIES IN THE TABLE IS: [(ETLF-BTLF)/DTLF]+1 AND IS LIMITED TO 51. THE TABLE IS READ WITH 216 IN COLUMNS 78-80 AND AN INCREASING SEQUENCE NUMBER IN COLUMN 76.	
TLF(I)	I=1,N		S 216



FADE COEFFICIENT VS TEMPERATURE

CONE	CTWO	CTHREE							217
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
CONE	C_1	AERODYNAMIC DRAG COEFFICIENT	lb-sec^2/in^2
CTWO	C_2	LINEAR ROLLING RESISTANCE COEFFICIENT (A FUNCTION OF LONGITUDINAL VEHICLE VELOCITY)	lb-sec/in
CTHREE	C_3	CONSTANT ROLLING RESISTANCE TERM	lb

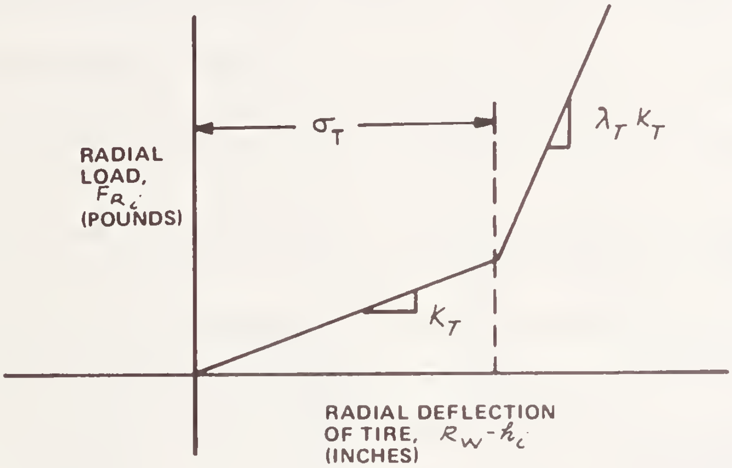
THED(I)	I=1,18								300
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
THED	-	TIRE TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING THE SIMULATED VEHICLE TIRES. NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	-

ITIR(1)	ITIR(2)	ITIR(3)	ITIR(4)	AMU	RWHJE	DRWHJ	NXFRCP	NXUGMU	301
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
ITIR(1)		INDICATOR TO IDENTIFY THE SET OF TIRE DATA TO BE USED FOR THE RF TIRE	-
ITIR(2)		INDICATOR TO IDENTIFY THE SET OF TIRE DATA TO BE USED FOR THE LF TIRE	-
ITIR(3)		INDICATOR TO IDENTIFY THE SET OF TIRE DATA TO BE USED FOR THE RR TIRE	-
ITIR(4)		INDICATOR TO IDENTIFY THE SET OF TIRE DATA TO BE USED FOR THE LR TIRE	-
AMU	μ	NOMINAL GROUND FRICTION COEFFICIENT (see Section 3.4.5.1.4.2)	-
RWHJE		FINAL DEFLECTION ($R_W-h'_j$) OF THE FORCE (F'_j) VERSUS DEFLECTION CHARACTERISTIC OF THE RADIAL SPRING TIRE MODEL	in
DRWHJ		INCREMENT OF DEFLECTION OF THE FORCE-DEFLECTION CHARACTERISTIC OF THE RADIAL SPRING TIRE MODEL. NOTE: RWHJE AND DRWHJ MUST BE SUPPLIED ONLY IF INDCRB=1 OR IRUF≠0. THE FORCE CORRESPONDING TO THE DEFLECTION VALUES IS COMPUTED AUTOMATICALLY IN SUBROUTINE WHEEL FOR EACH SET OF TIRE PROPERTIES. THE NUMBER OF FORCE ENTRIES IS LIMITED TO 35. THEREFORE $\frac{RWHJE}{DRWHJ} + 1 \le 35$	in
NXFRCP		NUMBER OF TIRE LOADS FOR WHICH TIRE FRICTION DATA IS SUPPLIED, $2 \le$ NXFRCP ≤ 6	
NXUGMU		NUMBER OF SPEEDS FOR WHICH TIRE FUNCTION DATA IS SUPPLIED. $2 \le$ NXUGMU ≤ 6	
		FOLLOWING THIS CARD ARE TWO TABLE CARDS CONTAINING:	
XXFRCP		XXFRCP - TIRE LOADS FOR WHICH FRICTION DATA IS SUPPLIED	lb
XXUGMU		XXUGMU - SPEEDS FOR WHICH FRICTION DATA IS SUPPLIED	in/sec
XXFRCP(I)		I = 1, NXFRCP	1 301
XXUGMU(I)		I = 1, NXUGMU	2 301

The following set of cards are required for each distinct tire data set. At least one set is required and no more than four (different sets for each vehicle tire) can be supplied. The first data set is read on cards 302, the second on cards 303, etc.



K									302
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

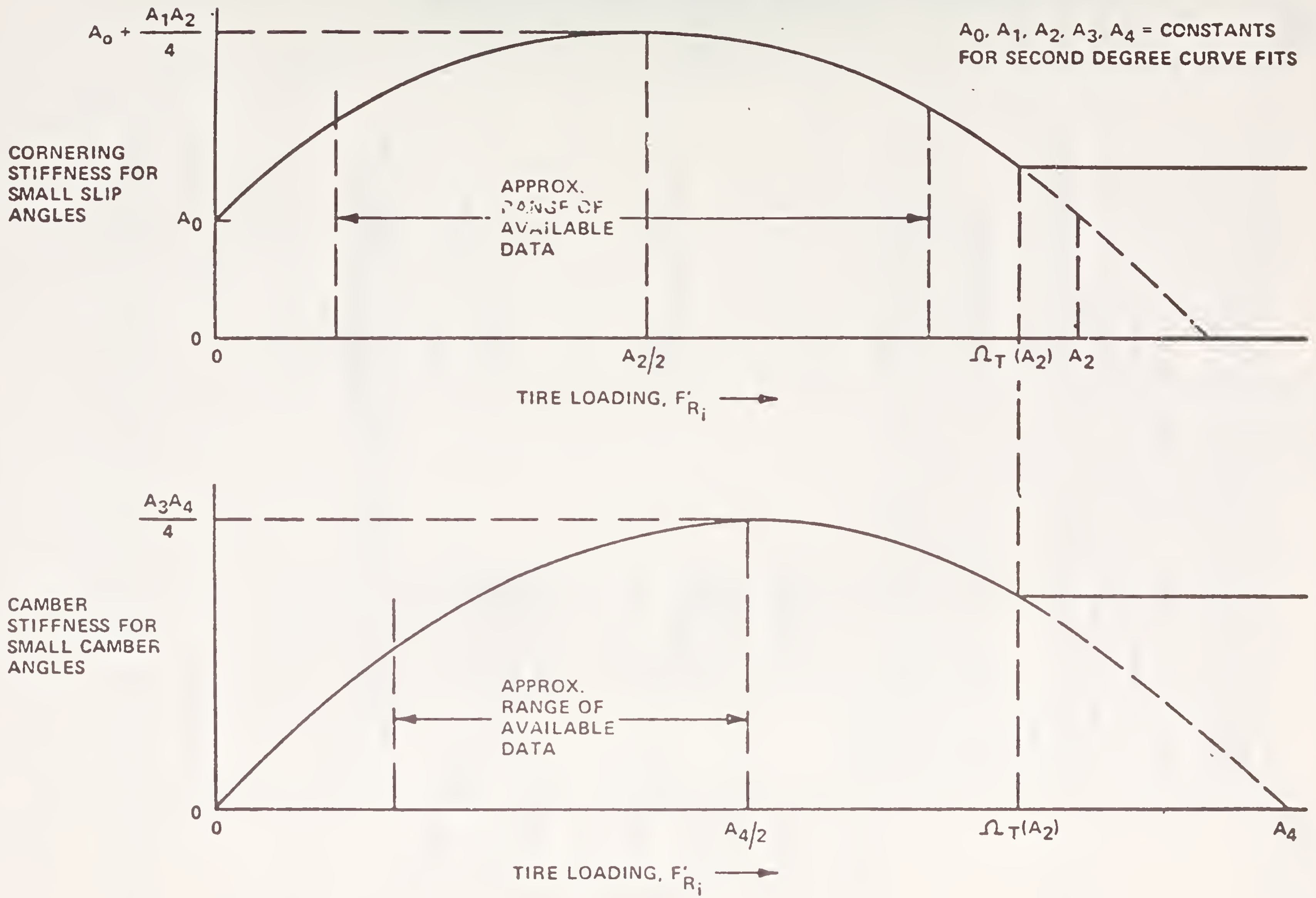
Program Variable	Analytical Variable	Description	Input Units
K	-	TIRE DATA SET NUMBER $1 \le K \le 4$ THE FOLLOWING TIRE DATA APPLIES TO EACH TIRE FOR WHICH ITIR(I) = K (I = 1 to 4)	

AKT(K)	SIGT(K)	XLAMT(K)	A0(K)	A1(K)	A2(K)	A3(K)	A4(K)		1 302
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

AKT(K)	K_T	TIRE LOAD-DEFLECTION RATE IN THE QUASI-LINEAR RANGE	lb/in
SIGT(K)	σ_T	TIRE DEFLECTION AT WHICH THE LOAD DEFLECTION RATE INCREASES	in
XLAMT(K)	λ_T	MULTIPLIER OF K_T USED TO OBTAIN TIRE STIFFNESS AT LARGE DEFLECTIONS	-
A0(K)	A_0	CONSTANT FOR TIRE SIDE FORCE VS SLIP ANGLE CHARACTERISTIC	
A1(K)	A_1	CONSTANT FOR TIRE SIDE FORCE CHARACTERISTICS DUE TO SLIP ANGLE	
A2(K)	A_2	CONSTANT FOR TIRE SIDE FORCE CHARACTERISTICS DUE TO SLIP ANGLE	
A3(K)	A_3	CONSTANT FOR TIRE SIDE FORCE CHARACTERISTICS DUE TO CAMBER ANGLE	
A4(K)	A_4	CONSTANT FOR TIRE SIDE FORCE CHARACTERISTICS DUE TO CAMBER ANGLE	

OMEGT(K)	RW(K)	XMUM(K)	CT(K)	RRMC(K)					2 302
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

OMEGT(K)	Ω_T	MULTIPLIER OF A_2 AT WHICH TIRE SIDE FORCE CHARACTERISTIC VARIATION WITH LOAD IS ABANDONED	-
RW(K)	R_w	UNDEFLECTED TIRE RADIUS	in
XMUM(K)	μ_m	FRICTION COEFFICIENT OF SURFACE ON WHICH TIRE MEASUREMENTS WERE TAKEN (see Section 3.4.5.1.4.2)	
CT(K)	C_T	CIRCUMFERENTIAL TIRE FORCE STIFFNESS	lbs/unit slip
RRMC(K)	R_{RMC}	ROLLING RESISTANCE MOMENT COEFFICIENT	lb-in/ lb

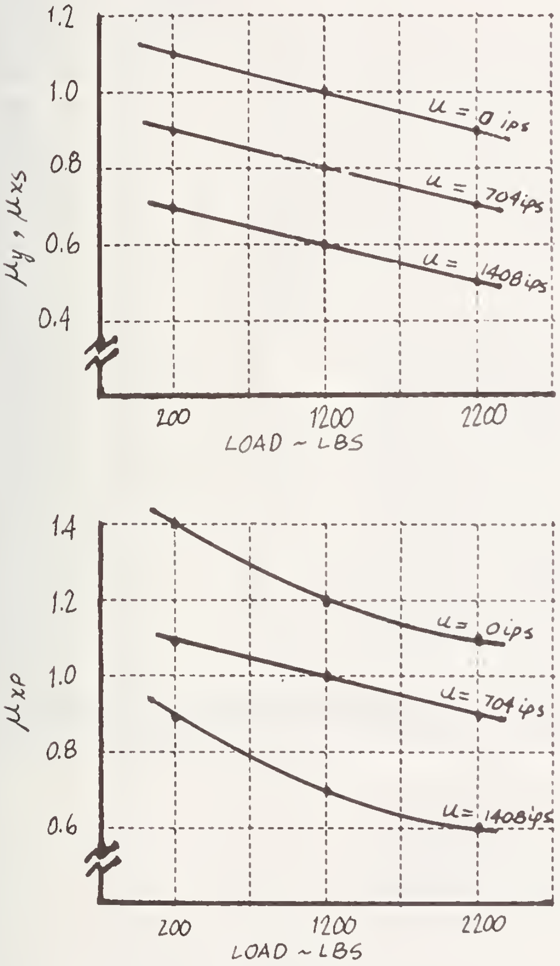


SIMULATED VARIATION OF SMALL-ANGLE CORNERING AND CAMBER STIFFNESS WITH VERTICAL TIRE LOAD

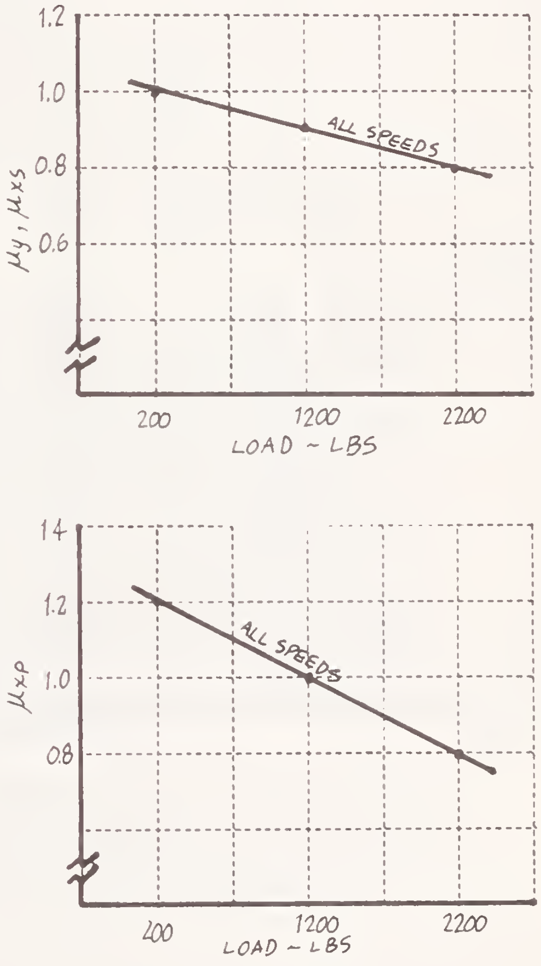
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		IMMEDIATELY FOLLOWING ARE THE TABLES OF FRICTION AS FUNCTIONS OF LOAD AND SPEED IN THE ORDER:	
XMUMAT		PEAK LATERAL FORCE FRICTION COEFFICIENT	
XMXPMT		PEAK CIRCUMFERENTIAL FORCE COEFFICIENT	
XMXSMT		SLIDING CIRCUMFERENTIAL FORCE COEFFICIENT	
SLIPMT		VALUE OF SLIP AT WHICH PEAK CIRCUMFERENTIAL FRICTION OCCURS	
		THESE TABLES ARE READ WITH THE FIRST SUBSCRIPT, CORRESPONDING TO TIRE LOAD, VARYING MOST RAPIDLY. VALUES FOR EACH SPEED BEGIN ON A NEW CARD. THE SAME CARD NUMBER AS USED ABOVE MUST APPEAR IN COLUMNS 78-80 AND AN INCREASING SEQUENCE NUMBER MUST APPEAR IN COLUMN 76.	
XMUMAT	(N,1,K)	N=1,NXFRCP	s 302
XMUMAT	(N,2,K)	N=1,NXFRCP	s 302
:			:
XMUMAT	(N,NXUGMU,K)	N=1,NXFRCP	s 302
XMXPMT	(N,1,K)	N=1,NXFRCP	s 302
XMXPMT	(N,2,K)	N=1,NXFRCP	s 302
:			:
XMXPMT	(N,NXUGMU,K)	N=1,NXFRCP	s 302
XMXSMT	(N,1,K)		s 302
XMXSMT	(N,2,K)		s 302
:			:
XMXSMT	(N,NXUGMU,K)	N=1,NXFRCP	s 302
SLIPMT	(N,1,K)	N=1,NXFRCP	s 302
SLIPMT	(N,2,K)	N=1,NXPRCP	s 302
:			:
SLIPMT	(N,NXUGMU,K)	N=1,NXFRCP	s 302
		IF ANOTHER TIRE DATA SET IS REQUIRED, THE INPUT FORMAT FOR CARDS 302 IS REPEATED CHANGING THE CARD NUMBER TO 303.	

As an example, consider the following two tire data sets. For both tires, the peak lateral friction and sliding circumferential friction coefficient are identical for all speeds and loads. Further, assume that for each tire, the slip ratio at which the peak circumferential friction coefficient occurs is independent of speed and load having the value 0.16 for the first tire and 0.14 for the second. Note that the coefficients for the second tire are also independent of speed.



TIRE DATA SET 1



TIRE DATA SET 2

If the first tire data set is to be used for the front tires of the vehicle and the second for the rear, the input data is:

1.0	1.0	2.0	2.0	0.7	6.0	.25	3.0	3.0	301
200.	1200.	2200.							1 301
0.0	704.	1408.							2 301
1.0									302
AKT(1)	. . .								1 302
OMEGT(1)	. . .								2 302
1.1	1.0	0.9							3 302
0.9	0.8	0.7							4 302
0.7	0.6	0.5							5 302
1.4	1.2	1.1							6 302
1.1	1.0	0.9							7 302
0.9	0.7	0.6							8 302
1.1	1.0	0.9							9 302
0.9	0.8	0.7							10 302
0.7	0.6	0.5							11 302
0.16	0.16	0.16							12 302
0.16	0.16	0.16							13 302
0.16	0.16	0.16							14 302
2.0									303
AKT(2)	. . .								1 303
OMEGT(2)	. . .								2 303
1.0	0.9	0.8							3 303
1.0	0.9	0.8							4 303
1.0	0.9	0.8							5 303
1.2	1.0	0.8							6 303
1.2	1.0	0.8							7 303
1.2	1.0	0.8							8 303
1.0	0.9	0.8							9 303
1.0	0.9	0.8							10 303
1.0	0.9	0.8							11 303
0.14	0.14	0.14							12 303
0.14	0.14	0.14							13 303
0.14	0.14	0.14							14 303
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

CHED(I)	I=1,18								400
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
CHED	-	VEHICLE CONTROL TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING VEHICLE CONTROL INPUTS. NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	-

TB	TE	TINCR	NTBL1						401
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
TB		INITIAL TIME FOR DRIVER CONTROL INPUT TABLES	sec
TE		FINAL TIME FOR DRIVER CONTROL INPUT TABLES	sec
TINCR		INCREMENT OF TIME FOR DRIVER INPUT TABLES	sec
NTBL1		INDICATOR FOR STEER ANGLE (ψ_f) TABLE; READ ψ_F TABLE ONLY IF NTBL1 $\neq$ 0.0 NOTE: TE MUST BE > TB AND THE NUMBER OF ENTRIES IN EACH TABLE [(TE-TB)/TINCR]+1 MUST BE $\leq$ 50. IF TB $\neq$ T0 (CONTROL INPUTS STARTING IN THE MIDDLE OF A RUN), THE FIRST THREE VALUES IN THE INPUT TABLES MUST BE ZERO CONTROL INPUTS BETWEEN T0 AND TB. ALSO IF TE < T1 (CONTROL INPUTS ENDING IN THE MIDDLE OF A RUN), THE CONTROL INPUTS BETWEEN TE AND T1 ARE DETERMINED BY QUADRATIC INTERPOLATION OF THE LAST THREE VALUES IN THE CONTROL TABLE. HENCE, IF ZERO CONTROL INPUTS ARE DESIRED BETWEEN TE AND T1, THE LAST THREE ENTRIES IN THE TABLES MUST BE ZERO. FOLLOWING THIS CARD IS THE TABLE OF:	
PSIF	ψ_F	PSIF - front wheel steer table EACH TABLE CARD MUST CONTAIN 401 IN COLUMNS 78-80 AND MUST ALSO CONTAIN AN INCREASING TABLE SEQUENCE NUMBER IN COLUMN 76. FOR EXAMPLE, IF PSIF IS TO BE READ FROM t = 0.0 TO 1.0 sec IN INCREMENTS OF 0.1 sec:	deg

0.0	1.0	0.1	1.0						401
PSIF(1)	PSIF(2)	...				...	PSIF(8)	PSIF(9)	1 401
PSIF(10)	PSIF(11)								2 401
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

BTT	ETT	DTT	NTT1	NTT2	NTT3				402
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
BTT		BEGINNING TIME FOR TABLES OF BRAKE SYSTEM PRESSURE, THROTTLE SETTING AND TRANSMISSION RATIO	sec
ETT		ENDING TIME FOR ABOVE TABLES	sec
DTT		TIME INCREMENT FOR ABOVE TABLES	sec
NTT1		INDICATOR FOR BRAKE SYSTEM PRESSURE TABLE; READ ONLY IS NTT1 $\neq 0$	
NTT2		INDICATOR FOR THROTTLE SETTING TABLE; READ ONLY IF NTT2 $\neq 0$	
NTT3		INDICATOR FOR TRANSMISSION RATIO TABLE; READ ONLY IF NTT3 $\neq 0$	
		NOTE: THE NUMBER OF ENTRIES IN THE SUBSEQUENT TABLES IS [(ETT-BTT)/DTT]+1 AND IS LIMITED TO 101. BEGINNING AND ENDING TIMES SHOULD BE CHOSEN SUCH THAT THE ENTIRE DURATION OF THE RUN IS INCLUDED. THE TABLES ARE READ IN THE FOLLOWING ORDER:	
TPC	P_C	TABLE OF BRAKE MASTER CYLINDER HYDRAULIC PRESSURE VS TIME	lb/in^2
TTS	(TS)	TABLE OF THROTTLE SETTING VS TIME RANGING FROM 0.0 FOR CLOSED THROTTLE TO 1.0 = WIDE OPEN THROTTLE	-
TTR	(TR)	TABLE OF TRANSMISSION RATIO VS TIME (RATIO OF ENGINE SPEED TO PROP SHAFT SPEED VS TIME)	-
		EACH TABLE CARD MUST CONTAIN 402 IN COLUMNS 78-80 AND AN INCREASING TABLE SEQUENCE NUMBER IN COLUMN 76	
TPC(I)	I=1,N		s 402
TTS(I)	I=1,N		s 402
TTR(I)	I=1,N		s 402

EMDT	EN	DS	TAUF	TIL	TL	TSTS10	TSTS20	TESTB0	403
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
EMDT		TIME BETWEEN DRIVER SAMPLES	sec
EN		NUMBER OF SAMPLE POINTS ALONG PROJECTED PATH $1 \leq EN \leq 7$	-
DS	ΔS	INCREMENTAL DISTANCE BETWEEN SAMPLE POINTS ALONG PROJECTED PATH	in
TAUF	τ	TIME DELAY BEFORE ONSET OF FILTERED STEER ANGLE	sec
TIL	T_I	DRIVER PHYSIOLOGICAL LAG TIME	sec
TL	T_L	DRIVER PHYSIOLOGICAL LEAD TIME	sec
TSTS10	T_{S_1}	DRIVER THRESHOLD FOR SPEED ERRORS	in/sec
TSTS20	T_{S_2}	DRIVER INDIFFERENCE LEVEL FOR SPEED ERRORS	in/sec
TESTB0	T_B	BRAKING INDIFFERENCE LEVEL	in/sec

TSTR10	TSTR20	APDMAX	FKD0	FKS10	FKS20	FKSKD0	BFP1	BFP2	404
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
TSTR10	T_{R_1}	LOWER SKID THRESHOLD	rad
TSTR20	T_{R_2}	UPPER SKID THRESHOLD	rad
APDMAX	APD_{max}	MAXIMUM ACCELERATOR PEDAL DEFLECTION	in
FKD0	K_d	PERFORMANCE PARAMETER CHARACTERIZING UNDERSTEER/ OVERSTEER PROPERTIES OF THE VEHICLE	sec^2/in
FKS10	K_{S_1}	DRIVER ESTIMATE OF VEHICLE BRAKING GAIN	$lb/in/sec^2$
FKS20	K_{S_2}	DRIVER ESTIMATE OF VEHICLE ACCELERATION GAIN	$in/in/sec^2$
FKSKD0	K_S	SKID CONTROL STEER GAIN	rad/rad
BFP1	B_{FP1}	FIRST AND SECOND ORDER COEFFICIENTS RELATING BRAKE PEDAL FORCE TO BRAKE SYSTEM PRESSURE	psi/lb
BPF2	B_{FP2}		

GEAR1	GEAR2	GEAR3	GEAR4						405
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	**Analytical Variable**	**Description**	**Input Units**
GEAR1	$GEAR_1$	SIMULATED AUTOMATIC TRANSMISSION GEAR RATIOS	
GEAR2	$GEAR_2$		
GEAR3	$GEAR_3$		
GEAR4	$GEAR_4$		

VGR12	VGR23	VGR34	VGR43	VGR32	VGR21				406
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	**Analytical Variable**	**Description**	**Input Units**
VGR12		ENGINE SPEED FOR FIRST TO SECOND GEAR UPSHIFT	RPM
VGR23		ENGINE SPEED FOR SECOND TO THIRD GEAR UPSHIFT	RPM
VGR34		ENGINE SPEED FOR THIRD TO FOURTH GEAR UPSHIFT	RPM
VGR43		ENGINE SPEED FOR FOURTH TO THIRD GEAR DOWNSHIFT	RPM
VGR32		ENGINE SPEED FOR THIRD TO SECOND GEAR DOWNSHIFT	RPM
VGR21		ENGINE SPEED FOR SECOND TO FIRST GEAR DOWNSHIFT	RPM
		NOTE: IF FOURTH GEAR IS NOT TO BE USED, THEN LARGE VALUES OF VGR34 AND VGR43 SHOULD BE INPUT.	

XIMPOR(1) XIMPOR(2) XIMPOR(3) XIMPOR(4) XIMPOR(5) XIMPOR(6) XIMPOR(7)									407
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	**Analytical Variable**	**Description**	**Input Units**
XIMPOR	WI	IMPORTANCE WEIGHTING FUNCTION FOR ERRORS. DETERMINED AT THE EN PROJECTED POINTS ALONG THE VEHICLE PATH	

TESTT(1)	TESTT(2)	TESTT(3)	TESTT(4)	TESTT(5)					408
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
TESTT		SIMULATED TIME AT WHICH A DESIRED SPEED CHANGE OCCURS	sec

DESSI(1)	DESSI(2)	DESSI(3)	DESSI(4)	DESSI(5)					409
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DESSI	DS	DESIRED VEHICLE SPEEDS CORRESPONDING TO THE SPEED CHANGE TIMES GIVEN ON CARD 408	in/sec

DISTI(1)	DISTI(2)	DISTI(3)	DISTI(4)	DISTI(5)					410
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DISTI	DIST	DISTANCES WITHIN SPEED CHANGES ARE TO OCCUR	in

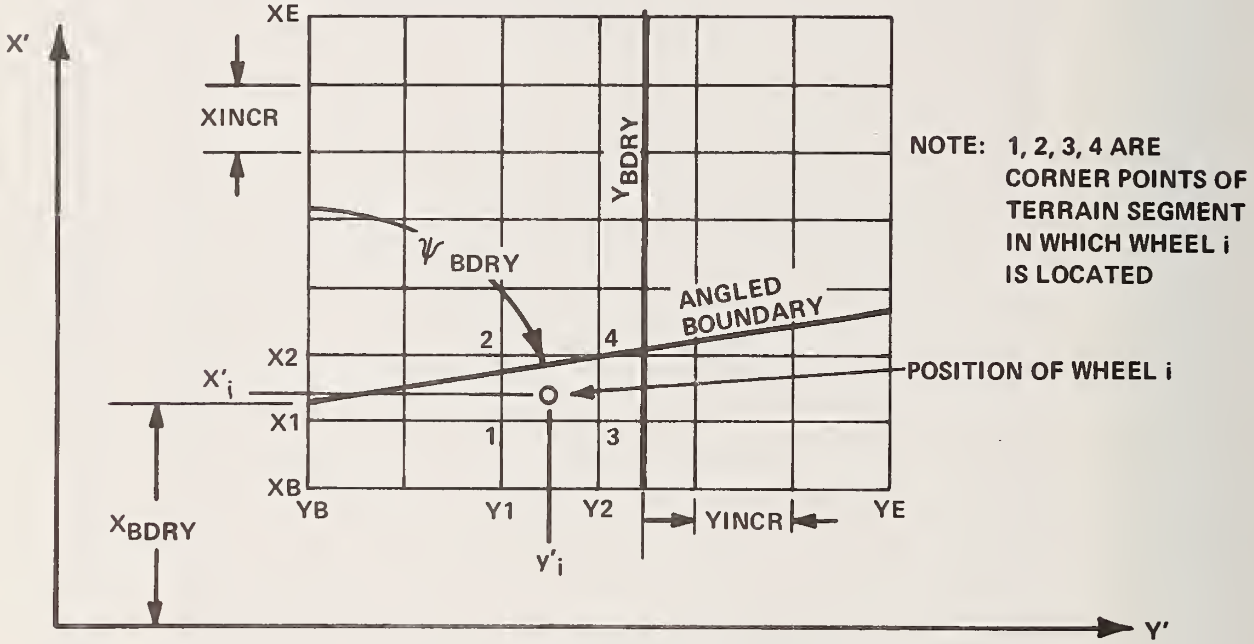
NTRAN									411
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
NTRAN		NUMBER OF STRAIGHT LINE SEGMENTS DEFINING THE DESIRED VEHICLE PATH $1 \le NTRAN \le 5$ NOTE: FOLLOWING THIS CARD ARE THREE TABLE CARDS CONTAINING:	-
YTRANS(I)		THE STARTING Y' BOUNDARY FOR STRAIGHT LINE SEGMENTS	in
ST(I,1)	SP_n	THE X' INTERCEPT OF THE I STRAIGHT LINE SEGMENTS DEFINING THE DESIRED VEHICLE PATH	in
ST(I,2)	SP_{n+1}	THE SLOPES OF THE I STRAIGHT LINE SEGMENTS DEFINING THE DESIRED VEHICLE PATH	-

GHED(I)	I=1,18								500
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
GHED	-	TERRAIN TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING THE SIMULATED VEHICLE'S ENVIRONMENTAL (CURBS, TERRAIN TABLES, BARRIER). NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	-

Cards 501 through 505 are employed for input of terrain tables. These tables include a maximum of four constant increment tables and one variable increment table which must be the highest numbered table in use. The constant increment tables are all read under the same format, table 1 being read on cards 501, etc. The variable increment table is read with a slightly different format on cards numbered one greater than the highest numbered constant increment table.



TERRAIN TABLE GRID

XB(I)	XE(I)	XINCR(I)	YB(I)	YE(I)	YINCR(I)	NBX(I)	NBY(I)		50I
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		CONSTANT INCREMENT TERRAIN TABLE	
		NOTE: THE CONSTANT INCREMENT TERRAIN TABLE NUMBER REPLACES THE LETTER I IN THE CARD NUMBER. THUS CONSTANT INCREMENT TABLE 1 BECOMES CARD 501, ETC.	
XB(I)		INITIAL X' VALUE OF TERRAIN TABLE I	in
XE(I)		FINAL X' VALUE OF TERRAIN TABLE I	in
XINCR(I)		INCREMENT OF X' BETWEEN TERRAIN TABLE ENTRIES	in
YB(I)		INITIAL Y' VALUE OF TERRAIN TABLE I	in
YE(I)		FINAL Y' VALUE OF TERRAIN TABLE I	in
YINCR(I)		INCREMENT OF Y' BETWEEN TERRAIN TABLE ENTRIES	in
NBX(I)		NUMBER OF ANGLED BOUNDARIES FOR TABLE I (0≤NBY≤2)	
NBY(I)		NUMBER OF Y' BOUNDARIES FOR TABLE I (0≤NBY≤2). CARD 50I CONTAINS THE CONTROL INFORMATION FOR TERRAIN TABLE I. THE REMAINDER OF THE DATA IS CONTAINED ON CARDS NUMBERED 50I WITH AN INCREASING TABLE SEQUENCE NUMBER CONTAINED IN COLUMN 76.	
		IF NBX(I) ≠ 0 THE FOLLOWING TWO CARDS ARE REQUIRED CONTAINING	
XBDRY(I)		XBDRY - THE XB INTERCEPT OF THE ANGLED BOUNDARIES	in
PSBDRO(I)		PSBDRO - THE ANGLED BOUNDARIES ANGLE FROM THE X' AXIS	deg
XBDRY(J,I) PSBDRO(J,I)		J=1, NBX(I) J=1, NBX(I)	1 50I 2 50I
		IF NBY(I) ≠ 0 THE FOLLOWING CARD IS REQUIRED CONTAINING	
YBDRY(1)		YBDRY - THE LOCATION OF THE Y' BOUNDARIES	in
YBDRY(J,I)		J=1, NBY(I)	n 50I
		where n is the largest sequence number yet supplied	
		NOTE: 0≤NBX(I)≤4 0≤NBY(I)≤2 No Boundary cards need be supplied if boundaries are not required for table I.	

Following the boundary cards, or card 50I, if no boundary cards are used, are the terrain elevation cards. These cards contain the elevation of the terrain (Z'_G) at each grid point within table I. NXxNY entries must be supplied where:

$$NX=[(XE(I)-XB(I))/XINCR(I)]+1$$
$$NY=[(YE(I)-YB(I))/YINCR(I)]+1$$

and $NX \leq 21$, $NY \leq 21$. Entries are made with the Y' coordinate varying most rapidly and must contain card number 50I in columns 78-80 and an increasing sequence number in column 76.

ZGP(I,J)	J=1,NY	Elevation for y' values at XB(I)	s	50I
ZGP(I,J)	J=1,NY	Elevation for y' values at XB(I)+XINCR(I)	s	50I
:			:	:
:			:	:
ZGP(NX,J)	J=1,NY	Elevation for y' grid points at XE(I)	s	50I

1 2 3 4 | 5 6 7 8 | 9 10 11 12 | 13 14 15 16 | 17 18 19 20 | 21 22 23 24 | 25 26 27 28 | 29 30 31 32 | 33 34 35 36 | 37 38 39 40 | 41 42 43 44 | 45 46 47 48 | 49 50 51 52 | 53 54 55 56 | 57 58 59 60 | 61 62 63 64 | 65 66 67 68 | 69 70 71 72 | 73 74 75 76 | 77 78 79 80

where s in column 76 represents the table sequence number which must increase with each card.

XB(I)	YE(I)	NX(I)	YB(I)	YE(I)	NY(I)	NBX(I)	NBY(I)	1.0	50I
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		VARIABLE INCREMENT TERRAIN TABLE NOTE: THE VARIABLE INCREMENT TERRAIN TABLE NUMBER REPLACES THE LETTER I IN THE CARD NUMBER. THUS, IF THE VARIABLE INCREMENT TABLE IS TABLE NUMBER 3, IT IS READ ON CARDS 503.	
XB(I)		INITIAL X' VALUE OF TERRAIN TABLE I	in
XE(I)		FINAL X' VALUE OF TERRAIN TABLE I	in
NX(I)		NUMBER OF X' GRID POINTS TO BE SUPPLIED	
YB(I)		INITIAL Y' VALUE OF TERRAIN TABLE I	in
YE(I)		FINAL Y' VALUE OF TERRAIN TABLE I	in
NY(I)		NUMBER OF Y' GRID POINTS TO BE SUPPLIED	
NBX(I)		NUMBER OF ANGLED BOUNDARIES FOR TABLE I ($0 \leq NBX \leq 4$)	
NBY(I)		NUMBER OF Y' BOUNDARIES FOR TABLE I ($0 \leq NBY \leq 2$)	
		NOTE: 1.0 MUST APPEAR IN COLUMNS 65-72. CARD 50I CONTAINS THE CONTROL INFORMATION FOR TERRAIN TABLE I. THE REMAINDER OF THE DATA IS CONTAINED ON CARDS NUMBERED 50I WITH AN INCREASING TABLE SEQUENCE NUMBER CONTAINED IN COLUMN 76. IF NBX(I) ≠ 0 THE FOLLOWING TWO CARDS ARE REQUIRED CONTAINING	
XBDRY(I)		XBDRY - THE XB INTERCEPT OF THE ANGLED BOUNDARIES	in
PSBDRO(I)		PSBDRO - THE ANGLED BOUNDARIES ANGLE FROM THE X' AXIS	deg
XBDRY(J,I)		J=1, NBX(I)	1 50I
PSBDRO(J,I)		J=1, NBX(I)	2 50I
		IF NBY(I) ≠ 0 THE FOLLOWING CARD IS REQUIRED CONTAINING	
YBDRY(1)		YBDRY - THE LOCATION OF THE Y' BOUNDARIES	in
YBDRY(J,I)		J=1, NBY(I)	n 50I
		where n is the largest sequence number yet supplied. NOTE: $0<NBX(I)<4$ $0 \leq NBY(I) \leq 2$	

No Boundary cards need be supplied if boundaries are not required for table I.

Following the boundary cards, or card 50I, if no boundary cards are used, are the terrain elevation cards. These cards contain the elevation of the terrain (Z'_G) at each grid point within table I. NXxNY entries must be supplied where NX and NY are read in fields 3 and 6 on card 50I and $NX \leq 21$, $NY \leq 21$. Entries are made with the Y' coordinate varying most rapidly and must contain card number 50I in columns 78-80 and an increasing sequence number in column 76.

ZGP(1,J)	J=1,NY	Elevation for y' values at XXZG5P(1)	s	50I
ZGP(2,J)	J=1,NY	Elevation for y' values at XXZG5P(2)	s	50I
:			:	:
:			:	:
ZGP(NX,J)	J=1,NY	Elevation for y' grid points at XE(I)	s	50I

1 2 3 4 | 5 6 7 8 | 9 10 11 12 | 13 14 15 16 | 17 18 19 20 | 21 22 23 24 | 25 26 27 28 | 29 30 31 32 | 33 34 35 36 | 37 38 39 40 | 41 42 43 44 | 45 46 47 48 | 49 50 51 52 | 53 54 55 56 | 57 58 59 60 | 61 62 63 64 | 65 66 67 68 | 69 70 71 72 | 73 74 75 76 | 77 78 79 80

where s in column 76 represents the table sequence number which must increase with each card.

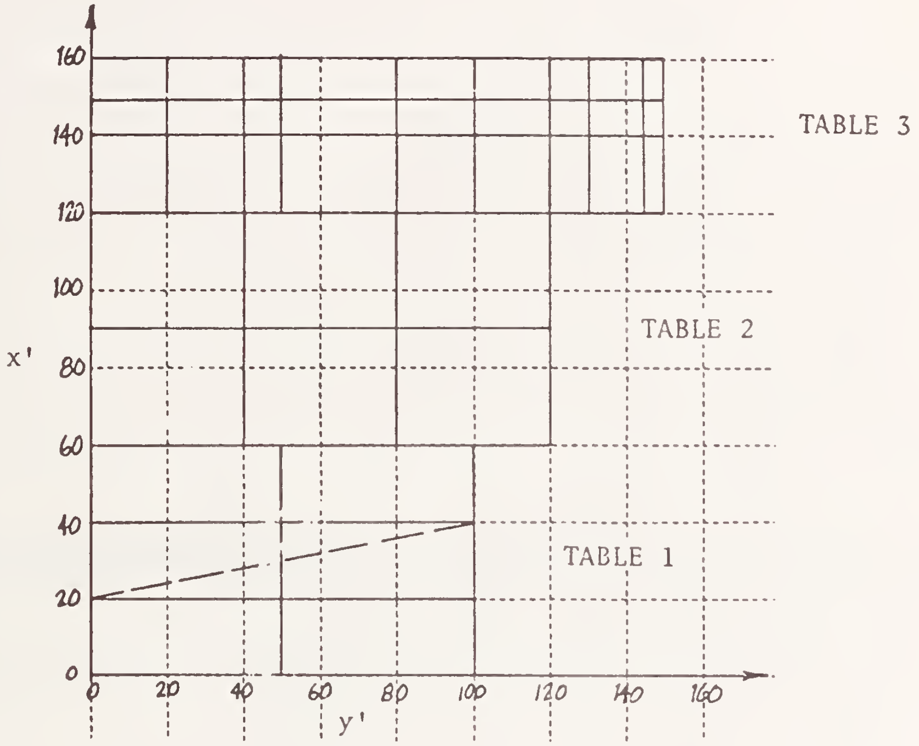
Following the elevation entries are two tables containing the Y' and X' grid locations for the variable increment table.

YYZG5P(N)	N=1,NY(I)	s	50I
XXZG5P(N)	N=1,NX(I)	s	50I

1 2 3 4 | 5 6 7 8 | 9 10 11 12 | 13 14 15 16 | 17 18 19 20 | 21 22 23 24 | 25 26 27 28 | 29 30 31 32 | 33 34 35 36 | 37 38 39 40 | 41 42 43 44 | 45 46 47 48 | 49 50 51 52 | 53 54 55 56 | 57 58 59 60 | 61 62 63 64 | 65 66 67 68 | 69 70 71 72 | 73 74 75 76 | 77 78 79 80

TERRAIN TABLE EXAMPLE

Consider three terrain tables as shown in the sketch:



Let table 1 have an x' increment of 20" and a y' increment of 50"; table 2 have an x' increment of 30" and a y' increment of 40". Table 3 is a variable increment table containing elevations at y' = 0, 20, 40, 50, 80, 100, 120, 130, 145 and 150 inches and x' = 120, 140, 150 and 160 inches. Also, let table 1 contain an angled boundary with an x' intercept of 20" and $\psi'_{BDRY} = \arctan\left(\frac{100}{20}\right) = 78.7°$.

Let the elevations for each grid point be determined from the following tables:

TABLE 1

		Y'		
		0.0	50.0	100.0
X'	0.0	0.0	0.0	0.0
	20.0	1.0	2.0	1.0
	40.0	2.0	3.0	2.0
	60.0	4.0	4.0	4.0

TABLE 2

		Y'			
		0.0	40.0	80.0	120.0
X'	60.0	4.0	4.0	4.0	4.0
	90.0	4.0	5.0	6.0	4.0
	120.0	3.0	4.0	5.0	5.0

TABLE 3

		Y'									
		0.0	20.	40.	60.	80.	100.	120.	130.	145.	150.
X'	120.	3.0	3.5	4.0	4.5	5.0	5.0	5.0	6.0	3.0	3.5
	140.	3.0	3.0	3.5	4.0	4.0	4.5	4.0	3.5	2.5	2.0
	150.	1.0	2.0	2.0	2.5	2.5	2.5	2.5	2.0	1.0	0.5
	160.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

0.0	60.0	20.0	0.0	100.0	50.0	1.0	0.0		501
20.0									1 501
78.7									2 501
0.0	0.0								3 501
1.0	2.0	1.0							4 501
2.0	3.0	2.0							5 501
4.0	4.0	4.0							6 501
60.0	120.0	30.0	0.0	120.0	40.0	0.0	0.0		502
4.0	4.0	4,0	4.0						1 502
4.0	5.0	6.0	4.0						2 502
3.0	4.0	5.0	5.0						3 502
120.	160.	4.0	0,0	150.	10.0	0.0	0.0	1.0	503
3.0	3.5	4.0	4.5	5.0	5.0	5.0	6.0	3.0	1 503
3.5									2 503
3.0	3,0	3,5	4.0	4.0	4.5	4.0	3.5	2.5	3 503
2.0									4 503
1.0	2.0	2.0	2.5	2.5	2.5	2.5	2.0	1,0	5 503
0.5									6 503
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7 503
0.0									8 503
0.0	20.0	40.0	60.0	80.0	100.0	120.0	130.0	145.0	9 503
150.0									10 503
120.0	140.0	150.0	160.0						11 503
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

AMUG (1)	AMUG (2)	AMUG (3)	AMUG (4)	AMUG (5)					506
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
AMUG (1) AMUG (2) AMUG (3) AMUG (4) AMUG (5)		TERRAIN TABLE FRICTION MULTIPLIERS. THESE FACTORS ARE A MULTIPLE OF THE NOMINAL TIRE-GROUND FRICTION COEFFICIENT THAT CHANGE THAT VALUE WHEN A TIRE IS WITHIN A GIVEN TERRAIN TABLE	

YC1P	YC2P	YC3P	YC4P	YC5P	YC6P	AMUC			507
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

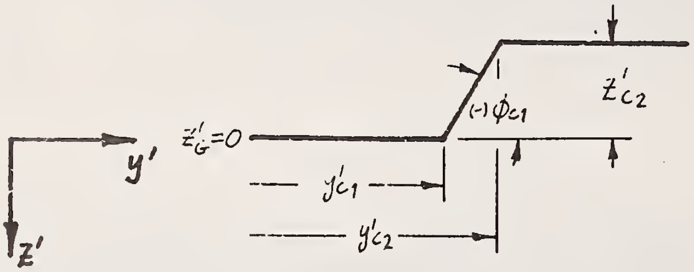
Program Variable	Analytical Variable	Description	Input Units
YC1P	y'_{c_1}	LATERAL POSITIONS OF THE FIRST THROUGH THE SIXTH SLOPE CHANGES DEFINING A CURB	in
YC2P	y'_{c_2}		in
YC3P	y'_{c_3}		in
YC4P	y'_{c_4}		in
YC5P	y'_{c_5}		in
YC6P	y'_{c_6}		in
		NOTE: ONLY AS MANY SLOPE CHANGE POSITIONS AS IN INDICATED BY NCRBSL, CARD 101 NEED BE SUPPLIED.	
AMUC	μ_c	CURB FRICTION MULTIPLIER. THIS FACTOR IS A MULTIPLE OF THE NOMINAL TIRE-GROUND FRICTION COEFFICIENT THAT CHANGES THAT VALUE WHEN IN CONTACT WITH A CURB	-

ZC2P	ZC3P	ZC4P	ZC5P	ZC6P					508
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
ZCZP	Z'_{c_2}	CURB ELEVATION AT Y'_{c_2} THROUGH Y'_{c_6}, RESPECTIVELY	in
ZC3P	Z'_{c_3}		in
ZC4P	Z'_{c_4}		in
ZC5P	Z'_{c_5}		in
ZC6P	Z'_{c_6}		in

PHIC1	PHIC2	PHIC3	PHIC4	PHIC5	PHIC6				509
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
PHIC1	ϕ_{c1}	FIRST THROUGH SIXTH CURB SLOPE ANGLE	deg
PHIC2	ϕ_{c2}		deg
PHIC3	ϕ_{c3}		deg
PHIC4	ϕ_{c4}		deg
PHIC5	ϕ_{c5}		deg
PHIC6	ϕ_{c6}		deg



TWO SLOPE CURB

$-90 < \phi_{c1} < 0$

$\phi_{c2} = 0$

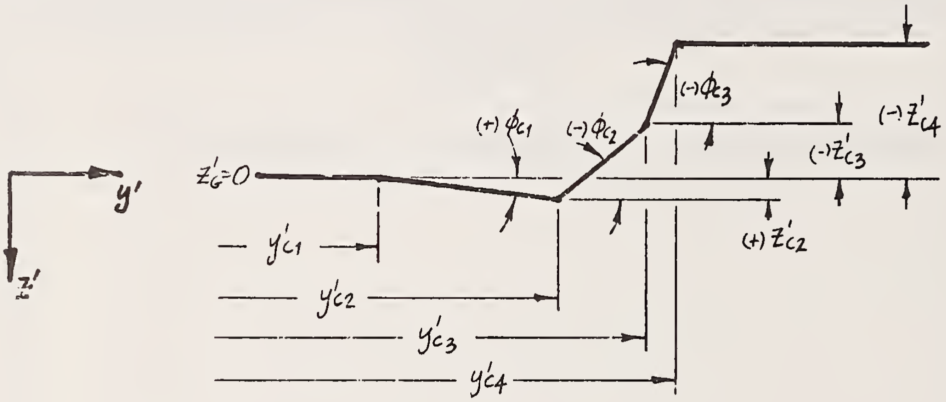
FOUR SLOPE CURB

$\phi_{c1} > 0$

$-90 < \phi_{c2} < 0$

$-90 < \phi_{c3} < \phi_{c2}$

$\phi_{c4} = 0$



DELG	NEND								510
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DELG	Δ_G	CONSTANT DISTANCE INCREMENT BETWEEN ROAD ROUGHNESS INPUT POINTS	in
NEND		NUMBER OF ROAD ROUGHNESS POINTS TO BE READ (NEND $\leq$ 2200) NOTE: ROAD ROUGHNESS DATA IN THE FORM OF ELEVATION CHANGE FROM THE DATUM ARE READ WITHIN SUBROUTINE RUFRED FROM FORTRAN DEVICE 4 VIA AN UNFORMATTED READ. IF THESE DATA ARE READ, THE ROAD ROUGHNESS INDICATOR IS SET TO 1 (IRUF=1). THE USE OF THE ROAD ROUGHNESS OPTION AND TERRAIN TABLES ARE MUTUALLY EXCLUSIVE	

SHED(I)	I=1,18								600
1 2 3 4 5 6 7 8	9 10 11 17 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
SHED	-	INITIAL CONDITION TITLE THIS CARD MAY CONTAIN UP TO 72 CHARACTERS OF ALPHANUMERIC INFORMATION DESCRIBING THE INITIAL CONDITIONS FOR THE RUN. NOTE THAT ONLY THE FIRST 40 CHARACTERS ARE PRINTED ON EACH OUTPUT PAGE.	-

PHIO	THETAO	PSIO	PO	QO	RO	PSIFIO	PSIFDO		601
1 2 3 4 5 6 7 8	9 10 11 17 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 78 80

Program Variable	Analytical Variable	Description	Input Units
PHIO	ϕ_o	INITIAL VEHICLE VEHICLE ROLL ANGLE	deg
THETAO	θ_o	INITIAL VEHICLE PITCH ANGLE EULER ANGLES, SEE FIGURE 3.5-1	deg
PHIO	ψ_o	INITIAL VEHICLE YAW ANGLE	deg
PO	P_o	INITIAL VEHICLE ANGULAR VELOCITY ABOUT THE x AXIS	deg/sec
QO	Q_o	INITIAL VEHICLE ANGULAR VELOCITY ABOUT THE y AXIS	deg/sec
RO	R_o	INITIAL VEHICLE ANGULAR VELOCITY ABOUT THE z AXIS	deg/sec
PSIFIO	ψ_{fo}	INITIAL FRONT WHEEL STEER ANGLE	deg
PSIFDO	$\dot{\psi}_{fo}$	INITIAL FRONT WHEEL STEER ANGULAR VELOCITY	deg/sec

XCOP	YCOP	ZCOP	UO	VO	WO				602
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
XCOP	X'_{co}	INITIAL x' COORDINATE OF THE SPRUNG MASS C.G. FROM THE SPACE AXES	in
YCOP	Y'_{co}	INITIAL y' COORDINATE OF THE SPRUNG MASS C.G. FROM THE SPACE AXES	in
ZCOP	Z'_{co}	INITIAL z' COORDINATE OF THE SPRUNG MASS C.G. FROM THE SPACE AXES	in
UO	U_o	INITIAL LONGITUDINAL VELOCITY OF THE VEHICLE C.G. ALONG THE VEHICLE AXES	in/sec
VO	V_o	INITIAL LATERAL VELOCITY OF THE VEHICLE C.G. ALONG THE VEHICLE AXES	in/sec
WO	W_0	INITIAL LONGITUDINAL VELOCITY OF THE VEHICLE C.G. ALONG THE VEHICLE AXES	in/sec

DEL10	DEL20	DEL30	PHIRO	DEL10D	DEL20D	DEL30D	PHIROD		603
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DEL10	δ_{10}	INITIAL RF WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL20	δ_{20}	INITIAL LF WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL30	δ_{30}	INITIAL REAR ROLL CENTER DISPLACEMENT FROM EQUILIBRIUM	in
PHIRO	ϕ_{R_o}	INITIAL REAR AXLE ROLL ANGLE WITH REPSECT TO THE VEHICLE	deg
DEL10D	$\dot{\delta}_{10}$	INITIAL RF WHEEL DEFLECTION VELOCITY	in/sec
DEL20D	$\dot{\delta}_{20}$	INITIAL LF WHEEL DEFLECTION VELOCITY	in/sec
DEL30D	$\dot{\delta}_{30}$	INITIAL REAR ROLL CENTER DISPLACEMENT VELOCITY	in/sec
PHIROD	$\dot{\phi}_{R_o}$	INITIAL REAR AXLE ROLL ANGULAR VELOCITY	deg/sec
		NOTE: THIS FORM OF CARD 503 IS USED ONLY FOR ISUS=0.	

DEL10	DEL20	DEL30	DEL40	DEL10D	DEL20D	DEL30D	DEL40D		603
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DEL10	δ_{10}	INITIAL RF WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL20	δ_{20}	INITIAL LF WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL30	δ_{30}	INITIAL RR WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL40	δ_{40}	INITIAL LR WHEEL DISPLACEMENT FROM EQUILIBRIUM	in
DEL10D	$\dot{\delta}_{10}$	INITIAL RF WHEEL DEFLECTION VELOCITY	in/sec
DEL20D	$\dot{\delta}_{20}$	INITIAL LF WHEEL DEFLECTION VELOCITY	in/sec
DEL30D	$\dot{\delta}_{30}$	INITIAL RR WHEEL DEFLECTION VELOCITY	in/sec
DEL40D	$\dot{\delta}_{40}$	INITIAL LR WHEEL DEFLECTION VELOCITY	in/sec
		NOTE: THIS FORM OF CARD 603 USED ONLY WHEN ISUS=1.	

DEL10	PHIF0	DEL30	PHIR0	DEL10D	PHIF0D	DEL30D	PHIR0D		603
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
DEL10		INITIAL FRONT ROLL CENTER DISPLACEMENT FROM EQUILIBRIUM	in
PHIF0		INITIAL FRONT AXLE ROLL ANGLE RELATIVE TO THE VEHICLE	deg
DEL30		INITIAL REAR ROLL CENTER DISPLACEMENT FROM EQUILIBRIUM	in
PHIR0		INITIAL REAR AXLE ROLL ANGLE RELATIVE TO THE VEHICLE	deg
DEL10D		INITIAL FRONT ROLL CENTER DEFLECTION VELOCITY	in/sec
PHIF0D		INITIAL FRONT AXLE ANGULAR VELOCITY	deg/sec
DEL30D		INITIAL REAR ROLL CENTER DEFLECTION VELOCITY	in/sec
PHIR0D		INITIAL REAR AXLE ANGULAR VELOCITY	deg/sec
		NOTE: THIS FORM OF CARD 603 USED ONLY WHEN ISUS=2.	

TAUA	TAU0(1)	TAU0(2)	TAU0(3)	TAU0(4)					604
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
TAUA	τ_A	AMBIENT TEMPERATURE	°F
TAU0(1)	$(\tau_1)_0$	INITIAL TEMPERATURE OF RF WHEEL BRAKE ASSEMBLY	°F
TAU0(2)	$(\tau_2)_0$	INITIAL TEMPERATURE OF LF WHEEL BRAKE ASSEMBLY	°F
TAU0(3)	$(\tau_3)_0$	INITIAL TEMPERATURE OF RR WHEEL BRAKE ASSEMBLY	°F
TAU0(4)	$(\tau_4)_0$	INITIAL TEMPERATURE OF LR WHEEL BRAKE ASSEMBLY	°F

									9999
1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	73 74 75 76 77 78 79 80

Program Variable	Analytical Variable	Description	Input Units
		THIS CARD SIGNIFIES THE END OF A DATA SET AND MUST BE SUPPLIED	

4.2 HVOSM OUTPUT

4.2.1 Roadside Design Version

The HVOSM-RD2 printed output is organized into nineteen output groupings. The output technique used allows suppression of output groups that are not desired. Output of groups is controlled by an array of indicators and output is suppressed if the indicator corresponding to a group is zero. These indicators are set internally for a number of output groups that are always printed or are set internally depending on program options being used, or are read as input for some groups.

Each output group being printed is written to a separate Fortran unit number commencing with 11. In this manner, core storage is not required to save output for subsequent printing. The user must supply nineteen DD cards to define the output data sets. An example is shown in Section 4.3.

Descriptions of each output grouping follows. Note that variables printed in some groupings are dependent on the suspension option in effect.

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 1

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	XCP	x'_c	Location of vehicle sprung mass c.g. with respect to the space fixed coordinate system	ft.
3	YCP	y'_c		
4	ZCP	z'_c		
5	ULON	u	Vehicle forward velocity	ft/sec.
6	VLAT	v	Vehicle lateral velocity	ft/sec.
7	WVER	w	Vehicle vertical velocity	ft/sec.
8	ACLON	$\dot{u}-vR+wQ$	Vehicle longitudinal acceleration	g's
9	ACLAT	$\dot{v}+uR-wP$	Vehicle lateral acceleration	g's
10	ACVER	$\dot{w}+vP-uQ$	Vehicle vertical acceleration	g's
11	ACRES		Resultant vehicle acceleration	g's

This group is always printed.

OUTPUT GROUP NUMBER 2a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	P	P	x-component of sprung mass angular velocity	deg/sec.
3	Q	Q	y-component of sprung mass angular velocity	deg/sec.
4	R	R	z-component of sprung mass angular velocity	deg/sec.
5	PHIT	ϕ	Vehicle roll angle	deg.
6	THETT	θ	Vehicle pitch angle	deg.
7	PSIT	ψ	Vehicle yaw angle	deg.
8	OBETA		Vehicle slip angle	deg.
9	ONU		Vehicle course angle	deg.
10	PSIF	ψ_F	Front wheel steer angle	deg.
11	OPSIR	ψ_3, ψ_4	Rear wheel steer angles	deg.

---

*This group is output when a solid rear axle suspension option is in effect (ISUS = 0 or 2).

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 2b*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	P	P	x-component of sprung mass angular velocity	deg/sec.
3	Q	Q	y-component of sprung mass angular velocity	deg/sec.
4	R	R	z-component of sprung mass angular velocity	deg/sec.
5	PHIT	ϕ	Vehicle roll angle	deg.
6	THETT	θ	Vehicle pitch angle	deg.
7	PSIT	ψ	Vehicle yaw angle	deg.
8	OBETA		Vehicle slip angle	deg.
9	ONU		Vehicle course angle	deg.
10	PSIF	ψ_F	Front wheel steer angle	deg.
11	PSI3	ψ_3	RR wheel steer angle	deg.
12	PSI4	ψ_4	LR wheel steer angle	deg.

---

[*] This group is output when the independent rear suspension option is in effect (ISUS = 1).

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 3a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DEL1	δ_1	RF wheel ride deflection	in.
3	DEL2	δ_2	LF wheel ride deflection	in.
4	OETA3	$\delta_3 + T_R\phi_R/2$	RR wheel ride deflection	in.
5	OETA4	$\delta_3 - T_R\phi_R/2$	LR wheel ride deflection	in.
6	DEL1D	$\dot{\delta}_1$	RF wheel ride velocity	in/sec.
7	DEL2D	$\dot{\delta}_2$	LF wheel ride velocity	in/sec.
8	OETA3D	$\dot{\delta}_3 + T_R\dot{\phi}_R/2$	RR wheel ride velocity	in/sec.
9	OETA4D	$\dot{\delta}_3 - T_R\dot{\phi}_R/2$	LR wheel ride velocity	in/sec.

---

* This group is output for the independent front suspension/solid rear axle option (ISUS = 0).

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 3b*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DEL1	δ_1	RF wheel ride deflection	in.
3	DEL2	δ_2	LF wheel ride deflection	in.
4	DEL3	δ_3	RR wheel ride deflection	in.
5	DEL4	δ_4	LR wheel ride deflection	in.
6	DEL1D	$\dot{\delta}_1$	RF wheel ride velocity	in/sec.
7	DEL2D	$\dot{\delta}_2$	LF wheel ride velocity	in/sec.
8	DEL3D	$\dot{\delta}_3$	RR wheel ride velocity	in/sec.
9	DEL4D	$\dot{\delta}_4$	LR wheel ride velocity	in/sec.

---

[*] This group is output for the independent front and rear suspension option (ISUS = 1).

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 3c*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	OETA1	$\delta_1 + T_F\phi_F/2$	RF wheel ride deflection	in.
3	OETA2	$\delta_1 - T_F\phi_F/2$	LF wheel ride deflection	in.
4	OETA3	$\delta_3 + T_R\phi_R/2$	RR wheel ride deflection	in.
5	OETA4	$\delta_3 - T_R\phi_R/2$	LR wheel ride deflection	in.
6	OETA1D	$\dot{\delta}_1 + T_F\dot{\phi}_F/2$	RF wheel ride velocity	in/sec.
7	OETA2D	$\dot{\delta}_1 - T_F\dot{\phi}_F/2$	LF wheel ride velocity	in/sec.
8	OETA3D	$\dot{\delta}_3 + T_R\dot{\phi}_R/2$	RR wheel ride velocity	in/sec.
9	OETA4D	$\dot{\delta}_3 - T_R\dot{\phi}_R/2$	LR wheel ride velocity	in/sec.

---

[*] This group is output for the solid axle front and rear suspension option (ISUS = 2).

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 4a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DP	$\dot{P}$	x-component of vehicle angular acceleration	deg/sec^2
3	DQ	$\dot{Q}$	y-component of vehicle angular acceleration	deg/sec^2
4	DR	$\dot{R}$	z-component of vehicle angular acceleration	deg/sec^2
5	DDEL1D	$\ddot{\delta}_1$	RF wheel ride acceleration	in/sec^2
6	DDEL2D	$\ddot{\delta}_2$	LF wheel ride acceleration	in/sec^2
7	DEL3	δ_3	Rear roll center ride deflection	in.
8	DEL3D	$\dot{\delta}_3$	Rear roll center ride velocity	in/sec.
9	DDEL3D	$\ddot{\delta}_3$	Rear roll center ride acceleration	in/sec^2
10	PHIR	ϕ_R	Rear axle roll angle	deg.
11	PHIRD	$\dot{\phi}_R$	Rear axle roll angular velocity	deg/sec.
12	DPHIRD	$\ddot{\phi}_R$	Rear axle roll angular velocity	deg/sec^2

*This group is output for the independent front suspension, solid rear axle option (ISUS = 0) when NPAGE(4) is read as 1.0 on card 104 field 1.

HVOSM-RD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 4b*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DP	$\dot{P}$	x-component of vehicle angular acceleration	deg/sec^2
3	DQ	$\dot{Q}$	y-component of vehicle angular acceleration	deg/sec^2
4	DR	$\dot{R}$	z-component of vehicle angular acceleration	deg/sec^2
5	DDEL1D	$\ddot{\delta}_1$	RF wheel ride acceleration	in/sec^2
6	DDEL2D	$\ddot{\delta}_2$	LF wheel ride acceleration	in/sec^2
7	DDEL3D	$\ddot{\delta}_3$	RR wheel ride acceleration	in/sec^2
8	DDEL4D	$\ddot{\delta}_4$	LR wheel ride acceleration	in/sec^2

---

[*] This group is output for the independent front and rear suspension option (ISUS = 1) when NPAGE(4) is read as 1.0 on card 104 field 1.

OUTPUT GROUP NUMBER 4c*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DP	$\dot{P}$	x-component of vehicle angular acceleration	deg/sec^2
3	DQ	$\dot{Q}$	y-component of vehicle angular acceleration	deg/sec^2
4	DR	$\dot{R}$	z-component of vehicle angular acceleration	deg/sec^2
5	DEL1	δ_1	Front roll center ride deflection	in.
6	DEL1D	$\dot{\delta}_1$	Front roll center ride velocity	in/sec.
7	DDEL1D	$\ddot{\delta}_1$	Front roll center ride acceleration	in/sec^2
8	DEL3	δ_3	Rear roll center ride deflection	in.
9	DEL3D	$\dot{\delta}_3$	Rear roll center ride velocity	in/sec.
10	DDEL3D	$\ddot{\delta}_3$	Rear roll center ride acceleration	in/sec^2
11	PHIFD	$\dot{\phi}_F$	Front axle roll angular velocity	deg/sec
12	DPHIFD	$\ddot{\phi}_F$	Front axle roll angular acceleration	deg/sec^2
13	PHIRD	$\dot{\phi}_R$	Rear axle roll angular velocity	deg/sec
14	DPHIRD	$\ddot{\phi}_R$	Rear axle roll angular acceleration	deg/sec^2

*This group is output for the solid front and rear axle option (ISUS = 2) when NPAGE(4) is read as 1.0 on card 104 field 1.

OUTPUT GROUP NUMBER 5

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	T1PSI	$T_{1\psi}$	Steering system friction torque	lb-in.
3	T2PSI	$T_{2\psi}$	Steering system stop torque	lb-in.
4	DPSIFI	$\dot{\psi}_F$	Front wheel steer angle velocity	deg/sec.
5	DDPSFI	$\ddot{\psi}_F$	Front wheel steer angular acceleration	deg/sec^2

This group is output when $INDCRB \neq 0$.

HVOSM-RD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 6a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	PSIIP(1)	ψ'_1	RF steer angle with respect to the ground	deg.
3	PSIIP(2)	ψ'_2	LF steer angle with respect to the ground	deg.
4	PSIIP(3)	ψ'_3	RR steer angle with respect to the ground	deg.
5	PSIIP(4)	ψ'_4	LR steer angle with respect to the ground	deg.
6	PHICI(1)	ϕ_{CG1}	RF camber angle with respect to the ground	deg.
7	PHICI(2)	ϕ_{CG2}	LF camber angle with respect to the ground	deg.
8	PHICI(3)	ϕ_{CG3}	RR camber angle with respect to the ground	deg.
9	PHICI(4)	ϕ_{CG4}	LR camber angle with respect to the ground	deg.
10	PHI1	ϕ_1	RF camber angle	deg.
11	PHI2	ϕ_2	LF camber angle	deg.

---

*This group is output for the independent front, solid rear axle suspension option (ISUS = 0) when NPAGE(6) is read as 1.0 on card 104 field 2.

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 6b*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	PSIIP(1)	ψ_1'	RF steer angle with respect to the ground	deg.
3	PSIIP(2)	ψ_2'	LF steer angle with respect to the ground	deg.
4	PSIIP(3)	ψ_3'	RR steer angle with respect to the ground	deg.
5	PSIIP(4)	ψ_4'	LR steer angle with respect to the ground	deg.
6	PHICI(1)	ϕ_{CG1}	RF camber angle with respect to the ground	deg.
7	PHICI(2)	ϕ_{CG2}	LF camber angle with respect to the ground	deg.
8	PHICI(3)	ϕ_{CG3}	RR camber angle with respect to the ground	deg.
9	PHICI(4)	ϕ_{CG4}	LR camber angle with respect to the ground	deg.
10	PHI1	ϕ_1	RF camber angle	deg.
11	PHI2	ϕ_2	LF camber angle	deg.
12	PHI3	ϕ_3	RR camber angle	deg.
13	PHI4	ϕ_4	LR camber angle	deg.

---

*This group is output for the independent front and rear suspension option (ISUS = 1) when NPAGE(6) is read as 1.0 on card 104 field 2.

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 6c*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	PSIIP(1)	ψ'_1	RF steer angle with respect to the ground	deg.
3	PSIIP(2)	ψ'_2	LF steer angle with respect to the ground	deg.
4	PSIIP(3)	ψ'_3	RR steer angle with respect to the ground	deg.
5	PSIIP(4)	ψ'_4	LR steer angle with respect to the ground	deg.
6	PHICI(1)	ϕ_{CG1}	RF camber angle with respect to the ground	deg.
7	PHICI(2)	ϕ_{CG2}	LF camber angle with respect to the ground	deg.
8	PHICI(3)	ϕ_{CG3}	RR camber angle with respect to the ground	deg.
9	PHICI(4)	ϕ_{CG4}	LR camber angle with respect to the ground	deg.
10	PHIF	ϕ_F	Front axle roll angle	deg.
11	PHIR	ϕ_R	Rear axle roll angle	deg.

[*] This group is output for the solid front and rear axle suspension option (ISUS = 2) when NPAGE(6) is read as 1.0 on card 104 field 2.

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 7

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	UG(1)	u_{G1}	RF wheel longitudinal velocity parallel to the ground	in/sec.
3	UG(2)	u_{G2}	LF wheel longitudinal velocity parallel to the ground	in/sec.
4	UG(3)	u_{G3}	RR wheel longitudinal velocity parallel to the ground	in/sec.
5	UG(4)	u_{G4}	LR wheel longitudinal velocity parallel to the ground	in/sec.
6	VG(1)	v_{G1}	RF wheel lateral velocity parallel to the ground	in/sec.
7	VG(2)	v_{G2}	LF wheel lateral velocity parallel to the ground	in/sec.
8	VG(3)	v_{G3}	RR wheel lateral velocity parallel to the ground	in/sec.
9	VG(4)	v_{G4}	LR wheel lateral velocity parallel to the ground	in/sec.

This group is output when NPAGE(7) is read as 1.0 on card 104 field 3.

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	ZGPP(1)	Z'_{GP1}	Elevation of RF ground contact point	in.
3	ZGPP(2)	Z'_{GP2}	Elevation of LF ground contact point	in.
4	ZGPP(3)	Z'_{GP3}	Elevation of RR ground contact point	in.
5	ZGPP(4)	Z'_{GP4}	Elevation of LR ground contact point	in.

This group is output when NPAGE(8) is read as 1.0 on card 104 field 4 or when the road roughness option is being used (IRUF≠0).

OUTPUT GROUP NUMBER 9

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	SI(1)	S_1	Total RF suspension force	lb.
3	SI(2)	S_2	Total LF suspension force	lb.
4	SI(3)	S_3	Total RR suspension force	lb.
5	SI(4)	S_4	Total LR suspension force	lb.
6	APITCH(1)	F_{AP1}	RF anti-pitch force	lb.
7	APITCH(2)	F_{AP2}	LF anti-pitch force	lb.
8	APITCH(3)	F_{AP3}	RR anti-pitch force	lb.
9	APITCH(4)	F_{AP4}	LR anti-pitch force	lb.

This group is output when NPAGE(9) is read as 1.0 on card 104 field 5.

HVOSM-RD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 10

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	OD1	$-C_F\dot{\zeta}_1$	RF suspension damping force	lb.
3	OD2	$-C_F\dot{\zeta}_2$	LF suspension damping force	lb.
4	OD3	$-C_R\dot{\zeta}_3$	RR suspension damping force	lb.
5	OD4	$-C_R\dot{\zeta}_4$	LR suspension damping force	lb.
6	-F2FI(1)	F_{2F1}	RF suspension spring force	lb.
7	-F2FI(2)	F_{2F2}	LF suspension spring force	lb.
8	-F2RI(1)	F_{2R1}	RR suspension spring force	lb.
9	-F2RI(2)	F_{2R2}	LR suspension spring force	lb.

This group is output when NPAGE(10) is read as 1.0 on card 104 field 6.

HVOSM-RD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 11

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	FR(1)	F_{R1}	RF tire radial force	lb.
3	FR(2)	F_{R2}	LF tire radial force	lb.
4	FR(3)	F_{R3}	RR tire radial force	lb.
5	FR(4)	F_{R4}	LR tire radial force	lb.
6	HI(1)	h_1	RF tire rolling radius	in.
7	HI(2)	h_2	LF tire rolling radius	in.
8	HI(3)	h_3	RR tire rolling radius	in.
9	HI(4)	h_4	LR tire rolling radius	in.

This group is always printed.

HVOSM-RD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 12

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	FRCP(1)	F'_{R1}	RF tire force normal to the ground	lb.
3	FRCP(2)	F'_{R2}	LF tire force normal to the ground	lb.
4	FRCP(3)	F'_{R3}	RR tire force normal to the ground	lb.
5	FRCP(4)	F'_{R4}	LR tire force normal to the ground	lb.
6	FS(1)	F_{S1}	RF tire side force	lb.
7	FS(2)	F_{S2}	LF tire side force	lb.
8	FS(3)	F_{S3}	RR tire side force	lb.
9	FS(4)	F_{S4}	LR tire side force	lb.
10	SLPANG(1)	$\arctan(v_{G1}/u_{G1})-\psi'_1$	RF tire slip angle	deg.
11	SLPANG(2)	$\arctan(v_{G2}/u_{G2})-\psi'_2$	LF tire slip angle	deg.
12	SLPANG(3)	$\arctan(v_{G3}/u_{G3})-\psi'_3$	RR tire slip angle	deg.
13	SLPANG(4)	$\arctan(v_{G4}/u_{G4})-\psi'_4$	LR tire slip angle	deg.

This group is always printed.

Note: An asterisk is printed after the respective side force when a given tire is skidding ($\bar{\beta}_i > 3$).

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	FC(1)	F_{C1}	RF circumferential tire force	lb.
3	FC(2)	F_{C2}	LF circumferential tire force	lb.
4	FC(3)	F_{C3}	RR circumferential tire force	lb.
5	FC(4)	F_{C4}	LR circumferential tire force	lb.
6	TQFO	TQ_F	Front wheel torque	lb-ft.
7	TQRO	TQ_R	Rear wheel torque	lb-ft.

This group is printed when a front or rear wheel torque table is input (NTBL2 ≠ 0 or NTBL3 ≠ 0).

OUTPUT GROUP NUMBER 14

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	FR10	$F_{Z'U1}$	RF vertical tire force	lb.
3	FR20	$F_{Z'U2}$	LF vertical tire force	lb.
4	FR30	$F_{Z'U3}$	RR vertical tire force	lb.
5	FR40	$F_{Z'U4}$	LR vertical tire force	lb.
6	FXPU1	$F_{X'U1}$	RF tire force in the X' direction	lb.
7	FXPU2	$F_{X'U2}$	LF tire force in the X' direction	lb.
8	FXPU3	$F_{X'U3}$	RR tire force in the X' direction	lb.
9	FXPU4	$F_{X'U4}$	LR tire force in the X' direction	lb.
10	FYPU1	$F_{Y'U1}$	RF tire force in the Y' direction	lb.
11	FYPU2	$F_{Y'U2}$	LF tire force in the Y' direction	lb.
12	FYPU3	$F_{Y'U3}$	RR tire force in the Y' direction	lb.
13	FYPU4	$F_{Y'U4}$	LR tire force in the Y' direction	lb.

This group is output when NPAGE(14) is read as 1.0 on card 104 field 7.

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	ZPGI(1)	Z'_{G1}	Terrain elevation under RF wheel center	in.
3	ZPGI(2)	Z'_{G2}	Terrain elevation under LF wheel center	in.
4	ZPGI(3)	Z'_{G3}	Terrain elevation under RR wheel center	in.
5	ZPGI(4)	Z'_{G4}	Terrain elevation under LR wheel center	in.
6	PHGI(1)	ϕ_{G1}	Terrain slope (camber) under RF wheel	deg.
7	PHGI(2)	ϕ_{G2}	Terrain slope (camber) under LF wheel	deg.
8	PHGI(3)	ϕ_{G3}	Terrain slope (camber) under RR wheel	deg.
9	PHGI(4)	ϕ_{G4}	Terrain slope (camber) under LR wheel	deg.
10	THGI(1)	θ_{G1}	Terrain slope (pitch) under RF wheel	deg.
11	THGI(2)	θ_{G2}	Terrain slope (pitch) under LF wheel	deg.
12	THGI(3)	θ_{G3}	Terrain slope (pitch) under RR wheel	deg.
13	THGI(4)	θ_{G4}	Terrain slope (pitch) under LR wheel	deg.

This group is output when terrain tables are being used (NZTAB $\geq$ 1).

HVOSM-RD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 16

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	AX1			
3	AY1		x, y, and z components and resultant acceleration of vehicle at point 1	g's
4	AZ1			
5	A1R			
6	AX2			
7	AY2		x, y, and z components and resultant acceleration of vehicle at point 2	g's
8	AZ2			
9	A2R			

This group is output when any of the coordinates of points 1 or 2 are input as non-zero on card 203.

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	AINTI	$(AINT)_i$	Vehicle-barrier interface area	in^2
3	VDEF	$y'_{cpm}-(y'_B)_t$	Vehicle deformation	in.
4	FN	F_N	Vehicle normal force	lb.
5	FRICT	FRICT	Vehicle-barrier friction force	lb.
6	DELBB	δ_B	Barrier deflection	in.
7	SXR	$(\Sigma X_R)_t$	Components of the location of the applied vehicle-barrier interference force in the vehicle axes.	in.
8	SYR	$(\Sigma Y_R)_t$		
9	SZR	$(\Sigma Z_R)_t$		

This group is output when INDB ≠ 0.

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	VMAX(1)	$1/\Delta t_B[y'_B)_t-(y'_B)_{t-1}]$	Velocity of barrier deflection	in/sec.
3	URP	U'_R	Velocity components of the point of application of the vehicle-barrier interference force with respect to the space fixed axes	in/sec.
4	VRP	V'_R		
5	WRP	W'_R		
6	EEE	$(E_1)_t$	Barrier conserved energy	lb/ft.
7	DISS	$1/12 \sum_o^t E-(E_1)_t$	Barrier dissipated energy	lb/ft.
8	SPENGY	$1/24\sum_o^t(F_{Nt}-F_{Nt-1})(\Delta y'_B(n'_t-n'_{t-1}))$	Sprung mass dissipated energy	lb/ft.
9	SWORK	$1/12\sum_o^t(FRICT)(VTAN)\Delta t$	Friction force energy dissipation	lb/ft.

This group is output when INDB $\neq$ 0.

OUTPUT GROUP NUMBER 19

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	HDEF(1)	y'_{ST10}	Deflection of vehicle structural hard points	in.
3	HDEF(2)	y'_{ST20}		
4	HDEF(3)	y'_{ST30}		
5	FNSTI(1)	F_{NST1}	Vehicle hard point crush forces	lb.
6	FNSTI(2)	F_{NST2}		
7	FNSTI(3)	F_{NST3}		

This group is output when INDB $\neq$ 0.

4.2.2 Vehicle Dynamics Version

The HVOSM-VD2 printed output is organized into twenty output groupings. The output technique used allows suppression of output groups that are not desired. Output of groups is controlled by an array of indicators and output is suppressed if the indicator corresponding to a group is zero. These indicators are set internally for a number of output groups that are always printed or are set internally depending on program options being used, or are read as input for some groups.

Each output group being printed is written to a separate Fortran unit number commencing with 11. In this manner, core storage is not required to save output for subsequent printing. The user must supply twenty DD cards to define the output data sets. An example is shown in Section 4.3.

Descriptions of each output grouping follows. Note that variables printed in some groupings are dependent on the suspension option in effect.

HVOSM-VD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 1

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	XCP	x'_c	Location of vehicle sprung mass c.g. with respect to the space fixed coordinate system	ft.
3	YCP	y'_c		
4	ZCP	z'_c		
5	ULON	u	Vehicle forward velocity	ft/sec.
6	VLAT	v	Vehicle lateral velocity	ft/sec.
7	WVER	w	Vehicle vertical velocity	ft/sec.
8	ACLON	$\dot{u}-vR+wQ$	Vehicle longitudinal acceleration	g's
9	ACLAT	$\dot{v}+uR-wP$	Vehicle lateral acceleration	g's
10	ACVER	$\dot{w}+vP-uQ$	Vehicle vertical acceleration	g's
11	ACRES		Resultant vehicle acceleration	g's

This group is always printed.

HVOSM-VD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 2a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	P	P	x-component of sprung mass angular velocity	deg/sec.
3	Q	Q	y-component of sprung mass angular velocity	deg/sec.
4	R	R	z-component of sprung mass angular velocity	deg/sec.
5	PHIT	ϕ	Vehicle roll angle	deg.
6	THETT	θ	Vehicle pitch angle	deg.
7	PSIT	ψ	Vehicle yaw angle	deg.
8	OBETA		Vehicle slip angle	deg.
9	ONU		Vehicle course angle	deg.
10	PSIF	ψ_F	Front wheel steer angle	deg.
11	OPSIR	ψ_3, ψ_4	Rear wheel steer angles	deg.

---

[*] This group is output when a solid rear axle suspension option is in effect (ISUS = 0 or 2).

HVOSM-VD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 2b*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	P	P	x-component of sprung mass angular velocity	deg/sec.
3	Q	Q	y-component of sprung mass angular velocity	deg/sec.
4	R	R	z-component of sprung mass angular velocity	deg/sec.
5	PHIT	ϕ	Vehicle roll angle	deg.
6	THETT	θ	Vehicle pitch angle	deg.
7	PSIT	ψ	Vehicle yaw angle	deg.
8	OBETA		Vehicle slip angle	deg.
9	ONU		Vehicle course angle	deg.
10	PSIF	ψ_F	Front wheel steer angle	deg.
11	PSI3	ψ_3	RR wheel steer angle	deg.
12	PSI4	ψ_4	LR wheel steer angle	deg.

---

[*] This group is output when the independent rear suspension option is in effect (ISUS = 1).

HVOSM-VD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 3a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DEL1	δ_1	RF wheel ride deflection	in.
3	DEL2	δ_2	LF wheel ride deflection	in.
4	OETA3	$\delta_3+T_R\phi_R/2$	RR wheel ride deflection	in.
5	OETA4	$\delta_3-T_R\phi_R/2$	LR wheel ride deflection	in.
6	DEL1D	$\dot{\delta}_1$	RF wheel ride velocity	in/sec.
7	DEL2D	$\dot{\delta}_2$	LF wheel ride velocity	in/sec.
8	OETA3D	$\dot{\delta}_3+T_R\dot{\phi}_R/2$	RR wheel ride velocity	in/sec.
9	OETA4D	$\dot{\delta}_3-T_R\dot{\phi}_R/2$	LR wheel ride velocity	in/sec.

---

[*] This group is output for the independent front suspension/solid rear axle option (ISUS = 0).

HVOSM-VD2 OUTPUT FORMAT   OUTPUT GROUP NUMBER 3a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DEL1	δ_1	RF wheel ride deflection	in.
3	DEL2	δ_2	LF wheel ride deflection	in.
4	OETA3	$\delta_3+T_R\phi_R/2$	RR wheel ride deflection	in.
5	OETA4	$\delta_3-T_R\phi_R/2$	LR wheel ride deflection	in.
6	DEL1D	$\dot{\delta}_1$	RF wheel ride velocity	in/sec.
7	DEL2D	$\dot{\delta}_2$	LF wheel ride velocity	in/sec.
8	OETA3D	$\dot{\delta}_3+T_R\dot{\phi}_R/2$	RR wheel ride velocity	in/sec.
9	OETA4D	$\dot{\delta}_3-T_R\dot{\phi}_R/2$	LR wheel ride velocity	in/sec.

---

[*] This group is output for the independent front suspension/solid rear axle option (ISUS = 0).

HVOSM-VD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 3b*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DEL1	δ_1	RF wheel ride deflection	in.
3	DEL2	δ_2	LF wheel ride deflection	in.
4	DEL3	δ_3	RR wheel ride deflection	in.
5	DEL4	δ_4	LR wheel ride deflection	in.
6	DEL1D	$\dot{\delta}_1$	RF wheel ride velocity	in/sec.
7	DEL2D	$\dot{\delta}_2$	LF wheel ride velocity	in/sec.
8	DEL3D	$\dot{\delta}_3$	RR wheel ride velocity	in/sec.
9	DEL4D	$\dot{\delta}_4$	LR wheel ride velocity	in/sec.

---

[*] This group is output for the independent front and rear suspension option (ISUS = 1).

OUTPUT GROUP NUMBER 3c*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	OETA1	$\delta_1+T_F\phi_F/2$	RF wheel ride deflection	in.
3	OETA2	$\delta_1-T_F\phi_F/2$	LF wheel ride deflection	in.
4	OETA3	$\delta_3+T_R\phi_R/2$	RR wheel ride deflection	in.
5	OETA4	$\delta_3-T_R\phi_R/2$	LR wheel ride deflection	in.
6	OETA1D	$\dot{\delta}_1+T_F\dot{\phi}_F/2$	RF wheel ride velocity	in/sec.
7	OETA2D	$\dot{\delta}_1-T_F\dot{\phi}_F/2$	LF wheel ride velicity	in/sec.
8	OETA3D	$\dot{\delta}_3+T_R\dot{\phi}_R/2$	RR wheel ride velocity	in/sec.
9	OETA4D	$\dot{\delta}_3-T_R\dot{\phi}_R/2$	LR wheel ride velocity	in/sec.

---

[*] This group is output for the solid axle front and rear suspension option (ISUS = 2).

OUTPUT GROUP NUMBER 4a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DP	$\dot{P}$	x-component of vehicle angular acceleration	deg/sec^2
3	DQ	$\dot{Q}$	y-component of vehicle angular acceleration	deg/sec^2
4	DR	$\dot{R}$	z-component of vehicle angular acceleration	deg/sec^2
5	DDEL1D	$\ddot{\delta}_1$	RF wheel ride acceleration	in/sec^2
6	DDEL2D	$\ddot{\delta}_2$	LF wheel ride acceleration	in/sec^2
7	DEL3	δ_3	Rear roll center ride deflection	in.
8	DEL3D	$\dot{\delta}_3$	Rear roll center ride velocity	in/sec.
9	DDEL3D	$\ddot{\delta}_3$	Rear roll center ride acceleration	in/sec^2
10	PHIR	ϕ_R	Rear axle roll angle	deg.
11	PHIRD	$\dot{\phi}_R$	Rear axle roll angular velocity	deg/sec.
12	DPHIRD	$\ddot{\phi}_R$	Rear axle roll angular acceleration	deg/sec^2

---

*This group is output for the independent front suspension, solid rear axle option (ISUS = 0) when NPAGE(4) is read as 1.0 on card 104 field 1.

HVOSM-VD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 4b*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DP	$\dot{P}$	x-component of vehicle angular acceleration	deg/sec^2
3	DQ	$\dot{Q}$	y-component of vehicle angular acceleration	deg/sec^2
4	DR	$\dot{R}$	z-component of vehicle angular acceleration	deg/sec^2
5	DDEL1D	$\ddot{\delta}_1$	RF wheel ride acceleration	in/sec^2
6	DDEL2D	$\ddot{\delta}_2$	LF wheel ride acceleration	in/sec^2
7	DDEL3D	$\ddot{\delta}_3$	RR wheel ride acceleration	in/sec^2
8	DDEL4D	$\ddot{\delta}_4$	LR wheel ride acceleration	in/sec^2

---

*This group is output for the independent front and rear suspension option (ISUS = 1) when NPAGE(4) is read as 1.0 on card 104 field 1.

OUTPUT GROUP NUMBER 4c*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DP	$\dot{P}$	x-component of vehicle angular acceleration	deg/sec^2
3	DQ	$\dot{Q}$	y-component of vehicle angular acceleration	deg/sec^2
4	DR	$\dot{R}$	z-component of vehicle angular acceleration	deg/sec^2
5	DEL1	δ_1	Front roll center ride deflection	in.
6	DEL1D	$\dot{\delta}_1$	Front roll center ride velocity	in/sec.
7	DDEL1D	$\ddot{\delta}_1$	Front roll center ride acceleration	in/sec^2
8	DEL3	δ_3	Rear roll center ride deflection	in.
9	DEL3D	$\dot{\delta}_3$	Rear roll center ride velocity	in/sec.
10	DDEL3D	$\ddot{\delta}_3$	Rear roll center ride acceleration	in/sec^2
11	PHIFD	$\dot{\phi}_F$	Front axle roll angular velocity	deg/sec.
12	DPHIFD	$\ddot{\phi}_F$	Front axle roll angular acceleration	deg/sec^2
13	PHIRD	$\dot{\phi}_R$	Rear axle roll angular velocity	deg/sec.
14	DPHIRD	$\ddot{\phi}_R$	Rear axle roll angular acceleration	deg/sec^2

---

*This group is output for the solid front and rear axle option (ISUS = 2) when NPAGE(4) is read as 1.0 on card 104 field 1.

HVOSM-VD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 5

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	T1PSI	$T_{1\psi}$	Steering system friction torque	lb-in.
3	T2PSI	$T_{2\psi}$	Steering system stop torque	lb-in.
4	DPSIFI	$\dot{\psi}_F$	Front wheel steer angle velocity	deg/sec.
5	DDPSFI	$\ddot{\psi}_F$	Front wheel steer angular acceleration	deg/sec^2

This group is output when INDCRB $\neq$ 0.

HVOSM-VD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 6a*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	PSIIP(1)	ψ'_1	RF steer angle with respect to the ground	deg.
3	PSIIP(2)	ψ'_1	LF steer angle with respect to the ground	deg.
4	PSIIP(3)	ψ'_3	RR steer angle with respect to the ground	deg.
5	PSIIP(4)	ψ'_4	LR steer angle with respect to the ground	deg.
6	PHICI(1)	ϕ_{CG1}	RF camber angle with respect to the ground	deg.
7	PHICI(2)	ϕ_{CG2}	LF camber angle with respect to the ground	deg.
8	PHICI(3)	ϕ_{CG3}	RR camber angle with respect to the ground	deg.
9	PHICI(4)	ϕ_{CG4}	LR camber angle with respect to the ground	deg.
10	PHI1	ϕ_1	RF camber angle	deg.
11	PHI2	ϕ_2	LF camber angle	deg.

---

*This group is output for the independent front, solid rear axle suspension option (ISUS = 0) when NPAGE(6) is read as 1.0 on card 104 field 2.

OUTPUT GROUP NUMBER 6b*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	PSIIP(1)	ψ'_1	RF steer angle with respect to the ground	deg.
3	PSIIP(2)	ψ'_2	LF steer angle with respect to the ground	deg.
4	PSIIP(3)	ψ'_3	RR steer angle with respect to the ground	deg.
5	PSIIP(4)	ψ'_4	LR steer angle with respect to the ground	deg.
6	PHICI(1)	ϕ_{CG1}	RF camber angle with respect to the ground	deg.
7	PHICI(2)	ϕ_{CG2}	LF camber angle with respect to the ground	deg.
8	PHICI(3)	ϕ_{CG3}	RR camber angle with respect to the ground	deg.
9	PHICI(4)	ϕ_{CG4}	LR camber angle with respect to the ground	deg.
10	PHI1	ϕ_1	RF camber angle	deg.
11	PHI2	ϕ_2	LF camber angle	deg.
12	PHI3	ϕ_3	RR camber angle	deg.
13	PHI4	ϕ_4	LR camber angle	deg.

---

*This group is output for the independent front and rear suspension option (ISUS = 1) when NPAGE(6) is read as 1.0 on card 104 field 2.

OUTPUT GROUP NUMBER 6c*

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	PSIIP(1)	ψ'_1	RF steer angle with respect to the ground	deg.
3	PSIIP(2)	ψ'_2	LF steer angle with respect to the ground	deg.
4	PSIIP(3)	ψ'_3	RR steer angle with respect to the ground	deg.
5	PSIIP(4)	ψ'_4	LR steer angle with respect to the ground	deg.
6	PHICI(1)	ϕ_{CG1}	RF camber angle with respect to the ground	deg.
7	PHICI(2)	ϕ_{CG2}	LF camber angle with respect to the ground	deg.
8	PHICI(3)	ϕ_{CG3}	RR camber angle with respect to the ground	deg.
9	PHICI(4)	ϕ_{CG4}	LR camber angle with respect to the ground	deg.
10	PHIF	ϕ_F	Front axle roll angle	deg.
11	PHIR	ϕ_R	Rear axle roll angle	deg.

---

[*] This group is output for the solid front and rear axle suspension option (ISUS = 2) when NPAGE(6) is read as 1.0 on card 104 field 2.

HVOSM-VD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 7

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	UG(1)	u_{G1}	RF wheel longitudinal velocity parallel to the ground	in/sec.
3	UG(2)	u_{G2}	LF wheel longitudinal velocity parallel to the ground	in/sec.
4	UG(3)	u_{G3}	RR wheel longitudinal velocity parallel to the ground	in/sec.
5	UG(4)	u_{G4}	LR wheel longitudinal velocity parallel to the ground	in/sec.
6	VG(1)	v_{G1}	RF wheel lateral velocity parallel to the ground	in/sec.
7	VG(2)	v_{G2}	LF wheel lateral velocity parallel to the ground	in/sec.
8	VG(3)	v_{G3}	RR wheel lateral velocity parallel to the ground	in/sec.
9	VG(4)	v_{G4}	LR wheel lateral velocity parallel to the ground	in/sec.

This group is output when NPAGE(7) is read as 1.0 on card 104 field 3.

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	ZGPP(1)	Z'_{GP1}	Elevation of RF ground contact point	in.
3	ZGPP(2)	Z'_{GP2}	Elevation of LF ground contact point	in.
4	ZGPP(3)	Z'_{GP3}	Elevation of RR ground contact point	in.
5	ZGPP(4)	Z'_{GP4}	Elevation of LR ground contact point	in.

This group is output when NPAGE(8) is read as 1.0 on card 104 field 4 or the road roughness option is being used (IRUF $\neq$ 0).

HVOSM-VD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 9

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	SI(1)	S_1	Total RF suspension force	lb.
3	SI(2)	S_2	Total LF suspension force	lb.
4	SI(3)	S_3	Total RR suspension force	lb.
5	SI(4)	S_4	Total LR suspension force	lb.
6	APITCH(1)	F_{AP1}	RF anti-pitch force	lb.
7	APITCH(2)	F_{AP2}	LF anti-pitch force	lb.
8	APITCH(3)	F_{AP3}	RR anti-pitch force	lb.
9	APITCH(4)	F_{AP4}	LR anti-pitch force	lb.

This group is output when NPAGE(9) is read as 1.0 on card 104 field 5.

HVOSM-VD2 OUTPUT FORMAT — OUTPUT GROUP NUMBER 10

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	OD1	$-C_F\dot{\zeta}_1$	RF suspension damping force	lb.
3	OD2	$-C_F\dot{\zeta}_2$	LF suspension damping force	lb.
4	OD3	$-C_R\dot{\zeta}_3$	RR suspension damping force	lb.
5	OD4	$-C_R\dot{\zeta}_4$	LR suspension damping force	lb.
6	-F2FI(1)	F_{2F1}	RF suspension spring force	lb.
7	-F2FI(2)	F_{2F2}	LF suspension spring force	lb.
8	-F2RI(1)	F_{2R1}	RR suspension spring force	lb.
9	-F2RI(2)	F_{2R2}	LR suspension spring force	lb.

This group is output when NPAGE(10) is read as 1.0 on card 104 field 6.

OUTPUT GROUP NUMBER 11

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	FR(1)	F_{R1}	RF tire radial force	lb.
3	FR(2)	F_{R2}	LF tire radial force	lb.
4	FR(3)	F_{R3}	RR tire radial force	lb.
5	FR(4)	F_{R4}	LR tire radial force	lb.
6	HI(1)	h_1	RF tire rolling radius	in.
7	HI(2)	h_2	LF tire rolling radius	in.
8	HI(3)	h_3	RR tire rolling radius	in.
9	HI(4)	h_4	LR tire rolling radius	in.

This group is always printed.

HVOSM-VD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 12

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	FRCP(1)	F'_{R1}	RF tire force normal to the ground	lb.
3	FRCP(2)	F'_{R2}	LF tire force normal to the ground	lb.
4	FRCP(3)	F'_{R3}	RR tire force normal to the ground	lb.
5	FRCP(4)	F'_{R4}	LR tire force normal to the ground	lb.
6	FS(1)	F_{S1}	RF tire side force	lb.
7	FS(2)	F_{S2}	LF tire side force	lb.
8	FS(3)	F_{S3}	RR tire side force	lb.
9	FS(4)	F_{S4}	LR tire side force	lb.
10	SLPANG(1)	$\arctan(v_{G1}/u_{G1})-\psi'_1$	RF tire slip angle	deg.
11	SLPANG(2)	$\arctan(v_{G2}/u_{G2})-\psi'_2$	LF tire slip angle	deg.
12	SLPANG(3)	$\arctan(v_{G3}/u_{G3})-\psi'_3$	RR tire slip angle	deg.
13	SLPANG(4)	$\arctan(v_{G4}/u_{G4})-\psi'_4$	LR tire slip angle	deg.

This group is always printed.

Note: An asterisk is printed after the respective side force when a given tire is skidding ($\overline{\beta} > 3$).

HVOSM-VD2 OUTPUT FORMAT

OUTPUT GROUP NUMBER 13

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	FC(1)	F_{C1}	RF circumferential tire force	lb.
3	FC(2)	F_{C2}	LF circumferential tire force	lb.
4	FC(3)	F_{C3}	RR circumferential tire force	lb.
5	FC(4)	F_{C4}	LR circumferential tire force	lb.
6	OTQD(1)		RF tire drive torque	lb-ft.
7	OTQD(2)		LF tire drive torque	lb-ft.
8	OTQD(3)		RR tire drive torque	lb-ft.
9	OTQD(4)		LR tire drive torque	lb-ft.
10	RPME	RPME	Engine speed	rpm
11	TQE	TQE	Engine torque	lb-ft.

This group is always printed.

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	FR10	$F_{Z'U1}$	RF vertical tire force	lb.
3	FR20	$F_{Z'U2}$	LF vertical tire force	lb.
4	FR30	$F_{Z'U3}$	RR vertical tire force	lb.
5	FR40	$F_{Z'U4}$	LR vertical tire force	lb.
6	FXPU1	$F_{X'U1}$	RF tire force in the x' direction	lb.
7	FXPU2	$F_{X'U2}$	LF tire force in the x' direction	lb.
8	FXPU3	$F_{X'U3}$	RR tire force in the x' direction	lb.
9	FXPU4	$F_{X'U4}$	LR tire force in the x' direction	lb.
10	FYPU1	$F_{Y'U1}$	RF tire force in the y' direction	lb.
11	FYPU2	$F_{Y'U2}$	LF tire force in the y' direction	lb.
12	FYPU3	$F_{Y'U3}$	RR tire force in the y' direction	lb.
13	FYPU4	$F_{Y'U4}$	LR tire force in the y' direction	lb.

This group is output when NPAGE(14) is read as 1.0 on card 104 field 7.

HVOSM-VD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 15

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	ZPGI(1)	Z'_{G1}	Terrain elevation under RF wheel center	in.
3	ZPGI(2)	Z'_{G2}	Terrain elevation under LF wheel center	in.
4	ZPGI(3)	Z'_{G3}	Terrain elevation under RR wheel center	in.
5	ZPGI(4)	Z'_{G4}	Terrain elevation under LR wheel center	in.
6	PHGI(1)	ϕ_{G1}	Terrain slope (camber) under RF wheel	deg.
7	PHGI(2)	ϕ_{G2}	Terrain slope (camber) under LF wheel	deg.
8	PHGI(3)	ϕ_{G3}	Terrain slope (camber) under RR wheel	deg.
9	PHGI(4)	ϕ_{G4}	Terrain slope (camber) under LR wheel	deg.
10	THGI(1)	θ_{G1}	Terrain slope (pitch) under RF wheel	deg.
11	THGI(2)	θ_{G2}	Terrain slope (pitch) under LF wheel	deg.
12	THGI(3)	θ_{G3}	Terrain slope (pitch) under RR wheel	deg.
13	THGI(4)	θ_{G4}	Terrain slope (pitch) under LR wheel	deg.

This group is output when the terrain tables are being used (NZTAB $\geq$ 1).

OUTPUT GROUP NUMBER 16

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	AX1		x, y, and z components and resultant acceleration of vehicle at point 1	g's
3	AY1			
4	AZ1			
5	A1R			
6	AX2		x, y, and z components and resultant acceleration of vehicle at point 2	g's
7	AY2			
8	AZ2			
9	A2R			

This group is output when any of the coordinates of points 1 or 2 are input as non-zero on card 203.

HVOSM-VD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 17

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	SLIPAV(1)	$(SLIP)_1$	RF wheel circumferential slip	%
3	SLIPAV(2)	$(SLIP)_2$	LF wheel circumferential slip	%
4	SLIPAV(3)	$(SLIP)_3$	RR wheel circumferential slip	%
5	SLIPAV(4)	$(SLIP)_4$	LR wheel circumferential slip	%
6	RHOSAV(1)	ρ_{S1}	RF wheel friction ratio	-
7	RHOSAV(2)	ρ_{S2}	LF wheel friction ratio	-
8	RHOSAV(3)	ρ_{S3}	RR wheel friction ratio	-
9	RHOSAV(4)	ρ_{S4}	LR wheel friction ratio	-
10	RPSI(1)	$(RPS)_1$	RF wheel rotational velocity	rev/sec.
11	RPSI(2)	$(RPS)_2$	LF wheel rotational velocity	rev/sec.
12	RPSI(3)	$(RPS)_3$	RR wheel rotational velocity	rev/sec.
13	RPSI(4)	$(RPS)_4$	LR wheel rotational velocity	rev/sec.

This group is always printed.

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	PP(1)	P_F	Front brake hydraulic pressure	psig
3	PP(2)	P_R	Rear brake hydraulic pressure	psig
4	TQB(1)	$(TQ)_{B1}$	RF brake torque	lb-ft.
5	TQB(2)	$(TQ)_{B2}$	LF brake torque	lb-ft.
6	TQB(3)	$(TQ)_{B3}$	RR brake torque	lb-ft.
7	TQB(4)	$(TQ)_{B4}$	LF brake torque	lb-ft.
8	TAU(1)	τ_1	RF brake assembly temperature	°F
9	TAU(2)	τ_2	LF brake assembly temperature	°F
10	TAU(3)	τ_3	RR brake assembly temperature	°F
11	TAU(4)	τ_4	LR brake assembly temperature	°F

This group is printed when the driver option is being used (IDRVER $\neq$ 0) or when the brake pressure, transmission ratio or throttle setting tables are input (NTTI + NTT2 + NTT3 $\neq$ 0).

HVOSM-VD2 OUTPUT FORMAT OUTPUT GROUP NUMBER 19

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	RPSSM(1)		RF brake dissipated energy	lb-ft.
3	RPSSM(2)	$-\sum_{o}^{t}(TQ)_{Bi}(RPS)_i\Delta t$	LF brake dissipated energy	lb-ft.
4	RPSSM(3)		RR brake dissipated energy	lb-ft.
5	RPSSM(4)		LR brake dissipated energy	lb-ft.
6	FCSLSM(1)		RF tire dissipated energy	lb-ft.
7	FCSLSM(2)	$-1/12\sum_{o}^{t}F_{Ci}(SLIP)_i U_{GWi}\Delta t$	LF tire dissipated energy	lb-ft.
8	FCSLSM(3)		RR tire dissipated energy	lb-ft.
9	FCSLSM(4)		LR tire dissipated energy	lb-ft.

This group is output when NPAGE(19) is read as 1.0 on card 104 field 7.

PRINT COLUMN	PROGRAM VARIABLE	ANALYTICAL VARIABLE	DESCRIPTION	UNITS
1	T	t	Simulated time	sec.
2	DPSISF	$\Delta\psi_{fi}$	Command steer angle	deg.
3	ET	$\Sigma WE_i WI_i e_i$	Steer error	in.
4	DELTAX	D_{ax}	Desired acceleration	in/sec^2
5	APD	APD	Accelerator pedal deflection	in.
6	FBRK	F_{BRK}	Brake pedal force	lb.
7	IGEAR		Transmission gear number	

This group is output when the driver option is being used (IDRVER $\neq$ 0).

4.3 External Data Files

Each version of the HVOSM writes an identical data file for use by the post-processing vehicle graphic display program. The data is written on FORTRAN device 1 from subroutine PLOTTP. Three types of records are written, a static data record, a dynamic data record, and an end of data file record. A calling argument to PLOTTP of 1, 2, or 3, respectively, determines which type of record is to be written. The contents of the respective records are listed below.

Static Data Record

HED(I), 1 = 1, 36	Run title
DADE(I), I = 1, 3	Current date
A	Distance from sprung mass c.g. to front wheel centerline (a)
B	Distance from sprung mass c.g. to rear wheel centerline (b)
TS	Rear spring track (T_S)
ZR	Static vertical distance from sprung mass c.g. to rear roll center (Z_R)
RHO	Distance between rear axle roll center and rear axle c.g. (ρ)
ZF	Static vertical distance between sprung mass c.g, and front wheel centers (Z_F)
RW	Undeflected wheel radius (R_W)
TF	Rear wheel track (T_F)
TR	Rear wheel track (T_R)

Dynamic Data Record

T	Simulated time (t)
XCP YCP ZCP	Coordinates of the sprung mass c.g. relative to the space axes (x'_c, y'_c, z'_c)
PHIT THETT PSIT	Sprung mass Euler (roll, pitch, and yaw) angles (ϕ, θ, ψ)
DEL1 DEL2	Right and left from wheel displacements (δ_1, δ_2)
DEL3	Rear axle roll center displacement from the equilibrium position (δ_3)
PHIR	Rear axle roll angle (ϕ_R)
PSI1	Front wheel steer angle (ψ_1)
PHI1 PHI2	Right and left front wheel camber angles (ϕ_1, ϕ_2)
XGPP(J) XGPP(J) J = 1, 4 XGPP(J)	Coordinates of the ground contact points of four tires with respect to the space axes (X'_{GPi}, Y'_{GPi}, Z'_{GPi})
ICONTW(J), J = 1, 4	Indicator for current status of wheel J: = 1, tire J is not skidding = -1, tire J is skidding = 0, tire J if off the ground

End of Data File Record

To indicate the end of the data file for a given run, a record comprised of 30 words of -9999.0 is written.

Note that this file is applicable only to the independent front suspension, solid rear axle option.

Job Control Language

The Data Definition Statement required to describe the data file written on the IBM System/370 Operating System is of the form:

```
//GO.FT01F001 DD UNIT=9TRACK,DSN=dsname,DISP=(NEW,KEEP),
//LABEL=(1,SL,OUT),DCB=(RECFM=VBS,LRECL=200,BLKSIZE=8004)
```

Road roughness data is input from FORTRAN unit 4 via an unformatted read statement in subroutine RUFRED. The data is assumed to be sequential elevation changes from a datum at constant intervals. The number of data points read is limited to 2200.

An example of the JCL requirements including printed output DD statements (FORTRAN units 11 through 30) is shown overleaf.

```
//  EXEC LOADGO,GCORE=320K,GTIME='(1,00)'
//GO.SYSLIN DD DSN=LOADLIB(DSHVOSR2),DISP=SHR
//GO.FT01F001 DD UNIT=9TRACK,DSN=LCDS.RCLL,DISP=(NEW,CATLG),
// DCB=(RECFM=VBS,LRECL=200,BLKSIZE=8004),LABEL=(1,,,OUT,RETPD=100)
//GO.FT02F001 DD DSN=&&DSIN,UNIT=SYSDA,DISP=(NEW,DELETE),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400),SPACE=(TRK,(1,1),RLSE)
//GO.FT03F001 DD DUMMY
//GO.FT04F001 DD DUMMY
//GO.FT11F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT12F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT13F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT14F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT15F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT16F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT17F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT18F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT19F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT20F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT21F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT22F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT23F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT24F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT25F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT26F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT27F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT28F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT29F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.FT30F001 DD SYSOUT=A,SPACE=(TRK,(0,15),RLSE),
// DCB=(RECFM=VBA,BLKSIZE=6447,LRECL=137,BUFNO=2)
//GO.SYSIN DD *
```

HVOSM DATA DECK

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4.4 Program Stops and Messages

4.4.1 Roadside Design Version

Program stops include both normal and abnormal stops. Normal stops occur when the cumulative simulated time (T) exceeds the desired final time (T1) as input in field 2 of card 101, or when the magnitudes of both the linear and angular velocities of the vehicle sprung mass are less than or equal to the input minimums (UVWMIN and PQRMIN, card 101, fields 6 and 7). When these stops occur, no message is output and the program attempts to read another set of data cards.

Abnormal stops occur when a condition is encountered that the program is not designed to handle or an unresolvable error has occurred. The first type of abnormal stop occurs when rollover of the vehicle is immenent. That is, when the vehicle has rolled to an angle of 90° in either direction.

The second program stop occurs when the barrier option is in effect (INDB $\neq$ 0) and the vehicle yaw angle (PSIT) is greater than 135°. This stop is necessary since the left rear corner of the vehicle is not tested for contact with the barrier.

Abnormal stops are also indicated by a non-zero value for the variable ISTOP. The following codes identify the type and location of error.

ISTOP = 4	Subroutine TMCNST. The denomenator of the expression used to caluclate the value of PSIT after indexing of coordinate system is zero.
ISTOP = 5	Subroutine TMCNST. The logic associated with coordinate system indexing has been unable to determine the correct quandrant for PSIT, PHIT or THETT.

ISTOP = 6	Subroutine TMCNST. The numerator in the expression for calculation of THETT after coordinate system indexing is zero.
ISTOP = 7	Subroutine TMCNST. The numerator in the expression for calculation of PHIT after coordinate system indexing is zero.
ISTOP = 30	Subroutine TMCNST. One of the recalculated Euler angles (PSIT, THETT, PHIT) has been computed as being very large (>3000 radians) after coordinate system indexing. A probable error has occurred.

When an ISTOP $\neq 0$ condition is encountered, the program prints all output up to the time of the error, prints the value of ISTOP, terminates execution of the current run and attempts to read another set of data cards.

In subroutine INPUT, the following messages are printed if difficulties are encountered in reading the card data deck.

```
UNEXPECTED END OF FILE ENCOUNTERED IN STMT NO. 1 OF
SUBROUTINE INPUT.  LAST CARD READ WAS XXXX.

A CARD NUMBERED LESS THAN OR EQUAL TO ZERO WAS
ENCOUNTERED IN SUBROUTINE INPUT.  CARD IMAGE PRINTED
ABOVE.

THE NUMBER OF CARDS READ IS ZERO.

A BLOCK NUMBER OF LESS THAN OR EQUAL TO ZERO HAS
BEEN OBTAINED.

A BLOCK NUMBER LARGER THAN THE ALLOWED NUMBER HAS BEEN
OBTAINED.
```

```
AN ERROR HAS OCCURRED IN STORING INPUT VALUES IN ONE
OF THE BLKXX SUBROUTINES.  THE CALLING ARGUMENTS
FROM INPUT ARE:  NBLK = XXXX   NBCRD = XXXX
NSEQ = XXXX   NCARD = XXXX   NERR = XXXX
```

In subroutine NLDFL, messages may be printed if the program determines that both constraints on the unloading curve (the input ratio of conserved to total energy, CONS, and the ratio of maximum to permanent displacement, SET) cannot be simultaneously satisfied. If this occurs, the energy ratio, CONS, is modified and a diagnostic is output.

In subroutine RUFRED, two messages may be printed if difficulties are encountered in reading road roughness data from FORTRAN device 4. They are:

```
END OF FILE ENCOUNTERED IN READ OF ROUGHNESS DATA
BEFORE NEND POINTS WERE READ.

NUMBER OF LAST ROUGHNESS DATA POINT IS GREATER THAN
THE ALLOWED 2200.  PROGRAM TERMINATED.
```

4.4.2 Vehicle Dynamics Version

Program stops include both normal and abnormal stops. Normal stops occur when the cumulative simulated time (T) exceeds the desired final time (T1) as input in field 2 of card 101, or when the magnitudes of both the linear and angular velocities of the vehicle sprung mass are less than or equal to the input minimums (UVWMIN and PQRMIN, card 101, fields 6 and 7). When these stops occur, no message is output and the program attempts to read another set of data cards.

Abnormal stops occur when a condition is encountered that the program is not designed to handle or an unresolvable error has occurred. The first type of abnormal stop occurs when rollover of the vehicle is immenent. That is, when the vehicle has rolled to an angle of 90° in either direction.

Abnormal stops are also indicated by a non-zero value for the variable ISTOP. The following codes identify the type and location of the error.

ISTOP = 1	Subroutine TIRFR. An error has occurred in determination of the wheel spin integration interval.
ISTOP = 4	Subroutine TMCNST. The denomenator of the expression used to calculate the value of PSIT after indexing of coordinate system is zero.
ISTOP = 5	Subroutine TMCNST. The logic associated with coordinate system indexing has been usable to determine the correct quadrant for PSIT, PHET or THETT.

ISTOP = 6	Subroutine TMCNST. The numerator in the expression for calculation of THETT after coordinate system indexing is zero.
ISTOP = 7	Subroutine TMCNST. The numerator in the expression for calculation of PHIT after coordinate system indexing is zero.
ISTOP = 30	Subroutine TMCNST. One of the recalculated Euler angles (PSIT, THETT, PHIT) has been computed as being very large (>3000 radians) after coordinate system indexing. A probable error has occurred.

When an ISTOP ≠ 0 condition is encountered, the program prints all output up to the time of the error, prints the value of ISTOP, terminates execution of the current run and attempts to read another set of data cards.

In subroutine CTQD, a message will be printed if the tabular time range of the TTS, TTR and TPC tables is exceeded. The program continues execution with the last entries in the tables.

Similarly, in subroutine CTQB, a message is printed if the temperature range of the FLF table is exceeded. The program again continues execution using the last value in the table.

In subroutine INPUT, the following messages are printed if difficulties are encountered in reading the card data deck.

```
UNEXPECTED END OF FILE ENCOUNTERED IN STMT NO. 1 OF
SUBROUTINE INPUT.  LAST CARD READ WAS XXXX.

A CARD NUMBERED LESS THAN OR EQUAL TO ZERO WAS
ENCOUNTERED IN SUBROUTINE INPUT.  CARD IMAGE
PRINTED ABOVE.
```

```
THE NUMBER OF CARDS READ IS ZERO.

A BLOCK NUMBER OF LESS THAN OR EQUAL TO ZERO HAS
BEEN OBTAINED.

A BLOCK NUMBER LARGER THAN THE ALLOWED NUMBER HAS
BEEN OBTAINED.

AN ERROR HAS OCCURRED IN STORING INPUT VALUES IN ONE
OF THE BLKXX SUBROUTINES.  THE CALLING ARGUMENTS
FROM INPUT ARE:  NBLK = XXXX   NBCRD = XXXX
NSEQ = XXXX   NCARD = XXXX.
```

In subroutine RUFRED, two messages may be printed if difficulties are encountered in reading road roughness data from FORTRAN device 4. They are:

```
END OF FILE ENCOUNTERED IN READ OF ROUGHNESS DATA
BEFORE NEND POINTS WERE READ.

NUMBER OF LAST ROUGHNESS DATA POINT IS GREATER THAN
THE ALLOWED 2200.  PROGRAM TERMINATED.
```

5. HVOSM PROGRAM EXAMPLES

5.1 Calculation of Inputs

5.1.1 Vehicle Weights and Center of Gravity Location

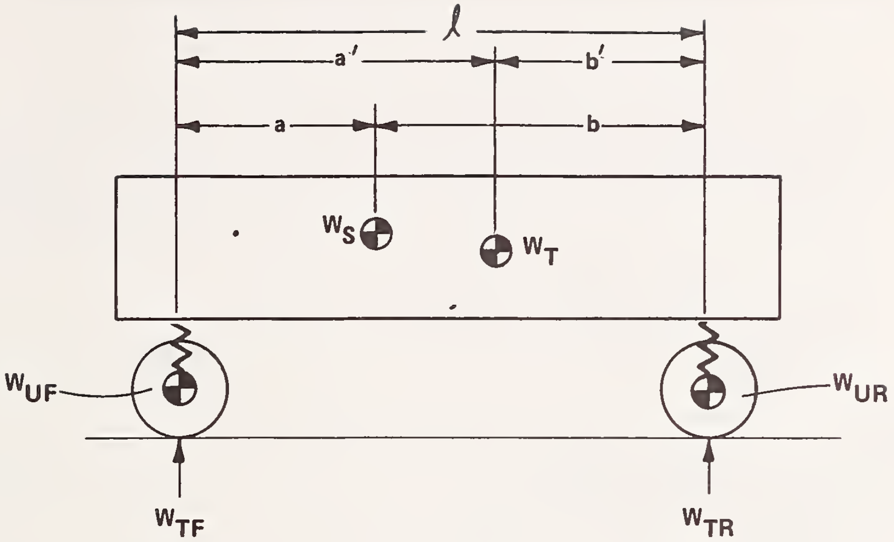
Given the total vehicle weight and its front to rear distribution, and the unsprung weights, the longitudinal position of the sprung mass c.g. can be obtained. If these parameters are not known, or a generic vehicle is to be simulated, they can be estimated* from the vehicle wheelbase by the following formulae from Reference 4.

Total vehicle weight: $W_T = 2.451 \times 10^{-3} \ell_w^{\ 3}$ lbs.
Total unsprung weight: $W_{UT} = 126.6 + 0.111\ W_T$ lbs.
Front unsprung weight: $W_{UF} = 0.385\ W_{UT}$ lbs.
Rear unsprung weight: $W_{UR} = W_{UT} - W_{UF}$ lbs.
Sprung weight: $W_S = W_T - W_{UT}$ lbs.
Total weight at front: $W_{TF} = \frac{1}{100}\ (62.727 - 0.0629\ \ell_w) W_T$ lbs.
Total weight at rear: $W_{TR} = W_T - W_{TF}$ lbs.
Sprung weight at front: $W_{FS} = W_{TF} - W_{UF}$ lbs.
Sprung weight at rear: $W_{RS} = W_{TR} - W_{UR}$ lbs.

where ℓ_w is the vehicle wheelbase in inches.

---

*Formulae were derived from linear fits to measurements of conventional domestic front engine-rear drive vehicles.



The spring rate of the tires (K_T) and the undeflected tire radius (R_W) are measured. Then the deflected tire radii are:

$$h_F = R_W - \frac{W_{TF}}{K_T}$$

$$h_R = R_W - \frac{W_{TR}}{K_T}$$

The longitudinal position of the sprung mass center of gravity is then:

$$\boxed{a = \frac{W_{RS}}{W_S} \ \ell w \text{ inches}}$$

$$\boxed{b = \ell w - a \text{ inches}}$$

And the masses required for input into the HVOSM are:

$$\boxed{M_S = \frac{W_S}{g} \text{ lb-sec}^2\text{/in}}$$

$$\boxed{M_{UF} = \frac{W_{UF}}{g} \text{ lb-sec}^2\text{/in}}$$

$$\boxed{M_{UR} = \frac{W_{UR}}{g} \text{ lb-sec}^2\text{/in}}$$

Further, knowing the total vehicle c.g. height above the ground (Z'_T), the sprung mass height above the groung (Z'_S) can be calculated:

$$Z'_s = (Z'_T W_T - h_F W_{UF} - h_R W_{UR})/W_s$$

Since the space coordinate system is assumed to be positive Z' down from ground level, the elevation of the sprung mass c.g. is:

$$\boxed{Z'c_o = -Z'_s}$$

5.1.2 Initial Vehicle Vertical Equilibrium

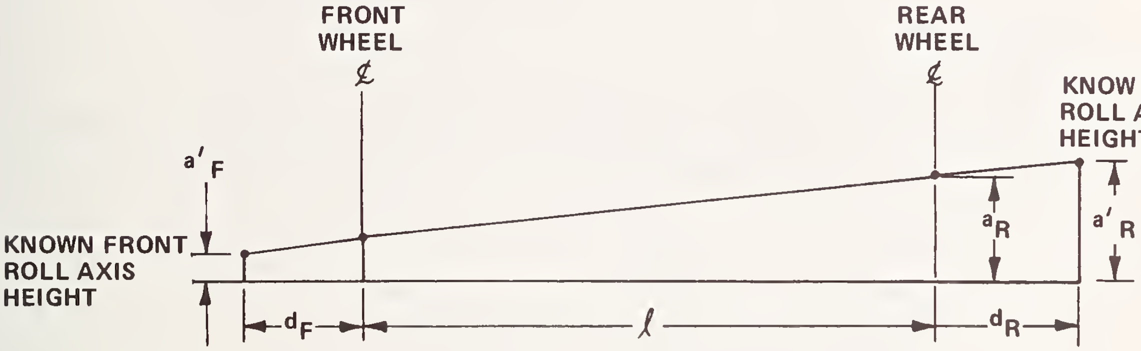
Assuming the longitudinal axis of the vehicle is horizontal, the initial vertical equilibrium of an independent front suspension, solid rear axle vehicle is specified by

$$\boxed{Z_F = (-Z'c_o - h_F) \text{ inches}}$$

$$\boxed{Z_R = (-Z'_{c_o} - h_R - \rho) \text{ inches}}$$

where ρ is the distance of the rear axle roll center above the rear axle c.g.

If the static roll axis height is given relative to the ground at two points along the vehicle longitudinal axis, as illustrated below, ρ can be computed as follows:



$$\boxed{\rho = a_R - h_R \text{ inches}}$$

where

$$a_R = a'_F + \frac{d_F + \ell}{d_F + \quad + d_R} (a'_R - a'_F)$$

5.1.3 Rotational Inertia Properties

Moments and product of inertia of the sprung mass about the sprung mass axes are best obtained by measurement, however, estimates can be made by using the following formulae developed from Reference 4. It should be noted, however, that these estimates are based on measurements of a number of vehicles and thus do not reflect a specific vehicle.

Pitch Inertia

$$\boxed{I_Y = I_{YT} - I_{YU} \quad \text{lb sec}^2\text{in}}$$

where

$$Iy_t = M_T\,(3.1104)\,W_T^{0.82} \quad \text{lb sec}^2\text{in,}$$

is the pitch inertia of the total vehicle about the total vehicle c.g.

$$Iy_u = M_{UF}(144 + a^2) + M_{UR}(144 + b^2)$$

is the pitch inertia of the unsprung masses about the total c.g.

Yaw Inertia

$$\boxed{I_z = M_S\,(26.352)\,W_T^{0.577} \quad \text{lb sec}^2\ \text{in}}$$

Roll Inertia

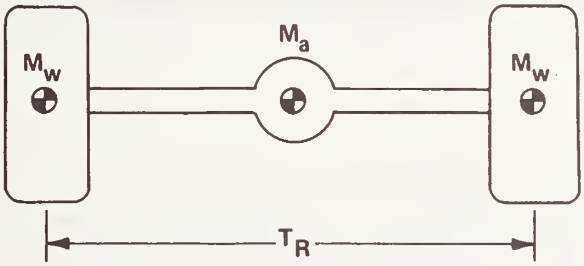
$$\boxed{I_x = M_S\,(4.752)\,W_T^{0.546} \quad \text{lb sec}^2\ \text{in}}$$

Yaw-Roll Product of Inertia

Reference 4 indicates no correlation of the yaw-roll product of inertia with any measured vehicle parameter. Measurements indicate a range of values from -1680 $\mathrm{lb/sec^2}$ into +1680 $\mathrm{lb/sec^2}$ in. There is no way to estimate this parameter without measurement.

Rear Axle Roll Inertia

An approximation to the rear axle roll moment of inertia can be made by assuming the axle to be a thin rod and the brake system/wheels as point masses, see sketch.



$$\boxed{I_R = (1/2M_w + 1/12\ M_a)\ T_R^2 \quad \mathrm{lb\ sec^2\ in}}$$

5.1.4 Suspension Properties

5.1.4.1 Ride Rates

Vehicle ride rate measurements effective at the wheel are typically presented as illustrated in Figure 5.1-1.

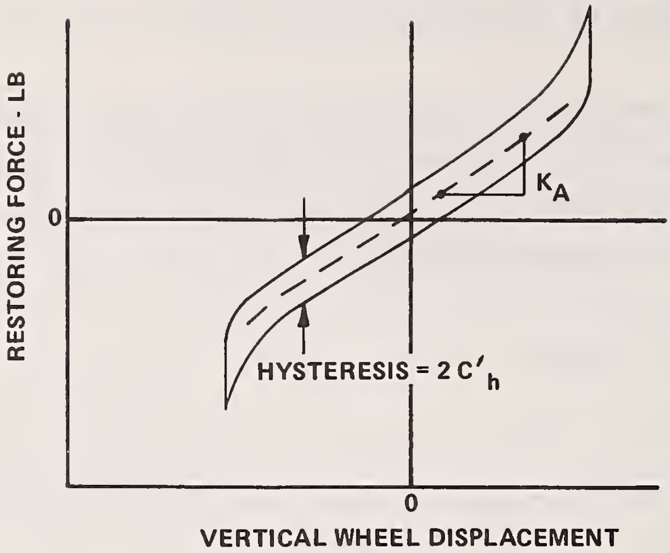


Figure 5.1-1 TYPICAL RIDE RATE CHARACTERISTIC

If the measured characteristic applies to the suspension only, the slope in the linear range, K_A, is directly interpreted as the HVOSM suspension rate, K_F for the front, K_R for the rear.

However, if the measured characteristic includes the effects of tire rates, the apparent ride rate, K_A, must be modified to remove the series spring rate of the tires, K_T, to obtain the suspension rate.

$$\boxed{K_{F,R} = \frac{K_A \; K_T}{K_T - K_A} \quad \text{lb/in}}$$

If measurements are not available, estimates can be made using the following:

Bounce natural frequence: $f_n = 1{,}696 - 1.415\times10^{-4} W_T$ Hz

Total spring rate: $\Sigma K = 4 f_n^2 \pi^2 M_S$ lb/in

Spring rate distribution: $R_K = 42.17 + 0{,}125\times10^{-2} W_T$ %

Front spring rate: $K_F = \frac{1}{2} \left(\frac{R_K}{100} \right) \Sigma K$

Rear spring rate: $K_R = \frac{1}{2} (\Sigma K - K_F)$

5.1.4.2 Auxiliary Roll Rates

Vehicle roll rates are typically presented as shown in Figure 5.1-2.

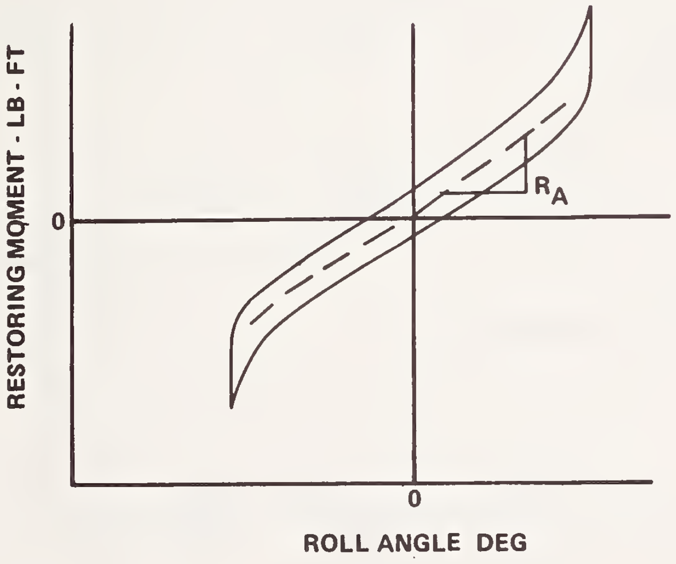


Figure 5.1-2 TYPICAL VEHICLE ROLL RATE MEASUREMENTS

If the measured characteristic applies to the suspension only, that is, does not include effects of tire deflections in the roll rate, the slope in the linear range, R_A (lb. ft/deg), can be used to obtain the auxiliary roll stiffness, R_F and R_R for the front and rear, respectively.

$$\boxed{R_F = 687.6\ R_A - \frac{K_F T_F^2}{2} \quad \frac{\text{lb in}}{\text{rad}}}$$

$$\boxed{R_R = 687.6\ R_A - \frac{K_R T_s^2}{2} \quad \frac{\text{lb in}}{\text{rad}}}$$

where $\frac{K_F T_F^2}{2}$ and $\frac{K_R T_s^2}{2}$ are the roll rate contributions due to the suspension ride rates.

However, if the roll rate characteristic includes the series effect of tire deformation, the auxiliary roll stiffnesses are obtained from

$$\boxed{R_F = \frac{687.6 R_A \left(\frac{K_T T_F^2}{2}\right)}{\frac{K_T T_F^2}{2} - 687.6\ R_A} - \frac{K_F T_F^2}{2} \quad \frac{\text{lb in}}{\text{rad}}}$$

$$\boxed{R_R = \frac{687.6 R_A \left(\frac{K_T T_R^2}{2}\right)}{\frac{K_T T_R^2}{2} - 687.6 R_A} - \frac{K_R T_s^2}{2} \quad \frac{\text{lb in}}{\text{rad}}}$$

5.1.4.3 Suspension Friction

Suspension friction (C'_F, C'_R) is comprised of two components, hysteresis in the ride rate characteristic and equivalent "blow-off" force level in the shock absorbers. The total hysteresis effective at the wheel from the ride rate diagram (Figure 5.1-1) as measured at a given ride position is twice the effective friction, C'_h.

A typical shock absorber force vs. velocity diagram is shown in Figure 5.1-3.

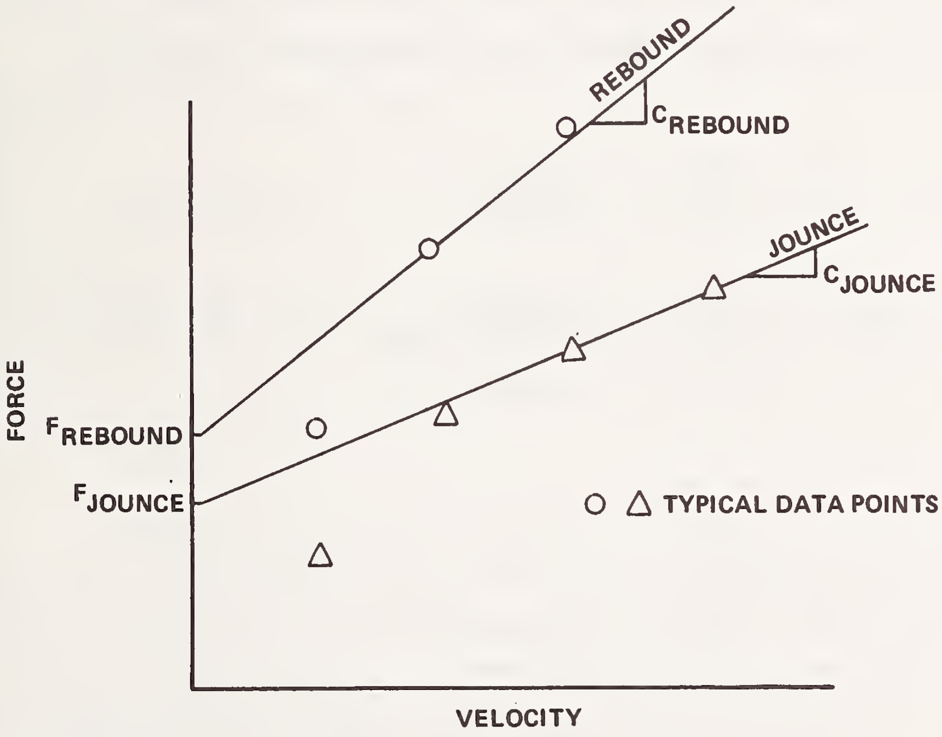


Figure 5.1-3 SHOCK ABSORBER FORCE VS VELOCITY DIAGRAM

A linear fit to the data points results in a slope and intercept which are the shock absorber viscous coefficient and "blow-off" force level for jounce (compression) and rebound. Since the HVOSM requires symmetric characteristics, these values must be averaged.

$$F_{AVE} = 1/2\ (F_{JOUNCE} + F_{REBOUND})$$

$$C_{AVE} = 1/2\ (C_{JOUNCE} + C_{REBOUND})$$

Further, since these properties are effective at the shock absorber, they must be modified to obtain their effects at the wheel as required by the program. If the shock absorber installation ratio, the ratio of the change in shock absorber length to the wheel center displacement, $(\Delta s/\Delta\delta)$ is known then the total suspension coulomb friction is obtained from

$$\boxed{C'_F = C'_h + \left(\frac{\Delta s}{\Delta\delta}\right)_F \ (F_{AVE})_F}$$

Where C'_h is obtained from the front suspension ride rate characteristic, $\left(\frac{\Delta s}{\Delta\delta}\right)$ from the shock absorber installation geometry and F_{AVE}, from the shock absorber force vs. velocity characteristics.

Similarly, for the rear:

$$\boxed{C'_R = C'_h + \left(\frac{\Delta s}{\Delta\delta}\right)_R \ (F_{AVE})_R}$$

Note that the installation ratio for a rigid rear axle results from out of vertical alignment of the shock absorber.

5.1.4.4 Suspension Viscous Damping

From the average viscous coefficient of the shock absorber (C_{AVE}) and the installation ratio, the equivalent "at the wheel" viscous coefficient is

$$\boxed{C_F = (C_{AVE})_F \left(\frac{\Delta s}{\Delta \delta} \right)_F^2 \quad \frac{\text{lb sec}}{\text{in}}}$$

$$\boxed{C_R = (C_{AVE})_R \left(\frac{\Delta s}{\Delta \delta} \right)_R^2 \quad \frac{\text{lb sec}}{\text{in}}}$$

If viscous damping coefficients cannot be obtained from measurement data, they may be estimated from:

Front damping: $C_F = \frac{(12.3)(2)}{100} \sqrt{K_F M_s}$ lb-sec/in

Rear damping: $C_R = \frac{(20.8)(2)}{100} \sqrt{K_R M_s}$ lb-sec/in

5.1.4.5 Suspension Stops

Given suspension ride rate data, as shown by the dashed lines in Figure 5.1-4, the suspension model used in these program versions requires a piecewise, nonlinear fit to be made as illustrated by the solid lines. Within the region bounded by initial contact with the suspension bumpers, $\Omega_c \leq \delta \leq \Omega_E$, the fit is linear with a slope of K, centrally located within the hysteresis loop of magnitude 2 C'_h. For deflections outside of Ω_c or Ω_E, the magnitude of the fitted curve should remain below the loading data curve by C'_h. Similarly, for unloading, the magnitude of the fitted curve should remain above the unloading data curve by C'_h.

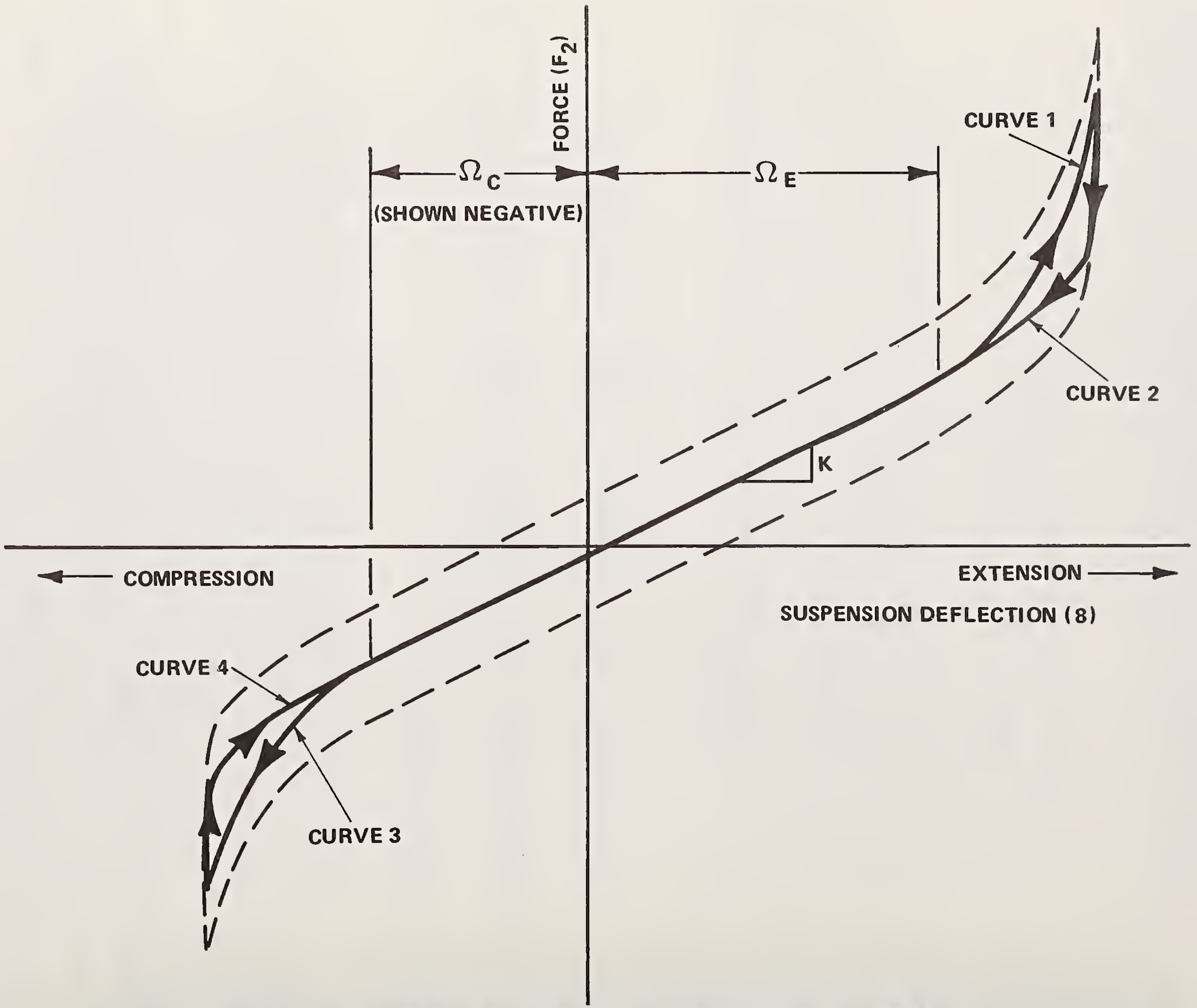


Figure 5.1-4 **SUSPENSION STOP BEHAVIOR (RP AND VD MODEL)**

The fit to the desired curves are made with the following:

curve 1:

$$F_2 = K\delta + K_E\,(\delta-\Omega_E) + K'_E\,(\delta-\Omega_E)^3 \quad \text{for } \delta>\Omega_E,\ \operatorname{sgn}\delta = \operatorname{sgn}\dot{\delta}$$

curve 2:

$$F_2 = K\delta + \lambda[K_E(\delta-\Omega_E) + K_{E'}\,(\delta-\Omega_E)^3] \quad \text{for } \delta>\Omega_E,\ \operatorname{sgn}\delta \neq \operatorname{sgn}\dot{\delta}$$

where $0 \leq \lambda \leq 1$

curve 3:

$$F_2 = K\delta + K_c\,(\delta-\Omega_c) + K'_c\,(\delta-\Omega_c)^3 \quad \text{for } \delta<\Omega_c,\ \operatorname{sgn}\delta = \operatorname{sgn}\dot{\delta}$$

curve 4:

$$F_2 = K\delta + \lambda[K_c\,(\delta-\Omega_c) + K'_c\,(\delta-\Omega_c)^3] \quad \text{for } \delta<\Omega_c,\ \operatorname{sgn}\delta \neq \operatorname{sgn}\dot{\delta}$$

Note that the factor λ accounts for energy dissipation in the suspension stops.

5.1.4.6 Camber Angles

Front (and rear for an independent rear suspension) wheel camber angle as a function of vertical displacement of the wheel is typically measured as shown in Figure 5.1-5.

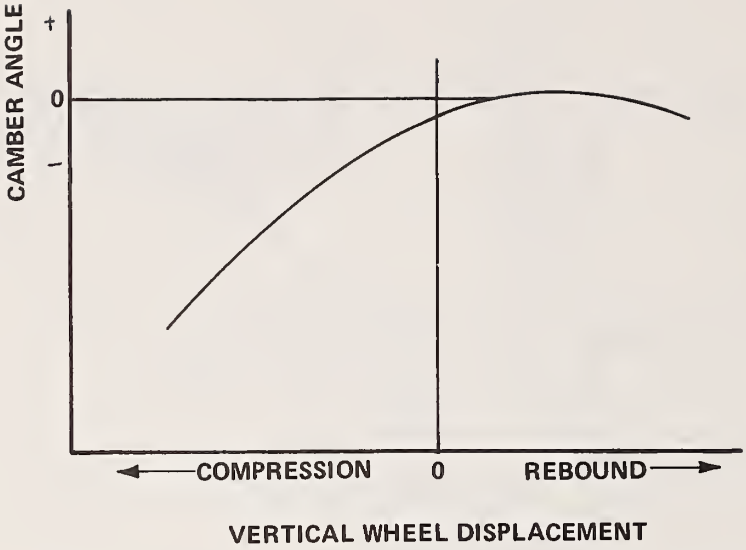


Figure 5.1-5 **TYPICAL CAMBER MEASUREMENTS**

Camber angle as measured is defined as positive when the top of the wheel is further from the vehicle centerline than the bottom. The camber table as a function of wheel displacement entered in the HVOSM is defined for the right front (or rear) wheel. In determination of the left wheel camber angle, the program changes the sign of the value obtained from the table since the sign of the angle of the wheel relative to the vehicle axis is opposite for a consistent camber angle sign as defined above.

5.1.4.7 Half-Track Change

The suspension linkages on an independent suspension not only control camber change but, in general, also introduce a half-track change (a change in the lateral distance between the wheel center and vehicle centerline) as the wheel moves vertically. In general the change is small and is usually neglected. However, for accurate simulation of jacking forces (vertical forces induced by tire side forces) it is required.

As applied to the HVOSM, a half-track change table is obtained from measurements as a function of wheel displacement in a manner similar to that of the camber tables. Note that by definition, this table represents a change from the half-track at equilibrium ($T_F/2$ or $T_R/2$) and is positive for an increase in distance from the vehicle center line and wheel center.

5.1.4.8 Suspension Anti-Pitch Coefficients

Suspension anti-pitch properties are generally presented in the form of percent anti-pitch as a function of wheel displacement, where 100% anti-pitch means that all of the weight transfer during braking is through the suspension linkages and no vehicle pitch occurs.

The approximate front and rear anti-pitch coefficients required by the HVOSM for 100% anti-pitch are:

$$(AP)_F \approx \frac{12Z'_T}{qh_F\,(a+b)} \qquad \frac{\text{lb}}{\text{lb-ft}}$$

$$(AP)_R \approx \frac{12Z'_T}{(1-q)h_R(a+b)} \qquad \frac{\text{lb}}{\text{lb ft}}$$

where	Z'_T	is the total vehicle c.g. height
	h_F, h_R	are the approximate rolling radii of the front and rear tires
	$(a+b)$	is the vehicle wheelbase and
	q	is the nominal front braking force distribution (fraction of total braking force at the front)

5.1.5 Tire Force Characteristics

5.1.5.1 Side Force Due to Slip Angle

Side force due to slip angle measurements are presented carpet plots which give side force produced by the tire as a function of slip angle and normal load, as illustrated in Figure 5.1-6. The HVOSM tire model coefficients A_o, A_1 and A_2 are obtained by fitting a parabolic variation of cornering stiffness (rate of change of side force with slip angle at small slip angles) as a function of vertical load in the form:

$$C_{s_0} = A_0 + A_1 \, F'_R + \frac{A_1}{A_2} \, (F'_R)^2$$

For exaple, a tabulation of C_{s_0} vs. F'_R from the carpet plot of Figure 5.1-6 is shown in Table 5.1-1.

Table 5.1-1

Side Force/Unit Slip Angle From Carpet Plot

Normal Load lbs.	Side Force/Deg. Slip Angle lbs./deg.	Side Force/Radian lbs./rad
400	104	5960
600	128	7334
800	138	7907
1000	141	8079
1200	138	7907
1400	135	7736
1600	135	7736

Fitting a second equation of the form

$$C_{s_o} = B_0 + B_1 F'_R + B_2 \, (F'_R)^2$$

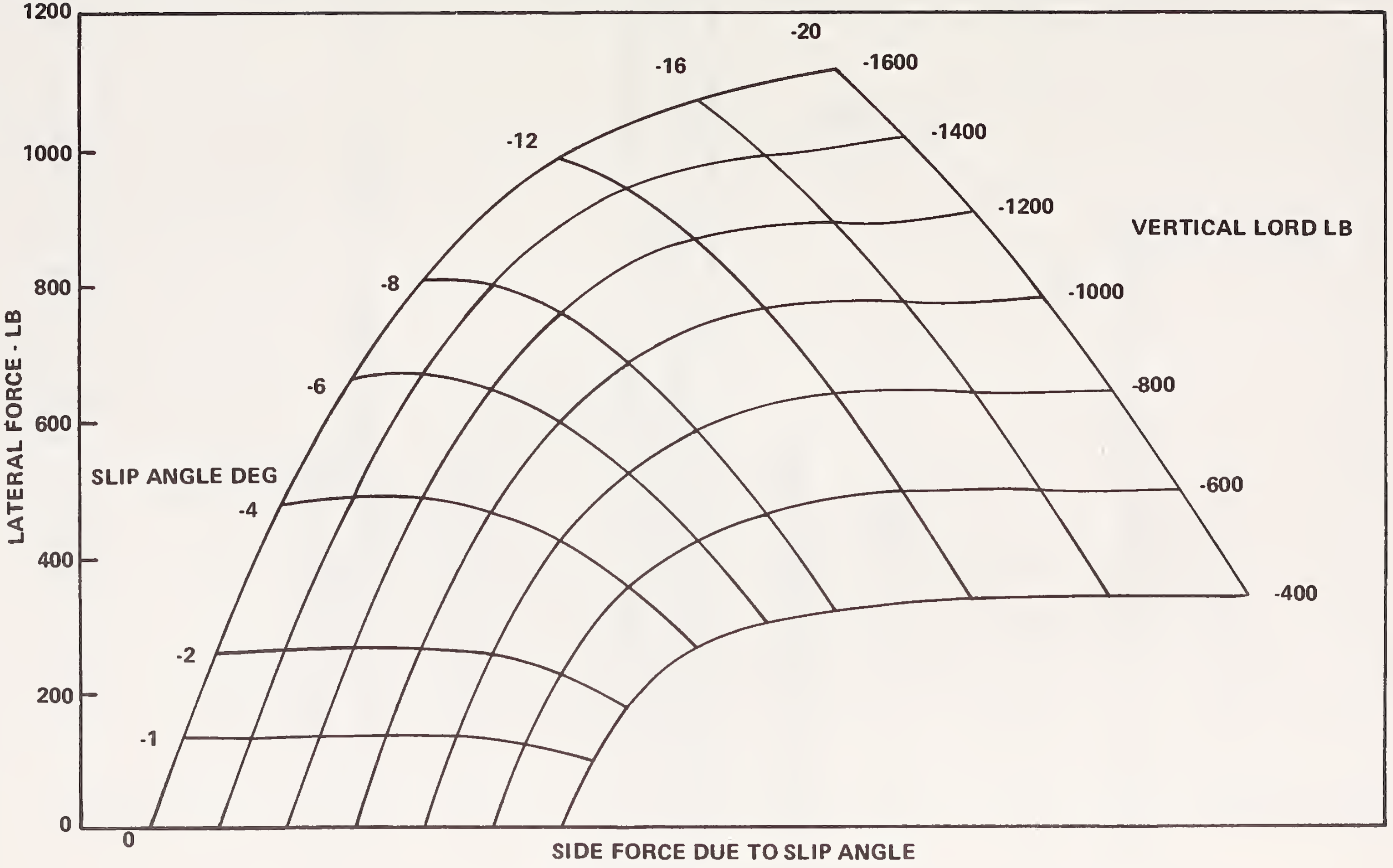


Figure 5.1-6 TYPICAL TIRE SIDE FORCE DUE TO SLIP ANGLE CARPET PLOT

results in coefficients of:

$$B_0 = 3625$$
$$B_1 = 7.711$$
$$B_2 = -3.288 \times 10^{-3}$$

Therefore, the HVOSM coefficients required are:

$$A_0 = B_0 = 3625$$
$$A_1 = B_1 = 7.7111$$
$$A_2 = -\frac{A_1}{B_2} = \frac{7.711}{3.288} \times 10^{-3} = 2345$$

5.1.5.2 Side Force Due to Camber Angle

Measurements of side force due to camber angle are presented in a manner similar to that for slip angle as shown in Figure 5.1-7. And in a similar manner, the small angle camber stiffness is fit to an equation of the form:

$$C_{c_0} = A_3 F'_R - \frac{A_3}{A_4} (F_R')^2$$

From Figure 5.1-7, the small angle camber stiffness vs. load (C_{c_0} vs. F_R') is listed in Table 5.1-2.

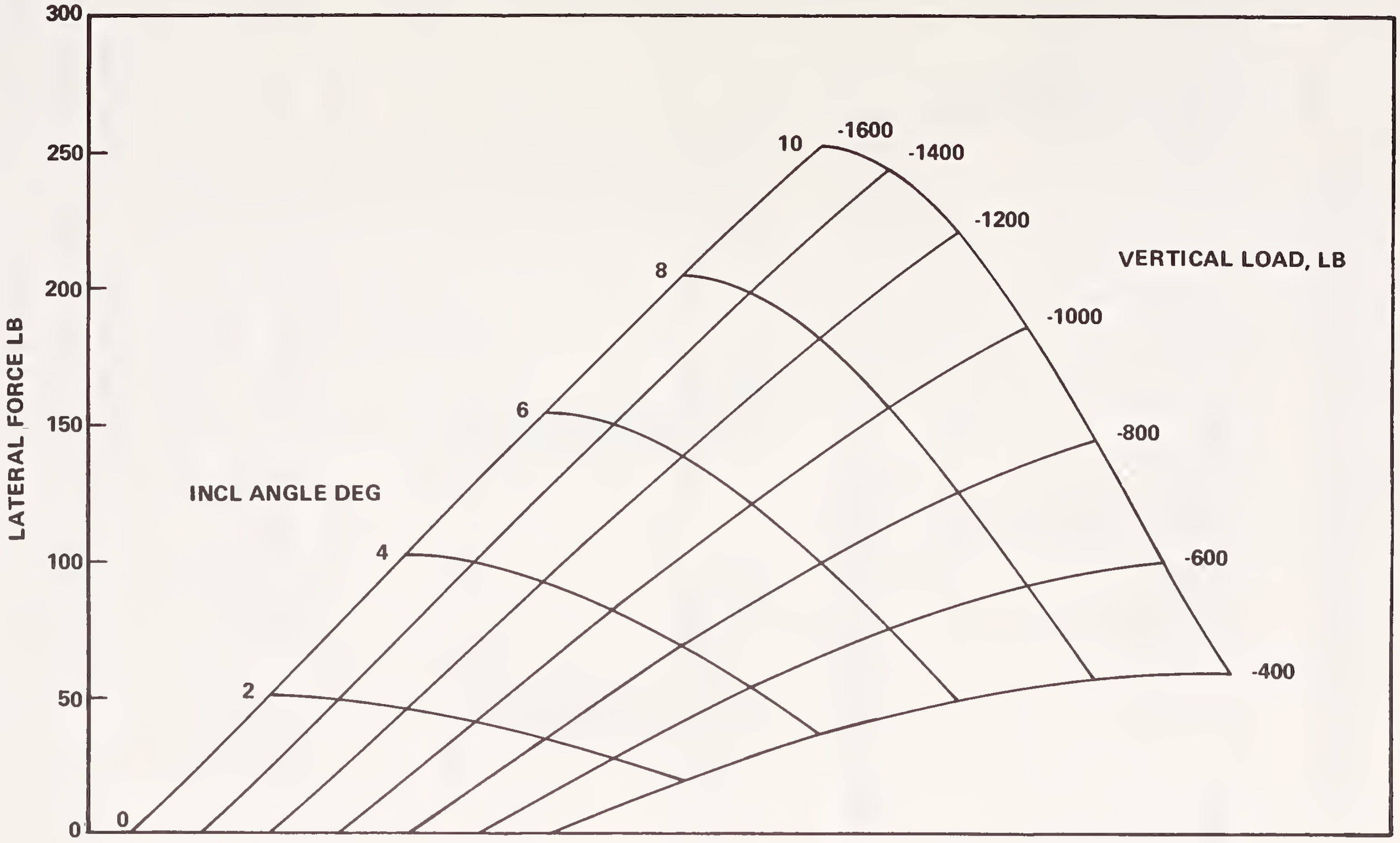


Figure 5.1-7 **TYPICAL TIRE SIDE FORCE DUE TO CAMBER ANGLE CARPET PLOT**

Table 5.1-2

Side Force/Unit Camber Angle From Carpet Plot

Normal Load lbs.	Side Force/Deg. Camber Angle lbs./deg.	Side Force/Radians lbs./rad.
400	10	573
600	14	804
800	19	1090
1000	21	1202
1200	23	1318
1400	24	1375
1600	25	1432

Fitting an equation of the form

$$C_{s_0} = B_1 F_R' + B_2 (F_R')^2$$

to the data of Table 5.1-2 results in coefficients of:

$$B_1 = 1.55$$

$$B_2 = -2.818 \times 10^{-4}$$

The required HVOSM coefficients are then:

$$A_3 = B_1 = 1.55$$

$$A_4 = -\frac{A_3}{B_2} = \frac{1.55}{2.818 \times 10^{-4}} = 5500$$

5.1.5.3 Effective Tire-to-Ground Friction

5.1.5.3.1 Roadside Design Version

A nominal tire-terrain friction coefficient can be determined from tire side force carpet plot as illustrated in Figure 5.1-6. The effective friction coefficient for side forces is determined from the saturated (horizontal) value of side force at a corresponding vertical load. Table 5.1-3 illustrates the side force to vertical load for the carpet plot of Figure 5.1-6.

Table 5.1-3

Maximum Lateral Friction Coefficient Vs. Vertical Load

Vertical Load lbs.	Maximum Side Force -lbs.	Friction Coefficient
400	350	.875
600	500	.833
800	650	.812
1000	780	.780
1200	910	.758
1400	1030*	.735
1600	1140*	.713

*Extrapolated saturation values.

As Table 5.1-3 indicates, the effective friction coefficient varies with load. Since the RD2 version of the HVOSM do not take this variation into account in their tire force model, the user must either employ an average value or use the value corresponding to the load range of interest.

When an area of differing friction (for example, terrain tables or curbs) is encountered, the program adjusts the side force characteristics according to the newly encounted friction coefficient.

5.1.5.3.2 Vehicle Dynamics Version

This version of the HVOSM uses the "friction ellipse" tire model. Therefore, the relative values of the two axes of the friction ellipse, the side force coefficient and the circumferential force friction coefficient are required. Further, this version requires a description of how the magnitudes of these coefficients vary with speed, loading and rotational slip.

The value of the side force coefficient is obtained from a two-way interpolation of the side force coefficient tabel as a function of speed and load. The variation with load is illustrated in Table 5.1-3. If data is available at various speeds, similar tables are constructed for each speed to enter the speed variation effect. Note that even if speed variation data is not available, entries for at least two speed (usually 0 in/sec and a high speed) must be entered. For this case the side force coefficients for each speed should be the same.

Similar tables are constructed for the peak and sliding circumferential coefficients, and the value of SLIP at which the peak occurs.

For example, consider the side force coefficient data shown in Table 5.1-3 at loads of 400,1000 and 1600 lbs. Further assume there is no variation with speed. A table would be constructed as follows:

μ_y vs. Speed and Load

		LOAD-lbs		
		400	1000	1600
SPEED in/sec	0	.875	.780	.713
	10000	.875	.780	.713

From Figure 5.1-8, and again assuming no variation with speed, the following tables are constructed:

μ_{xp} vs. Speed and Load

		LOAD-LBS		
		400	1000	1600
SPEED	0	1.1	0.9	0.8
in/sec	10000	1.1	0.9	0.8

μ_{xs} vs. Speed and Load

		LOAD-LBS		
		400	1000	1600
SPEED	0	.9	.8	.7
in/sec	10000	.9	.8	.7

$SLIP_1$ vs. Speed and Load

		LOAD-LBS		
		400	1000	1600
SPEED	0	.25	.20	.15
in/sec	10000	.25	.20	.15

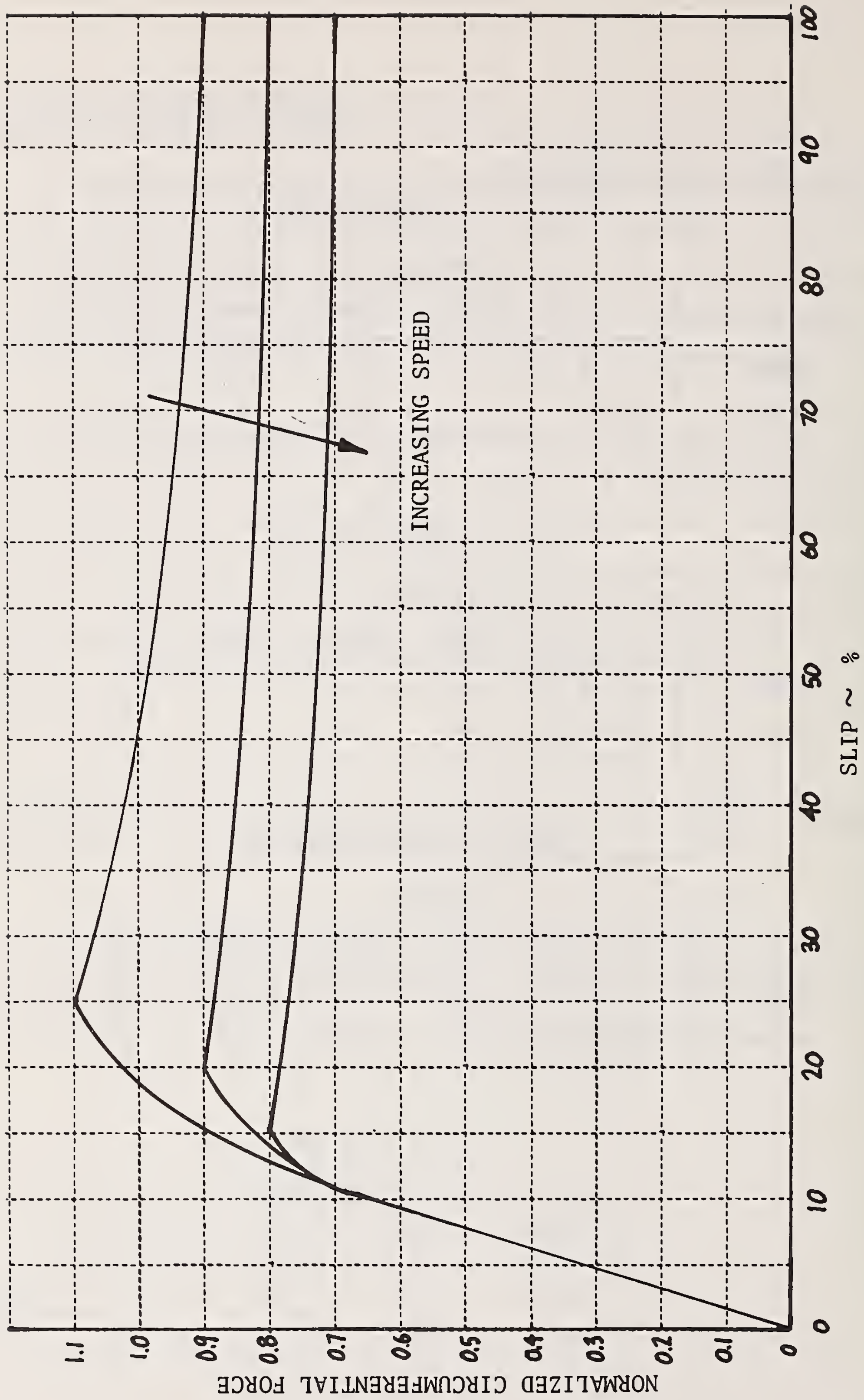


Figure 5.1-8 NORMALIZED CIRCUMFERENTIAL FORCE AS A FUNCTION OF SLIP AND SPEED

5.2 HVOSM Sample Runs

5.2.1 HVOSM-RD2 Skidding Example

The sample skidding run is a simulation of a validation test originally reported in Reference 1. The test consisted of driving straight ahead on wet pavement, initiating a steer input and nearly simultaneously locking the rear brakes.

The vehicle inputs used in this run were based on measurements and estimates of a 1963 Ford used in the validation testing and reported, in detail, in Reference 1 and the "HVOSM Engineers Manual - Validation". A card image image format of the run inputs are shown in Figure 5.2-1, corresponding to the input format described in Section 4.1.1 of this manual.

In Figure 5.2-1, the simulation control data is shown in the one-hundreds block of cards. Card 101 indicates that the simulated run time is to be from 0.0 to 5.0 seconds with an integration step size of 0.01 seconds and a printout interval of 0.05 seconds. Card 103 indicates that the fixed step Runge-Kutta integration technique is to be used. The two NPAGE indicators input in the fifth and sixth field of card 104 will result in all suspension force components being output. Note that card 102 is not present and therefore all variables read on that card will default to 0.0. This implies that the independent front suspension-rigid rear axle option is to be used (ISUS=0), and neither the curb option nor the sprung mass impact option is to be used.

The two-hundreds card block contains the vehicle data. Note that Z_F and Z_R are input in fields 7 and 8 of card 203 and therefore the initial equilibrium subroutine will not be used. Card 209 indicates that a camber table (front only for this suspension option) will be supplied with entries from -5.0 to +5.0 inches of suspension travel in increments of 1.0 inch. Since NDTHF is entered in the fourth field as 0.0, a front suspension half-track change table will not be supplied. The subsequent two cards numbered 209

```
 HVOSM-RD2  REPEAT OF TEST 10 VALIDATION                                           0 100
 0.0       5.0       .01       .05       70.       0.0       0.0                     0 101
 1.0                                                                               0 103
 0.0       0.0       0.0       0.0       1.0       1.0       0.0                     0 104
  1963 FORD  BEST ESTIMATE PARAMETERS                                              0 200
 10.818    0.608     0.945     6000.     35477.    35800.    -192.     435.6         0 201
 54.63     64.62     61.2      60.5      -2.0      46.52                           0 202
 -34.48    0.0       4.0       -112.48   -16.0     -0.5      9.038     10.938        0 203
 131.      300.      600.      300.      600.      0.5       -2.9      4.3           0 204
 194.      300.      600.      300.      600.      0.5       -4.3      4.5           0 205
 1.3       58.       .05       1.75      97.       .05                             0 206
 266000.   59244.    .059                                                          0 207
 -5.0      5.0       1.0       0.0       0.0                                       0 209
 -5.7      -3.9      -2.45     -1.3      -0.4      0.3       0.6       0.65      0.3 1 209
 -0.4      -1.3                                                                    2 209
 -5.0      5.0       0.5                                                           0 210
 .1079     .1053     .1030     .1011     .0994     .0981     .0971     .0964   .0959 1 210
 .0958     .0960     .0965     .0973     .0984     .0998     .1015     .1035   .1058 2 210
 .1085     .1114     .1147                                                         3 210
 -5.0      5.0       5.0                                                           0 211
 .092      .092      .092                                                          1 211
  STANDARD TIRES                                                                   0 300
 1.0       1.0       1.0       1.0                                                 0 301
 1098.     3.0       10.       4400.     8.276     2900.     1.78      3900.     .75 1 301
 0.4                                      14.0                                     0 302
  FORWARD SKID CONTROLS                                                            0 400
 0.0       4.9       0.1       1.0       0.0       1.0                             0 401
 0.0       0.0       1.17      3.73      7.17      11.97     16.27     17.93    18.0 1 401
 18.0      18.0      18.0      18.0      18.1      18.2      18.4      18.53    18.8 2 401
 19.0      19.23     19.5      19.77     20.03     20.3      20.5      20.63    20.8 3 401
 20.85     20.9      20.95     21.0      21.0      21.0      21.0      21.0     21.0 4 401
 21.0      21.0      21.0      21.0      21.0      21.0      21.0      21.0     21.0 5 401
 21.0      21.0      21.0      21.0      21.0                                      6 401
 0.0       -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.  -5000. 7 401
 -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.  -5000. 8 401
 -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.  -5000. 9 401
 -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.  -5000. 10 401
 -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.    -5000.  -5000. 11 401
 -5000.    -5000.    -5000.    -5000.    -5000.                                    12 401
   25 MPH                                                                          0 600
 0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0           0 601
 0.0       0.0       -21.9     440.      0.0       0.0                               0 602
 0.0       0.0       0.0       0.0       0.0       0.0                               0 603
                                                                                   09999
```

Figure 5.2-1   CARD IMAGE INPUTS FOR TEST 10 SIMULATION with sequence numbers contain the front wheel camber table. Cards numbered 210 and 211 contain the front and rear anti-pitch coefficient tables.

Card 301 contains 1.0's in the first four fields indicating that all four tires will be defined by the first tire data set on the first table sequence card following. Note that since the curb option is not being used, RWHJE and DRWHJ need not be supplied. Card 302 contains the tire/ground friction coefficient for the first (and only) tire data set in field 1 and the wheel radius for the first (and only) tire data set in field 5.

Control tables are input on cards 401 from 0.0 to 4.9 seconds in increments of 0.1 second. The presence of 1.0 in fields 4 and 6 indicate that the front wheel steer table and rear wheel torque tables are to follow. The front wheel steer table follows on sequence cards 1 through 6 and the rear wheel torque table on sequence cards 7 through 12.

The absence of any five hundreds block cards indicates that no terrain information is supplied. The only non-zero initial conditions supplied are the sprung mass c.g. elevation and forward speed on card 603.

Figure 5.2-2 illustrates the output from the HVOSM-RD2 as compared with a previous HVOSM version (V-3) and test results.

5.2.2 HVOSM-RD2 Median Earth Berm Example

The median earth berm example illustrates the use of HVOSM terrain tables. The card image input is shown in Figure 5.2-3. The vehicle used in this run is a hypothetical solid front and rear axle vehicle as indicated by the input of 2.0 for ISUS on card 102. Since this option is used, I_F, ρ_F, and T_{SF} are input on cards 201 and 202. No camber or half-track change tables are needed for solid axles, therefore card 209 is not supplied. The hypothetical vehicle also has different tires on the front and back. Card 301 indicates that the RF and LF tires are defined by tire data set 1.0 and the

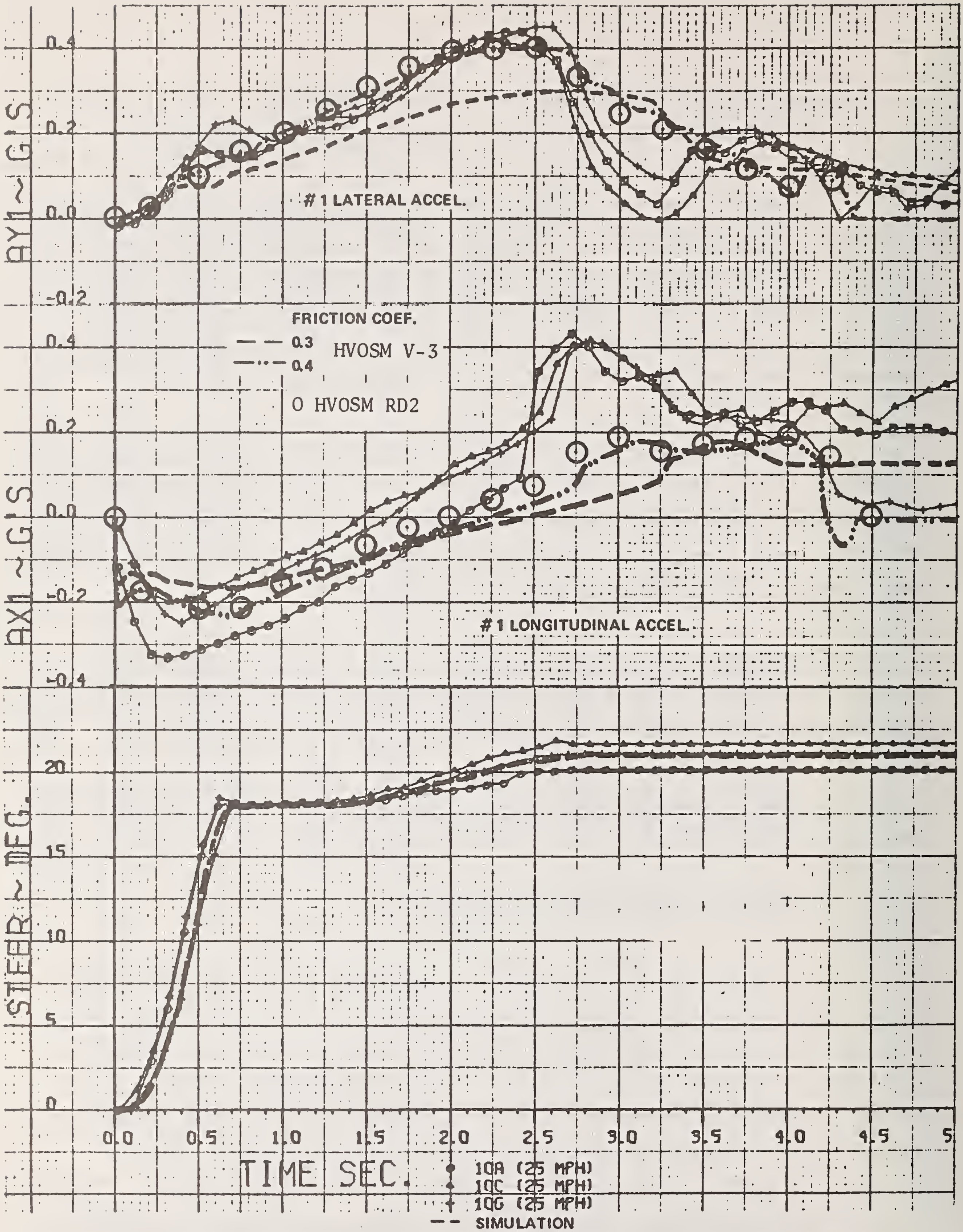


Figure 5.2-2 MEASURED AND PREDICTED RESPONSES OF VEHICLE IN FORWARD SKID ON WET PAVEMENT

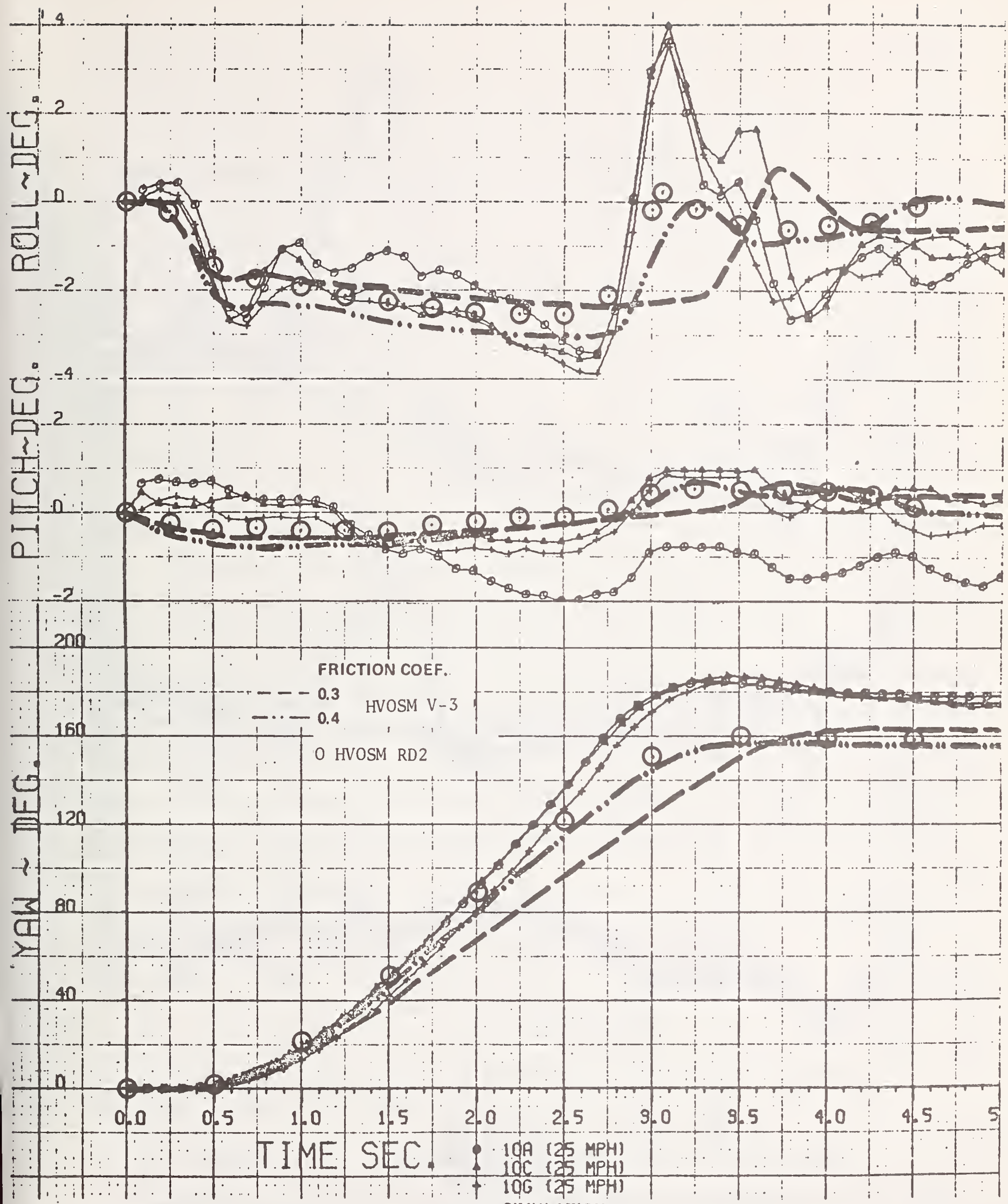


Figure 5.2-2 MEASURED AND PREDICTED RESPONSES OF VEHICLE IN FORWARD SKID ON WET PAVEMENT (continued)

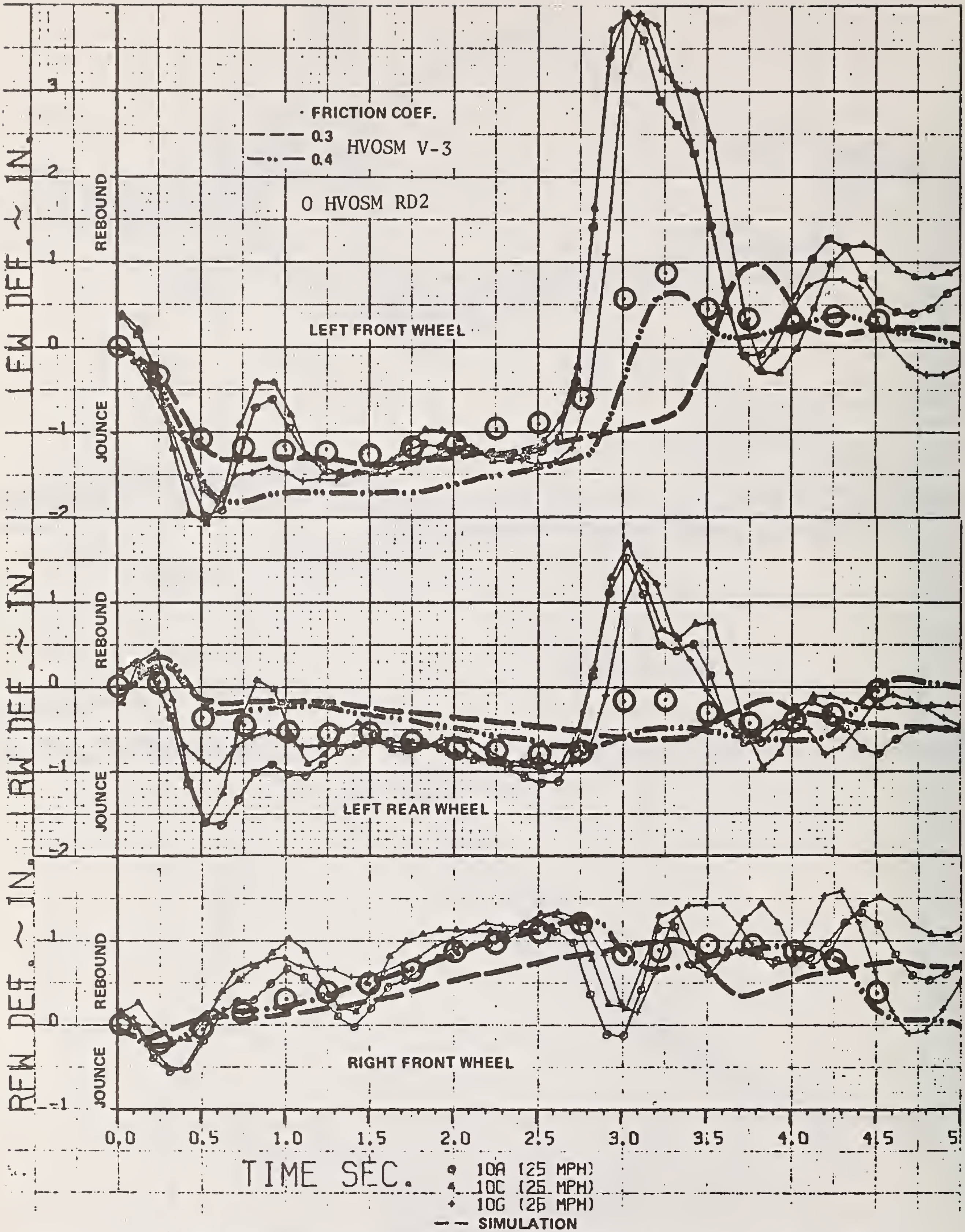


Figure 5.2-2 MEASURED AND PREDICTED RESPONSES OF VEHICLE IN FORWARD SKID ON WET PAVEMENT (continued)

```
    SAMPLE EARTH BERM RUN                                                             0 100
0.0       5.0       .01       .05       70.0      0.0       0.0                     0 101
2.0                                                                                   0 102
1.0                                                                                   0 103
    SOLID FRONT AXLE VEHICLE                                                          0 200
10.818    0.608     0.945     6000.     35477.    35800.    -192.     435.6     400.  0 201
54.63     64.62     61.2      60.5      -2.0      46.52     -2.0      46.52           0 202
130.      300.      600.      300.      600.      0.5       -4.3      4.5             0 204
194.      300.      600.      300.      600.      0.5       -4.3      4.5             0 205
1.5       70.       .05       1.75      97.       .05                                 0 206
60000.    59244.    .059                                                              0 207
    DIFFERENT FRONT/REAR TIRES                                                        0 300
1.0       1.0       2.0       2.0                                                     0 301
1098.     3.0       10.0      4400.     6.276     2900.     1.78      3900.     .75   1 301
2200.     3.0       10.0      11500.    7.53      4000.     3.47      5400.     .75   2 301
0.75      0.80                          14.0      14.0                                0 302
    E&O EARTH BERM                                                                    0 500
0.0       10000.    5000.     144.0     384.      20.       0.0       1.0             0 501
264.                                                                                  1 501
0.0       1.25      2.50      3.75      5.0       6.25      7.5       12.5      17.5  2 501
22.5      27.33     30.46     31.5                                                    3 501
0.0       1.25      2.5       3.75      5.0       6.25      7.5       12.5      17.5  4 501
22.5      27.33     30.46     31.5                                                    5 501
0.0       1.25      2.5       3.75      5.0       6.25      7.5       12.5      17.5  6 501
22.5      27.33     30.46     31.5                                                    7 501
0.0       10000.    5000.     384.      624.      12.0      0.0       0.0             0 502
31.5      30.75     28.25     24.75     19.5      13.5      7.5       1.5       -4.5  1 502
-8.88     -10.24    -8.88     -4.5      1.5       7.5       13.5      19.4      24.75 2 502
28.25     30.75     31.5                                                              3 502
31.5      30.75     28.25     24.75     19.5      13.5      7.5       1.5       -4.5  4 502
-8.88     -10.24    -8.88     -4.5      1.5       7.5       13.5      19.4      24.75 5 502
28.25     30.75     31.5                                                              6 502
31.5      30.75     28.25     24.75     19.5      13.5      7.5       1.5       -4.5  7 502
-8.88     -10.24    -8.88     -4.5      1.5       7.5       13.5      19.4      24.75 8 502
28.25     30.75     31.5                                                              9 502
0.0       10000.    5000.     624.      864.      20.       0.0       1.0             0 503
744.                                                                                  1 503
31.5      30.46     27.33     22.5      17.5      12.5      7.5       6.25      5.0   2 503
3.75      2.5       1.25      0.0                                                     3 503
31.5      30.46     27.33     22.5      17.5      12.5      7.5       6.25      5.0   4 503
3.75      2.5       1.25      0.0                                                     5 503
31.5      30.46     27.33     22.5      17.5      12.5      7.5       6.25      5.0   6 503
3.75      2.5       1.25      0.0                                                     7 503
1.0       1.0       1.0                                                               0 506
    50 MPH  -3. DEG.                                                                  0 600
0.0       0.0       -3.0      0.0       0.0       0.0       0.0       0.0             0 601
100.      920.      -23.      880.      0.0       0.0                                 0 602
                                                                                      09999
```

Figure 5.2-3 CARD IMAGE INPUTS FOR EARTH BERM SIMULATION

RR and LR tires by data set 2. The first tire data set is contained on the tire sequence card 1 and the second on sequence card 2. Friction coefficients for data sets 1 and 2 are on card 302 fields 1 and 2 and tire radii in fields 5 and 6, respectively.

The terrain tables, representing the cross section shown in Figure 5.2-4 and Table 5.2-1, are input in the five hundreds card block. The control card for the first terrain table (card 501) indicates that this table extends from X' = 0 to X' = 10000 inches with an additional cross section supplied at X' = 5000 inches.

Each cross-section is defined from y' = 144 to y' = 384 inches in increments of 20 inches. The 1.0 in field 7 indicates the one y' boundary is to be supplied. The first sequence and for this table specifies the y' boundary as being located at y' = 264 inches. The next two sequence cards contain terrain elevations at 20 inch intervals from y' = 144 to y' = 384 inches at the X' = 0 station. Since this terrain cross section does not vary with X', the next four sequence cards repeat the cross section at X' = 5000 and X' = 10000 inches, respectively.

The second terrain table is input on cards 502 with y' grid points from 384 to 624 inches in increments of 12 inches. This table contains no boundaries and is a constant increment table. The terrain elevation for the cross section at X' = 0 is input on the first three sequence cards followed by the cross sections at X' = 5000 and X' = 10000 inches.

The third terrain table is similar to the first with a y' boundary at y' = 744 inches and is input on cards 503. Card 506 contains the terrain friction factors. Since they are 1.0 for all tables, the friction coefficients as supplied on card 302 for each tire data set apply to the terrain tables as well as the ground outside of the tables.

The vehicle response to the terrain is illustrated in Figure 5.2-5.

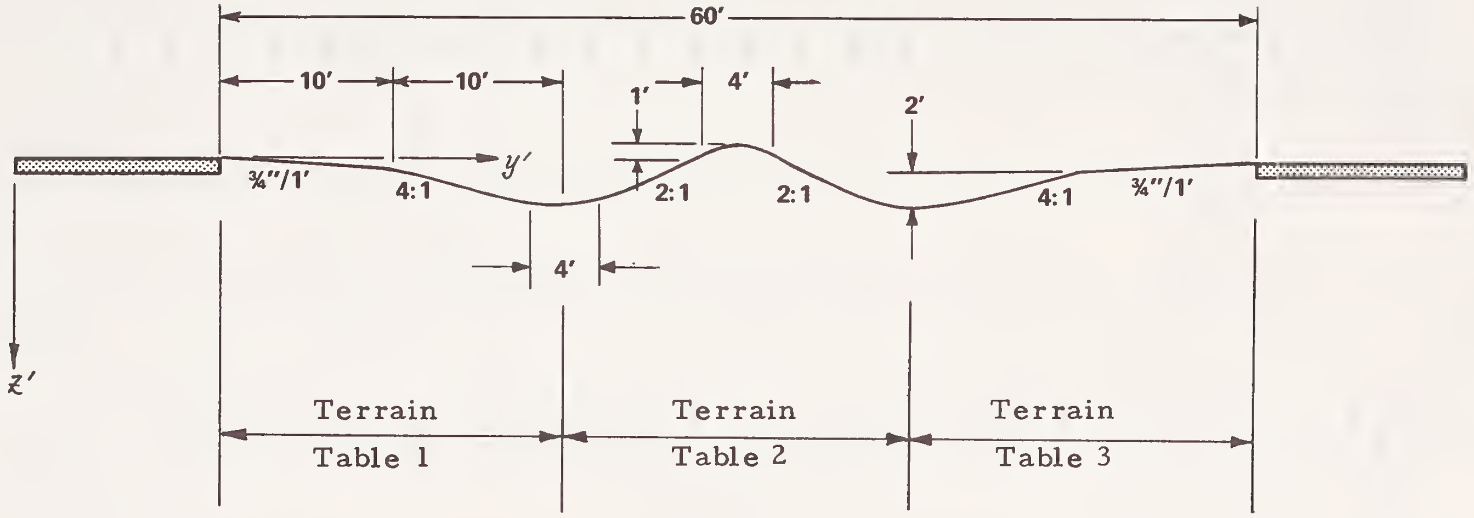


Figure 5.2-4 Earth Berm Cross-Section

Table 5.2-1

EARTH BERM PROFILE

LATERAL POSITION Y' - IN	ELEVATION Z' - IN
144 (EOP)	0.0
164	1.25
184	2.50
204	3.75
224	5.00
244	6.25
264	7.50
284	12.5
304	17.5
324	22.5
344	27.33
364	30.46
384	31.5
396	30.75
408	28.25
420	24.75
432	19.5
444	13.5
456	7.5
468	1.5
480	-4.5
492	-8.88

LATERAL POSITION Y' - IN	ELEVATION Z' - IN
504	-10.44
516	-8.88
528	-4.5
540	1.5
552	7.5
564	13.5
576	19.5
588	24.75
600	28.25
612	30.75
624	31.5
644	30.46
664	27.33
684	22.5
704	17.5
724	12.5
744	7.5
764	6.25
784	5.0
804	3.75
824	2.5
844	1.25
864 (EOP)	0.0

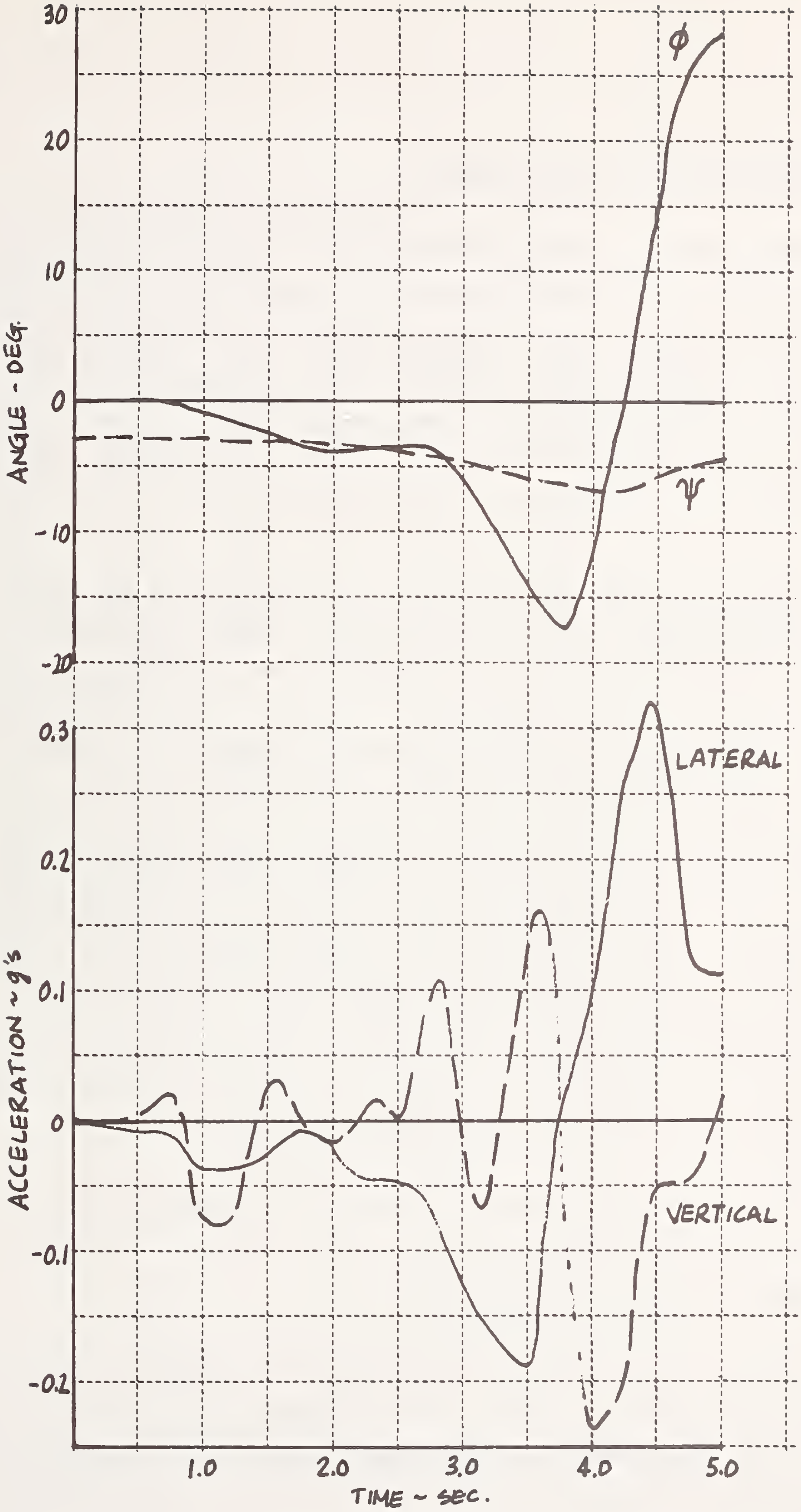


Figure 5.2-5 VEHICLE RESPONSE TO EARTH BERM TERRAIN

5.2.3 HVOSM-RD2 Curb Impact Example

This sample run illustrates the use of the curb impact with the HVOSM-RD2 version. This option is invoked by input of 1.0 for the indicator INDCRB in field 2 of card 102 as shown in Figure 5.2-6. The next two fields on that card contain the number of finite planes used to define the curb and the integration time increment used when the vehicle is in contact with the curb. Note that three additional output groups are printed in this run due to the presence of 1.0 in fields 2, 3 and 4 of card 104.

The vehicle used for this run is one contained in the HVOSM Preprocessing Program data library. The curb is defined on cards 507 through 509. The first six entries on card 507 contain the y' coordinate of the beginning of each of the six curb slopes. The last entry on card 507 is the curb friction factor which is used to modify the nominal tire-ground friction coefficient. In this case, each tire has a coefficient of friction of 0.8 (card 302, field 1) on the flat ground. However, when in contact with the curb, the coefficient is multiplied by 0.5 resulting in a tire to curb coefficient of friction of 0.4. Card 508 contains the elevation of the beginning of curb slopes 2 through 6. The elevation of the beginning of the first curb slope is assumed to be zero and is therefore not input. The curb slope angles with respect to horizontal are input on card 509. If a vertical faced curb is to be simulated, an angle near but not equal to -90 degrees should be input to avoid possible singularities in the solution procedure.

An example of the output from this run is shown in Figure 5.2-7.

5.2.4 HVOSM-VD2 Control Input Example

This sample run illustrates the use of the HVOSM with simultaneous braking and steering control inputs. The card image input format is shown in Figure 5.2-8. The simulation control data contained on cards 100 through 104 indicates that the duration of the run is to be 4.5 seconds with an

```
    REPEAT OF TTI CURB TEST  TYPE C CURB                                                      0 100
  0.0       1.5       .005      .01       70.       0.0       0.0                             0 101
  0.0       1.0       6.0       .001                                                          0 102
  1.0                                                                                         0 103
            1.0       1.0       1.0                                                           0 104
       1963 FORD GALAXY FOUR - DOOR SEDAN                                                     0 200
  10.818    0.608     0.945     6000.     35477.    35800.    -192.     435.6                 0 201
  54.63     64.62     61.2      60.5      -2.0      46.52                                     0 202
                                                            10.138    12.038                  0 203
  131.0     300.      600.      300.      600.      .05       -3.0      5.0                   0 204
  194.0     300.      600.      300.      600.      .05       -4.0      4.5                   0 205
  1.3       58.0      0.001     1.75      97.0      0.001                                     0 206
  266000.   59244.    0.059                                                                   0 207
  492.0     600.      0.4       5000.     0.075     1.5                                       0 208
  -5.0      5.0       1.0                                                                     0 209
  -5.7      -3.9      -2.45     -1.3      -0.4      0.3       0.6       0.65      0.3         1 209
  -0.4      -1.3                                                                              2 209
  -5.0      5.0       0.5                                                                     0 210
  .1079     .1053     .1030     .1011     .0994     .0981     .0971     .0964     .0959       1 210
  .0958     .0960     .0965     .0973     .0984     .0998     .1015     .1035     .1058       2 210
  .1085     .1114     .1147                                                                   3 210
  -5.0      5.0       5.0                                                                     0 211
  0.092     0.092     0.092                                                                   1 211
    STANDARD TIRES                                                                            0 300
  1.0       1.0       1.0       1.0       6.0       .25                                       0 301
  1098.     3.0       10.       4400.     8.276     2900.     1.78      3900.     1.0         1 301
  0.8                                     14.                                                 0 302
    TYPE C CURB                                                                               0 500
  200.      215.      217.25    217.7     219.55    224.55    0.5                             0 507
  .88       -.8       -3.45     -5.0      -5.1                                                0 508
  3.35      -36.75    -80.367   -39.95    -1.15     0.0                                       0 509
      12.5 DEG  30 MPH                                                                        0 600
  0.0       0.0       12.5      0.0       0.0       0.0       0.0       0.0                   0 601
  0.0       150.      -23.      528.                                                          0 602
                                                                                              09999
```

Figure 5.2-6   CARD IMAGE INPUTS FOR CURB SAMPLE RUN

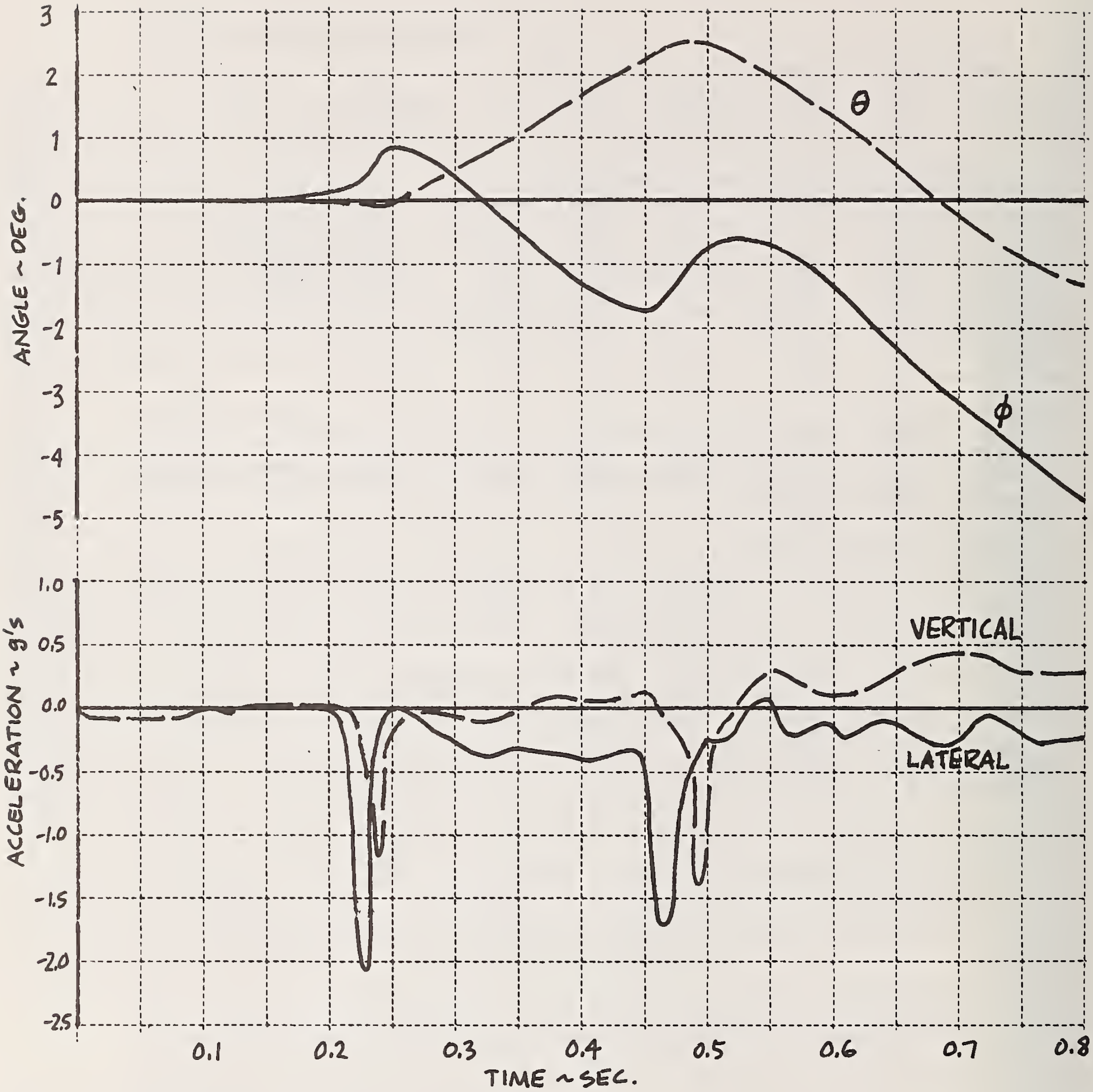


Figure 5.2-7 VEHICLE RESPONSE TO CURB PROFILE

```
  BRAKING DYNAMICS VALIDATION RUNS 38-40                                                    0 100
0.0       4.5       .005      .02       70.       1.3       60.       .001                  0 101
1.0                                                                                         0 103
1.0       0.0       0.0       0.0       1.0       1.0       0.0       1.0                   0 104
    1963 FORD DATA                                                                          0 200
11.05     .608      .945      6000.     40000.    40000.    -192.     453.6                 0 201
58.5      60.75     61.2      60.5      -2.0      46.52                                     0 202
0.0       0.0       2.52      -97.      0.0       0.0       7.83      9.73                  0 203
131.      300.      600.      300.      600.      0.5       -2.9      4.3                   0 204
194.      300.      600.      300.      600.      0.5       -4.3      4.5                   0 205
1.3       58.       0.1       1.75      97.       0.1                                       0 206
59244.    266000.   .059                                                                    0 207
-5.       5.0       1.0                                                                     0 209
-5.7      -3.9      -2.45     -1.3      -0.4      0.3       0.6       0.65      0.3         1 209
-0.4      -1.3                                                                              2 209
-5.0      5.0       0.5                                                                     0 210
.1079     .1053     .103      .1011     .0994     .0981     .0971     .0964     .0959       1 210
.0958     .096      .0965     .0973     .0984     .0998     .1015     .1035     .1058       2 210
.1085     .1114     .1147                                                                   3 210
-5.0      5.0       5.0                                                                     0 211
.092      .092      .092                                                                    1 211
0.0       12.2      6.5       13.6      1.0       3.0                                       0 212
1.0       1.0       1000.     1000.     110.      192.      0.1                             0 213
3.0       3.0                                                                               0 214
7.62      1.4       0.48      .942      0.0       3.12      6.21      6.43      4.62        1 214
1.0       9.25      .384      0.0       10.          10.E10    10.E10                       2 214
7.62      1.4       .476      .691      0.0       3.12      6.21      6.43      4.62        3 214
1.0       9.25      .381      0.0       10.          10.E10    10.E10                       4 214
500.      4900.     400.                                                                    0 215
500.      563.      594.      613.      630.      621.      600.      561.      516.        1 215
480.      438.      420.                                                                    2 215
0.0       -12.      -144.     -165.     -180.     -192.     -204.     -216.     -231.       3 215
-249.     -267.     -288.                                                                   4 215
0.0       1000.     20.                                                                     0 216
.96       .974      .965      .996      1.0       1.03      1.01      1.0       .995        1 216
.982      .972      .952      .930      .907      .859      .814      .77       .727        2 216
.687      .645      .609      .586      .561      .536      .515      .5        .488        3 216
.475      .465      .454      .444      .441      .438      .435      .432      .429        4 216
.425      .422      .419      .416      .414      .410      .407      .404      .401        5 216
.398      .395      .391      .388      .385      .382                                      6 216
9.611E-52.853E-260.336                                                                      0 217
      STANDARD TIRES                                                                        0 300
1.0       1.0       1.0       1.0       .987      0.        0.        3.        3.          0 301
200.      1200.     2200.                                                                   1 301
0.0       704.      1408.                                                                   2 301
1.0                                                                                         0 302
1300.     3.        10.       4000.     8.4       3000.     1.71      4200.                 1 302
1.        14.68     .987      20160.    0.0                                                 2 302
1.123     .987      .918                                                                    3 302
.917      .782      .713                                                                    4 302
.710      .574      .506                                                                    5 302
1.404     1.234     1.148                                                                   6 302
1.146     .978      .891                                                                    7 302
.888      .718      .633                                                                    8 302
1.123     .987      .918                                                                    9 302
.917      .782      .713                                                                   10 302
.710      .574      .506                                                                   11 302
.16       .16       .16                                                                    12 302
.16       .16       .16                                                                    13 302
.16       .16       .16                                                                    14 302
```

Figure 5.2-8   CARD IMAGE INPUT FOR CONTROL INPUT EXAMPLE

```
   CORNERING STOP CONTROLS                                                                  0 400
0.0       4.5        0.1       1.0                                                          0 401
0.        0.         0.        0.        0.        0.        0.        -.3       -3.        1 401
-6.       -6.9       -7.15     -7.       -6.85     -6.6      -6.8      -6.9      -6.97      2 401
-6.95     -6.95      -6.95     -6.95     -6.95     -6.95     -6.95     -6.92     -6.91      3 401
-6.9      -6.9       -6.88     -6.86     -6.82     -6.80     -6.78     -6.77     -6.75      4 401
-6.72     -6.7       -6.7      -6.7      -6.6      -6.45     -6.32     -6.23     -6.2       5 401
-6.2                                                                                        6 401
0.0       4.5        0.1       1.0                                                          0 402
0.        0.         0.        0.        0.        0.        410.      425.      412.       1 402
409.      405.       403.      402.      400.      398.      395.      390.      388.       2 402
387.      386.       385.      383.      382.      381.      378.      375.      372.       3 402
371.      370.       370.      369.      369.      368.      367.      365.      362.       4 402
360.      357.       355.      355.      402.      437.      437.      437.      437.       5 402
437.                                                                                        6 402
  41.25 MPH                                                                                 0 600
0.        0.         0.        0.        0.        0.        0.        0.                   0 601
0.        0.         -21.52    726.      0.        0.                                       0 602
0.        0.         0.        0.        0.        0.        0.        0.                   0 603
170.      170.       170.      170.      170.                                               0 604
                                                                                            09999
```

Figure 5.2-8 (Continued)

integration increment of 0.005 seconds. The value of the multiplier used in the test of wheel spin integration stability (COMEN4) is input in field 8 of card 101 as 0.001 which is the recommended value. The absence of card 102 indicates that the default suspension option (independent front, solid axle rear) is used and that the curb and driver options are not used.

Cards 200 through 211 contain vehicle data in the same format as input to the RD2 versions. Card 212 contains wheel and driveline inertias and axle ratios. The first four fields on card 213 describe the brake system proportioning valve characteristics. Note that in this example, there is no brake system proportioning valve so the ratio of the rear to front brake pressures is unity and the pressures at which the proportioning valve is activated are set to an arbitrarily large number. The remaining three fields on card 213 contain the front and rear brake push-out pressures and the wheel rotational velocity threshold for brake torque limitation.

Card 214 indicates that both front and rear brakes are type 3 and the parameters describing the brakes are contained on the four following sequence cards, the first two for the front brakes and the last two for the rear. Engine torque characteristics are supplied on cards 215 from 500 to 4900 rpm at intervals of 400 rpm. Sequence cards 1 and 2 contain the wide open throttle torque followed by the closed throttle torque on cards 3 and 4. The brake lining fade coefficient table is read from cards 216 at temperatures from 0 to 1000 °F at increments of 20 °F. Card 217 contains coefficients for approximating rolling resistance and aerodynamic drag.

Tire data is supplied on cards 301 and 302. All four tires on the vehicle use the same tire data (tire data set number 1) as indicated by the first four fields of card 301. The fifth field contains the value of the nominal tire-ground friction coefficient. Since the curb or road roughness options are not used, RWHJE and DRWHJ need not be supplied in fields 6 and 7. Fields 8 and 9 indicate that tabular tire data is to be supplied for three tire loads and three speeds. The first card 301 sequence card contains the three loads and the second contains the three speeds. Card 302 indicates that the first tire data set follows. The first two sequence cards contain various tire parameters as specified in the input format. Sequence cards 3, 4 and 5 contain the lateral force friction coefficient table. The coefficients are supplied for loads of 200, 1200 and 2200 pounds at 0.0 inches/second on card 3, at 704 inches/second on card 4 and 1408 inches/sec on the fifth sequence card. Following the same format, sequence cards 6, 7 and 8 contain the peak circumferential force coefficient table, and cards 9, 10 and 11 contain the sliding circumferential force table. Sequence cards 12, 13 and 14 contain the value of SLIP at which the peak circumferential friction occurs for each speed and load, completing the tire data set.

The front wheel steer angle is supplied at 0.1 sec and intervals from 0 to 4.5 seconds on table cards 401. The brake master cylinder pressure is supplied on table cards 402. Vehicle initial conditions are input on cards 601 through 603. Card 604 contains the initial temperatures of each brake and the ambient temperature.

Results from this sample run are presented in Figure 5.2-9.

5.2.5 HVOSM-VD2 Driver Model Example

This sample run illustrates the use of the driver model to execute a lane change maneuver with an independent front and rear suspension vehicle. The card image input format is shown in Figure 5.2-10. Note that the independent front and rear suspension option is specified by the value of 1.0 in the first field of card 102. The values of 1.0 in fields 5 and 6 of card 102 indicate that the driver model is to be used and that limited additional output from the driver model will be printed.

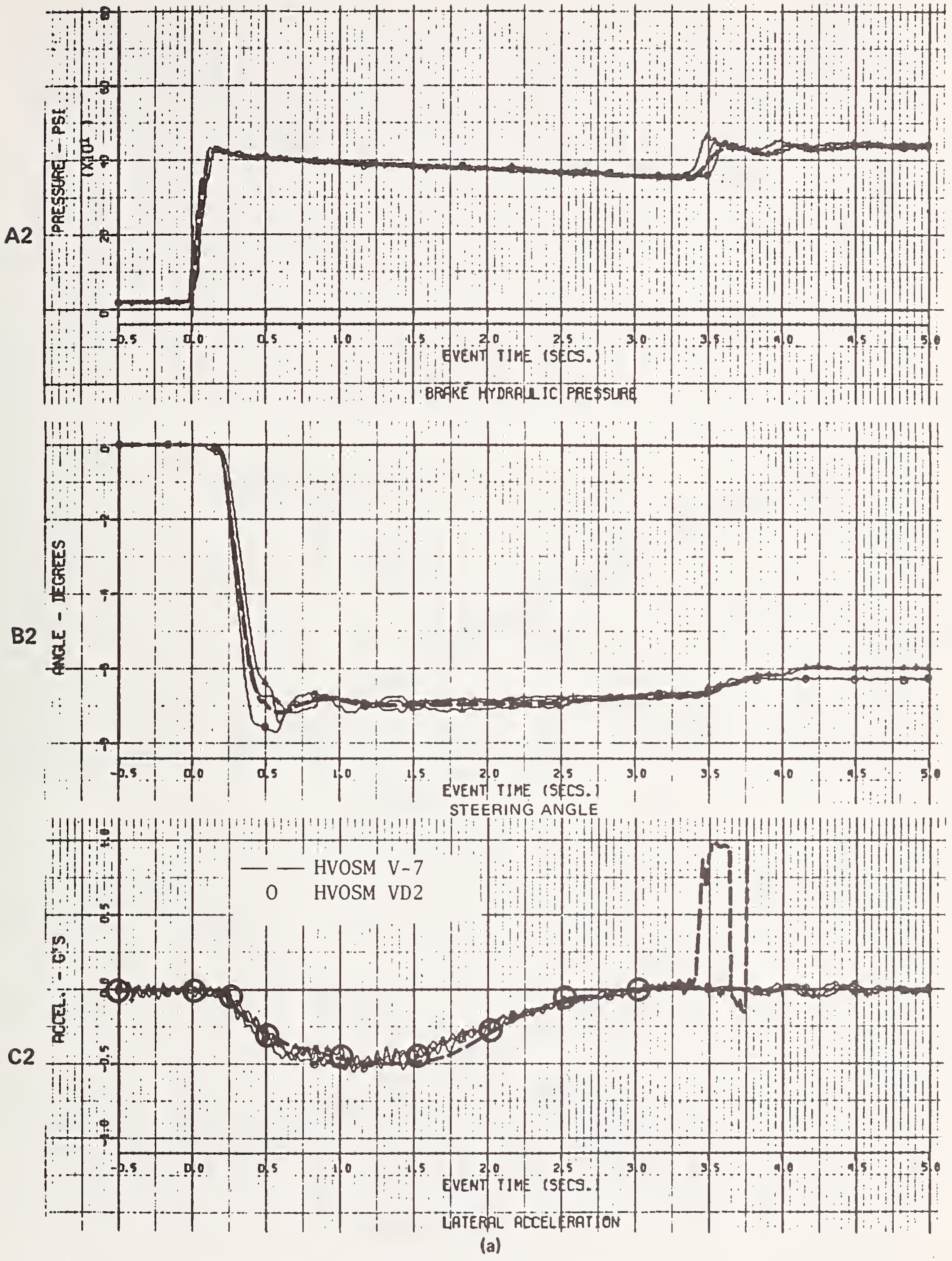
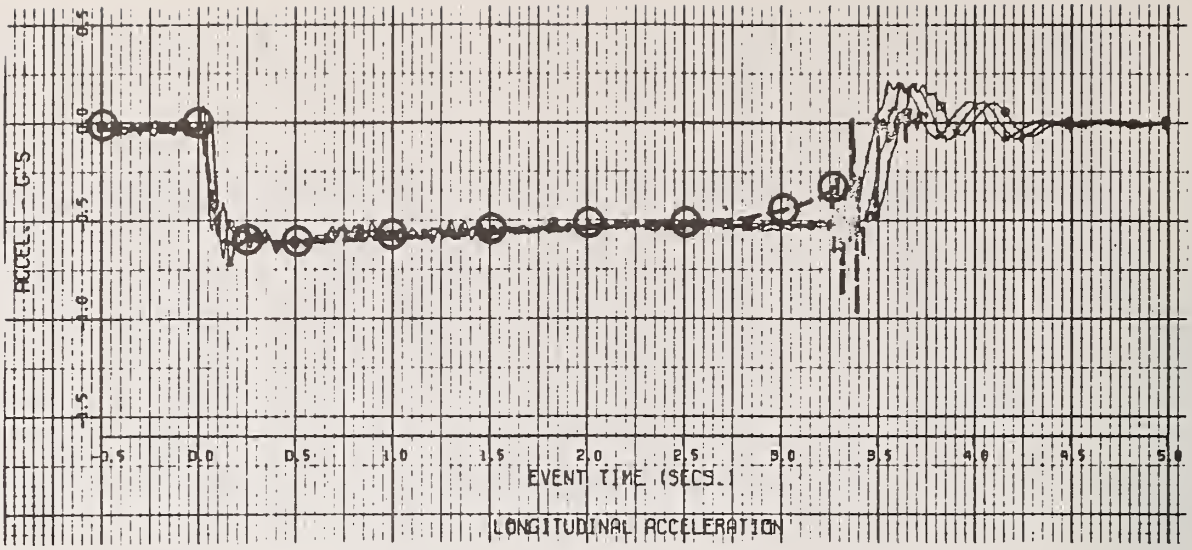
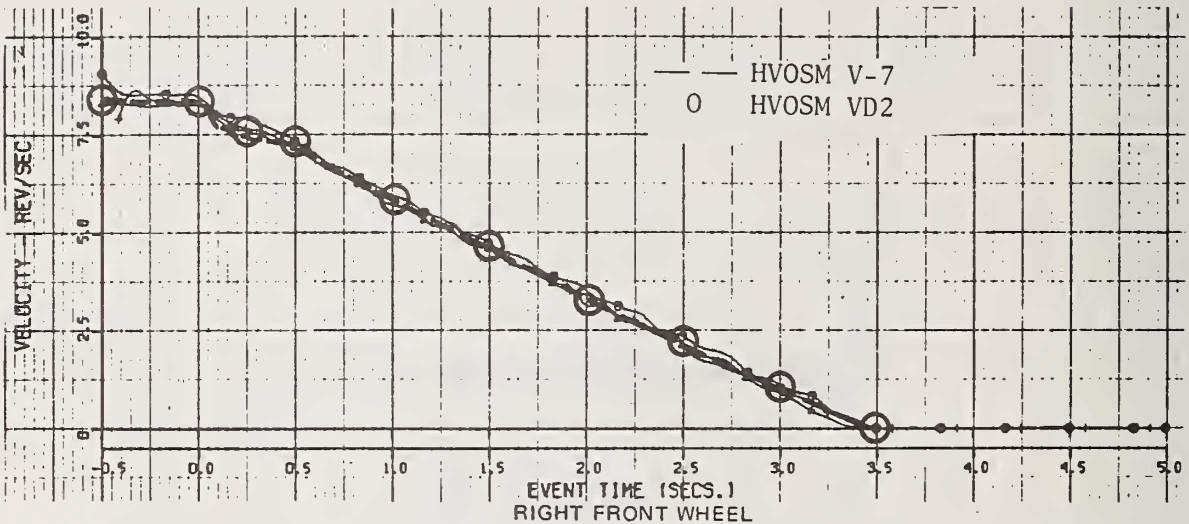


Figure 5.2-9 COMPARISON OF MEASURED AND COMPUTED VEHICLE RESPONSES — CORNERING AND BRAKING MANEUVER

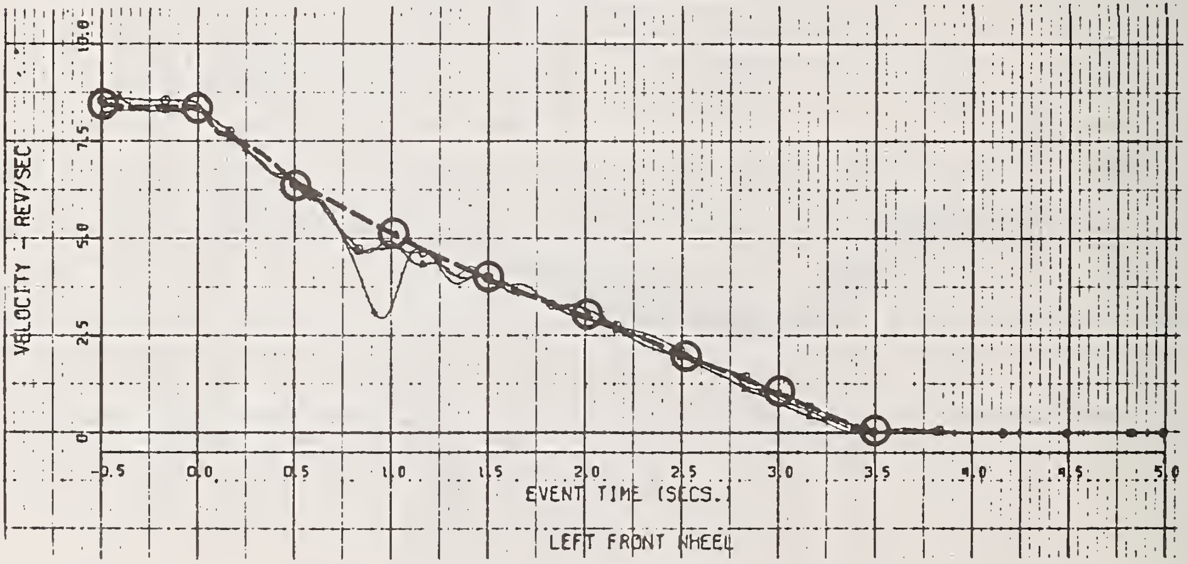
D2



E2

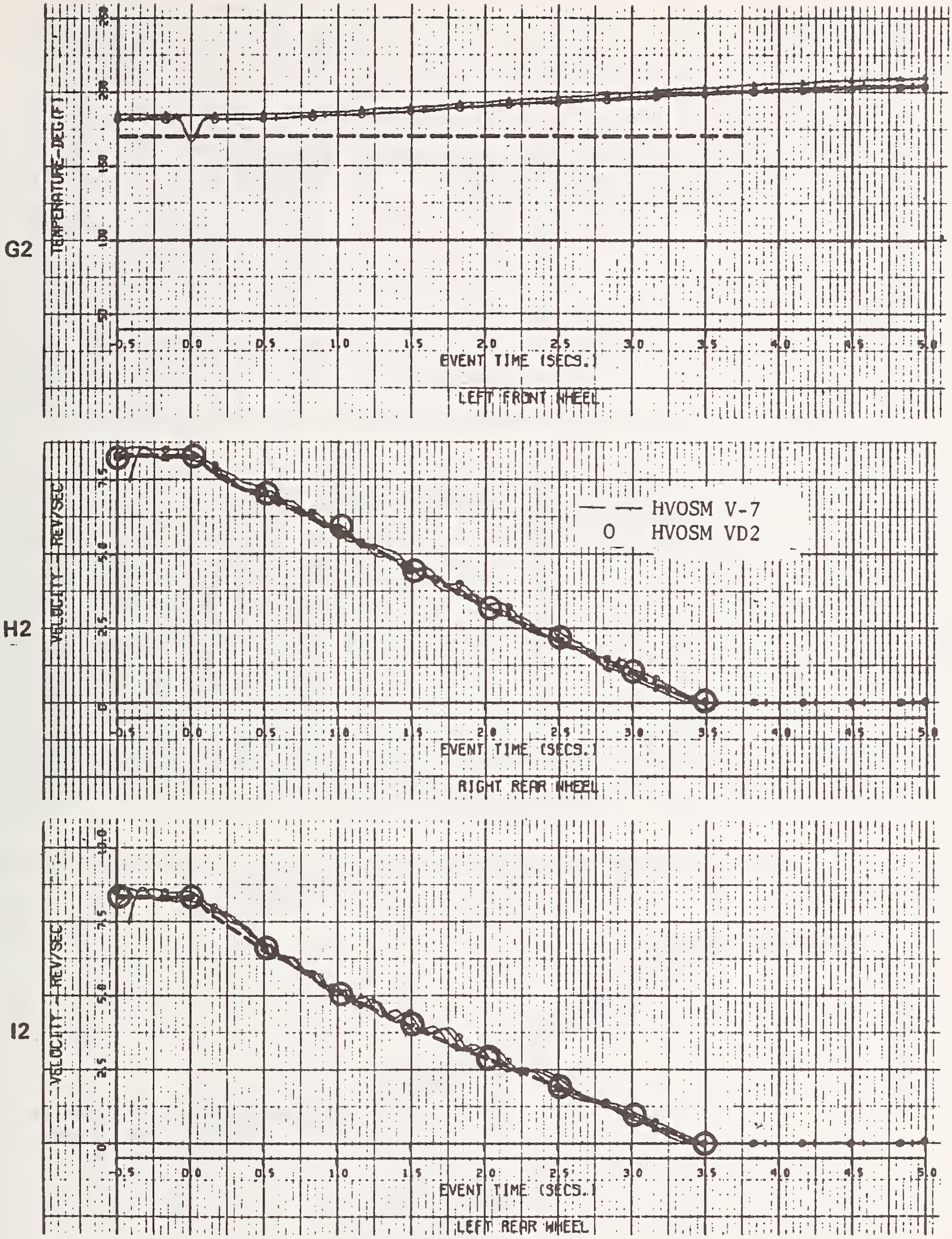


F2



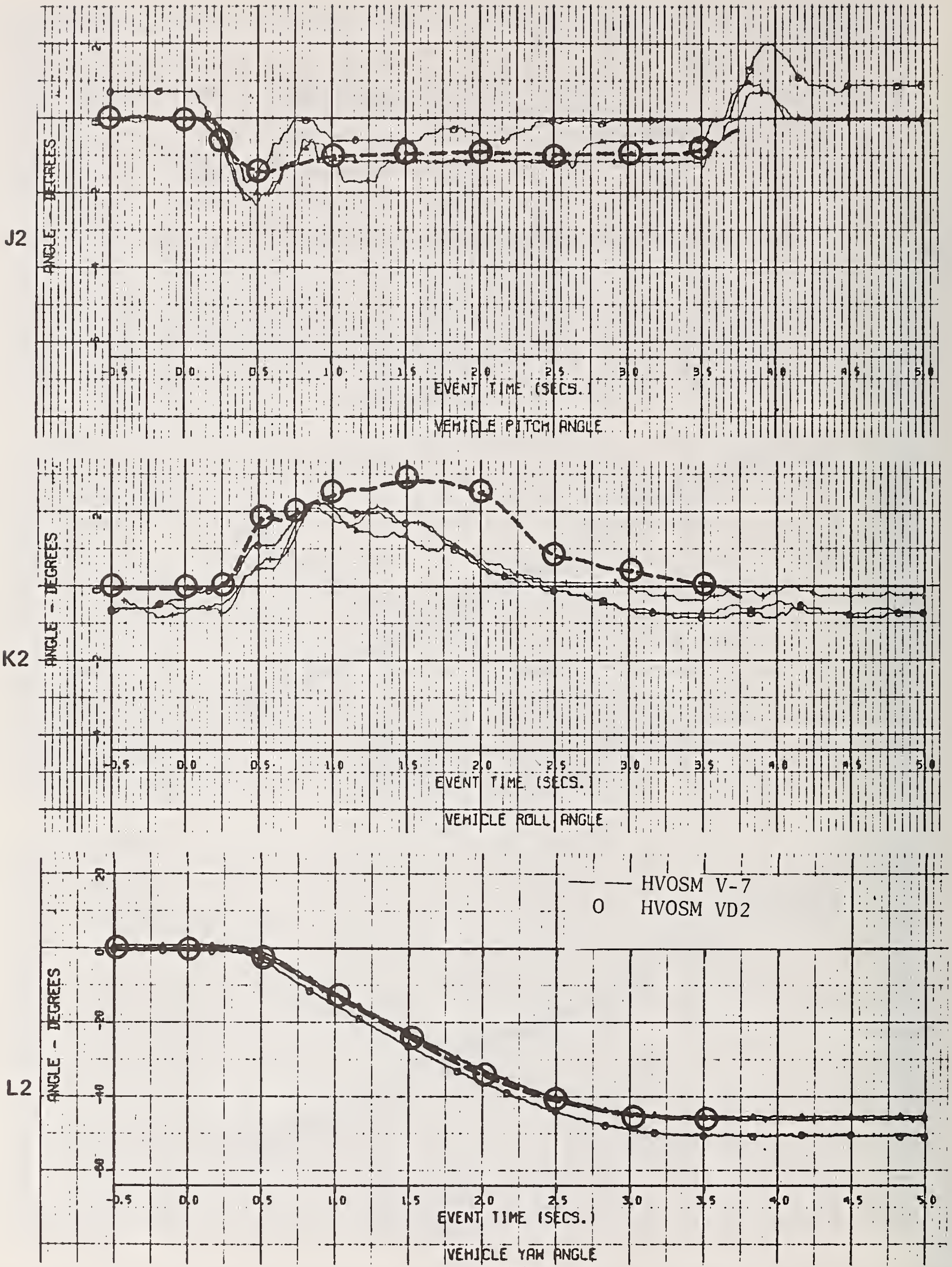
(b)

Figure 5.2-9 (Cont.) COMPARISON OF MEASURED AND COMPUTED VEHICLE RESPONSES CORNERING AND BRAKING MANEUVER



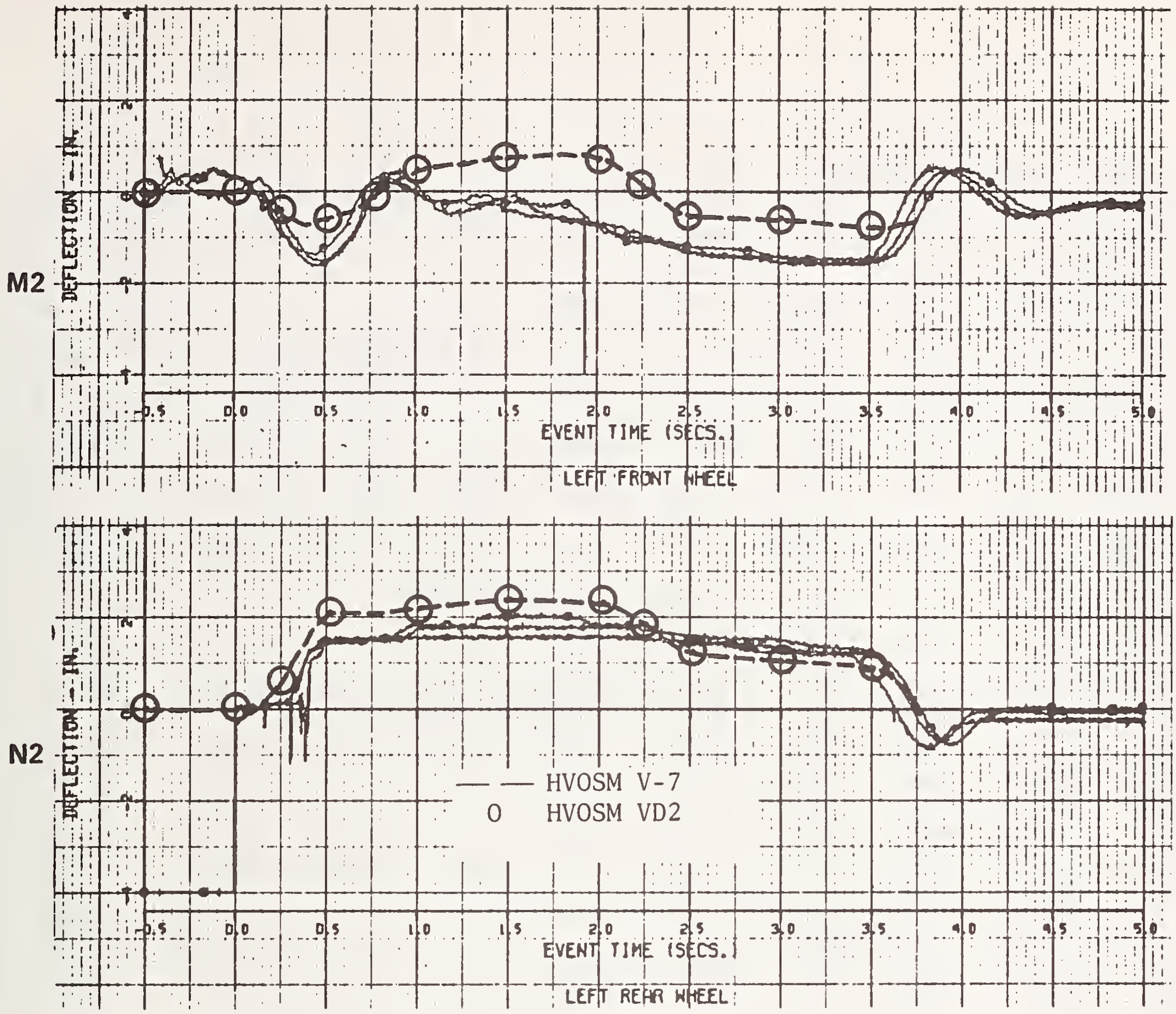
(c)

Figure 5.2-9 **(Cont.)** COMPARISON OF MEASURED AND COMPUTED VEHICLE RESPONSES — CORNERING AND BRAKING MANEUVER



(d)

Figure 5.2-9 (Cont.) COMPARISON OF MEASURED AND COMPUTED VEHICLE RESPONSES — CORNERING AND BRAKING MANEUVER



(e)

Figure 5.2-9 (Cont.) COMPARISON OF MEASURED AND COMPUTED VEHICLE RESPONSES — CORNERING AND BRAKING MANEUVER

```
    SAMPLE DRIVER CONTROL RUN                                                                0 100
0.0       4.0       .01       .05       70.       0.0       0.0       .001                   0 101
1.0       0.0       0.0       0.0       1.0       1.0                                        0 102
1.0                                                                                        0 103
    IRS VEHICLE                                                                            0 200
4.23      0.36      0.57      1300.     8900.     7900.     -100.                            0 201
57.1      38.7      53.8      51.47                                                        0 202
65.7      98.6      0.0       460.      0.0       0.5       -3.0      3.4                    0 204
115.0     69.0      0.0       333.5     0.0       0.5       -3.0      3.35                   0 205
2.75      17.0      0.1       2.1       20.0      0.1                                        0 206
-5.0      5.0       1.0       0.0       1.0                                                  0 209
0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0          1 209
0.0       0.0                                                                              2 209
-9.82     -7.47     -5.1      -2.73     -.364     2.0       4.37      6.74      9.13         3 209
11.53     13.95                                                                            4 209
-.344     -.191     -.081     -.031     0.15      0.0       -.055     -.153     -.292        5 209
-.474     -.7                                                                              6 209
93000.    28300.              0.0       .03025    -1.56E-2-6.48E-4                         0 207
0.0       7.35      0.3       7.35      1.0       4.13                                     0 212
1.0       1.0       1000.     2000.     10.0      10.0      .05                              0 213
3.0       3.0                                                                              0 214
7.62      1.4       0.48      .942      0.0       3.12      6.21      6.43      4.62         1 214
1.0       9.25      .384      0.0       10.0       10.E+10 10.E+10                         2 214
7.62      1.4       .476      .691      0.0       3.12      6.21      6.43      4.62         3 214
1.0       9.25      .381      0.0       10.0       10.E+10 10.E+10                         4 214
500.      4900.     400.                                                                   0 215
67.5      80.       90.       100.      102.5     106.      107.5     106.      102.5        1 215
100.      92.5      84.                                                                    2 215
0.0       -12.5     -22.5     -29.      -32.5     -35.      -37.5     -39.      -42.5        3 215
-47.5     -53.75    -62.5                                                                  4 215
0.0       200.      50.                                                                    0 216
1.0       1.0       1.0       1.0       1.0                                                1 216
    19 PSI FRONT, 27 PSI REAR                                                              0 300
1.0       1.0       2.0       2.0       0.8       0.0       0.0       3.0       2.0          0 301
400.      800.      1200.                                                                  1 301
0.0       2000.                                                                            2 301
1.0                                                                                        0 302
760.      6.0       10.       5835.     -2.9      2860.     1.79      2499.                  1 302
1.0       12.6      .95       12050.    0.1                                                2 302
1.08      0.95      0.65                                                                   3 302
1.08      0.95      0.65                                                                   4 302
1.0       .88       0.6                                                                    5 302
1.0       .88       0.6                                                                    6 302
.73       .64       .55                                                                    7 302
.73       .64       .55                                                                    8 302
.13       .13       .13                                                                    9 302
.13       .13       .13                                                                   10 302
2.0                                                                                        0 303
1060.     6.0       10.0      4037.     3.9       1728.     1.41      3902.                  1 303
1.0       12.6      .98       9200.     .05                                                2 303
1.14      .98       .86                                                                    3 303
1.14      .98       .86                                                                    4 303
1.08      .93       .82                                                                    5 303
1.08      .93       .82                                                                    6 303
.81       .70       .62                                                                    7 303
.81       .70       .62                                                                    8 303
.20       .2        .2                                                                     9 303
.2        .2        .2                                                                    10 303
    DRIVER CONTROL LANE CHANGE                                                             0 400
.15       7.0       300.      .01       0.2       0.0       5.0       12.0      30.          0 403
```

Figure 5.2-10 CARD IMAGE INPUT FOR DRIVER MODEL SAMPLE RUN

```
.0874     .122      1.5       0.0       .268      .04       0.1       6.67      0.0           0 404
2.6       1.2       1.0       .88                                                             0 405
3000.     3000.     3000.     1200.     1100.     1000.                                       0 406
0.0       0.5       1.0       2.0       3.0       3.0       2.0                               0 407
0.0       50.                                                                                 0 408
704.      704.                                                                                0 409
600.      600.                                                                                0 410
4.0                                                                                           0 411
-500.     1700.     1844.     99999.                                                          1 411
0.0       -1700.    144.      144.                                                            2 411
0.0       1.0       0.0       0.0                                                             3 411
  40 MPH                                                                                      0 600
0.0       0.0       90.0      0.0       0.0       0.0       0.0       0.0                     0 601
0.0       0.0       -23.17    704.      0.0       0.0                                         0 602
0.0       0.0       0.0       0.0       0.0       0.0                                         0 603
70.       70.       70.       70.       70.                                                   0 604
                                                                                              09999
```

Figure 5.2-10 (Continued)

The vehicle parameters are contained in the two hundreds card block. Since this vehicle has an independent rear suspension, tables of both front and rear wheel camber change must be supplied on cards 209. In addition, the values of 0.0 and 1.0 in fields 4 and 5 of card 209 indicate that the front half-track change table will not be supplied (it is assumed to be zero) but the rear is supplied. Therefore, the first two card 209 sequence cards contain the front wheel camber table, the second two contain the rear wheel camber table and the last two contain the rear half-track change table. Note that card 207 is not in numerical order as this is not required. Note also that card 203 is not supplied and therefore all variables read on that card default to zero. Values of ZF and ZR are normally read on this card, however since they are not supplied, they are calculated automatically in subroutine INITEQ. Since the driver model requires certain variables to be initialized in INITEQ, ZF and ZR should not be supplied when this option is excersized.

The tire data is supplied in the three hundreds card block. The first four entries on card 301 indicate that the two front tires use tire data set number 1.0 and the two rear tires use tire data set number 2.0. The nominal tire-terrain friction coefficient is 0.8 and tire data is entered for 3 loads and 2 speeds. The two sequence cards following card 301 contain the three loads and two speeds, respectively, at which tire measurements were made. Card 302 indicates that the first tire data set follows. The first two sequence cards contain various information as specified in the input format. The next two cards contain the lateral force friction coefficient at loads of 400, 800 and 1200 pounds at a speed of 0.0 in/sec on the first and 2000 in/sec on the second. In a similar manner, sequence cards 5 and 6 contain the peak circumferential friction coefficients for the three loads and two speeds and sequence cards 7 and 8, the sliding circumferential friction coefficient. Sequence cards 9 and 10 contain the value of SLIP at which the peak circumferential friction occurs for the loads and speeds. The same format is repeated for tire data set number 2 on cards 303.

The driver model inputs are contained on cards 403 through 411. Cards 403 and 404 contains various driver data as indicated in the input format. Transmission gear ratios, upshift and downshift engine speeds are on cards 405 and 406. The relative importance weights of the errors determined at the seven driver look ahead points are on card 407. Cards 408, 409 and 410 contain the speed change information. Since this lane change is made at constant speed, card 408 contains times of 0 and 50 seconds at which speed changes are to be made, thus no speed change command is made during the run. Card 409 contains the speed commands at the above times, both 704 in/sec since no speed change is to be made. Card 410 contains the distances within which the speed changes are to be made. These data are not applicable to this run. Cards 411 contain the path information. Four path segments are provided. The straight line path segments are bounded by the y' values on the first sequence card, the x' intercepts of the lines are on the second sequence card and the slopes on the third.

Output from this sample run is illustrated graphically in Figure 5.2-11.

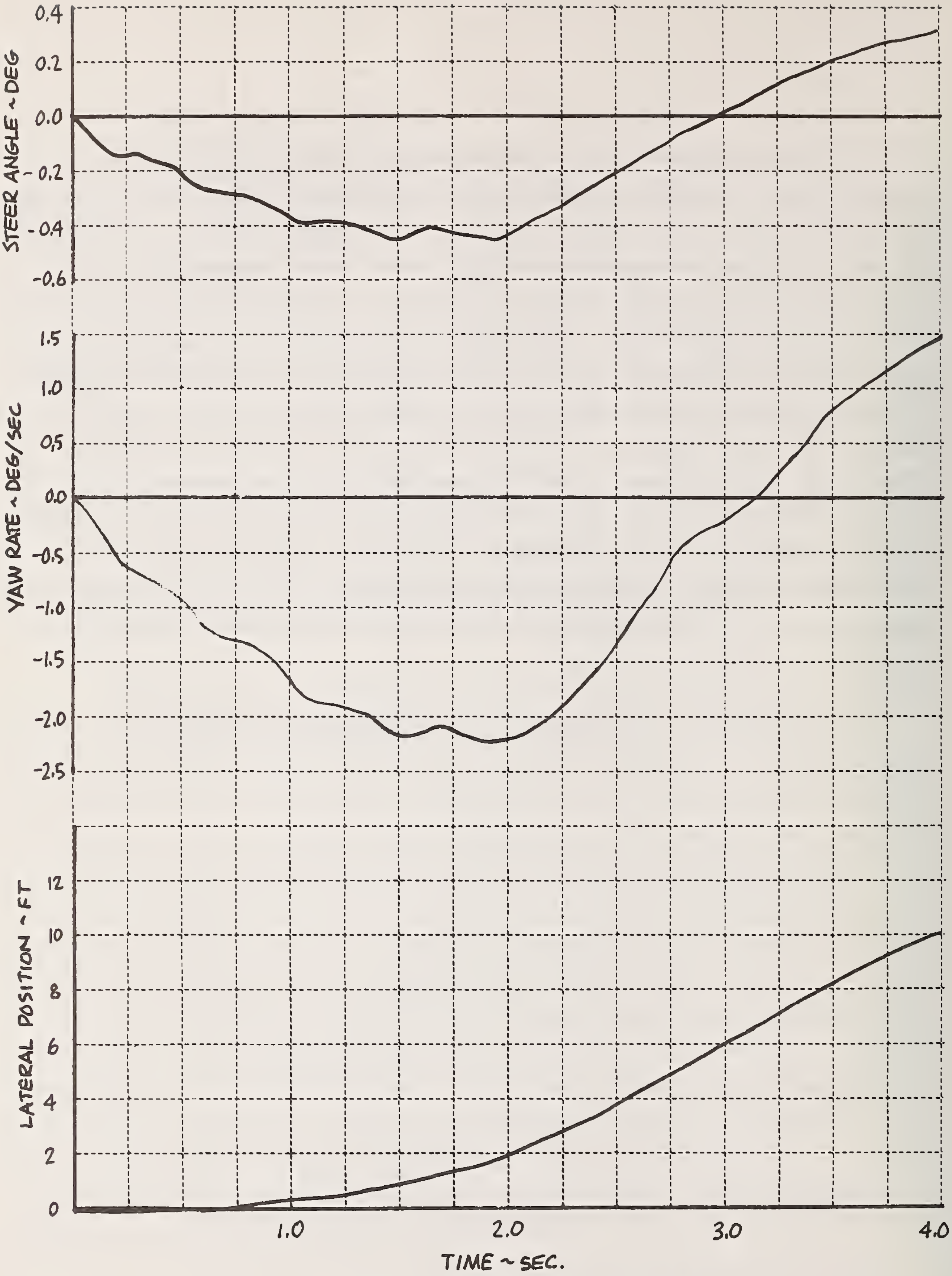


Figure 5.2-11 VEHICLE RESPONSE TO DRIVER LANE CHANGE

6. AUXILIARY HVOSM PROGRAMS

6.1 HVOSM Pre-Processing Program

6.1.1 General Description

The HVOSM Pre-Processing Program was developed to ease the task of input generation for the HVOSM. The program supplies the user with vehicle data either from a library of measurements or from a calculation procedure based on regressions to measured vehicle data reported in Reference 4. Vehicle data output is obtained as both printed listings and punched cards in a format ready for use with the HVOSM. The program also will generate, at the request of the user, terrain data for certain roadside configurations as originally reported in Reference 5.

A block diagram of the program is shown in Figure 6.1-1.

6.1.2 Input

The first card of input contains control information as follows:

IVEH = Vehicle number contained in the vehicle data library for which data is to be obtained.

IVER = Indicator for vehicle data output. If IVER = 1, data from library is output for the HVOSM-RD2 version. If IVER = 2, data from library is output for the HVOSM-VD2 version.

IOUT = Optional output device number for vehicle library data. If IOUT = 0, data is only printed. If IOUT ≠ 0, data is written to FORTRAN unit IOUT in 10A8 Format. For punched card output, IOUT = 7 should be specified.

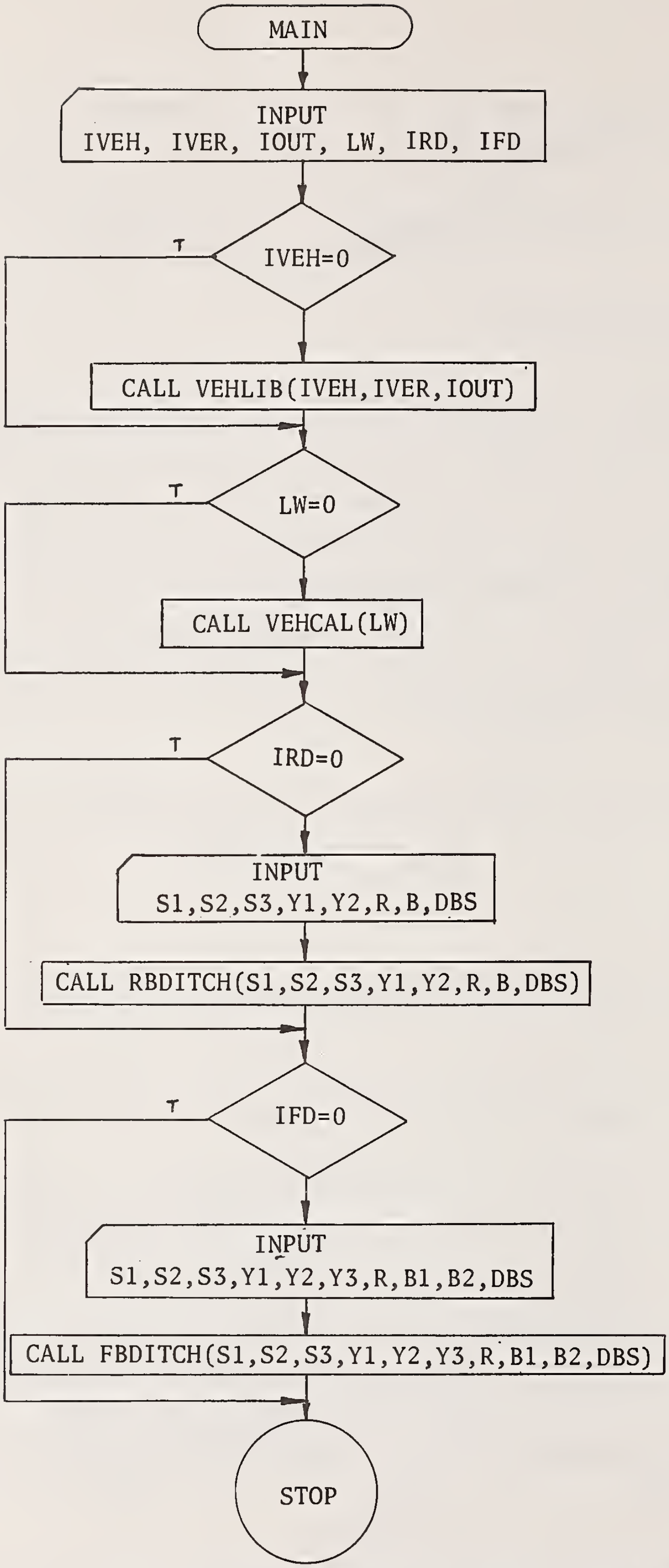


Figure 6.1-1 BLOCK DIAGRAM OF PRE-PROCESSING PROGRAM MAIN ROUTINE

IRD = Indicator for round-bottom ditch terrain generator subroutine. If IRD ≠ 0, a subsequent input card is required and the terrain data is generated and printed and punched in a format suitable for inclusion into the HVOSM data deck.

IFD = Indicator for flat-bottom ditch terrain generator subroutine. If IFD ≠ 0, a subsequent input card is required and the terrain data is generated and printed and punched in a format suitable for inclusion into the HVOSM data deck.

LW = Wheelbase of vehicle for calculation of typical vehicle parameters. If LW ≠ 0, typical vehicle parameters are calculated and printed.

The input format for the control card is as follows:

Column	Format	Symbol	Description
1-4	I4	IVEH	Data library vehicle number
5-8	I4	IVER	Indicator for HVOSM version
9-12	I4	IOUT	Output device number
13-16	I4	IRD	Indicator for round-bottom ditch subroutine
17-20	I4	IFD	Indicator for flat-bottom ditch subroutine
21-30	F10.0	LW	Wheelbase for calculation of typical vehicle parameters

If IRD ≠ 0 a card containing input information for the round-bottom ditch program is input containing:

S1 = Shoulder slope (ratio of vertical to horizontal)
S2 = Side slope (ratio of vertical to horizontal)
S3 = Back slope (ratio of vertical to horizontal)

Y1 = Lateral position of shoulder break (inches)

Y2 = Lateral position of intersection of side slope and flat ditch bottom (inches)

Y3 = Lateral position of intersection of flat ditch bottom and back slope (inches)

R = Tangent point of shoulder rounding from shoulder break measured along shoulder and side slopes (inches)

B1 = Tangent point of side slope-ditch bottom rounding from intersection measured along slope and bottom (inches)

B2 = Tangent point of ditch bottom-back slope rounding from intersection measured along bottom and slope (inches)

DBS = Lateral run-out distance of the back slope (inches)

The input card format is as follows:

Column	Format	Fortran Symbol	Description
1-8	F8.0	S1	Shoulder slope
9-16	F8.0	S2	Side slope
17-24	F8.0	S3	Back slope (enter as negative)
25-32	F8.0	Y1	First slope break Y-value
33-40	F8.0	Y2	Second slope break Y-value
41-48	F8.0	Y3	Third slope break Y-value
49-56	F8.0	R	Tangent to break point distance (shoulder)
57-64	F8.0	B1	Tangent to break point distance (back of ditch)
65-72	F8.0	B2	Tangent to break point distance (back of ditch)
73-80	F8.0	DBS	Back slope runout Y-value

Input requirements:

- The three input slopes must be entered as non-zero (the back slope is entered as a negative quantity).
- $0<Y1<Y2<Y3$
- Inputs must be compatible such that the lateral position of the end of the shoulder rounding is less than the lateral position of the beginning of the side slope-bottom rounding. If this condition is not met an error message is output.
- $Y3-Y2>B1+B2$
- $$R \left[\frac{1}{\sqrt{s_1^2+1}} + \frac{1}{\sqrt{s_2^2+1}} \right] \overline{>} \text{ 6 in.}$$
- $$B_1 \left[\frac{1}{\sqrt{s_2^2+1}} + 1 \right] \overline{>} \text{ 6 in.}$$

If IFD $\neq 0$, a card containing input information for the flat-bottom ditch program is input containing:

S1 = Shoulder slope (ratio of vertical to horizontal)
S2 = Side slope (ratio of vertical to horizontal)
S3 = Back slope (ratio of vertical to horizontal)
Y1 = Lateral position of shoulder break (inches)
Y2 = Lateral position of intersection of side and back slopes (inches)
R = Tangent point of shoulder rounding from shoulder break measured along shoulder and side slopes (inches)
B = Ditch width, measured horizontally between tangent points (inches)
DBS = Lateral run-out distance of the back slope (inches)

The input card format is as follows:

Column	Format	Fortran Symbol	Description
1-8	F8.0	S1	Shoulder slope
9-16	F8.0	S2	Side slope
17-24	F8.0	S3	Back slope (enter as negative)
25-32	F8.0	Y1	First slope break Y-value
33-40	F8.0	Y2	Second slope break Y-value
41-48	F8.0	R	Tangent to breakpoint distance (shoulder)
49-56	F8.0	B	Ditch width
57-64	F8.0	DBS	Back slope runout Y-value

Input requirements:

- The three slopes must be entered as non-zero (the back slope is entered as a negative quantity).
- 0<Y1<Y2
- Inputs must be compatible such that the lateral position of the end of the shoulder rounding is less than the lateral position of the beginning of the bottom rounding. If this condition is not met an error is output.
- $R \left[\frac{1}{\sqrt{s_1^2 +1}} + \frac{1}{\sqrt{s_2^2 +1}} \right] \geq 6$ in.
- $B \geq 6$ in.

6.1.3 Calculation of Typical Vehicle Parameters

Typical vehicle parameters are calculated based on functional relationships presented in Reference 4. The functional relationships presented were based on an extensive parametric description of subcompact, compact, intermediate and standard size vehicles are related to the vehicle wheelbase, ℓ_w

The relationships employed are given below.

Input wheelbase: ℓ_w

1) Total weight $W_T = 2.451\text{x}10^{-3}\ell^3_w$ lb.

2) Total unsprung weight $W_{UT} = 126.6 + 0.111\ W_T$ lb.

3) Front unsprung weight $W_{UF} = 0.385\ W_{UT}$ lb.

4) Rear unsprung weight $W_{UR} = W_{UT} - W_{UF}$ lb.

5) Sprung weight $W_S = W_T - W_{UT}$ lb.

6) Total weight @ front $W_{FT} = \frac{1}{100}(62.727 - 0.0629\ell_w)W_T$ lb.

7) Total weight @ rear $W_{RT} = W_T - W_{FT}$ lb.

8) Sprung weight @ front $W_{FS} = W_{FT} - W_{UF}$ lb.

9) Sprung weight @ rear $W_{RS} = W_{RT} - W_{UR}$ lb.

10) Sprung mass c.g. $\boxed{a = \frac{W_{RS}}{W_S}\ \ell_w}$ in.

$\boxed{b = \ell_w - a}$ in.

12) Spurng mass $\boxed{M_S = W_S/g}$ lb-sec^2/in

13) Front unsprung mass $\boxed{M_{UR} = W_{UF}/g}$ lb-sec^2/in

14) Rear unsprung mass $\boxed{M_{UR} = W_{UR}/g}$ lb-sec^2/in

15) Front track $\boxed{T_F = 12.571 + 0.419\ \ell_w}$ in.

16) Rear track $\boxed{T_R = 11.211 + 0.428\ \ell_w}$ in.

17) Yaw inertia $\boxed{I_Z = M_S\ (26.352)\ W_T^{0.577}}$ lb-sec^2-in

18) Roll inertia $\boxed{I_X = M_S\ (4.752) W_T^{0.546}}$ lb-sec^2-in

19) Total pitch inertia $I_{Y_T} = M_T\ (3.1104)\ W_T^{0.82}$ lb-sec^2-in

20) Approximate pitch inertia due to unsprung masses:

$$I_{yu} = M_{UF}\ (144+a^2) + M_{UR}\ (144+b^2) \quad \text{lb-sec}^2\text{-in}$$

21) Pitch inertia $\boxed{I_y = I_{yT} - I_{Yu}}$ lb-sec^2-in

22) Bounce natural frequency $f_n = 1.696 - 1.415 \times 10^{-4} W_T$ Hz.

23) Total spring rate $\Sigma K = 4 f_n^2 \pi M_s$

24) Spring rate distribution $R_K = 42.17 + 0.125 \times 10^{-2} W_T$ %

25) Front spring rate $\boxed{K_F = \frac{1}{2}\ \left(\frac{R_K}{100} \right) \Sigma K}$ lb/in

26) Rear spring rate $\boxed{K_R = \frac{1}{2}\ \Sigma K - K_F}$ lb/in

27) Front damping $\boxed{C_F = \frac{(12.3)(2)}{100} \sqrt{K_F M_s}}$ lb-sec/in

28) Rear damping $\boxed{C_R = \frac{(20.8)(2)}{100} \sqrt{K_R M_s}}$ lb-sec/in

29) Rear spring track $\boxed{T_S = .702\ T_R}$ (1) in.

30) Rear axle inertia $\boxed{XIR = XMS\ (.12484)\ T_R^2}$

6.1.4 Vehicle Data Library

The vehicle data library contains best available data for six vehicles in a BLOCK DATA subprogram. The vehicles currently contained in the library are:

Vehicle Number		
1	1963 Ford Galaxie Four-Door Sedan	(Reference 1)
2	1971 Dodge Coronet	(Reference 6)
3	1971 Chevrolet Brookwood Station Wagon	(Reference 6)
4	1971 Pontiac Trans-Am	(Reference 6)
5	1971 Volkswagen Super Beetle	(Reference 6)
6	1971 Vega Sport-Coupe	(Reference 7)

---

(1) Average of coil and leaf spring rear suspension.

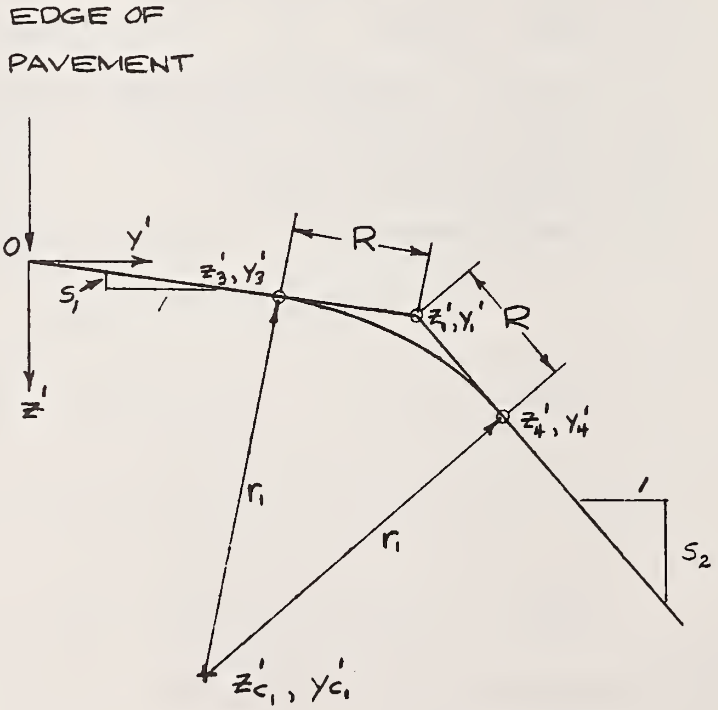
6.1.5 Round Bottom Ditch Program

6.1.5.1 Analysis

The general configuration of the terrain cross section described by the round bottom ditch program is illustrated in Figure 6.1-2. The elements of the profile are: a shoulder with slope S1, rounding of the shoulder-side slope break, a side slope S2, a fully rounded ditch, and the back slope S3. The edge of the pavement is assumed to lie along the X' axis at zero elevation. All roundings are circular arcs between the points of tangency with the respective slopes. The ditch is formed by two circular arcs, each tangent to the horizontal at the bottom of the ditch which is midway between the slope tangency points defined by the width of the ditch.

1. Shoulder-Side Slope Rounding

Referring to the sketch below, the rounding at this intersection is defined as 2R, or twice the distance from the Y' intersection of the slopes to the point of tangency with the slope as measured along the slope.



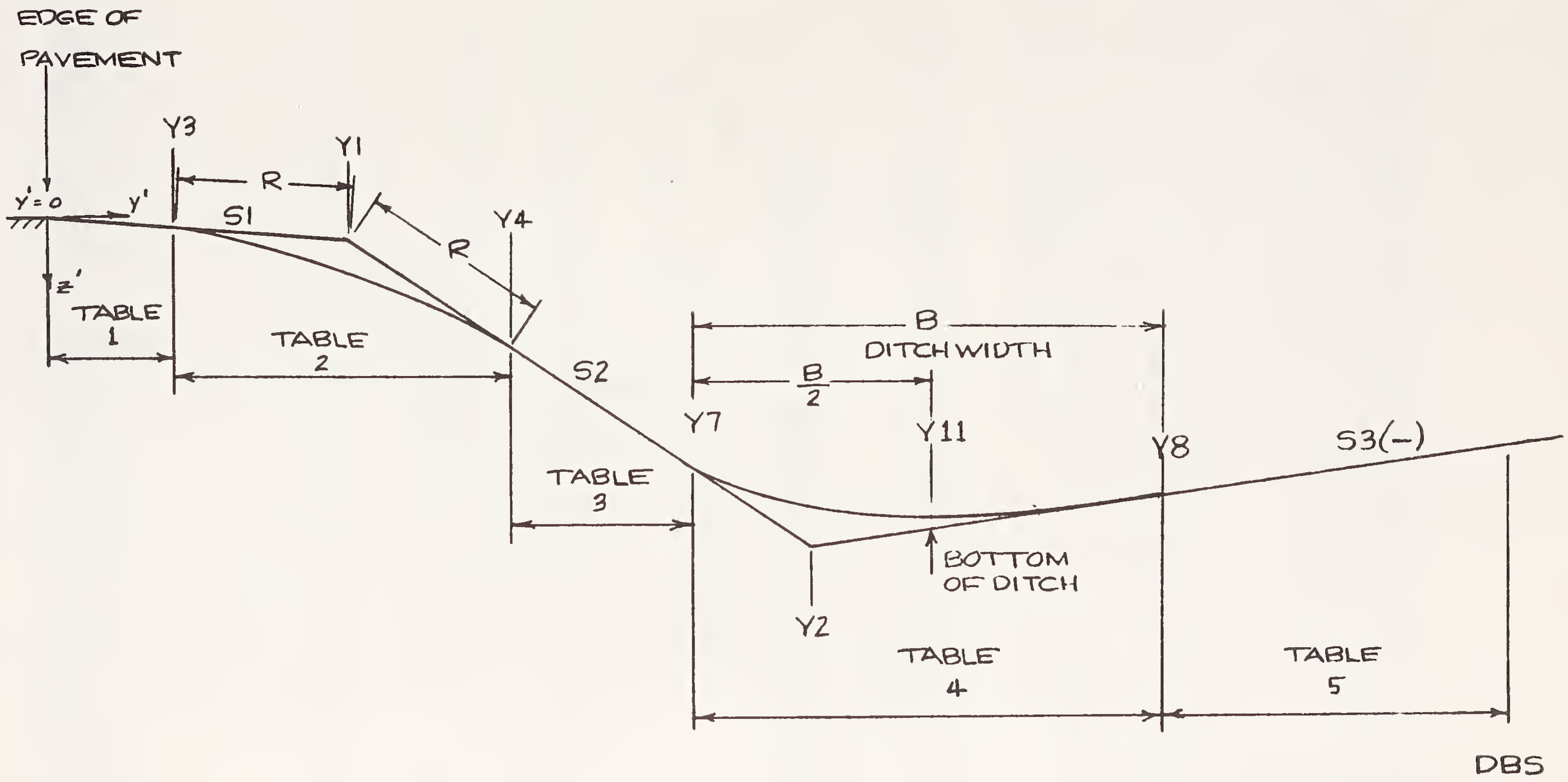


Figure 6.1-2

Round Bottom Ditch

Given the lateral distance from the edge of pavement (the X' axis) to the shoulder break, Y'_1, the shoulder slope, S_1[*], the side slope, S_2, and the tangent distances, R, the elevation of the shoulder break is

$$Z'_1 = S_1 Y'_1$$

and the coordinates of the tangent points are

$$Y'_3 = Y'_1 - \frac{R}{\sqrt{S_1^2+1}} \qquad Y'_4 = Y'_1 + \frac{R}{\sqrt{S_2^2+1}}$$

$$Z'_3 = Z'_1 - \frac{RS_1}{\sqrt{S_1^2+1}} \qquad Z'_4 = Y'_1 + \frac{RS_2}{\sqrt{S_2^2+1}}$$

The coordinates of the rounding circle center are

$$Y'_{c_1} = \frac{S_1 S_2}{S_1 - S_2} \left(Z'_4 - Z'_3 + \frac{1}{S_1} Y'_3\right)$$

$$Z'_{c_1} = -\frac{1}{S_1} Y'_{c_1} + Z'_3 + \frac{1}{S_1} Y'_3$$

and the rounding circle radius is given by

$$r_1 = \sqrt{(Y'_3 - Y'_{c_1})^2 + (Z'_3 - Z'_{c_1})^2}$$

---

[*] Slopes S_1, S_2 and S_3 are defined as the ratio of vertical to horizontal.

Included in the computer program coding is logic to insure that the elevation of the terrain on the shoulder rounding arc is not more than 10 inches below the edge of the pavement at a lateral distance of 10 feet from the roadway. This constraint* on the shoulder profile was adopted in consideration of the need for disabled vehicles parked on the shoulder to be in a reasonably level attitude so as to facilitate tire changes or other repairs. If the terrain drop is more than 10 inches at 10 feet, the center of the rounding arc of the same radius (r_1) is adjusted along a line parallel to the shoulder slope such that the terrain elevation will be 10 inches below the pavement at the 10 ft. lateral distance.

Denoting the coordinates of the adjusted center of the rounding arc by (Z'_c, Y'_c):

$$Z'_c = S_1(Y'_c - Y'_{c1}) = Z'_{c1}$$

Noting that

$$(Z'_c - 10)^2 + (120 - Y'_c)^2 = r_1^2$$

and combining the above expressions results in the following equation

$$(S_1^2+1)Y_c'^2 - 2[Y'_{c1}S_1^2 - S_1(Z'_{c1}-10)+120]Y'_c + [S_1Y'_{c1} - Z'_{c1})+10]^2$$

$$- r_1^2 + (120)^2 = 0$$

This equation is solved for Y'_c, the coordinate of the adjusted arc center.

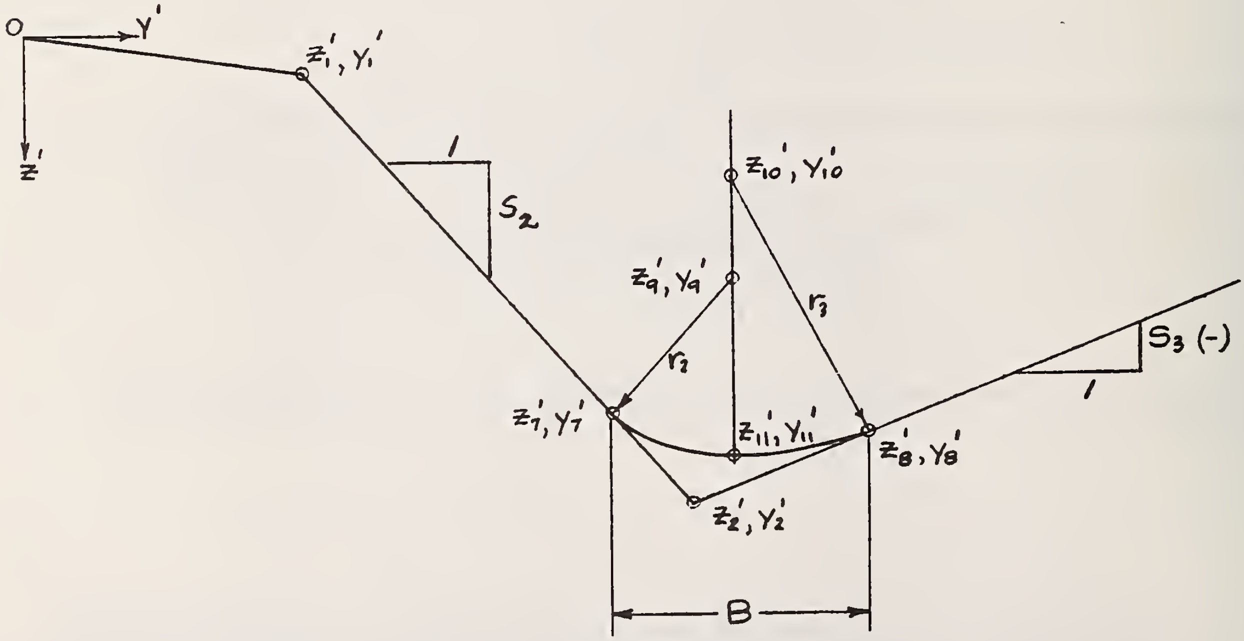
---

[*] To increase the utility of the program, the constraint is removed if values for input variables are specified such that $Y'_4 < 120$ in. of $Y'_3 > 120$ in. or the shoulder slope (S_1) is greater than 0.08333 (1 inch/ft).

Since the adjusted arc center would result in rounding that was not centered about shoulder-side slope break point (i.e., the tangency points to slopes S_1 and S_2 would no longer be the same distance R from the slope break), the input values of Y'_1 and Y'_2 are also adjusted by the same amount as the lateral shift $(Y'_c - Y'_{c1})$ of the arc center. New values for the elevation of the shoulder break (Z'_1) and for the coordinates of the tangency points are then used in the subsequent calculation of the terrain profile beyond the shoulder-side slope rounding.

2. Ditch Bottom Rounding

Ditch bottom rounding is defined by the ditch width which is the lateral distance between the points of tangency with the side and back slopes. It is assumed that the lowest point of the ditch cross section is at the lateral midpoint of the rounding. Thus, as illustrated in the sketch below, the rounding is determined by two circular arcs of, in general, different radii with their centers at the same lateral position.



These radii are related to the corresponding slopes and ditch width by

$$r_2 = \frac{B}{2S_2} \qquad \sqrt{1 + S_2^{\,2}}$$

and

$$r_3 = -\frac{B}{2S_3} \qquad \sqrt{1 + S_3^{\,2}}$$

The elevation of points 7 and 8 are

$$Z'_7 = Z'_1 + S_2\,(Y'_7 - Y'_1)$$

$$Z'_8 = Z'_2 + S_3\,(Y'_8 - Y'_2)$$

Therefore, the elevation of point 11 must be

$$Z'_{11} = Z'_7 + r_2 - \sqrt{r_2^{\,2} - \left(\frac{B}{2}\right)^2}$$

$$= Z'_8 + r_3 - \sqrt{r_3^{\,2} - \left(\frac{B}{2}\right)^2}$$

$$Z'_{11} = \frac{S_2S_3}{S_2-S_3}\ \Big[B + \frac{1}{S_3}\,(Z'_2+r_3) - \frac{1}{S_2}\,(Z'_1+r_2) + Y'_1 - Y'_2 + \frac{1}{S_2}\sqrt{r_2^{\,2} - \left(\frac{B}{2}\right)^2} - \frac{1}{S_3}\sqrt{r_3^{\,2} - \left(\frac{B}{2}\right)^2}$$

Therefore,

$$Z'_9 = Z'_{11} - r_2 \qquad\qquad Y'_1 = Y'_1 + \frac{1}{S_2}\,(Z'_7 - Z'_1)$$

$$Z'_{10} = Z'_{11} - r_3 \qquad\qquad Y'_8 = Y'_2 + \frac{1}{S_3}\,(Z'_8 - Z'_2)$$

$$Z'_7 = Z'_9 + \sqrt{r_2^{\,2} - \left(\frac{B}{2}\right)^2} \qquad\qquad Y'_{10} = Y'_9 = Y'_{11} = Y'_7 + \frac{B}{2}$$

$$Z'_8 = Z'_{10} + \sqrt{r_3^{\,2} - \left(\frac{B}{2}\right)^2}$$

6.1.5.2 Subroutine Functional Description

From a set of 8 input variables, the program computes all of the data required to describe the profile of the terrain cross section illustrated in Figure 6.1-2, and provides punched cards for HVOSM terrain card input card (except the values of the terrain friction coefficients which must be punched by the user). The routine also supplies a printout of the information contained on these cards. The cross section is divided into 5 discrete parts, each of which is represented in a separate terrain table as indicated in Figure 6.1-2.

The cross section is the same at all longitudinal stations and the beginning, end and increment values for each table in the X' direction are fixed at -500 inches, 9500 inches, and 5000 inches, respectively. In the lateral direction, Tables 1, 3 and 5 contain only 3 points each (2 equal lateral increments) since the surfaces are planar. The lateral increment for the tables describing the roundings at the shoulder and the ditch bottom, Tables 2 and 4, respectively, is nominally 6 inches unless the roundings are so large that the number of such increments exceeds 20 (i.e., exceeds the limit of 21 points allowed for each table). In that case, the lateral distance covered by the rounding is divided into 20 equal increments (21 points) in the table. None of the tables contain interpolation boundaries.

A listing of program source deck is presented in the HVOSM-Programmers Manual. Briefly, the procedural steps are as follows.

1. Read input data.

2. Compute geometry associated with shoulder/side slope rounding. Print coordinates of shoulder rounding circle center and the arc radius.

3. Test if terrain drop exceeds 10" at 10 ft. from EOP. (Test is bypassed for certain conditions. See Analysis Section 6.1.5.1).

4. Modifies terrain, if necessary, so that shoulder rounding results in 10" drop at 10 ft. lateral distance.

5. Prints adjusted values of shoulder rounding circle center coordinates and inputted slope break points (Y_1 and Y_2).

6. Computes lateral position of start of side slope toe rounding (Y_7).

7. Terminates the program and prints message of input incompatibility if $Y_7 < Y_4$.

8. Computes geometry associated with rounding of ditch.

9. Prints values of all input (or adjusted input) variables.

10. Prints and punches HVOSM input Cards 501-505 and the set of cards for each of the five terrain tables.

6.1.5.3 Symbol Dictionary

Formulation Symbol	Program Symbol	Definition
B	B	ditch width, measured horizontally between tangent points, inches
DBS	DBS	lateral run-out distance of the back slope, inches
-	DX	increment of X' in terrain table, inches
-	DY	increment of Y' in terrain table, inches
-	N	number of Y' points in terrain table
r_1	R1	radius of shoulder rounding, inches
r_2	R2	radius of ditch rounding (nearest to road), inches
r_3	R3	radius of ditch rounding (backslope side of ditch), inches
R	R	distance to tangent points of shoulder rounding from shoulder break, measured along shoulder and side slopes, inches
S_1	S1	shoulder slope ratio (vertical to horizontal)
S_2	S2	side slope ratio (vertical to horizontal)
S_3	S3	initial X'-value in terrain table, inches
X'_B	XB	initial X'-value in terrain table, inches
X'_E	XE	final X'-value in terrain table, inches
X	X(I)	X'-value in the terrain table (distance parallel to the edge of pavement), inches
-	XNB	number of X' (angled) boundaries for terrain table (= 0)
Y'_B	YB	initial Y'-value in terrain table, inches
Y'_E	YE	final Y'-value in terrain table, inches
Y'	Y(I)	Y'-value in the terrain table (lateral location from the edge of pavement), inches
-	YNB	number of Y' boundaries for terrain table (= 0)
Y'_1, Z'_1	Y1,Z1	lateral location and elevation of shoulder break, inches

Formulation Symbol	Program Symbol	Definition
Y'_2, Z'_2	Y2,Z2	lateral location and elevation of intersection of side and back slopes, inches
Y'_3, Z'_3	Y3,Z3	lateral location and elevation of the tangent point of the shoulder rounding at the shoulder break, inches
Y'_4, Z'_4	Y4,Z4	lateral location and elevation of the tangent point of the shoulder rounding and the side slope, inches
Y'_7, Z'_7	Y7,Z7	lateral location and elevation of the tangent point of the ditch rounding circle (nearest to road) and the side slope, inches
Y'_8, Z'_8	Y8,Z8	lateral location and elevation of the tangent point of the ditch rounding circle (back slope of ditch) and the back slope, inches
Y'_9, Z'_9	Y9,Z9 YC2,ZC2	lateral location and elevation of the center of the ditch rounding circle (nearest to road), inches
Y'_{10}, Z'_{10}	Y10,Z10 YC3,ZC3	lateral location and elevation of the center of the ditch rounding circle (back slope side of ditch), inches
Y'_{11}, Z'_{11}	Y11,Z11	lateral location and elevation of the bottom of the ditch, inches
Y'_{c_1}, Z'_{c_1}	YC1,ZC1	lateral location and elevation of the center of the shoulder rounding circle, inches
-	ZI	terrain table number
Z'	Z(I)	Z'-value in the terrain table (elevation from the edge of pavement), inches

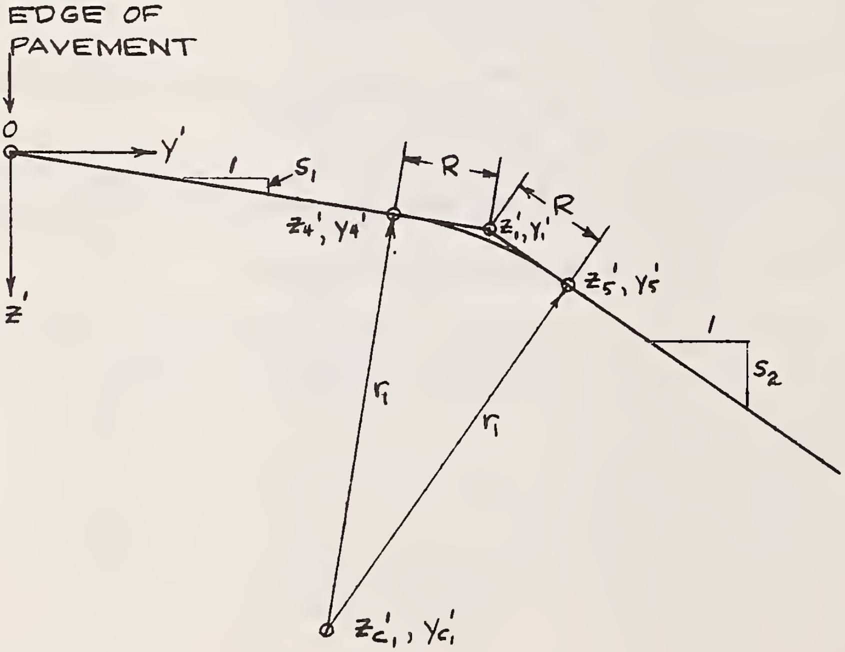
6.1.6 Flat Bottom Ditch Program

6.1.6.1 Analysis

The general configuration of the terrain cross section described by the flat bottom ditch program is illustrated in Figure 6.1-3. The elements of the profile are: a shoulder with slope S1, rounding of the shoulder-side slope break, a side slope S2, rounding of the slope break at the near side of the ditch, flat ditch bottom, rounding of the slope break at the far side of the ditch, and the back slope S3. The edge of the pavement is assumed to lie along the X' axis at zero elevation and the three roundings are assumed to be circular arcs between the points of tangency with the respective slopes.

1. Shoulder-Side Slope Rounding

Referring to the sketch below, the rounding at this intersection is defined as 2R, or twice the distance from the Y' intersection of the slopes to the point of tangency with the slope as measured along the slope.



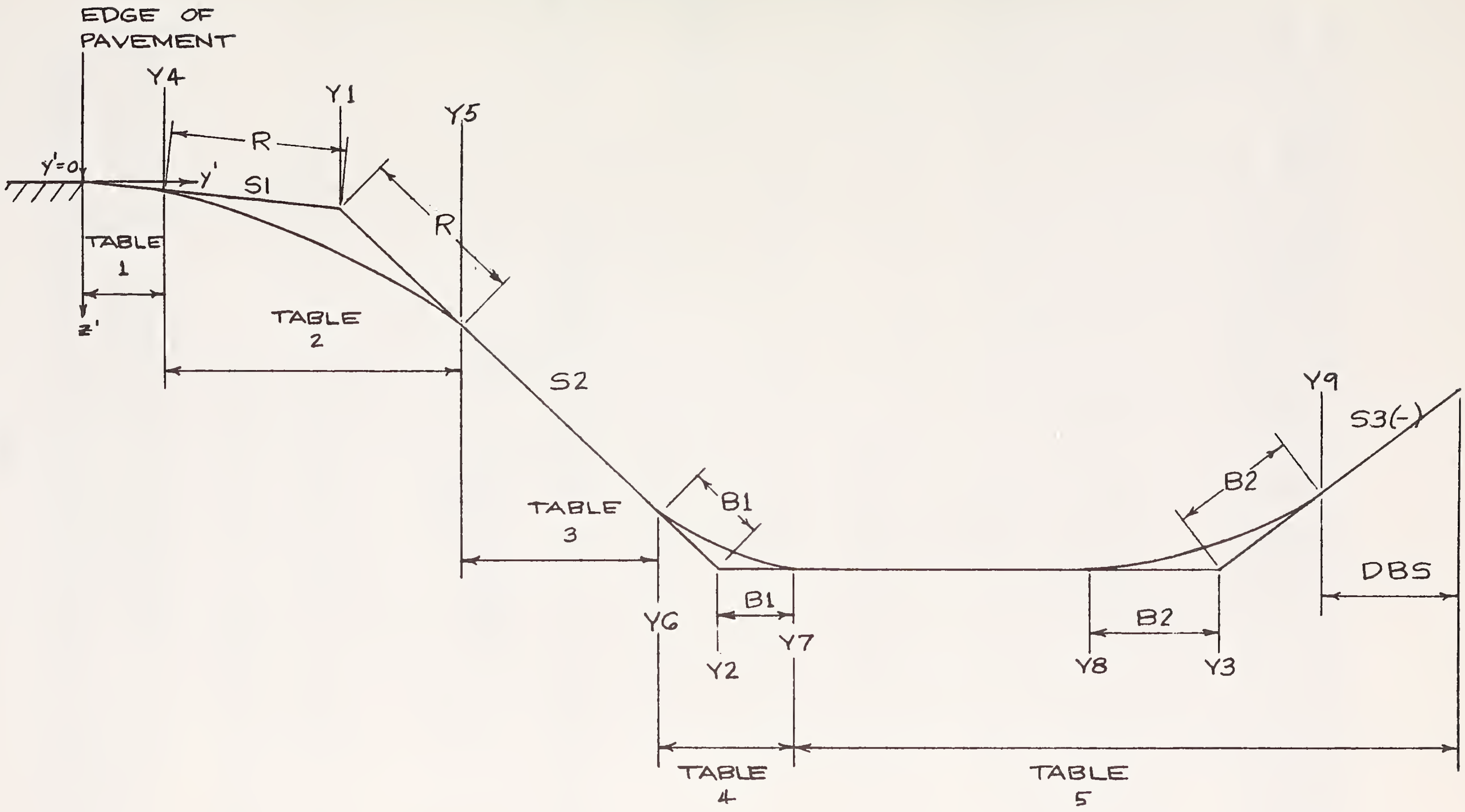


Figure 6.1-3

Rounded Flat Bottom Ditch

Given the lateral distance from the edge of pavement (the X' axis) to the shoulder break, Y'_1, the shoulder slope S_1*, the side slope, S_2, and the tangent distance, R, the elevation of the shoulder break is

$$Z'_1 = Y'_1 S_1 .$$

and the coordinates of the tangent points are

$$Y'_4 = Y'_1 - \frac{R}{\sqrt{S_1^2+1}}$$

$$Z'_4 = Z'_1 - S_1(Y'_1 - Y'_4)$$

$$Y'_5 = Y'_1 + \frac{R}{\sqrt{S_2^2+1}}$$

$$Z'_5 = Z'_1 + S_2(Y'_5 - Y'_1)$$

The coordinates of the rounding circle center are

$$Y'_{c_1} = \frac{S_1 S_2 \left(Z'_5 - Z'_4 + \frac{Y'_5}{S_2} - \frac{Y'_4}{S_1}\right)}{S_1 - S_2}$$

$$Z'_{c_1} = - \frac{Y'_{c_1}}{S_1} + Z'_4 + \frac{Y'_4}{S_1}$$

and the radius of the rounding circle is given by

$$r_1 = \sqrt{(Y'_4 - Y'_{c_1})^2 + (Z'_4 - Z'_{c_1})^2}$$

---

*Slopes S_1, S_2 and S_3 are defined as the ratio of vertical to horizontal.

Included in the computer program coding is logic to insure that the elevation of the terrain on the shoulder rounding arc is not more than 10 inches below the edge of the pavement at a lateral distance of 10 feet from the roadway. This constant* on the shoulder profile was adopted in consideration of the need for disabled vehicles parked on the shoulder to be in a reasonably level attitude so as to facilitate tire changes or other repairs. If the terrain drop is more than 10 inches at 10 feet, the center of the rounding arc of the same radius (r_1) is adjusted along a line parallel to the shoulder slope such that the terrain elevation will be 10 inches below the pavement at the 10 ft. lateral distance.

Denoting the coordinates of the adjusted center of the rounding arc by (Z'_c, Y'_c):

$$Z'_c = S_1 (Y'_c - Y'_{c1}) + Z'_{c1}$$

Noting that

$$(Z'_c - 10)^2 + (120 - Y'_c)^2 = r_1^2$$

and combining the above expressions results in the following equation

$$(S_1^2+1)Y'^2_c-2[Y'_{c1}S_1^2-S_1(Z'_{c1}-10)+120]Y'_c+[(S_1Y'_{c1}-Z'_{c1})+10]^2$$
$$- r_1^2 + (120)^2 = 0$$

This equation is solved for Y'_c, the coordinate of the adjusted arc center.

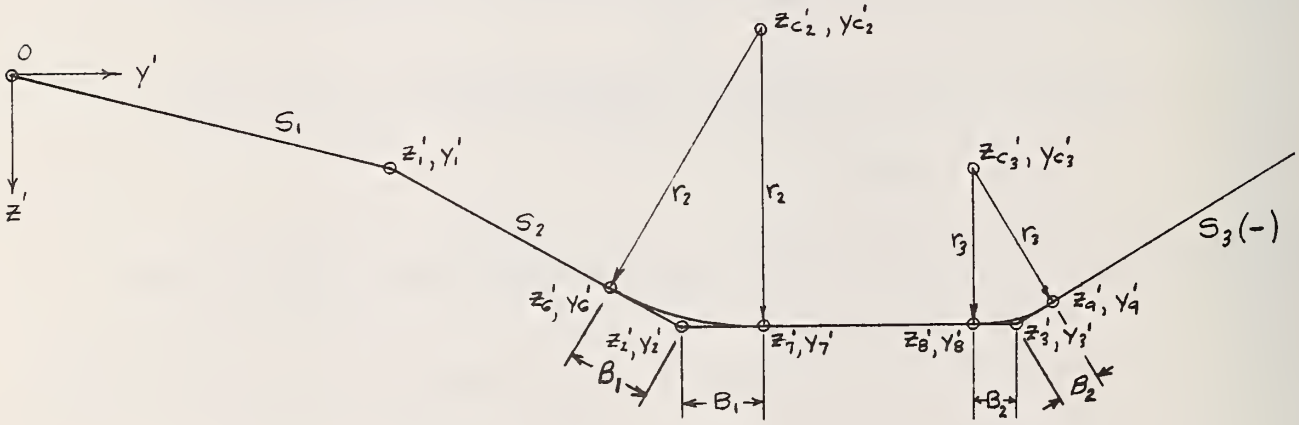
---

*To increase the utility of the program, the constraint is removed if values for input variables are specified such that $Y'_5<120$ in. or $Y'_4>120$ in. or the shoulder slope (S_1) is greater than 0.08333 (1 inch/ft).

Since the adjusted arc center would result in rounding that was not centered about shoulder-side slope breakpoint (i.e., the tangency points to slopes S_1 and S_2 would no longer be the same distance R from the slope break), the input values of Y'_1, Y'_2 and Y'_3 are also adjusted by the same amount as the lateral shift $(Y'_c - Y'_{c1})$ of the arc center. New values for the elevation of the shoulder break (Z'_1) and for the coordinates of the tangency points are then used in the subsequent calculation of the terrain profile beyond the shoulder-side slope rounding.

2. Ditch Bottom Rounding

The ditch section, illustrated in the sketch below, includes independent roundings of the slope breaks at the intersection of the horizontal ditch bottom and the side and back slopes. As in the case of the shoulder rounding, the analysis is based on the assumption that the points of tangency of the roundings are equidistant from the breakpoint as measured along the tangents.



The coordinates of the corner points and tangency points are determined from the geometry and ditch bottom roundings $2B_1$ and $2B_2$, respectively, as

$$Z'_2 = Z'_1 + S_2 (Y'_2 - Y'_1)$$

$$Z'_3 = Z'_2$$

$$Y'_7 = Y'_2 + B_1$$

$$Z'_7 = Z'_2$$

$$Y'_6 = Y'_2 - \frac{B_1}{\sqrt{S_2^2+1}}$$

$$Z'_6 = Z'_2 - S_2 (Y'_2 - Y'_6)$$

$$Y'_8 = Y'_3 - B_2$$

$$Z'_8 = Z'_3$$

$$Y'_9 = Y'_3 + \frac{B_2}{\sqrt{S_3^2+1}}$$

$$Z'_9 = Z'_3 + S_3 (Y'_9-Y'_3)$$

The coordinates of the rounding circle centers and rounding circle radii are

$$Y'_{c_2} = Y'_7$$

$$Z'_{c_2} = Z'_7 - r_2$$

$$r_2 = \frac{(Y'_7-Y'_6) \sqrt{S_2^2+1}}{S_2}$$

for the rounding at the near side of the ditch, and

$$Y'_{c_3} = Y'_8$$

$$Z'_{c_3} = Z'_3 - r_3$$

$$r_3 = \frac{-(Y'_9-Y'_8) \sqrt{S_3^2+1}}{S_3}$$

for the rounding at the far side of the ditch.

6.1.6.2 Subroutine Functional Description

From a set of 10 input variables, the program computes all of the data required to describe the profile of the terrain cross section illustrated in Figure 6.1-3, and provides punched cards for HVOSM terrain card input (except the values of the terrain friction coefficients which must be punched by the user). The routine also supplies a printout of the information contained on these cards. The cross section is divided into 5 discrete parts, each of which is represented in a separate terrain table as indicated in Figure 6.1-3.

The cross section is the same at all longitudinal stations and the beginning, end and increment values for each table in the X' direction are fixed at -500 inches, 9500 inches, and 5000 inches, respectively. In the lateral direction, Tables 1 and 3 contain only 3 points each (2 equal lateral increments) since the surfaces are planar. The lateral increment for the tables describing the roundings at the shoulder and at the toe of the side slope, Tables 2 and 4, respectively, is nominally 6 inches unless the roundings are so large that the number of such increments exceeds 20 (i.e., exceeds the limit of 21 points allowed for each table). In that case, the lateral distance covered by the rounding is divided into 20 equal increments (21 points) in the table. Table 5, for which the increment between points need not be constant, always contains 20 increments (21 points) as follows: one increment for the flat bottom of the ditch (between points labeled 7 and 8 in Figure 6.1-3), 18 equal lateral increments for the rounding at the toe of the backslope (between labeled points 8 and 9), and one increment for the backslope (DBS). Note of the tables contain interpolation boundaries.

A listing of program source deck is presented in the HVOSM-Programmers Manual. Briefly, the procedural steps are as follows:

1. Read input data.

2. Compute geometry associated with shoulder/side slope rounding. Print coordinates of shoulder rounding circle center and the arc radius.

3. Test if terrain drop exceeds 10" at 10 ft. from EOP. (Test is bypassed for certain conditions. See Analysis Section 6.1.6.1)

4. Modifies terrain, if necessary, so that shoulder rounding results in 10" drop at 10 ft. lateral distance.

5. Prints adjusted values of shoulder rounding circle center coordinates and inputted slope break points (Y_1, Y_2 and Y_3).

6. Computes lateral position of start of side slope toe rounding (Y_6).

7. Terminates the program and prints messages of input incompatibility of $Y_6 < Y_5$.

8. Computes geometry associated with rounding of each corner of ditch.

9. Prints values of all input (or adjusted input) variables.

10. Prints and punches HVOSM input cards 501-505 and the set of cards for each of the five terrain tables.

6.1.6.3 Symbol Dictionary

Formulation Symbol	Program Symbol	Definition
B_1	B1	distance to tangent points of side slope-ditch bottom rounding from intersection, measured along slope and bottom, inches
B_2	B2	distance to tangent points of ditch bottom-back slope rounding from intersection, measured along bottom and slope, inches
DBS	DBS	lateral run-out distance of the back slope, inches
-	DX	increment of X' in terrain table, inches
-	DY	increment of Y' in terrain table, inches
-	N	number of Y' points in terrain table
r_1	R1	radius of shoulder rounding, inches
r_2	R2	radius of ditch rounding (nearest to road), inches
r_3	R3	radius of ditch rounding (back slope side of ditch), inches
R	R	distance to tangent points of shoulder rounding from shoulder break, measured along shoulder and side slopes, inches
S_1	S1	shoulder slope ratio (vertical to horizontal)
S_2	S2	side slope ratio (vertical to horizontal)
S_3	S3	back slope ratio (vertical to horizontal)
X'_B	XB	initial X'-value in terrain table, inches
X'_E	XE	final X'-value in terrain table, inches
X	X(I)	X'-value in the terrain table (distance parallel to the edge of pavement), inches
	XNB	number of X' (angled) boundaries for terrain table (= 0)

Formulation Symbol	Program Symbol	Definition
Y'_B	YB	initial Y'-value in terrain table, inches
Y'_E	YE	final Y'-value in terrain table, inches
Y'	Y(I)	Y'-value in the terrain table (lateral location from the edge of pavement), inches
-	YNB	number of Y' boundaries for terrain table (= 0)
Y'_1,Z'_1	Y1,Z1	lateral location and elevation of shoulder break, inches
Y'_2,Z'_2	Y2,Z2	lateral location and elevation of intersection of side slope and ditch, inches
Y'_3,Z'_3	Y3,Z3	lateral location and elevation of ditch and back slope, inches
Y'_4,Z'_4	Y4,Z4	lateral location and elevation of tangent point of the shoulder rounding and shoulder slope, inches
Y'_5,Z'_5	Y5,Z5	lateral location and elevation of tangent point of shoulder rounding and side slope, inches
Y'_6,Z'_6	Y6,Z6	lateral location and elevation of tangent point of side slope and ditch rounding, inches
Y'_7,Z'_7	Y7,Z7	lateral location and elevation of tangent point of ditch rounding (nearest to road) and ditch, inches
$Y'_8-Z'_8$	Y8,Z8	lateral location and elevation of tangent point of ditch and ditch rounding (back slope side of dtich), inches
$Y'_9-Z'_9$	Y9,Z9	lateral location and elevation of tangent point of ditch rounding and back slope, inches
Y'_{c_1},Z'_{c_1}	YC1,ZC1	lateral location and elevation of center of shoulder rounding circle, inches
Y'_{c_2},Z'_{c_2}	YC2,ZC2	lateral location and elevation of center of ditch rounding circle (nearest to road), inches

Formulation Symbol	Program Symbol	Definition
Y'_{c_2}, Z'_{c_2}	YC2,ZC2	lateral location and elevation of center of ditch rounding circle (nearest to road), inches
Y'_{c_3}, Z'_{c_3}	YC3,ZC3	lateral location and elevation of center of ditch rounding circle (back slope side of ditch), inches
-	ZI	terrain table number
Z'	Z(I)	Z'-value in the terrain table (elevation from the edge of pavement)

6.2 HVOSM Vehicle Graphics Program

The HVOSM Vehicle Graphics Program (Reference 8) makes use of the dynamic output of the HVOSM together with user specified straight line descriptions of the vehicle outline and various background objects to produce either single frame "snapshots" on a peripheral plotting device or animated movies with the appropriate hardware.

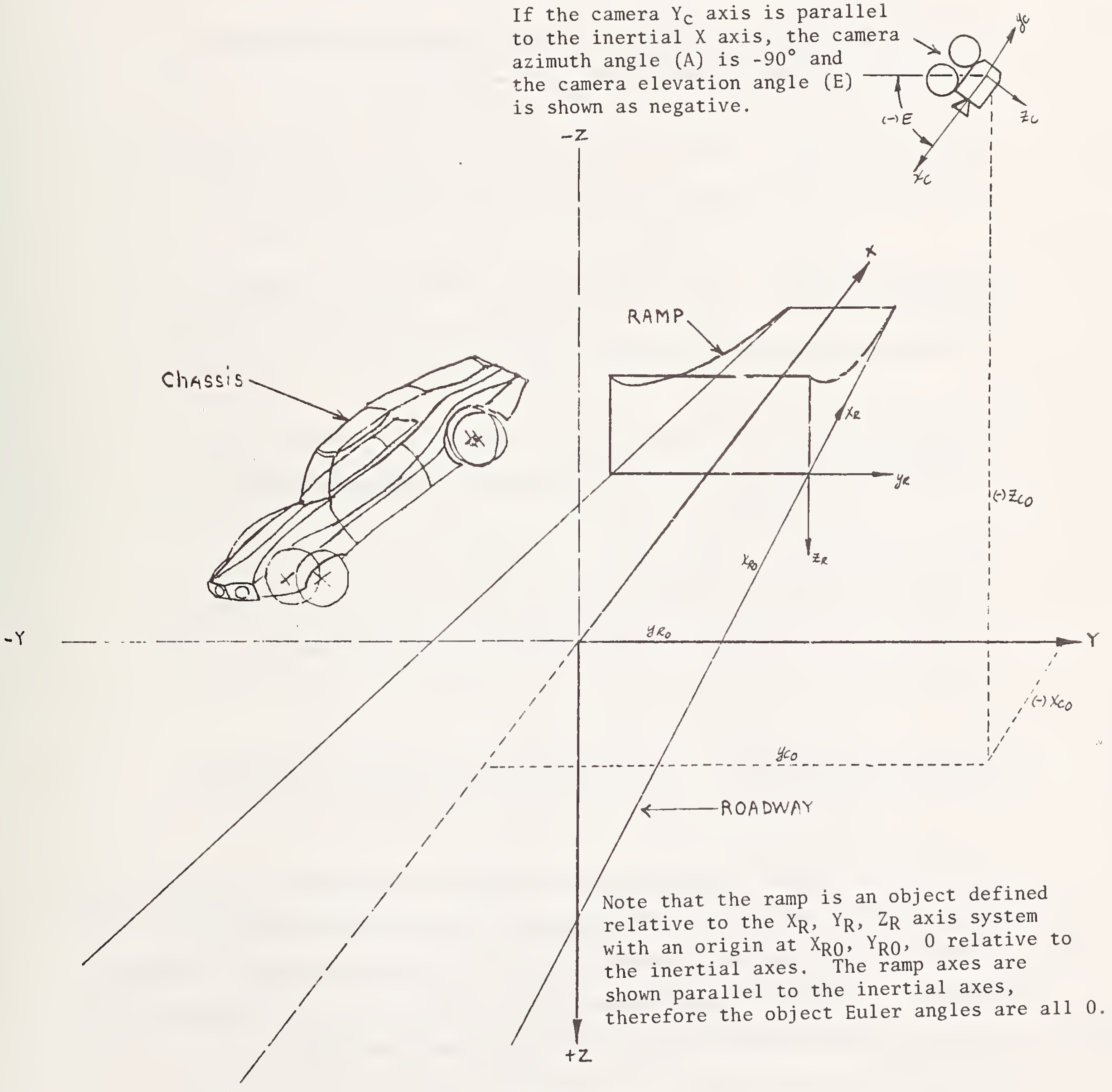
Each object is defined in three dimensions relative to an object fixed coordinate system, which is in turn located and oriented in space, and is transformed to a two-dimensional perspective picture by a simulated pinhole camera. The following coordinate systems are employed in the transformation.

a) Inertial coordinate system: a rectangular coordinate system fixed in free space. This is the fundamental reference base for spatial relationships among the various components. Note that as in the HVOSM, the Z axis is positive downward.

b) Object coordinate system: a rectangular coordinate system fixed to the object. One exists for each object.

CAMERA VIEWING POSITION

Camera origin at X_{co}, Y_{co}, Z_{co} relative to the inertial axes. If the camera Y_c axis is parallel to the inertial X axis, the camera azimuth angle (A) is -90° and the camera elevation angle (E) is shown as negative.



Note that the ramp is an object defined relative to the X_R, Y_R, Z_R axis system with an origin at X_{R0}, Y_{R0}, 0 relative to the inertial axes. The ramp axes are shown parallel to the inertial axes, therefore the object Euler angles are all 0.

Figure 6.2-1

THREE DIMENSIONAL VIEW OF A TYPICAL VEHICLE GRAPHICS SETUP

c) Camera coordinate system: a rectangular coordinate system fixed to the camera, with the origin in the center of the picture plane and the positive X axis extending toward and through the focal point.

d) Picture coordinate system: a two-dimensional rectangular coordinate system fixed to the picture frame.

e) Object position: the position of the origin of the object coordinates, with respect to the inertial coordinate system.

f) Object attitude: the angular relationship of the object coordinates with respect to the inertial coordinates in terms of Euler angles, yaw, ψ; pitch, θ and roll ϕ.

g) Camera position: the position of the origin of the camera coordinates with respect to the inertial coordinate system.

h) Camera attitude: three angles, aximuth, A, elevation, E, of the camera line of sight (camera X axis) and the orientation of the picture (tilt), T, with respect to the inertial coordinates.

i) Camera focal length: distance from the film plane to the pinhole aperture.

Motion and dynamic activity in the simulated scene to be "photographed" is reflected in changes over time of the position and attitude parameters (a total of six) for each object. Furthermore, change in the camera parameters is also possible. The camera could be mounted on a vehicle. Panning (attitude changing) and/or zooming (changes in focal length) are included.

The HVOSM Vehicle Graphics Program also permits the user to choose among many options to best illustrate his particular simulation run. These choices are exercised through use of data cards which describe in detail the various options. The program's capabilities include:

a) Camera motion and frame size.

b) Camera panning and/or zooming (if desired), both automatic and specified.

c) The vehicle outline (shape, style, size, etc.) may be specified by the user.

d) Background options, which remain fixed in space are easily specified.

e) The "frame rate" for a motion picture output may be set at any value to produce "slow motion" or a normally timed movie.

f) Single frame pictures may be drawn at any point in time to produce "still pictures".

g) Any number of "exposures" may be drawn in the same frame to show the progress of the vehicle in a single picture.

h) In illustrating a simulation test of some violent maneuver, the user may desire to show a sequence of normal vehicle motion prior to the maneuver but has not run the simulation program during this pre-event period for economical reasons. He may do this by a pre-run phase of the movie program which conducts a simplified straight line simulation of the vehicle travel leading to the first recorded data set of the test.

i) Titles and subtitles may be printed anywhere in the picture sequence.

j) Any of the above characteristics may be changed at any time in the picture sequence by use of the change cards.

Program inputs include a data file generated by the HVOSM as described in Section 4.3 of this report and data cards as described below.

1. Identification Card - Gives a name to this particular run. (Slight variation of this card terminates run.)

2. Instruction Card - Provides simulation type information, such as number of frames per second, starting and ending times, etc.

3. First Camera Card - Provides program with details on position of camera, if auto. pan and zoom is wanted, etc.

4. Second Camera Card - If it is desired that the camera position parameters are to change by some increment each new frame, this card describes these increments.

5. Basic Dimension Card - This card sends basic chassis dimensions to the program.

6. Object Delete Cards - Note that an object is any entity that is included in the picture (chassis, roadway, tree). If an object is already in storage, it can be removed by this card.

Note: A blank card is used to specify if there are no more object delete cards.

7. Object Cards

A. Object Title Cards - Specify that the next group of cards represents some plottable object like a chassis or tree.

B. Object Specification Card - Sequential list of points that are to be connected together to draw an object.

Note: Each group of connected points in an object will have a modified object title card. A blank card indicates no more objects to be read in.

8. Skip Cards - Occasionally one will want to process the first three runs on a dynamic tape and then jump to the last three runs on the tape; the skip cards allow one to skip around the tape this way.

9. Pattern Cards - The pattern cards specify which of the aforementioned objects are not to be moved, rotated, or translated by the dynamics tape (example: roadways, curbs, etc.).

Note: A blank card means no more pattern cards.

10. Stop Card - A modified form of the Identification Card, this card ends the input deck.

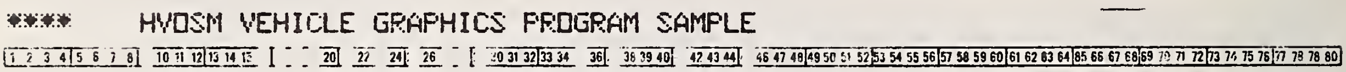
6.1 Input Data Card Format

1. Identification Card

72 columns of optional script, 8 columns of integers, DENT, ITEST.

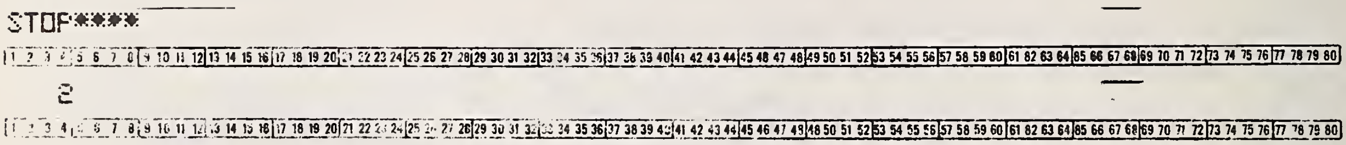
First 4 columns are important: **** —— Read rest of card
STOP —— terminates the program
Note: If columns 5-8 have ****
(STOP —— col 1-4, then the *next* card must have the number of frames in which THE END is printed (4 integers).

Example: First card in the data deck:



```
****    HVOSM VEHICLE GRAPHICS PROGRAM SAMPLE
```

Example: Last card in the data deck:



```
STOP****
   2
```

2. Instruction Card

Col. 1-6	Width of picture	WIDE
Col. 7-12	Height of picture frame	HIGH
Col. 13-18	Time when movie sequence begins	TB
Col. 19-24	Time when movie sequence ends	TE
Col. 25-30	Time between movie frames	DT
Col. 31-36	Size of lettering on frames	STDISP
Col. 37-42	Time tolerance on matching frames	EPST

Col. 43-44	-1 previously run sequence with previously used velocity and acceleration vectors. +1 previously run sequence with a prerun card setting velocity and accleration vectors. 0 new sequence of vectors.	IPRUN
Col. 45-46	-1 omit front end detail. +1 draw in front end detail. 0 no change from last run.	IFR
Col. 47	-1 omit C.G. point. +1 draw C.G. point. 0 no change Note: -1 doesn't work because of error in format (1 col. field).	ICG
Col. 48	1 lay down tire tread tracks. 0 do nothing with above.	ITRK
Col. 49	1 print time of each frame. 0 do not print frame time.	LF
Col. 50	1 new camera data will be read in. 0 no new camera data.	ICAM
Col. 51	1 put all sequences on one frame (double) exposure effect). 0 one picture/frame.	IREP
Col. 52	1 draw a border. 0 no border.	IFRAME
Col. 53-54	No. of trajectory tape (minus sign rewinds it).	IT
Col. 55-56	-1 use old chassis. 0 use no chassis. 1 read in new chassis.	ICHAS
Col. 57-58	0 do nothing. 1 rear in new dimensions.	INIT
Col. 59-60	0 no change card expected. NN No. of tests in which change card will be used.	ICHANG

Col. 61-64	n No. of skip numbers that will be expected. 0 default values will be used.	NSKIP
Col. 65-68	1 ignore previously specified backgrounds. 0 use previously specified backgrounds.	IOBC
Col. 69-72	0 no title shots produced. n No. of frames that title is generated.	ITIT
Col. 73-74	no. of characters in the title.	NTIT
Col. 75-80	height of title characters.	STIT

Example: Instruction Card

```
14.0  14.0 0.0   1.8   .05   .14   .001  00000 11 101010100   2  ‾‾  100280.28
1 2 3  5 6 7 8 9  11 12 13  15 16 17 18 19  21 22 23 24  26 27 28 29 30  32 33 34 35 36  38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75  77 78 79 80
```

3. Camera Cards (used only if ICAM ≠ 0)

(first camera card)

Col. 1-4 Printing Parameter for diagnostics

Col. 5-8	1 focal point in cartesian coordinates. 2 focal point in polar coordinates. 3 automatic panning and zooming. 4 automatic panning only. 5 focal point in rectangular, parameters may vary. 6 focal point in polar, parameters may change. 7 automatic panning, zooming, parameters not re-initiated. 8 automatic panning, parameters not re-initiated. 9 focal point in rectangular, parameters not re-initiated. 10 focal point in polar, parameters not re-initiated.	JDCAM

Note: JDCAM = 5 through 10 is used for moving camera option as defined on the second camera card.

Col. 9-12	1 picture printed as is. 2 vertical axis reversed. 3 horizontal axis reversed. 4 both axis reversed (normal mode to compensate for camera inversion).	INVT
Col. 13-20	X-pos. of camera.	SCRAT(1)
Col. 21-28	Y-pos. of camera.	SCRAT(2)
Col. 29-36	Z-pos. of camera.	SCRAT(3)
Col. 37-44	user defined (see note).	SCRAT(4)
Col. 45-52	user defined (see note).	SCRAT(5)
Col. 53-60	user defined (see note).	SCRAT(6)
Col. 61-68	camera tilt angle.	SCRAT(7)

Note:

If JDCAM = 1,5 or 9 (focal point in rectangular coordinates)	SCRAT(4) - X component of focal point SCRAT(5) - Y component of focal point SCRAT(6) - Z component of focal point SCRAT(7) - camera tile angle Note: X, Y and Z components are with respect to the space fixed axes.
If JDCAM = 2,6 or 10 (focal point in polar coordinates)	SCRAT(4) - aximuth of camera's line-of-sight SCRAT(5) - elevation of camera's line-of-sight SCRAT(6) - focal length SCRAT(7) - camera tilt angle
If JDCAM = 3,7,4 or 8 (automatic panning and zooming) NOTE: See Figure 6.2-2 for definition of SCRAT(4) and SCRAT(5)	SCRAT(4) - horizontal distance (full size) from C.G. to picture edge (not used JDCAM = 4, 8) SCRAT(5) - vertical distance from CG to center of picture (negative for car C.G. below center of frame) SCRAT(6) - focal length (not used JDCAM = 3, 7) SCRAT(7) - camera tilt angle

For JDCAM = 5 through 10, the SCRAT values are changed each frame by some increment described by entries on the second camera card. The law that increments these values (like camera XYZ position) is obscure and the user is advised to study Reference 8 thoroughly. The second camera card and the varying camera parameters concept seems to be useful when the user wishes the camera to act like a "chase car", accelerating alongside the moving vehicle.

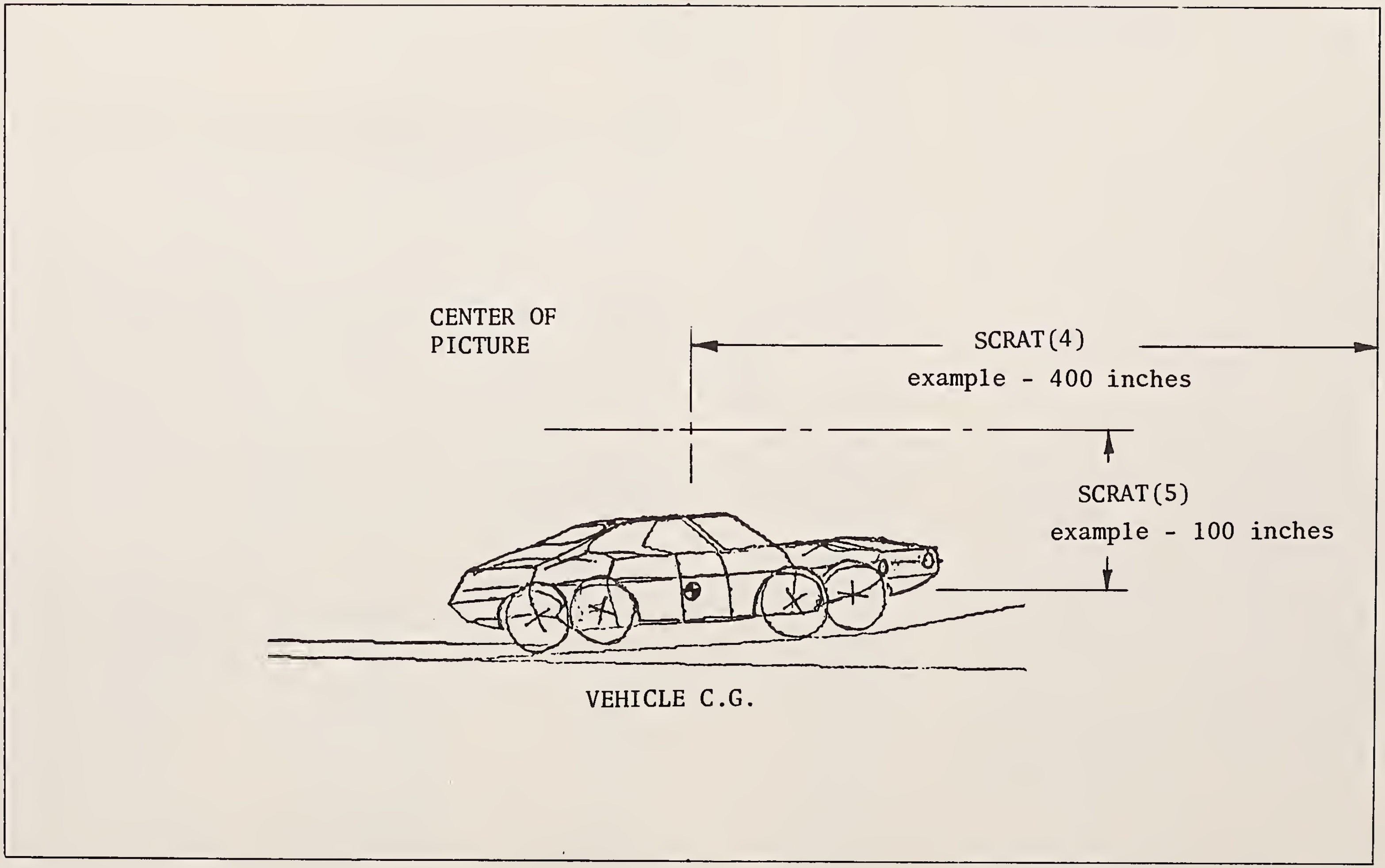


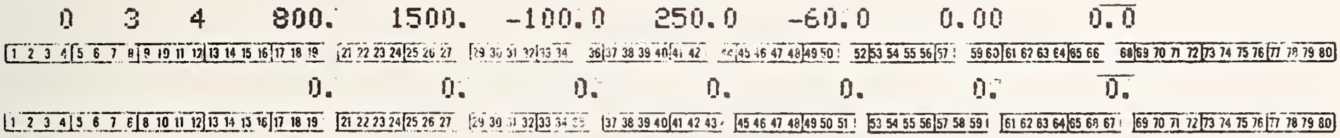
Figure 6.2-2 EXAMPLE OF VEHICLE POSITION WITHIN FRAME

(second camera card)

Col. 1-12	not used	
Col. (12J+1)-(12J+8) J=1,7	amount by which SCRAT(J) changes between frames	SCRAT(J+7)

Note: The second camera card must be supplied even though it may not be used.

Example: Camera Cards

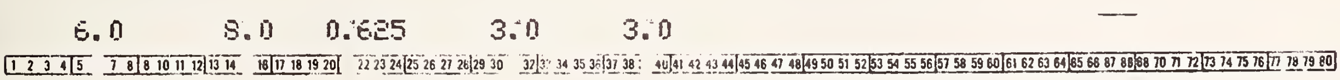


```
0   3   4     800.     1500.   -100.0    250.0    -60.0     0.00      0.0
                    0.       0.       0.       0.       0.       0.       0.
```

4. Basic Dimension Card (used only INIT = 1)

Col. 1-8	length of wheel spokes	default=4	WHEEL(6)
Col. 9-16	thickness of differential	default=8	DL
Col. 17-24	see manual	default=.625	REAR(24)
Col. 25-32	see manual	default=3.0	REAR(25)
Col. 33-40	see manual	defalut=3.0	TOPIN
Col. 41-48	set to zero		TWID
Col. 49-56	set to zero		DOT

Example: Basic Dimension Card



```
6.0       8.0    0.625      3.0      3.0
```

5. Object Delete Cards

Col. 1-8	name of previously read in object that is to be released from storage (don't use WHEEL, REAREND, CHASSIS).	DAY

.
.
.

Col. 1-80 blank specifies no more object delete cards.

Note: This feature is useful if you use a new instruction card, etc. and want to eliminate some object plotted in the first part of the run. Remember to include a blank card even if there are no object delete cards.

6. Object Cards

(object title card)

Note: All objects are assumed to move with the vehicle unless they are specified on a PATTERN card.

Col. 1-8	title or name of object (blank implies no more cards)	TITL
Col. 9-16	1 get new object title card. 2 X, Y, Z parameters coming up. 3 circle to be drawn coming up. 4 circle's coordinates, rectangular	IT
Col. 17-24	No. of points for upcoming specifications or number of straight line segments for a circle.	IN
Col. 25-32	identification: blank, coordinates in inches 1 , coordinates in feet	ID

(object specification card) (These points will be connected by lines) If IT = 2, there are IN triplets of points or IN/2 cards. Coordinates are with respect to the object coordinate system.

Col. 1-12	X-coordinate	DAT
Col. 13-24	Y-coordinate	DAT(J+1)
Col. 25-36	Z-coordinate	DAT(J+2)
Col. 37-38	X-coordinate	DAT(J+3)
Col. 49-60	Y-coordinate	DAT(J+4)
Col. 61-72	Z-coordinate	DAT(J+5)

(object specification cards)

If IT = 3 or 4 (draw a circle)

Col. 1-12	X-position of center of circle	SCRAT(1)
Col. 12-24	Y-position of center of circle	SCRAT(2)
Col. 25-36	Z-position of center of circle	SCRAT(3)
Col. 37-48	radius of circle	SCRAT(4)
Col. 49-56	azimuth of circle axis (degrees)	SCRAT(5)
Col. 57-64	elevation of circle axis (degrees)	SCRAT(6)
Col. 65-72	tilt of circle	SCRAT97)

If the same object is not completely specified by the above title and specs, then an object type card followed by new spec. cards may be used.

(object type cards)

Col. 1-8	blank
Col. 9-16	IT as on title card for the next set of points IT
Col. 17-24	IN as on title card for the next set of points IN

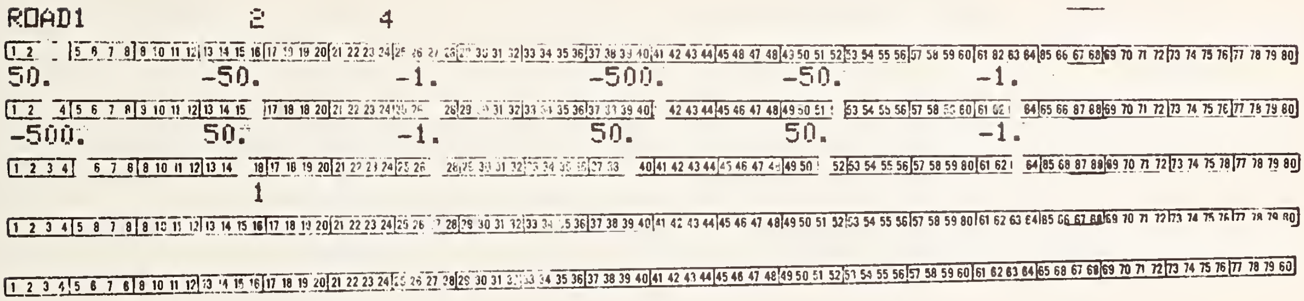
Notes:

(1) Object specification cards define points that are to be connected together. Use object type cards to break up object into distinct line segments (that is, to make the pen lift).

(2) Last card in any object is an object type card with a 1 in columns 9-16.

(3) A blank card must be used to indicate that there are no more object decks to be read in.

Example: A Simple Object



```
ROAD1          2       4
50.           -50.           -1.           -500.          -50.           -1.
-500.          50.           -1.            50.            50.           -1.
               1

```

7. Skip Cards No. of skip entries = NSKIP

Col. 1-4	No. of consecutive runs to be skipped
Col. 5-8	No. of consecutive runs to be processed
Col. 9-12	No. of consecutive runs to be skipped
Col. 13-16	No. of consecutive runs to be processed
	Etc.
default:	no skips.

Example: Skip Card (Processes the first run only on the dynamics tape)

```
   0   1
```

8. Pattern Cards (Those objects that are to remain stationary during the run)

Col. 1-4	Pattern number	J
Col. 5-8	Leave blank	
Col. 9-16	Name of object to be printed on film	PATIN
Col. 17-20	Leave blank	
Col. 21-28	X-position of object in pattern	POSIN(1)
Col. 29-36	Y-position of object in pattern	POSIN(2)
Col. 37-44	Z-position of object in pattern	POSIN(3)
Col. 45-52	Euler angle phi	POSIN(4)
Col. 53-60	Euler angle theta	POSIN(5)
Col. 61-68	Euler angle psi	POSIN(6)

Notes:

(1) Pattern cards must be used for objects that are not to move with the vehicle.

(2) The POSIN values allow you, if desired, to plot an object several times at different locations.

(3) A blank card must be used to indicate no more pattern cards.

(4) Position and orientation of objects are with respect to the space fixed axes.

Example: Pattern Cards

```
   1    OFFRAMP
   2    ONRAMP
   3    ROAD1
   4    ROAD2
   5    ROAD3

```

The preceding cards are enough to run an elementary job with the HVOSM Vehicle Graphics Program. The last card in the input deck should be the Stop Card, described with the Identification Card.

There are two other card types that are not necessary to obtain a picture, but are optionally used for more complex movie generation.

<ins>Pre-Run Card</ins> if IPRUN 0

Col. 1-8	vehicle velocity with respect to fixed axis	V(1)
Col. 9-16	vehicle velocity with respect to fixed axis	V(2)
Col. 17-24	vehicle velocity with respect to fixed axis	V(3)
Col. 25-32	acceleration component	A(1)
Col. 33-40	acceleration component	A(2)
Col. 41-48	acceleration component	A(3)

<ins>Notes on Pre-Run Card:</ins>

The Pre-Run feature allows the user to generate simple motion of chassis prior to the run from the dynamics tape. For example, if the dynamics tape has the chassis crossing a bridge, the Pre-Run Card can be used to simulate the approach to the bridge (even though that isn't on the tape).

<ins>Change Cards</ins> (only if ICHANG≠0)

(first change card)

Col. 1-6	time new sequence begins	TB
Col. 7-12	time new sequence ends	TE
Col. 13-18	1 new time increment between frames 2 retain old time increment	TQ
Col. 19-22	0 read no new camera cards 1 read new set of camera cards	ICAM
Col. 23-26	No. of frames used/subtitle printed	JTIT
Col. 27-30	0 is not expecting another set of change cards 1 new set of change cards expected	ICHANG

Col. 31-34	No. of lines of subtitles to be read same	NOLINE
Col. 35-38	as previously described	IPRUN
Col. 39-42	-1 draw sequence in same frame (double exposure) 0 no double exposure +1 double exposure in a different frame	IREP
Col. 43-46	-1 delete front end 0 no change 1 draw front end	IFR
Col. 47-50	-1 delete C.G. point 0 no change 1 draw C.G. point	ICG
Col. 51-54	0 delete printing of frame time 1 print frame time	LF

(second change card) Subtitle Cards

Col. 1-4	No. of letters on subtitle	NOLET
Col. 5-12	X-position of starting point	XL
Col. 13-20	Y-position of starting point	YL
Col. 21-28	size of printed text	SL
Col. 29-76	characters or text to be printed	VERB

(third change card)

Pattern Cards

(fourth change card)

blank card to indicate no more pattern cards

(fifth change card)

Camera Change Cards

(sixth change card)

Pre-Run Card (if applicable)

Notes on Change Cards

Change Cards are used to change some simulation parameters during a run, such as switching to automatic panning or adding subtitles to a group of frames. It is worthy to note that a new identification card with associated data input deck can be processed also. This allows one continuous movie to be made from two tapes, etc.

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