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THE AMC '74 MOBILITY MODEL

M. Peter Jurkat, et al

Stevens Institute of Technology

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by
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TACOM

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The AMC '74 Mobility Model is an improved, updated and extended revision of the AMC '71 Mobility Model. The main improvements include: specifications for axle-by-axle traction, braking and resistance calculations with recently developed equations to simulate slippery soil, muskeg and snow interaction; a corrected acceleration/deceleration model; enhanced scenario input specifications; a road module simulating travel on primary, secondary roads and trails; an improved hasty river and dry linear feature crossing module; a vehicle preprocessor module and a terrain preprocessor module; an improved obstacle

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crossing module; and an updated ride dynamics module.

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A three-man working group was directly responsible for the generation of this report. Members of the working group were: Messrs. C. J. Nuttall, Jr. (WES); P. W. Haley (TACOM); and Dr. M. P. Jurkat (SIT).

Mr. D. A. Sloss (SIT) assembled the Hasty River Crossing Model. Dr. Alan Lessem (WES) and Mr. R. W. Jacobson (TACOM) created the Obstacle Crossing Module.

Mr. T. Washburn (SIT) contributed significantly by assembling the Vehicle Preprocessor and participated in the development of the structure and logic flow of the whole model.

Mr. D. D. Randolph (WES) contributed significantly to the maintenance of realism in governing algorithms.

The following supervisory personnel directed this work: Dr. J. G. Parks, Chief, Engineering Science Division, and Mr. Z. J. Janosi, Supervisor, Methodology Function (TACOM), Messrs. W. G. Shockley, Chief, Mobility and Environmental Systems Lab, and A. A. Rula, Chief, Mobility Systems Division (WES), Dr. I. R. Ehrlich, Dean of Research and Mr. I. O. Kamm, Chief, Transportation Research Group (SIT).

Mrs. Maxine Gianfermi and Ms. Marian Czaiczynski, both from TACOM, performed the extremely difficult task of typing the text.

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FOREWORD

TACOM and the US Army Corps of Engineers Waterways Experiment Station compiled a comprehensive computerized simulation of the interaction of a vehicle, a terrain and a human operator in 1971. This mathematical model, called the AMC '71 Mobility Model, represented the existing technology for predicting the performance of a wheeled or tracked vehicle across any type of terrain (AMC stands for Army Materiel Command, the sponsoring agency).

A report was published by TACOM (1) whose first volume discusses the input requirements, the model structure and several applications. Volume II of this report contains all the details necessary to fully understand and reproduce the entire program (explanations, flow charts and listings).

AMC '71 has been utilized for performing and/or supporting several important cross-country mobility analyses relative to the development of Army vehicles as well as various concept studies. These and on-going research and exploratory development programs were the main driving factors in the process of improving and expanding the model.

This report documents the resulting improved computer simulation called the AMC '74 Mobility Model.

Volume I of Reference 1 discusses the historical background of mobility research, describes the input requirements, explains the structure of the model and shows certain output modules which had been in use prior to the publication of Reference 1. Finally, a few early applications are explained. The text of Volume I of Reference 1 was written approximately three years ago. Since then, the model has extensively been used. Revisions in AMC '71 have largely been dictated by customer request. As a result, certain new output routines have been created and some segments have been detached from the main body of the model.

However, it is felt that Reference 1 is still valid and therefore there was no need for a revised discussion of the underlying philosophy, purpose and possible application of AMC '74. Thus, this report was written for the reader who is familiar with Volume I of the AMC '71 Mobility Model and for the programmer who is acquainted with Volume II.

INTRODUCTION

The AMC '71 Mobility Model (1) is a comprehensive computerized series of calculations simulating the interaction of a vehicle, a terrain and an operator. AMC '71 represented, at the time it was compiled, the best existing relations for predicting the performance of wheeled or tracked vehicles across most types of terrain.

The AMC '74 Mobility Model is, as its name is intended to imply, an updated version of AMC '71. In the course of three years of studies using AMC '71, including the "WHEELS" Study (2), certain anomalies and crude approximations as well as restrictions in AMC '71 became apparent. This was only to be expected because AMC '71 was the first attempt in developing a comprehensive mobility model. It was assembled and released in a relatively short time.

Since then, TACOM, WES and Stevens Institute have continuously updated the model.

The major revisions incorporated into AMC '74 are:

1. To allow the modeling of vehicle combinations containing various configurations of powered, braked and towed wheels and tracks (towed tracks not modeled).
2. To allow modeling travel over slippery soils, muskeg and shallow snow.
3. Inclusion of vehicle and terrain preprocessor modules.
4. Inclusion of a road module.
5. Separation of the hasty river and dry linear features crossing from the main body of the model.
6. An improved obstacle crossing simulation.
7. An updated two-dimensional combined ride and obstacle crossing dynamics simulation.

8. To rearrange the logic within the model to allow more modularity and precision in calculation and output.

9. To correct errors in computation.

10. To allow an extended set of scenario specifications.

Revision 1 now allows the modeling of the movement of vehicles such as half-tracks, towed and/or powered and/or braked trailers, pitch articulated vehicles, vehicles with gross variations in load distribution and vehicles with variations in axle geometries in soft soil, snow or muskeg.

Revision 2 now allows modeling of many terrains and operations in rain and other inclement weather conditions in the areal crossing module.

Revision 3 simplifies the supplying of vehicle data information by the user to the model. The terrain data is also preprocessed and placed in a form that is required for use in the main model.

Revision 4 is a new module which simulates travel on primary, secondary roads and trails. The outputs of this simulation are similar to the outputs of the areal module; i.e., maximum speed on a road segment.

Revision 5 is the result of experience gained in using AMC '71 for special studies and user vehicle evaluations. The areal crossing is exercised independent of any linear feature terrain data.

Under Revision 6, the obstacle crossing problem is examined external to the areal crossing module. The force required to cross an obstacle and the geometric interference history between the obstacle and the vehicle are calculated.

Under Revision 7, an updated dynamics module which includes a two-dimensional ride dynamics simulation for rough terrain and a dynamics simulation for either single or multiple obstacle crossing has been added. Both simulations use a driver limited tolerance to vibration or shock for determining maximum speed. The updated dynamics module will be published separately (Reference 3).

Included under Revision 8 is the clear separation of vehicle travel between obstacles and over obstacles.

Revision 9 is primarily a correction to the acceleration/deceleration times and distances which now are calculated in closed form. This was done by approximating the power train in each gear by an analytic function and integrating these functions. The gear-by-gear modeling also allows the addition of gear change times and velocity losses. Various other corrections were made throughout.

Under Revision 10, the user has been given control over operational variables, such as weather and driver characteristics and motivation, so that the model may be used for a variety of scenarios.

AMC '74 is the precursor of the Army Mobility Model (AMM) which is due for Army-wide release in the first quarter of FY76. AMC '74 will be used in several studies before AMM is finally developed.

The term <u>model</u> is used here to denote the algorithms and operational procedures published in this report. They are intended for computer implementation; a specific such implementation will be referred to as a <u>programmed version</u> of the model. AMM will be released with an accompanying programmed version which will, insofar as possible, have the following features:

- the programmed version of computational modules will be coded in machine independent FORTRAN IV.

- the coding will stress transparency and direct correspondance between documentation and code.

- all machine dependent functions (overlays, input/output, etc.) will be consolidated in a single command and control module. However, the user will have to write his own input/output modules if his computer is different from the one at TACOM.

AMC '74 consists of 8 modules:

I. Control and I/O.

II. Vehicle Preprocessor.

III. Terrain Preprocessor.

IV. Areal Module.

V. Hasty River and Dry Linear Feature Crossing.

VI. Road.

VII. Ride Dynamics.

VIII. Obstacle Crossing.

These are briefly explained below:

I. The Input/Output module contains files of input (vehicle, terrain, scenario) and output. It is a general executive program. The structure of this module can be easily changed, if necessary, depending on the user's needs.

II. The Vehicle Preprocessor consists of algorithms which transform vehicle input data into quantities needed as inputs to the various submodels. Some of these required data have to be hand-calculated for AMC '71.

III. The Terrain Preprocessor is a set of algorithms whose function is to convert the class interval number of the terrain input to quantitative values associated with terrain features or accept the quantitative values directly.

IV. The Areal Module simulates vehicle travel across the areal terrain units.

V. The Hasty River and Dry Linear Feature Crossing Module simulates a single vehicle crossing a linear feature without external aid or a bridge.

VI. The Road Module is a simulation of travel on primary, secondary roads and trails.

VII. The Ride Dynamics Module is a two-dimensional digital simulation of the dynamic interaction of the vehicle, rough terrain and obstacles resulting in speed limitations due to human tolerance to rough ride and shock.

This is an externally executed module which provides input data for the areal and road modules. The description of the dynamics module will be published separately. The data supplied by the ride dynamics module may alternatively be obtained from field tests.

VIII. The Obstacle Crossing Module is a detailed and improved simulation of the crossing of obstacles. This also is an externally executed module which provides the tractive effort required to cross the obstacles and determines interference geometry for the areal module.

MODULE I.

Control and Input/Output

CONTROL AND INPUT/OUTPUT MODULE

The Control and Input/Output Module, acting in the role of a program executive, coordinates the access of the processing modules (Areal, Hasty River and Dry Linear Features Crossing, and Road) to their respective input and output files.

It is the intention of the model designers that the processing modules be as machine independent as possible, and that all machine dependent coding be concentrated in the control and I/O module. This implies that this module will open and close all files, read all input and write all output, and, therefore, for efficiency, provide all software links between modules and routines.

Inputs consist of:

1. Basic vehicle data files
2. Terrain data files
3. Scenario data
4. Run specifications
   a. Output file name
   b. Output level indicator

The basic mode of operation of the model is to make a series of speed or crossing time predictions for a given vehicle in each of the terrain, road or linear feature units described in the terrain data file, under a single set of scenario specifications. At the conclusion of such a run, vehicle, scenario and/or terrain inputs are changed as required to make a new set of predictions.

For each run so defined, the output file records the vehicle data used, identifies the terrain data file and scenario data used, and accumulates derived data from the working modules according to user needs as specified by the output level indicator. Four levels (1, 2, 3 and 10) are presently provided, but others can be inserted readily to meet special user requirements.

Level 1 saves and records only the basic in-patch or in-unit average maximum speed prediction from the Areal and/or Road Modules, or crossing time and speed from the Linear Features Module, for each terrain unit, road unit or linear feature in the terrain data file. These data may be used subsequently in an appropriate output processing module to generate speed maps, statistics and/or indices, or to make best route selections or simple traverse time predictions.

Level 2 adds to the level 1 output, NO-GO or speed limit diagnostics for each unit or feature. It provides data for maps or statistics identifying the reasons for vehicle performance limits throughout the area to which the terrain data are related.

Level 3 saves all level 1 and level 2 information and, for each area or road unit, adds resistances and some intermediate speeds needed to determine fuel consumption or to introduce acceleration and deceleration across unit boundaries for more precise traverse predictions.

Selection of other derived data for further output analysis to meet the needs of other types of studies can be rapidly developed as needed. Upon identification of such additional needs, new output levels can be developed and added as a simple specification call. Levels 4 through 9 have been reserved for such future developments.

Level 10 saves all derived outputs for special program diagnostic studies.

Description of Files Contained in Control and I/O Module

Inputs

VEHIC = generic name of file containing the basic vehicle data

DYNAM = generic name of file containing the tabulated outputs from the dynamics module

OBSTC = generic name of file containing the tabulated outputs from the obstacle crossing module

TERRN = generic name of terrain file containing the primary and secondary proper natural terrain units descriptors.

SCENA = generic name of file containing the scenario inputs

AMMOU = generic name of file in which all output is written

LEVELO = output level of detail desired

General Output

The general output is written to the output file (AMMOU) at the beginning of each run of a vehicle (at a given loading, tire inflation specification, etc.) over all areal terrain, linear feature and/or road units described in a given (preprocessed) terrain data file (TERRN), under a given set of scenario conditions (SCENA). The output file contains:

- output file name
- vehicle identification
- payload description
- terrain data file identification
- scenario input data (SCENA)
- run specifications (LEVELO)

and (optional):

- complete vehicle input data (VEHIC)
- dynamics module data (DYNAM)
- obstacle crossing module data (OBSTC)
- complete derived vehicle data

(See Module II. Vehicle Preprocessor.)

Areal Module Output

Level 1

NTU = terrain unit number

ITUT = 1 if normally dry patch

= 2 if marsh or other water covered patch

VSEL = selected average speed in patch, in/sec

VSLOPE(K) = final selected average speed on slope K = up, level and down, in/sec

NOTE: If scenario variable NTRAV = 1, then Slope, K, contains only one direction as specified by terrain variable (GRADE).

Level 2

Level 2 output is intended for use in determining what aspect of cross country travel is limiting the speed of the vehicle, or causing immobilization (NO-GO). Level 2 includes Level 1 and:

BFGONO = 1 if vehicle braking is inadequate for downslope operation

= 0 otherwise

IFLOAT = 0 if no standing water

= 1 if vehicle is fording

= 2 if vehicle is fully swimming

ISLCT(K) = one greater than the stem diameter class selected to be overridden on slope K = up, level and down

MAXI = one greater than the index of the maximum stem diameter class that can be overridden

NEVERO = 0 if override/avoidance strategy could have chosen obstacle override

= 1 if override/avoidance strategy never chose obstacle override due to belly/axle interference with stumps or boulders

= 2 if override/avoidance strategy never chose obstacle override due to lack of penalty for obstacle avoidance

= 3 if detailed obstacle override determined interference

SRFO(ISLCT(K)) = speed reduction factor due to avoiding obstacles and vegetation in stem diameter class ISLCT(K)-1 and greater on slope K = up, level and down

SRFV(ISLCT(K)) = speed reduction factor due to avoiding vegetation in stem diameter class ISLCT(K)-1 and greater on slope K = up, level and down

VA(K,ISLCT(K)) = obstacle approach speed on slope K = up, level and down while overriding vegetation in stem diameter class ISLCT(K)-1 and smaller and avoiding vegetation in stem diameter class ISLCT(K) and greater, in/sec

VAVCHK(K,ISLCT(K)) = 1 if combination can override a single tree of class ISLCT(K)-1 at speed VAVOID(K,ISLCT(K))

= 0 otherwise

VAVOID(K,ISLCT(K)) = speed on slope K = up, level and down avoiding obstacles but overriding vegetation in stem diameter class ISLCT(K)-1 and smaller and avoiding vegetation in stem diameter class ISLCT(K) and greater, in/sec

VBO(K,ISLCT(K)) = speed on slope K = up, level and down between obstacles overriding vegetation in stem diameter class ISLCT(K)-1 and smaller and avoiding vegetation in stem class ISLCT(K) and greater, in/sec

VELV(K) = speed limited by visibility on slope K = up, level and down, in/sec

VOCHK(K,ISLCT(K)) = 1 if combination can override a single tree of class ISLCT(K)-1 at speed VOVER(K,ISLCT(K))

= 0 otherwise

VOLA = maximum speed with which vehicle may contact obstacle as limited by driver or cargo, in/sec

VOVER(K,ISLCT(K)) = average speed on slope K = up, level and down while overriding obstacles and vegetation in stem diameter class ISLCT(K)-1 and smaller and avoiding vegetation in stem diameter class ISLCT(K) and greater, in/sec

VRID = speed limited by surface roughness, in/sec

VSOIL(K,ISLCT(K)) = maximum speed while overcoming soil, slope and vegetation resistance while overriding vegetation in stem diameter class ISLCT(K)-1 and smaller between obstacles without reduction for avoidance on slope K = up, level and down, in/sec

VTT(K,ISLCT(K)) = speed between obstacles (without allowance for maneuvering) overriding vegetation in stem diameter class ISLCT(K)-1 and smaller on slope K = up, level and down, in/sec

VXT(K,ISLCT(K)) = obstacle exit speed on slope K = up, level and down while overriding vegetation in stem diameter class ISLCT(K)-1 and smaller and avoiding vegetation in stem diameter class ISLCT(K) and greater, in/sec

WDGONO = 1 if water too deep for operation

= 0 otherwise

WRATIO = proportion of combination weight supported by ground

Level 3

This level of output is designed to allow acceleration/deceleration times and distances to be calculated in travel from one terrain unit to another. Subroutines ACCEL and TXGEAR from the Areal Module may be used to do this. Includes level 2 plus:

NGR = number of gears

GCW = gross combined weight, lb.

SHIFTT = gear shift time, sec.

NGR, GCW and SHIFTT need be included in the output just once but all following variables must be output for each terrain unit.

VG(NG,MN) = minimum speed in gear NG modified by slip, in/sec

VG(NG,MD) = mid-range speed in gear NG modified by slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec

STRACT(NG,L,K) = slip modified tractive effort in gear NG at speed index L = MN, MD or MX and slope K = up, level and down, lb.

FA(NG,K), FB(NG,K), FC(NG,K) = constant, linear and quadratic term coefficient of quadratic fitted to slip modified tractive effort versus speed curve for gear NG and slope K = up, level and down, lb., lb/(in/sec), $lb/(in/sec)^2$

FORMX(K) = maximum tractive effort available in soil on slope K = up, level and down, lb.

VFMAX(K) = speed at which maximum tractive effort on slope K = up, level and down is available, in/sec

TR(K,ISLCT(K)) = total soil, slope and vegetation resistance while overriding vegetation in stem class ISLCT(K)-1 and smaller, lb.

MXBF(K) = maximum braking force on slope K = up, level and down, lb.

Level 10

Level 10 output is intended for program diagnosis. Included in Level 10 are:

- primary and secondary terrain descriptors
- all derived performance variables
- all Level 1 and 2 output

Hasty River and Dry Linear Features Crossing Module Output

Level 1

NTU = feature unit number

ITUT = 4 man-made ditch

= 5 natural ditch (river or trench)

= 6 mound

TCROS = time required to cross feature, sec.

VSEL = average speed across feature, in/sec

Level 2

This level is intended to aid vehicle design evaluation by identifying the specific reasons for a NO-GO. It includes Level 1 and:

NOGO = 0 potential GO

= 1 NO-GO due to water depth greater than fording depth

= 2 NO-GO due to bank slope and height

= 3 NO-GO due to insufficient level traction on bank soil type

= 4 NO-GO due to vehicle front end too low

= 5 NO-GO over step

= 6 NO-GO due to lack of traction on deformed slope

= 7 NO-GO due to lack of traction on natural slope

= 8 NO-GO on deformed slope

= 9 NO-GO due to front end angle too shallow

Level 3

Level 3 provides data to examine operational alternatives to crossing the feature. Level 3 includes Level 2 and:

DB = mean distance to nearest bridge, ft.

DX = mean distance to nearest exit site, ft.

T = mean travel time to nearest crossing site, min.

Level 10

All derived performance variables including all of the above.

Road Module Output

Level 1

NTU = road unit number

ITUT = 11 for superhighway

= 12 for primary roads

= 13 for secondary roads

= 14 for trails

VSLOPE(K) = final selected average speed on slope K = 1, up; = 3, down; in/sec

VSEL = average speed (up slope and down slope), in/sec

BFGONO = 1 if vehicle braking is inadequate for downslope operation

= 0 otherwise

Level 2

This level of output is intended for vehicle design evaluation. Level 2 includes Level 1 and:

VRSIST(K) = speed limited by aerodynamic, rolling, cornering and grade resistance for K = up, and down, in/sec

VRID = speed limited by roadway roughness, in/sec

VELV(K) = speed limited by visibility, in/sec

VSLID = speed limited by sliding off curves, in/sec

VTIP = speed limited by tipping in curves, in/sec

Level 3

This level of output is designed to allow acceleration/deceleration times and distance calculations between one type of road segment and another. Subroutines ACCEL and TXGEAR from the Areal Module may be used for this purpose. Level 3 includes Level 2 and:

NGR = number of gears

GCW = gross combination weight, lb.

SHIFTT = gear shift time, sec.

NGR, GCW and SHIFTT need to be included in the output just once but all the following variables must be associated with a terrain unit.

VGV(NG,MN), VGV(NG,MD),VGV(NG,MX) = minimum, mid-range and maximum speed in gear NG, respectively, in/sec

STRACT(NG,L,K) = resistance modified tractive effort available in gear NG at speed index L = MN, MD or MX and slope K = up, level and down, lb.

FA(NG,K), FB(NG,K), FC(NG,K) = constant, linear and quadratic term coefficients of quadratic fitted to slip modified tractive effort versus speed curve for gear NG and slope K; lb., lb/(in/sec), lb/(in/sec)^2

FORMX(K) = maximum tractive effort available for slope K, lb.

VFMAX(K) = speed at which maximum tractive effort is available on slope K, in/sec

MXBF(K) = maximum braking force on slope K, lb.

Level 10

All derived performance variables including all of the above.

MODULE II

VEHICLE PREPROCESSOR

VEHICLE PREPROCESSOR MODULE

The vehicle preprocessor module performs four basic operations:

1. It converts the dimensional units of the vehicle's nomenclature to the inch, pound, second, radians units used for all variables in the Areal, Hasty River and Dry Linear Features Crossing and Road Modules.

2. It computes the vehicle cone index (VCI) for fine grained, coarse grained and muskeg soils.

3. It characterizes the theoretical tractive effort versus vehicle speed relation, either from an experimental data array or from engine-transmission-final drive data, in terms of a series of quadratic expressions.

4. Finally, the preprocessor calculates a number of derived vehicle characteristics which recur in several modules or submodels such as gross combined weight, minimum path width of traction elements, etc.

The vehicle nomenclature that appears on the vehicle data sheets has conventional dimensional units. Speeds are in MPH, lengths in inches, weights in pounds, and angles in degrees. The preprocessor converts MPH to in/sec and degrees to radians. The weight and length units are retained.

The tractive effort speed relation is built by using a series of quadratic curve fits to the engine-transmission-drive train data in each gear. The quadratic curve in each gear eliminates the table look-up procedure employed in AMC '71 and permits a closed form integration for distance in the Acceleration/Deceleration (AC/DC) routine. Use of the quadratic functions reduces the number of computations required whenever the AC/DC routine is used. This is important because revisions to the obstacle crossing speed algorithm in the areal module introduce AC/DC considerations more often than they occurred in AMC '71.

A significant advance over AMC '71 is in the computation of Vehicle Cone Index (VCI). The preprocessor addresses the VCI computations on an axle-by-axle or track unit-by track unit basis. Each of these individual running gear units is called an assembly. The individual assembly procedure enables the model to accommodate powered, unpowered, braked and unbraked assemblies. For each assembly which is powered and/or braked, the VCI and contact pressure factor (CPF) are calculated for fine grained and muskeg soils. These values are passed into submodels 3a and 3c of the Areal Module where the pull force coefficients for fine grained and muskeg soils are calculated per assembly. It is assumed that the running gear assemblies slip uniformly. To implement this assumption in the slip modified tractive effort routine of the areal module a series of effective contact pressure factors is computed for the vehicle as a whole (CPFCFG, CPFCCG).

The derived vehicle characteristics are peculiar to the specific algorithms within a routine. They are vehicle characteristics not ordinarily found on data sheets. Examples are: gross combined weight on non-braked assemblies, minimum lateral distance from CG to outer wheels, percent distribution of weight on front assembly.

The nomenclature of the vehicle and its components which is used throughout the AMC '74 Mobility Model is as follows:

Element - single tire or track

Assembly - axle with wheels and tires or a pair of left and right tracks

Unit - prime mover, trailer

Combination - whole vehicle composed of the sum of all units

Specification/Scenario Variables Required by Vehicle Preprocessor

APGDAT	= 1 choose power train data (if available)
	= 2 choose measured tractive effort data (if available)

Specification/Scenario Variables Required by Vehicle Preprocessor

APGDAT = 1 choose power train data (if available)

= 2 choose measured tractive effort data (if available)

PRIMARY VEHICLE DESCRIPTORS USED IN VEHICLE PREPROCESSOR

Variable	Routine	Meaning
ASHOE(i)	2	area of one track shoe on track assembly i, in^2
CGLAT	3	lateral distance of CG measured from centerline of combination, in.
CLRMIN(i)	2	minimum ground clearance of assembly i, in.
CONV1(RPM,N)	4	input speed component of the torque converter speed ratio versus torque speed curve, rpm
CONV1(SR,N)	4	speed ratio component of the torque converter speed ratio versus torque converter input speed curve at constant input torque, TQIND
CONV2(SR,N)	4	speed ratio component of the torque converter speed ratio versus torque converter ratio curve
CONV2(TR,N)	4	torque ratio component of the torque converter speed ratio versus torque converter torque ratio curve
DFLCT(i,j)	2,3	deflection of each tire on axle assembly i under load WGHT(i)/NWHL(i), in., at the pressure specified for j=1 fine grained, =2 coarse grained, =3 highway
DIAW(i)	2	outside wheel diameter of unloaded tires on running gear assembly i, in.
ENGINE(RPM,N)	4	engine speed component of engine speed versus engine torque curve, rpm
ENGINE(TORQUE,N)	4	engine torque component of engine speed versus engine torque curve, lb-ft

Variable	Routine	Meaning
FD(EFF)	4	final drive efficiency
FD(GR)	4	final drive gear ratio
GROUSH(i)	2	track grouser height of track assembly i, in.
i	1,2,3	assembly index i
IAPG	4	= 0 if power train data available only
		= 1 if both measured tractive effort and power train data given
		= 2 if measured tractive effort given only
IB(i)	3	= 1 if running gear assembly i is braked
		= 0 otherwise
ICONST(i)	3	= 0 if radial tires
		= 1 if bias tires
ICONV1	4	number of point pairs in the array CONV1(SR,N), CONV1(RPM,N)
ICONV2	4	number of point pairs in the array CONV2(SR,N), CONV2(TR,N)
ID(i)	3	= 0 if wheels are singles
		= 1 if duals
IENGIN	4	number of point pairs in the array ENGINE(RPM,N), ENGINE(TORQUE,N)

Variable	Routine	Meaning
IP(i)	1,3	= 1 if running gear assembly i is powered = 0 otherwise
IPOWER	1,4,5	number of point pairs in the array POWER(FORCE,N), POWER(SPEED,N)
ITCASE	4	= 1 if engine to transmission transfer gear box = 0 otherwise
ITRAN	4	= 0 if manual transmission with clutch = 1 if automatic transmission with torque converter
ITVAR	2	= 1 if transmission is mechanical = 0 if transmission is hydraulic
j	2,3	surface index j
LOCKUP	4	= 0 if torque converter does not lockup = 1 if torque converter has lockup
MAXIPR	1	number of surface roughness values per tolerance level
MAXL	1	number of roughness tolerance levels specified
NAMBLY	1,2,3	total number of running gear assemblies
NBOGIE(i)	2	number of road wheels on track assembly i
NCHAIN(i)	2	= 1 if chains are present on tire = 0 otherwise

Variable	Routine	Meaning
NETHP	1	maximum net horsepower
NGR	4	number of transmission gear ratios
NHVALS	1	number of height values used in arrays VOOB and HVALS
NSVALS	1	number of obstacle spacing values used in arrays VOOBS and SVALS
NVEH(i)	2,3,4	= 0 if running gear assembly i is tracked ≠ 0 if wheeled
NWHL(i)	2	number of tires on wheeled assembly i
POWER(FORCE,N)	4,5	tractive force component of the tractive force versus speed curve, lb.
POWER(SPEED,N)	1,4,5	vehicle velocity component of the tractive effort versus speed curve, in/sec
RDIAM(i)	2,3	rim diameter of wheel for tires on axle assembly i
REVM(i)	3	revolutions/mile of tire element on assembly i, rev/mi
RIMW(i)	3	wheel rim width of assembly i, in.
RR	4	tracked: sprocket pitch radius,in.
SECTH(i)	2	section height of tires on running gear assembly i, in.
SECTW(i)	2	section width of tires on running gear assembly i, in.

Variable	Routine	Meaning
TCASE(EFF)	4	efficiency of gear between engine and transmission = 1. if no such gear
TCASE(GR)	4	gear ratio between engine and transmission = 1. if no such gear
TPLY(i)	2	tire ply rating of tires on axle i
TPSI(i,j)	2,3	tire inflation pressure of tires on axle i, psi, specified for j=1 fine grained, =2 coarse grained, =3 highway
TQIND	4	constant torque converter input torque at which torque converter performance curves are measured, lb-ft
TRAKLN(i)	2,3	track length of track assembly i, in.
TRAKWD(i)	2,3	track width of track assembly i, in.
TRANS(EFF,NG)	4	transmission efficiency of gear NG
TRANS(GR,NG)	4	transmission gear ratio of gear NG
VAA	1	vehicle approach angle, deg.
VDA	1	vehicle departure angle, deg.
VOOB(NH)	1	maximum driver limited speed at which vehicle can impact an obstacle of height HVALS(NH) if obstacles are spaced farther than two vehicle lengths apart, mph
VOOBS(NS)	1	maximum driver limited speed at which vehicle can impact successive obstacles spaced SVALS(NS) apart, mph

Variable	Routine	Meaning
VRIDE(NR,L)	1	maximum speed over ground for surface roughness class NR at roughness tolerance level L, mph
VSS	1	maximum combination still water speed without auxiliary propulsion, mph
WGHT(i)	1,2,3	weight on running gear assembly i, lb.
WT(i)	3	tread width of running gear assembly i, in. (center to center plane if duals)
WTE(i)	3	minimum width between left-right elements on assembly i, in.
XBRCOF	3	maximum combination braking coefficient per assembly in lb/lb of load carried

VEHICLE PREPROCESSOR OUTPUT

Variable	Routine	Meaning
ATF(NG)	5	Constant of quadratic fitted to vehicle tractive effort curve in gear NG, lb.
BTF(NG)	5	Coefficient of linear term of quadratic fitted to vehicle tractive effort curve in gear NG, lb(in/sec)
CHARLN(i)	3	Characteristic length of tire element or track on running gear assembly i, in.
CPFCCG(j)	3	Maximum contact pressure factor of all running gear assemblies of the type specified by NVEHC for coarse grained soil, lb/in^2, at pressure specified for j = 1 fine grained, = 2 coarse grained, = 3 highway
CPFCFG(j)	3	Maximum contact pressure factor of all running gear assemblies of the type specified by NVEHC for fine grained soil, lb/in^2, at pressure specified for j = 1 fine grained, = 2 coarse grained, = 3 highway
CPFFG(i,j)	2,3	Contact pressure factor of running gear assembly i, lb/in^2, fine grained soil at pressure specified for j = 1 fine grained, = 2 coarse grained, = 3 highway
CTF(NG)	5	Coefficient of quadratic term of quadratic fitted to vehicle tractive effort in gear NG, $lb/(in/sec)^2$

Variable	Routine	Meaning
DIAW(i)	2,3	Outside wheel diameter of unloaded tires on running gear assembly i, in.
DRAT(i,j)	2	deflection ratio of each tire on running gear assembly i under load WGHT(i)/NWHL(i) at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway
GCA(i,j)	3	nominal ground contact area per tire element or track pair on running gear assembly i, in^2, at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway
GCW	3	gross combination weight, lb.
GCWB	3	gross combined weight on all braked running gear assemblies, lb.
GCWNB	3	gross combined weight on all non-braked running gear assemblies, lb.
GCWNP	3	gross combined weight on all non-powered running gear assemblies, lb.
GCWP	3	gross combined weight on all powered running gear assemblies, lb.
HVALS(NH)	1	value of NHth obstacle height, in.
i	1,2,3	running gear assembly index
IB(i)	1,2,3	=1 if running gear assembly i is braked = 0 otherwise
ID(i)	3	= 0 if wheels are singles = 1 if duals
IP(i)	1,2,3	= 1 if running gear assembly i is powered = 0 otherwise

Variable	Routine	Meaning
j	2,3	Surface index indicator
MAXIPR	1	Number of surface roughness values per tolerance level
MAXL	1	Number of roughness tolerance levels specified
NAMBLY	1,2,3	Total number of running gear assemblies of the combination
NGR	4	Number of gears
NHVALS	1	Number of obstacles height values used in VOOB and HVALS
NSVALS	1	Number of obstacle spacing values used in VOOBS and SVALS
NVEH(i)	2,3	= 0 if running gear assembly i is tracked
		≠ 0 if wheeled
NVEHC	3	= 0 if one or more of the powered running gear assemblies is tracked
		≠ 0 otherwise
NWHL(i)	2,3	Number of tires on wheeled assembly i
PWTE	3	Maximum path width of traction elements for one side of combination, in.
SECTW(i)	2,3	Section width of tires on running gear assembly i, in.
TRACTF(NG,MD)	5	Tractive force available from drive train at mid-range speed index MD in gear NG, lb.

Variable	Routine	Meaning
TRACTF(NG,MN)	5	Tractive force available from drive train at minimum speed index MN in gear NG, lb.
TRACTF(NG,MX)	5	Tractive force available from drive train at maximum speed index MX in gear NG, lb.
TRAKLN(i)	2,3	Ground length of track on running gear assembly i, in.
TRAKWD(i)	2,3	Track width of track assembly i, in.
VCIFG(i,j)	2,3	One pass vehicle cone index in fine grained soil applied to running gear assembly i, lb/in^2 at pressure specified for j = 1 fine grained, = 2 coarse grained, = 3 highway
VCIMUK(i)	3	One pass vehicle cone index in muskeg applied to running gear assembly i, lb/in^2
VGV(NG,MD)	5	Mid-range speed in gear NG, in/sec
VGV(NG,MN)	5	Minimum speed in gear NG, in/sec
VGV(NG,MX)	5	Maximum speed in gear NG, in/sec
VOOB(NH)	1	Maximum driver limited speed at which vehicle can cross an obstacle of height HVALS(NH) if obstacles are spaced further than two vehicle lengths apart, in/sec
VOOBS(NS)	1	Maximum driver limited speed at which vehicle can cross successive obstacles spaced SVALS(NS) apart, in/sec
VRIDE(NR,L)	1	Maximum speed over ground for a surface roughness class NR and roughness tolerance level index L, in/sec

Variable	Routine	Meaning
VAA	1	Vehicle approach angle, deg.
VDA	1	Vehicle departure angle, deg.
VSS	1	Maximum vehicle combination swimming speed, in/sec
VTIRE(j)	3	Maximum steady state speed allowed beyond which structural damage will occur to tires, in/sec at pressures specified for j = 1 fine grained, = 2 coarse grained, = 3 highway
WGHT(i)	1,2,3	Weight on running gear assembly i, lb.
WTMAX	3	Minimum width between combination running gear elements, in.
XBR	3	Maximum braking effort vehicle can develop, lb.
HPT	1	Net horsepower/ton

1. Conversion of Units (From miles/hr to in/sec, degrees to radians)

<u>Description</u> This routine converts the units of the vehicle data as entered on the vehicle data sheets to conform to the standard lb., in., sec., radians units used throughout the working modules. When the standard input data sheets are used (and data are entered in the units indicated on the sheet for each entry), only units of velocity and angles must be converted; velocity from miles/hr to in/sec; and angles from degrees to radians.

a. $$VSS * \frac{5280\ ft.}{mile} * \frac{12\ in.}{ft.} * \frac{hr.}{60\ min.} * \frac{min.}{60\ sec.}$$

b. Do for NH = 1 to NHVALS

$$VOOB(NH) * \frac{5280\ ft.}{mile} * \frac{12\ in.}{ft.} * \frac{hr.}{60\ min.} * \frac{min.}{60\ sec.}$$

c. Do for NS = 1 to NSVALS

$$VOOBS(NS) * \frac{5280\ ft.}{mile} * \frac{12\ in.}{ft.} * \frac{hr.}{60\ min.} * \frac{min.}{60\ sec.}$$

d. Do for NR = 1 to MAXIPR and L = 1 to MAXL

$$VRIDE(NR,L) * \frac{5280\ ft.}{mile} * \frac{12\ in.}{ft.} * \frac{hr.}{60\ min.} * \frac{min.}{60\ sec.}$$

e. $$VAA * \frac{\pi}{180.} * \frac{rad}{deg.}$$

f. $$VDA * \frac{\pi}{180.} * \frac{rad}{deg.}$$

g. Conversion of input tractive effort versus speed curve speed data from MPH to in/sec, where supplied as input data (IAPG = 1 or 2)

```
if IAPG = 0
   then do h.
else do for N = 1 to IPOWER
   POWER(SPEED,N) * (88./60.) *12.
   next N
```

h. Conversion of net horsepower to net horsepower/ton on powered assemblies

$$GCWP = \sum_{i=1}^{NAMBLY} WGHT(i)*IP(i)$$

$$HPT = NETHP/(\frac{GCWP}{2000.})$$

2. Vehicle Cone Index

Description This routine calculates the vehicle cone index (VCI) for fine grained, coarse grained and muskeg soils. A new feature of AMC '74 is the assembly-by-assembly calculation of VCI. This approach accommodates vehicles whose running gear type, geometry, and/or loading varies from assembly to assembly, and on which not all of the assemblies are powered and/or braked. Drawbar force for pull or braking is developed only on powered or braked assemblies and therefore, the VCI is calculated for the powered and braked assemblies only. All of the running gear variables and factors used for the calculation of VCI in AMC '71 are now applied to an assembly, i. These assembly-by-assembly VCI's are used in submodel 3 of the areal module to compute pull, braking and resistance forces developable at each assembly. These forces are subsequently summed in submodel 4 for the entire vehicle, along with the resistance of any unpowered or unbraked assemblies (computed in submodel 4) to arrive at the tractive and braking performance for the complete vehicle, or combination in a given soil type and strength.

Two new features are incorporated in the calculation of VCI for wheeled assemblies. In calculating the fine grained VCI (VCIFG(i,j)) the influence of tire deflection is taken into account. This feature is included recognizing that tires operating at cross-country inflation pressures may have deflection ratios higher than the 15-20% deflection ratios which were implicit in the relevent AMC '71 algorithms. The tire deflection factor (TDF) is derived from the numeric representation of VCI described by Turnage (4). The tire deflection factor also allows examining performance of rigid and near-rigid wheels in soft soil for which TDF may be as small as zero.

The second feature now included in VCI calculation for wheeled assemblies allows for a scenario input of surface-dependent operating tire inflation pressure. The scenario input (NOPP) to either the areal or road modules permits the user either to fix the operating tire inflation pressure of the vehicle or to allow the tire inflation pressure to vary depending on whether the vehicle is traveling in a fine grained or coarse grained soil or on the highway. To accommodate this user choice, VCI's for all three surfaces are calculated (VCIFG(i,j)) VCICG(i,j)) where j is the indicator for fine grained, coarse grained or highway inflation pressure.

A further new feature is the implementation of the VCI calculation for wheeled and tracked vehicles in muskeg soils (VCIMUK(i)) which is lacking in AMC '71. Expressions used to calculate VCI for muskeg soils are developed in Reference 5.

Inputs

NAMBLY = total number of running gear assemblies of the combination

HPT = net horsepower/ton on powered assemblies

ITVAR = 1 if transmission is mechanical

= 0 if transmission is hydraulic

For each assembly, i: NVEH(i) = 0 if running gear assembly is tracked

≠ 0 if wheeled

IP(i) = 1 if running gear assembly i is powered

= 0 otherwise

IB(i) = 1 if running gear assembly i is braked

= 0 otherwise

WGHT(i) = weight on running gear assembly i, lb.

CLRMIN(i) = minimum ground clearance of assembly i, in.

For each tracked assembly TRAKLN(i) = ground length of track on running gear assembly i, in.

TRAKWD(i) = track width of track assembly i, in.

GROUSH(i) = track grouser height of track assembly i, in.

NBOGIE(i) = number of bogies on track assembly i

ASHOE(i) = area of one track shoe on track assembly i, in^2

For each wheeled assembly SECTW(i) = section width of tires on running gear assembly i, in.

NWHL(i) = number of tires on wheeled assembly i

DIAW(i) = outside wheel diameter of unloaded tires on running gear assembly i, in.

NCHAIN(i) = 1 if chains are present on tire

= 0 otherwise

DFLCT(i,j) = deflection of each tire on axle assembly i under load WGHT(i)/NWHL(i), in., at specified pressure for j = 1 fine grained, = 2 coarse grained, = 3 highway

SECTH(i) = section height of tires on running gear assembly i, in.

RDIAM(i) = rim diameter of wheel for tires on axle assembly i

TPSI(i,j) = tire inflation pressure of tires on axle i, psi., at specified pressure for j=1 fine grained, = 2 coarse grained, =3 highway

TPLY(i) = tire ply rating of tires on axle i

<u>Output</u> VCIFG(i,j) = one pass vehicle cone index in fine grained soil applied to running gear assembly i, lb/in^2, at specified pressure for j=1 fine grained, =2 coarse grained, =3 highway

VCICG(i,j) = one pass vehicle cone index in coarse grained soil applied to running gear assembly i, lb/in^2, at specified pressure for j = 1 fine grained, =2 coarse grained, =3 highway

VCIMUK(i) = one pass vehicle cone index in muskeg applied to running gear assembly i, lb/in^2

CPFFG(i,j) = contact pressure factor of running gear assembly i, lb/in^2, fine grained, at specified pressure for j=1 fine grained, =2 coarse grained, =3 highway

CPFCG(i,j) = contact pressure factor of running gear assembly i, lb/in^2, coarse grained soil, at specified pressure for j=1 fine grained, =2 coarse grained, =3 highway

Algorithm

a. Fine Grained Soil VCI

```
do for i=1 to NAMBLY
if IP(i) and IB(i) = 0
   then next i
else if NVEH(i) = 0
   then do Tracked Assembly Routine a.1
else do Wheeled Assembly Routine a.2
```

a.1 Tracked Assembly Routine

Contact Pressure Factor - CPF

$$\mathrm{CPFFG}(i,1) = \frac{\mathrm{WGHT}(i)}{2.*\mathrm{TRAKLN}(i)*\mathrm{TRAKWD}(i)}$$

$$\mathrm{CPFFG}(i,2) = \mathrm{CPFFG}(i,3) = \mathrm{CPFFG}(i,1)$$

Weight Factor - WF

```
if $\mathrm{WGHT}(i) < 50{,}000$
    then WF = 1.0
else if $50{,}000 \le \mathrm{WGHT}(i) < 70{,}000$
    then WF = 1.2
else if $70{,}000 \le \mathrm{WGHT}(i) < 100{,}000$
    then WF = 1.4
else if $100{,}000 \le \mathrm{WGHT}(i)$
    then WF = 1.8
```

Track Factor - TF

$$\mathrm{TF} = \mathrm{TRAKWD}(i)/100.$$

Grouser Factor - GF

```
if $\mathrm{GROUSH}(i) < 1.5$
    then GF = 1.0
else GF = 1.1
```

Bogie Load Range Factor - WLORF

$$\mathrm{WLORF} = \frac{\mathrm{WGHT}(i)*\mathrm{NBOGIE}*\mathrm{ASHOE}}{10.}$$

Clearance Factor - CLF

$$\mathrm{CLF} = \mathrm{CLRMIN}(i)/10.$$

```
    Engine Factor - EF
       if HPT < 10
          then EF = 1.05
       else EF = 1.0
    Transmission Factor - TFX
       if ITVAR = 0
          then TFX = 1.0
       else TFX = 1.05
    Mobility Index - XMI
       XMI =[CPFFG(i,1)*WF/TF/GF+WLORF-CLF]*EF*TFX
    Vehicle Assembly Cone Index
       VCIFG(i,1) = 7.0 + 0.2 * XMI-39.2/(XMI+5.6)
       VCIFG(i,2) = VCIFG(i,3) = VCIFG(i,1)
       next i
a.2 Wheeled Assembly Routine
    Contact Pressure Factor
       CPFFG(i,1) = WGHT(i)/[SECTW(i)*NWHL(i)*DIAW(i)/2.]
       CPFFG(i,2) = CPFFG(i,3) = CPFFG(i,1)
    Weight Factor - WF
       if WGHT(i) < 2000.0
          then WF = 0.553*WGHT(i)/NWHL(i)/1000.
       else if 2000 ≤ WGHT(i) < 13,500
          then WF = 0.033*WGHT(i)/NWHL(i)/1000.+1.0
```

```
   else if 13,500 ≤ WGHT(i) < 20,000
      then WF = 0.142*WGHT(i)/NWHL(i)/1000.-0.42
   else if 20,000 ≤ WGHT(i)
      then WF = 0.278*WGHT(i)/NWHL(i)/1000.-3.115
Tire Factor - TF
   TF = [10.+SECTW(i)]/100.
Grouser Factor - GF
   if NCHAIN(i) = 0
      then GF = 1.0
   else GF = 1.05
Wheel Load Factor - WLORF
   $WLORF = \frac{WGHT(i)}{1000.*NWHL(i)*2.}$
Clearance Factor - CLF
   CLF = CLRMIN(i)/2.
Engine Factor - EF
   if HPT < 10.
      then EF = 1.05
   else EF = 1.0
Transmission Factor - TFX
   if ITVAR = 0
      then TFX = 1.0
   else TFX = 1.05
   do for j = 1 to 3
```

```
    Tire Deflection Factor - TDF
        TDF(j) = $\left[\frac{1.15}{1.+DFLCT(i,j)/SECTH(i)}\right]^{3/2}$
        next j
    Mobility Index - XMI
        XMI = [CPFFG(i,1)*WF/TF/GF+WLORF-CLF]*EF*TFX
    Vehicle Cone Index
        do for j = 1 to 3
        VCIFG(i,j) = [11.48+0.2*XMI-39.2/(XMI+3.74)]*TDF(j)
        next j
        next i
b.  Coarse Grained Soil VCI
    do for i = 1 to NAMBLY
        if IP(i) and IB(i) = 0
           then next i
        else if NVEH(i) = 0
        then do Tracked Assembly Routine b.1
    else do Wheeled Assembly Routine b.2
b.1 Tracked Assembly Routine
    Vehicle Cone Index
    do for j = 1 to 3
        VCICG(i,j) = 0
        next j
        next i
```

```
b.2 Wheeled Assembly Routine
    Wheel Diameter Factor - WDF
       if SECTW(i)/RDIAM(i) < 2.4
          then WDF = 5.0
       else WDF = 2.0
    Contact Pressure Factor - CPF
    do for j = 1 to 3
       CPFCG(i,j) = 0.607*TPSI(i,j)+1.35*[117.*TPLY(i)/
                               (WDF*SECTW(i)+RDIAM(i))]-4.93
    Contact Area Factor - CAF
       CAF = $LOG_{10}$ [WGHT(i)/CPFCG(i,j)]
    Strength Factor - STF
       STF = 0.0526*NWHL(i)+0.0211*TPSI(i,j)-0.35*CAF+1.587
    Vehicle Cone Index
       VCICG(i,j) = $ANTILOG_{10}$ (STF)
       next j
       next i
c.  Muskeg VCI
    do for i = 1 to NAMBLY
       if IP(i) and IB(i) = 0
          then next i
       else if NVEH(i) = 0
            then do Tracked Assembly Routine c.1
       else do Wheeled Assembly Routine c.2
```

```
c.1 Tracked Assembly Routine

    Vehicle Cone Index

       VCIMUK(i) = 13.0+0.125*WGHT(i)/(TRAKWD(i)+2.*
                                          TRAKLN(i))
       next i

c.2 Wheeled Assembly Routine

    Vehicle Cone Index

       VCIMUK(i) = 13.0+0.535*WGHT(i)/(SECTW(i)+2.*
                                       DIAW(i)*NWHL(i))

       next i

       exit
```

3. Required Outputs Not Directly Available From Vehicle Data Sheets

Description	This routine calculates several vehicle descriptors which are not entered on the vehicle data sheets. Included are combined contact pressure factors for fine grained soil (CPFCFG) and coarse grained soil (CPFCCG), weights on various combinations of running gear assemblies, maximum speed beyond which tire disintegration can be expected to occur (primarily needed for low inflation tires on highways VTIRE(j)), and various derived geometric values describing the running gear.

a. Combined Vehicle Designation and Contact Pressure Factor For Use in Slip Modified Tractive Effort Submodel

```
do for IP(i) or IB(i) $\neq 0$
do for j = 1 to 3
   if NVEH(i) = 0 for any i
      then NVEHC = 0
      CPFCFG(j) = max {CPFFG(i,j) of the type for which
                  NVEHC = 0}
      CPFCCG(j) = max {CPFCG(i,j) of the type for which
                  HVEHC = 0}
      next j
   else NVEHC = 1
      CPFCFG(j) = max {CPFFG(i,j) for all i}
      CPFCCG(j) = max {CPFCG(i,j) for all i}
      next j
```

b. Gross Combined Weight

$$GCW = \sum_{i=1}^{NAMBLY} WGHT(i)$$

$$GCWB = \sum_{i=1}^{NAMBLY} WGHT(i)*IB(i)$$

$$GCWP = \sum_{i=1}^{NAMBLY} WGHT(i)*IP(i)$$

$$GCWNP = GCW - GCWP$$

$$GCWNB = GCW - GCWB$$

c. Maximum Tire Speed

```
do for j = 1 to 3
do for i = 1 to NAMBLY
    if NVEH(i) = 0
       then next i
    else $S1 = \frac{SECTW(i) - 0.4*RIMW(i)}{0.75}$
$EL = 0.425*(S1)^{1.39}*[TPSI(i,j)]^{.7}*[RDIAM(i)+S1]$
$TRAPSI(j) = TPSI(i,j)*\left[\frac{WGHT(i)/NWHL(i)}{EL}\right]^{1.43}$
if $(TRAPSI(j) \leq TPSI(i,j))$
   then if ICONST(i) = 0. (radials)
           then $VT(i,j) = 100.*\left[\frac{TPSI(i,j)}{TPSI(i,3)}\right]^{2}*\frac{1}{60}*\frac{1}{60}*$
                                $\frac{5280}{1}*\frac{12}{1}\quad\left[\frac{in}{sec}\right]$
        else ICONST(i) = 1 (bias ply)
           then $VT(i,j) = 70.*\left[\frac{TPSI(i,j)}{TPSI(i,3)}\right]^{2.25}*\frac{1}{60}*\frac{1}{60}*$
                                $\frac{5280}{1}*\frac{12}{1}\quad\left[\frac{in}{sec}\right]$
else (TRAPSI(j) > TPSI(i,j) underinflated)
     then $LM = \left[\frac{WGHT(i)/NWHL(i)}{EL}\right]/.445$
          if ICONST(i) = 0
             then $VT(i,j) = 100.*\left[\frac{TPSI(i,j)}{TPSI(i,3)}\right]^{LM}*\frac{1}{60}*\frac{1}{60}*$
                                $\frac{5280}{1}*\frac{12}{1}\quad\left[\frac{in}{sec}\right]$
```

```
        else ICONST(i) = 1
            then VT(i,j) = $70.*\left[\frac{TPSI(i,j)}{TPSI(i,3)}\right]^{LM} * \frac{1}{60} * \frac{1}{60} * \frac{5280}{1} * \frac{12}{1} \left[\frac{in}{sec}\right]$
            next i
            VTIRE(j) = min{VT(i,j) for all i}
            next j
```

d. Maximum Path Width of Combination's Traction Elements

```
PWTE = max{WT(i) -WTE(i) for all i}
```

e. Tire Deflection Ratios - DRAT(i,j)

```
do for j = 1 to 3
do for i = 1 to NAMBLY
if NVEH(i) = 0
   then next i
else DRAT(i,j) = DFLCT(i,j)/SECTH(i)
next i
next j
```

f. Characteristic Length of Elements - CHARLN(i,j)

```
do for j = 1 to 3
do for i = 1 to NAMBLY
   if NVEH(i) = 0
      then CHARLN(i,j) = TRAKLN(i)
      next i
   else CHARLN(i,j) = 2.*SQRT(DFLCT(i,j)*DIAW(i) -
                              DFLCT(i,j)*DFLCT(i,j))
```

```
                  next i
                  next j
      g.    Ground Contact Area of Elements - GCA(i,j)
            do for j = 1 to 3
            do for i = 1 to NAMBLY
               if NVEH(i) = 0
                  then GCA(i,j) = CHARLN(i,j)*TRAKWD(i)*2.
                  next i
               else GCA(i,j) = CHARLN(i,j)*SECTW(i)
                    next i
                    next j
      h.    Controlling Lateral Distance to C.G.
            WTMAX = 500.
            do for i = 1 to NAMBLY
            if NVEH(i) ≠ 0
               then TEMP = $\frac{WT(i)}{2} - CGLAT + \frac{SECTW(i)}{2.} * ID(i)$
                    do h.1
            else TEMP = WT(i)/2-CGLAT
     h.1    if TEMP < WTMAX
               then WTMAX = TEMP
               next i
            else next i
```

i. Rolling Radius of Largest Powered Tire Element

```
do for i = 1 to NAMBLY
if NVEH(i) = 0 for any i
   then do j.
else if IP(i) = 0
        then next i
     else RR = max {$\frac{2.*REVM(i)*\pi}{5280.*12.}$ for all i such that
                                   IP(i) = 1}
```

j. Maximum Braking Force Developed by Braked Assemblies

$$XBR = \sum_{i=1}^{NAMBLY} XBRCOF*WGHT(i)*IB(i)$$

4. Tractive Effort Versus Speed Curve From Power Train Data

Description This routine calculates the tractive effort POWER(FORCE,N) of the vehicle at a series of speeds POWER(SPEED,N) from zero velocity to the speed in the highest gear at the governed RPM of the engine.

One of two subroutines are used; AUTOM for vehicles with automatic transmissions, or STICK for vehicles with manual transmissions.

The tractive effort calculated in this routine is equal to the "rim pull" since slip and resistances are not included at this stage.

Inputs Vehicle: ITRAN = 0 if manual transmission with clutch

= 1 if automatic transmission with torque converter

IAPG = 1 if power train data available only

= 0 if both measured tractive effort and power train data given

= 2 if measured tractive effort given only

TCASE(EFF) = efficiency of gear between engine and transmission
= 1 if no such gear

IENGIN = number of point pairs in the array ENGINE(RPM,N), ENGINE(TORQUE,N)

ENGINE(RPM,N) = engine speed component of engine speed versus engine torque curve, rpm

ENGINE(TORQUE,N) = engine torque component of engine speed versus engine torque curve, lb-ft.

LOCKUP = 0 if torque converter does not lockup

= 1 if torque converter has lockup

RR = Tracked: sprocket pitch radius, in.

= Wheeled: rolling radius of largest tire element of powered assemblies, in.

FD(GR) = final drive gear ratio

FD(EFF) = final drive efficiency

ITCASE = 1 if engine to transmission transfer gear box

= 0 otherwise

NGR = number of transmission gear ratios

TRANS(GR,NG) = transmission gear ratio of gear NG

TRANS(EFF,NG) = transmission efficiency of gear NG

TQIND = constant torque converter input torque at which torque converter performance curves are measured, lb-ft.

ICONV1 = number of point pairs in the array CONV1(SR,N), CONV1(RPM,N)

CONV1(SR,N) = speed ratio component of the torque converter speed ratio versus torque converter input speed curve at constant input torque, TQIND

CONV1(RPM,N) = input speed component of the torque converter speed ratio versus torque converter speed curve, rpm

ICONV2 = number of point pairs in the array CONV2(SR,N), CONV2(TR,N)

CONV2(SR,N) = speed ratio component of the torque converter speed ratio versus torque converter ratio curve

CONV2(TR,N) = torque ratio component of the torque converter speed ratio versus torque converter torque ratio curve

TCASE(GR) = gear ratio between engine and transmission

= 1 if no such gear

RPM = array subscript indicating the column used to store values of RPM = 1

TORQUE = array subscript indicating the column used to store values of torque = 2

SR = array subscript indicating the column used to store values of speed ratio = 2

TR = array subscript indicating the column used to store values of torque ratio = 1

SPEED = array subscript indicating the column used to store values of force = 1

FORCE = array subscript indicating the column used to store values of force = 2

GR = array subscript indicating the column used to store values of gear ratio = 1

EFF = array subscript indicating the column used to store values of efficiency = 2

Scenario: APGDAT = 1 choose power train data (if available)

= 2 choose measured tractive effort data (if available)

<u>Outputs</u>

IPOWER = number of point pairs in the array POWER(SPEED,N), POWER(FORCE,N)

POWER(SPEED,N) = vehicle velocity component of the tractive effort versus speed curve, in/sec.

POWER(FORCE,N) = tractive force component of the tractive force versus speed curve, lb.

APGDAT = 1, 2 if choice satisfied

= 4 if power train data used in lieu of no measured data available

= 3 if measured data used in lieu of no power train data available

Algorithm

a. Check tractive effort versus speed scenario selection and available data.

```
If APGDAT = 2
   then if IAPG = 0 or 2
           do routine 5 (curve fit to measured data)
        else APGDAT = 4
        do b.
else if APGDAT = 1
        then if IAPG = 2
                APGDAT = 3
                do routine 5.
             else do b.
```

```
b.  Build speed array in 1/2 MPH increments
    RPM = TR = GR = SPEED = 1
    Torque = SR = EFF = FORCE = 2
    do for N=1 to 201
    POWER(SPEED,N) = (N-1)*0.5*(88./60.)*12.
    POWER(FORCE,N) = 0.
    Next N
c.  Adjust transmission input for engine to transmission gear
    if ITCASE ≠ 0
       then do for N=1 to IENGIN
       ENGINE(RPM,N) = ENGINE(RPM,N)/TCASE(GR)
       ENGINE(TORQUE,N) = ENGINE(TORQUE,N)*TCASE(GR)*TCASE(EFF)
       next N
    else IPOWER = 0
d.  Choose transmission routine to use
    if ITRAN < 1
       then error return to Module I. Control and I/O Module
    else if ITRAN = 1
            then CALL AUTOM(ENGINE,IENGIN,CONV1, ICONV1, CONV2,
            ICONV2,TRANS,  NGR, FD,RR,POWER,IPOWER,RPM,TORQUE,
            SR,TR,GR,EFF,SPEED,FORCE)
            if LOCKUP = 1
               then CALL STICK (ENGINE,IENGIN,TRANS.NGR,
               FD,RR,POWER,IPOWER,RPM,TORQUE,GR,EFF,SPEED,
               FORCE)
            exit
```

```
        else exit

    else if ITRAN = 0

            CALL STICK(ENGINE,IENGIN,TRANS,NGR,FD,RR,
            POWER,IPOWER,RPM,TORQUE,GR,EFF,SPEED,FORCE)

    exit
```

Automatic Transmission with Torque Converter Routine

Description This subroutine, AUTOM, calculates the tractive effort POWER(FORCE,N) at various vehicle speeds POWER(SPEED,N) for vehicles with automatic transmissions. This subroutine is identical to AUTOF of AMC '71.

Subroutine AUTOM(ENGINE,IENGIN,CONV1,ICONV1,ICONV2,CONV2,
ICONV2,TRANS,NGR,FD, RR ,POWER,IPOWER,RPM,TORQUE,
SR,TR,GR,EFF,SPEED,FORCE)

<u>Inputs</u> Vehicle: NGR = number of transmission gear ratios

ENGINE(RPM,N) = engine speed component of engine speed versus engine torque curve, rpm

IENGIN = number of point pairs in the array ENGINE(RPM,N), ENGINE(TORQUE,N)

POWER(SPEED,N) = vehicle velocity component of the tractive effort versus speed curve, in/sec.

RR = Tracked: sprocket pitch radius, in.

Wheeled: rolling radius of largest tire element of powered assemblies, in.

FD(GR) = final drive gear ratio

TRANS(GR,NG) = transmission gear ratio of gear NG

ICONV1 = number of point pairs in the array CONV1(SR,N),CONV1(RPM,N)

CONV1(SR,N) = speed ratio component of the torque converter speed ratio versus torque converter input speed curve at constant input torque, TQIND

CONV1(RPM,N) = input speed component of the torque converter speed ratio versus torque converter speed curve, rpm

ENGINE(TORQUE,N) = engine torque component of engine speed versus engine torque curve, lb-ft.

ICONV2 = number of point pairs in the array CONV2(SR,N), CONV2(TR,N)

CONV2(SR,N) = speed ratio component of the torque converter speed ratio versus torque converter ratio curve

CONV2(TR,N) = torque ratio component of the torque converter speed ratio versus torque converter torque ratio

TRANS(EFF,NG) = transmission efficiency of gear NG

FD(EFF) = final drive efficiency

Outputs

POWER(FORCE,N) = tractive force component of the tractive force versus speed curve, lb.

IPOWER = number of point pairs in the array POWER(SPEED,N), POWER (FORCE,N)

Algorithms

a. Find engine speeds matched to set vehicle speeds in 1/2 MPH increments

```
PI = 3.14159265

   ESMIN = ENGINE(RPM,1)

   ESMAX = ENGINE(RPM,IENGIN)

   do for NG=1 to NGR

   do for N=1 to 201

   RPMOUT = (POWER(SPEED,N)*60./(2.*PI*RR))*FD(GR)*
            TRANS(GR,NG)
```

```
a1.  Bisection of MIN and MAX engine speeds to estimate engine
     speed matched to vehicle speed

     RPMIN = (ESMIN + ESMAX)/2.

     SRATIO = RPMOUT/RPMIN

     if SRATIO > 1.

        then SRATIO = 1.

     else CALL LINEAR(CONV1,ICONV1,SR,RPM,SRATIO,SPDIND)

     $TORQIN = TQIND * (RPMIN/SPDIND)^2$

     CALL LINEAR(ENGINE,IENGIN,RPM,TORQUE,RPMIN,TORQEN)

     if TORQEN = TORQIN

        then do linear interpolation of torque converter
        routine a2.

     else if TORQEN < TORQIN

             then ESMAX = RPMIN

             if absolute (ESMAX - ESMIN) ≤ 1.

                then do routine a2.

             else restart bisection routine a1.

     else if TORQEN > TORQIN

             then ESMIN = RPMIN

             if absolute (ESMAX - ESMIN) ≤ 1.

                then do routine a2.

             else restart bisection routine a1.

a2.  Linear interpolation of torque converter

     CALL LINEAR(CONV2,ICONV2,SR,TR,SRATIO,TRATIO)
```

```
TF = TORQIN * TRATIO * TRANS(GR,NG)*TRANS(EFF,NG)*FD(GR)*
     FD(EFF)/RR

if POWER(FORCE,N) < TF

   then POWER(FORCE,N) = TF

else if IPOWER < N

        then IPOWER = N

        next N

        next NG

        exit

    else next N

         next NG

         exit
```

Manual Transmission Routine

Description This subroutine, STICK, calculates the tractive effort POWER(FORCE,N) at various vehicle speeds POWER(SPEED,N) for vehicles with manual transmissions. This subroutine is identical to STICK of AMC '71.

Subroutine STICK(ENGINE,IENGIN,TRANS,NGR,FD,RR,POWER,IPOWER,
RPM,TORQUE,GR,EFF,SPEED,FORCE)

<u>Inputs</u> Vehicle: NGR = number of transmission gear ratios

ENGINE(RPM,N) = engine speed component of engine speed versus engine torque curve, rpm.

IENGIN = number of point pairs in the array ENGINE(RPM,N),ENGINE (TORQUE,N)

POWER(SPEED,N) = vehicle velocity component of the tractive effort versus speed curve, in/sec.

RR = Tracked: sprocket pitch radius, in.

Wheeled: rolling radius of largest tire element of powered assemblies, in.

FD(GR) = final drive gear ratio

TRANS(GR,NG) = transmission gear ratio of gear NG

ENGINE(TORQUE,N) = engine torque component of engine speed versus engine torque curve, lb-ft.

TRANS(EFF,NG) = transmission efficiency of gear NG

FD(EFF) = final drive efficiency

Outputs

POWER(FORCE,N) = tractive force component of the tractive force versus speed curve, lb.

IPOWER = number of point pairs in the array POWER(SPEED,N), POWER(FORCE,N)

Algorithms

a. Find engine speeds matched to set vehicle speeds in 1/2 MPH increments

```
PI = 3.14159265

ESMIN = ENGINE(RPM,1)

ESMAX = ENGINE(RPM,IENGIN)

do for NG=1 to NGR

do for N=1 to 201

RPMEN = (POWER(SPEED,N)*60./(2.*PI*RR))*FD(GR)*TRANS(GR,
        NG)

if RPMEN < ESMIN

   then next N

else if RPMEN > ESMAX

        then next NG

     else do linear interpolation of torque versus engine
     speed curve routine a1.
```

a1. Linear interpolation of engine speed versus engine torque curve

```
CALL LINEAR(ENGINE,IENGIN,RPM,TORQUE,RPMEN,TORQEN)

TF = TORQEN*TRANS(GR,NG)*TRANS(EFF,NG)*FD(GR)*FD(EFF)/RR
```

```
if POWER(FORCE,N) < TF
   then POWER(FORCE,N) = TF
else if IPOWER < N
        then IPOWER = N
        next N
        next NG
        exit
     else next N
          next NG
          exit
```

Linear Interpolation Routine

Description: This subroutine (LINEAR) is used to linearly interpolate arrays of power train data such as: engine rpm versus engine torque, torque converter speed ratio versus torque converter ratio and torque converter speed ratio versus torque converter input speed. The data interpolated are the data supplied on the vehicle data sheets. This subroutine is called by subroutines AUTOM and STICK during the course of building the tractive effort versus speed curve in each gear. It replaces subroutine CURVE in AMC '71.

Subroutine LINEAR(ARRAY,IARRAY,IND,DEP,X,Y)

Inputs Vehicle:

IARRAY = number of point pairs in array ARRAY

ARRAY = two-dimensional array of point pairs to be interpolated

IND = index indicating the independent variable to be interpolated

DEP = index indicating the dependent variable to be interpolated

X = independent variable value to be interpolated

Outputs

Y = dependent variable value resulting from interpolation

Algorithm

```
if ARRAY(IND,1) > ARRAY(IND,IARRAY)
        then error. Return to Module I. I/O Control Module
else if X < ARRAY(IND,1)
            then Y = 0
            exit
    else if X > ARRAY(IND,IARRAY)
                then Y = 0
                exit
        else do for N = 1 to IARRAY-1
            if X ≤ ARRAY(IND,N)
              then next N
            else Y = ARRAY(DEP,N)+[ARRAY(DEP,N+1)-ARRAY(DEP,N)]*
                     [X-ARRAY(IND,N)]/[ARRAY(IND,N+1)-ARRAY(IND,N)]
                     next N
                     exit
```

5. Second Order Curve Fit to Tractive Effort Versus Speed Curve

Description: In this routine the tractive effort POWER (FORCE,N) versus speed POWER(SPEED,N) data are fitted to a series of quadratic curves. A separate curve, specified by a constant term (FA) and the coefficients (FB,FC) of the linear and quadratic terms respectively is calculated for each gear. The number of curves fitted (gears) depends on the smoothness of the data over the speed valves examined. Consequently, artificial gears may be inserted to insure an 80th percent confidence interval of the expected tractive effort point in a gear.

The curve fitting is done sequentially from the lowest to the highest attainable speed. The first four speed tractive effort points are fitted with a quadratic according to the least square criterion. A predicted value for the tractive effort of the next point is determined from its speed value and the fitted curve. If the actual value of the tractive effort of this point lies within a calculated range from the predicted value, it is assumed that this speed-tractive effort point is part of the same gear as the points already included in the curve. If not, a new gear is started.

When a speed-tractive effort point is considered part of the previous gear, a new curve is fitted, by the least square criterion, which includes all the speed-tractive effort points already part of the gear plus the new point. A subsequent point is then tested using the new curve.

The range within which the new point must lie to be considered part of the gear determined by the previous points is given by the 80th percent confidence interval of the expected tractive effort value of the new point. This value is based on the observed deviation of the tractive efforts to their expected values of all the points already in the gear.

When the points included within each gear are determined, the lowest, mid-range and the highest speed in each gear are placed in the array VGV. The corresponding tractive effort values are given in the array TRACTF.

In the Areal Module, these three points are adjusted for slip and tractive effort degradation on slopes in submodel 5, Slip Modified Tractive Effort, and then refitted, exactly, by a new quadratic using the subroutine QUAD. These quadratics are then, later, integrated exactly in subroutine TXGEAR to allow time and distance calculation for acceleration between obstacles.

Inputs Derived: POWER(FORCE,N) = tractive force component of the tractive force versus speed curve, lb.

POWER(SPEED,N) = vehicle velocity component of the tractive effort versus speed curve, in/sec.

IPOWER = number of point pairs in the array POWER(SPEED,N), POWER(FORCE,N)

FORCE = array subscript indicating the column used to store values of force = 2

SPEED = array subscript indicating the column used to store values of speed = 1

Outputs

ATF(NG) = constant of quadratic fitted to vehicle tractive effort curve in gear NG, lb.

BTF(NG) = coefficient of linear term of quadratic fitted to vehicle tractive effort curve in gear NG, lb/(in/sec)

CTF(NG) = coefficient of quadratic term of quadratic fitted to vehicle tractive effort in gear NG, lb/(in/sec)^2

NGR = number of gears

TRACTF(NG,MD) = tractive force available from drive train at mid-range speed in gear NG, lb.

TRACTF(NG,MN) = tractive force available from drive train at minimum speed in gear NG, lb.

TRACTF(NG,MX) = tractive force available from drive train at maximum speed in gear NG, lb.

VGV(NG,MD) = mid-range speed in gear NG, in/sec.

VGV(NG,MN) = minimum speed in gear NG, in/sec.

VGV(NG,MX) = maximum speed in gear NG, in/sec.

Algorithm

a. Select a quadratic fitted to the points in the vehicle tractive force versus speed array by minimizing the least square deviation.

a1. Student's "t" Table for 80% Confidence Level:

T80(38): 0.325, 0.289, 0.277, 0.271, 0.267, 0.265, 0.263, 0.262, 0.261, 0.260, 0.260, 0.259, 0.259, 0.258, 0.258, 0.258, 0.257, 0.257, 0.257, 0.257, 0.257, 0.256, 0.256, 0.256, 0.256, 0.256, 0.256, 0.256, 0.256, 0.256, 0.255, 0.255, 0.254, 0.254, 0.254, 0.254, 0.253, 0.253

a2. Degree of Freedom Table:

NDF(38): 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, 40, 50, 60, 80, 100, 200, 500, 999

a3. SPEED = 1

FORCE = 2

NGR = 1

NLEFT = 1

NRIGHT = 4

```
b. If NRIGHT > IPOWER
          then return to Module I. Control and I/O
     Fit a curve through points from NLEFT to NRIGHT inclusive.
     Form the normal equations:  {Y} = [A]{X}
     Do for N = NLEFT to NRIGHT
     Y(1) = $\sum_N$ POWER(FORCE,N)
     Y(2) = $\sum_N$ POWER(FORCE,N)*POWER(SPEED,N)
     Y(3) = $\sum_N$ POWER(FORCE,N)*[POWER(SPEED,N)]$^2$
     A(1,1) = $\sum_N$ 1
     A(1,2) = $\sum_N$ POWER(SPEED,N)
     A(1,3) = $\sum_N$ [POWER(SPEED,N)]$^2$
     A(2,1) = $\sum_N$ POWER(SPEED,N)
     A(2,2) = $\sum_N$ [POWER(SPEED,N)]$^2$
     A(2,3) = $\sum_N$ [POWER(SPEED,N)]$^3$
     A(3,1) = $\sum_N$ [POWER(SPEED,N)]$^2$
     A(3,2) = $\sum_N$ [POWER(SPEED,N)]$^3$
     A(3,3) = $\sum_N$ [POWER(SPEED,N)]$^4$
Find coefficients of fitted equation
     {X} = [A]$^{-1}$ {Y}
Test to see whether the next point in the array can be
fitted to the same curve within an 80% confidence interval
     If NRIGHT + 1 > IPOWER
        then do c.
```

```
else do for N=NLEFT to NRIGHT

    S2 = ${\{\sum_N [POWER(FORCE,N)]^2-\sum_N[POWER(FORCE,N)*}$
          $(X(1)+X(2)*POWER(SPEED,N)+X(3)*POWER(SPEED,N)^2)]\}/$
         $((NRIGHT-NLEFT+1)-3)$

    R(1) = 1

    R(2) = POWER(SPEED,NRIGHT+1)

    R(3) = $[POWER(SPEED,NRIGHT+1)]^2$

U2 = $\{R\}^T[A]^{-1}\{R\}$

    do for K = 1 to 37

    INDEX = K

    if (NRIGHT-NLEFT+1)-3 = NDF(K)

        then do b1.

    else INDEX = K+1

    if (NRIGHT-NLEFT+1)-3 > NDF(K)

                  and

      (NRIGHT-NLEFT+1)-3 < NDF(K)

        then do b1.

    else next K

        if no exit from within loop after all K

        error:  degree of freedom not found in Student's "t"
                table

        return to Module I. Control and I/O

b1.  BL = $X(1)+X(2)*POWER(SPEED,N)+X(3)*POWER(SPEED,N)^2$
          -T80(INDEX)*SQRT[S2*U2]
```

```
        BU = X(1)+X(2)*POWER(SPEED,N)+X(3)*POWER(SPEED,N)^2
               +T80(INDEX)*SQRT[S2+U2]

        if POWER(FORCE,NRIGHT+1) < BL  or

           POWER(FORCE,NRIGHT+1) > BU

           then do c.

        else next point on the curve is within the 80%
        confidence level

        Reset the indices defining that portion of the curve to
        be fitted by adding the next point

           NRIGHT = NRIGHT+1

           do b.

    c.  Record parameters of curve fit

        ATF(NGR) = X(1)

        BTF(NGR) = X(2)

        CTF(NGR) = X(3)

        VGV(NGR,MN) = POWER(SPEED,NLEFT)

        VGV(NGR,MX) = POWER(SPEED,NRIGHT)

        VGV(NGR,MD) = [VGV(NGR,MX)+VGV(NGR,MN)]/2.

        TRACTF(NGR,MN) = ATF(NGR)+BTF(NGR)*VGV(NGR,MN)+
                         CTF(NGR)*VGV(NGR,MN)**2

        TRACTF(NGR,MD) = ATF(NGR)+BTF(NGR)*VGV(NGR,MD)+
                         CTF(NGR)*VGV(NGR,MD)**2

        TRACTF(NGR,MX) = ATF(NGR)+BTF(NGR)*VGV(NGR,MX)+
                         CTF(NGR)*VGV(NGR,MX)**2

    Reset the indices defining that portion of the curve to be
    fitted.    Establish the next portion of the curve to be
    fitted.
```

```
If NRIGHT + 4 > IPOWER

   then not enough points to start another gear
   error.  Return to Module I. Control and I/O

else NGR = NGR+1

     NLEFT = NRIGHT+1

     NRIGHT = NLEFT+3

     do b.
```

MODULE III

TERRAIN PREPROCESSOR

TERRAIN PREPROCESSOR MODULE

The Terrain Preprocessor Module creates the terrain descriptors of each terrain unit for use in the Areal, Hasty River and Dry Linear Features Crossing, and Road Modules. This preprocessor produces, according to several scenario inputs, primary terrain descriptors as well as several secondary terrain descriptors derived from the primary descriptors.

All of the terrain features used in AMC '71 and reported in Reference 1 are used in AMC '74. In addition, AMC '74 includes various other terrain characteristics. These are:

1. Presence of surface water causing slippery conditions from recent rainfall.
2. Shallow snow cover.
3. Altitude.

The Terrain Preprocessor Module is a stand alone module which is executed external to the main model of AMC '74. It consists of three preprocessing sections which may be executed in whole or in part depending on the specification/scenario inputs. Once a terrain transect has been preprocessed and the terrain descriptors (primary and secondary) are entered in a file, the terrain preprocessor need not be called again for subsequent execution of the model.

The first section of the module is an Ad Hoc Preprocessor which accepts source terrain data and if necessary, converts the source terrain data to primary proper natural terrain units descriptors (e.g., class interval numbers, topographic map data, climatic map data converted to terrain feature values (soil strength, grade, etc.)) (See Terrain Preprocessing Flow Chart.) At present, only the conversion of class interval numbers to primary proper natural terrain units descriptors is included with the other source data conversions to be implemented later.

The Standard Preprocessor section is entered next with either the primary descriptors from the Ad Hoc Preprocessor or proper natural terrain units descriptors obtained directly from the source terrain data. This preprocessor converts all dimensional units of the primary descriptors to the lb., in., rad., sec. units required by the main model and develops the secondary terrain unit descriptors, such as, patch area per obstacle, etc. The entire set of primary and secondary descriptors are placed in the proper format required by the Areal, Road and Hasty River and Dry Linear Features Crossing Modules and stored on the Terrain File. This file becomes a permanent file of processed terrain data.

The execution of the third section of the preprocessing module depends on a snow scenario. If shallow snow covers the entire terrain transect or a portion of it, then the Terrain File and a Snow File (snow source terrain data) are brought into a Snow Machine which modifies the primary and secondary descriptors affected by snow cover. The Snow Modified Terrain File then becomes the permanent file of processed terrain data.

The terrain preprocessor can accommodate a mixture of terrain unit types on a given source terrain data file. In special cases where a single traverse is to be executed, the terrain data file may contain areal, road and linear features data. The only requirement is that the data for a particular terrain unit be complete.

Specification/Scenario Variables Required by the Terrain Preprocessor

ISEASN = 1 for dry

= 2 for normal

= 3 for wet

ITERI input type:

= 1 if primary proper natural terrain units descriptors are presented

= 2 if class interval codes are presented and given representatives for each class are to be used

= 3 if topographic map source data

= 4 if climatic map source data

TRCLAS = name of the file containing the terrain descriptor class interval boundaries and representatives

PFNAM = generic name of the file containing the source terrain primary terrain variables (either as actual values or class interval codes)

ISNOW = 0 if no shallow snow cover

= 1 otherwise

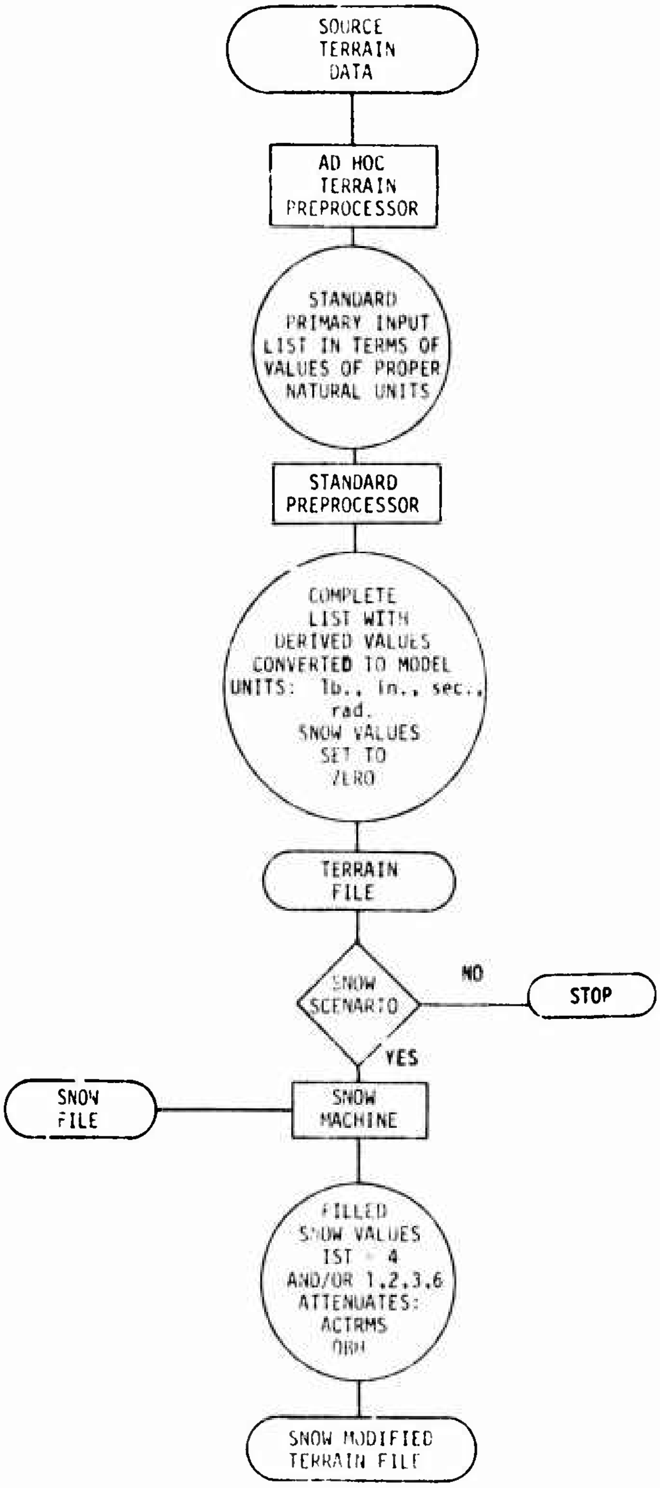
SNOWN = generic name of the file containing the primary proper natural terrain units descriptors for snow cover

TERRN = generic name of the output terrain file containing the primary and secondary proper natural terrain units descriptors properly formatted for use in Modules IV, V, VI

Contents of the File TRCLAS Containing Class Interval Boundaries and Representatives

The following information is given for each primary terrain descriptor:

IPTD	descriptor number
PTDNAM	descriptor name
NUMCL	number of class intervals
FLOW	lower boundary of first class interval (leave blank for open first interval)
REP(i)	representative value of i^{th} class interval
HIGH(i)	upper boundary of i^{th} class interval (leave blank for open last interval)



TERRAIN PREPROCESSING FLOW CHART

1. Ad Hoc Preprocessor

Description The Ad Hoc Preprocessor acts as a translator between the source terrain data and the Standard Preprocessor. This preprocessor reads the Source Terrain Data File containing primary terrain descriptors either in proper natural units form or a form that reflects the source of the terrain data. If the latter form of the data is present then the Ad Hoc Preprocessor, according to a predetermined translator, transcribes the source terrain data into the primary proper natural terrain units descriptors. At present, the translator being used is the class interval translator from AMC '71 with updates to accommodate for the additional terrain characteristics in AMC '74. The file (TRCLAS), containing the representatives of the terrain feature values in proper natural terrain units, is used for the translator.

The listing of variables given are those describing a terrain unit. These are the primary descriptors for the Areal, Road, and Hasty River and Dry Linear Features Crossing Modules.

Primary Terrain Descriptors

All Modules

NTU	terrain unit number
ITUT	terrain unit type: = 1 if normally dry patch = 2 if marsh, lake or other water covered patch = 4 man-made ditch = 5 natural ditch or river = 6 mound = 11 super highway = 12 primary road = 13 secondary road = 14 trails

Areal Module

If ITUT = 1 or 2, the following variables are used to describe the terrain unit:

IST	soil type
	= 1 if fine grained soil not CH impervious to water
	= 2 if coarse grained soil
	= 3 if muskeg
	= 6 if fine grained soil CH impervious to water
RCIC(j)	surface strength (rated cone index or cone index depending on soil type) for j = dry, normal and wet season, lb/in^2
GRADE	slope, percent
AA	obstacle approach angle, deg.
OBH	obstacle height, in.
OBW	obstacle base width, ft.
OL	obstacle length, ft.
IOBS	= 1 if terrain unit is bare of obstacles
	≠ 1 if not
OS	obstacle spacing, ft.
IOST	= 1 if obstacles are potentially avoidable
	= 2 if obstacles are unavoidable
ATCRMS	surface roughness, in. (this value is the RMS microelevation)
NI	number of stem diameter classes

IS(i)	= 1 if patch is bare of vegetation in stem diameter class i
	≠ 1 otherwise
SD(i)	mean stem diameter of vegetation in stem diameter class i, in.
SDL(i)	maximum stem diameter of vegetation in stem diameter class i, in.
S(i)	mean spacing of stems in stem diameter class i and greater, ft.
RDA	visibility, ft.
WD	depth of standing water, in.
ELEV	mean elevation, ft.

River and Dry Linear Feature Crossing Module

If ITUT = 4, 5 or 6, the following variables are used to describe the terrain unit:

WD	**water depth, in.**
RBA	right bank angle, deg.
LBA	left bank angle, deg.
RBH	right bank height, in.
LBH	left bank height, in.
FWDTH	trench bottom, water width, or mound top width, ft.
C	bank soil cohesion, lb/in^2
TANP	tangent of internal friction angle
RCI	bank rating cone index, lb/in^2
IST	soil type:
	= 1 or 6 for fine grained soil
	= 2 for coarse grained soil
	= 7 for gravel
	= 12 for clay/sand
	= 17 for clay/gravel
	= 27 for sand/gravel
BRIDGS	mean bridge spacing along feature, ft.
SLOPE	nominal terrain slope, percent

Road Module

If ITUT = 11, 12, 13 or 14, the following variables are used to describe the terrain unit:

ACTRMS, ELEV, GRADE as for Module IV. Areal

HG	atmospheric pressure, inches of Hq
SURFF	= 1 for highway
	> 1 for rougher
RADCUR	radius of curvature, ft.
EANG	superelevation angle degrees positive for vehicle lean into curve
FMU(i)	roadway coefficient of sliding friction for i=1 if dry, i=2 if wet, and i=3 if ice-covered
VISW	width of unobstructed view from mid lane, ft.

2. Standard Preprocessor

Description The Standard Preprocessor derives the secondary descriptors of the terrain and converts all descriptor dimensional units to the lb., in., sec., rad. units used throughout the model. All terrain descriptors are then written onto file (TERRN) in the proper format acceptable to the three working modules mentioned earlier.

The variable list provided contains all variables required by the three working modules.

Secondary Terrain Descriptors

For All Types of Terrain Units

```
    ECF = 1. - .04 * ELEV/ 1000.
```

Areal Terrain Units

```
    a.  Unit Conversions
        OBL = 12. * OL
        OBS = 12. * OS
        OBW = 12. * OBW
        RD = 12. * RDA
        OBAA = (180. - AA) * π/180.
    b.  Mean Spacing of Stems
        do for i = 1 to NI
        S(i) = 12. * S(i)
        next i
    c.  Obstacle Dimensions
        if IOS > 1 (patch not bare of obstacles)
           then if OBAA < 0.
                   WA = OBW-2.*OBH/tan(OBAA)
                else (OBAA ≥ 0.)
                   WA = OBW+2.*OBH/tan(OBAA)
           $ODIA = [OBL^2 + WA^2]^{1/2}$
           OAW = 2. * (OBL + WA)/π
           $AREAO = \pi * OBS^2/4.$
```

else (IOS = 1) patch bare of obstacles

set obstacle dimensions to zero

Hasty River and Dry Linear Features Crossing Module

a. Unit Conversions

$LBA = LBA * \pi/180.$

$RBA = RBA * \pi/180.$

$FWDTH = FWDTH * 12.$

b. There are no secondary descriptors in this terrain data.

Road

a. Unit Conversions

$EANG = EANG * \pi/180.$

$RADC = 12. * RADCUR$

b. Recognition Distance

$RECD = 2. * RADC * \cos^{-1}(1.-VISW/RADCUR)$

Terrain File (TERRN) Output

Areal Module

Variable	Routine	Meaning
ACTRMS	10.	surface roughness, in.
AREAO	1	patch area per obstacle, in^2
CI	3b.	cone index, lb/in^2
ECF	5	elevation correction factor for tractive effort
GRADE	5,8,11	grade, percent
IOBS	1,2	= 1 if patch is bare of obstacles ≠ 1 otherwise
IOST	1	obstacle spacing type
IS(i)	1,6	= 1 if patch is bare of vegetation in stem class i or greater ≠ 1 otherwise
IST	2,3a.,5	soil type
ITUT	2	terrain unit type: = 1 if normally dry patch = 2 if marsh = 4 if man-made ditch = 5 if natural ditch or river

Variable	Routine	Meaning
ITUT	2	= 6 mound = 11 superhighway = 12 primary road = 13 secondary road = 14 trails
NI	1,6,7	number of stem diameter classes
OAW	1	mean obstacle approach width, in.
OBAA	1,16	obstacle approach angle, rad.
OBH	1,16,17	obstacle height, in.
OBL	1	obstacle length, in.
OBS	1	obstacle spacing, in.
OBW	16	obstacle width, in.
ODIA	1	maximum extent across obstacle, in.
RCI	3a., 3c.	rating cone index, lb/in^2
RD	13	recognition distance for braking, in.
S(i)	1,6	mean spacing of stems in class i, in.
SD(i)	6	mean stem diameter of class i, in.

Variable	Routine	Meaning
WA	1,17,18,19	obstacle ground level width, in.
WD	2	water depth, in.

Hasty River and Dry Linear Features Crossing

Variable	Routine	Meaning
BRIDGS	6	mean bridge spacing along feature, ft.
C	1,2,4	bank soil cohesion, lb/in^2
FWDTH	5	trench bottom, water width, or mound top width, in.
IST	2	soil type: = 1 or 6 for fine grained soil = 2 for coarse grained soil = 7 for gravel = 12 for clay/sand = 17 for clay/gravel = 27 for sand/gravel
ITUT	1,2,4	terrain unit: = 1 if normally dry patch = 2 if marsh, lake or other water covered patch = 4 man-made ditch = 5 natural ditch or river = 6 mound = 11 superhighway = 12 primary road = 13 secondary road = 14 trails

Variable	Routine	Meaning
LBA	1,2,3,4,5	left bank angle, rad.
LBH	1,4,5	left bank height, in.
RCI	1,2,3,4	bank rating cone index, lb/in^2
RBA	1,2,3,4,5	right bank angle, rad.
RBH	1,4,5	right bank height, in.
SLOPE	6	nominal terrain slope, percent
TANP	1,2,4	tangent of internal friction angle
WD	1,2,5	water depth, in.

Road Module

Variable	Routine	Meaning
ACTRMS	2	surface roughness, in.
EANG	1,3,4	superelevation angle, radians positive for vehicle lean into curve
ECF	1	elevation correction factor for tractive effort
FMU(i)	1,3,5	roadway coefficient of sliding friction for i = 1 if dry, i=2 if wet, i=3 if ice-covered
GRADE	1,5	grade, percent
HG	1	atmospheric pressure, inches of Hg
RADC	1,3,4	radius of curvature, in.
RECD	7	recognition distance, in.
SURFF	1	= 1 if highway > 1 if rougher

3. Snow Machine

Description The Snow Machine is a routine which modifies certain primary and secondary terrain descriptors whenever shallow snow covers the entire areal terrain transect or a portion of it. This routine reads the Snow File containing primary proper natural terrain units descriptors for each terrain unit covered by snow, which corresponds to a terrain unit number (NTU) in the Terrain File and performs three operations, namely;

- sets soil type IST = 4
- attenuates obstacle height (OBH) for mound type obstacles
- attenuates the microprofile surface roughness (ACTRMS)

The terrain descriptors modified for snow cover are then written onto the Terrain File (TERRN) in the proper format. Only the terrain unit types appearing as normal dry patches (ITUT = 1) are modified, and among these, only those which are designated as snow covered are modified.

Primary Descriptors

COHES	cohesion, lb/in^2
GAMMA	snow specific gravity
PHI	internal friction angle, deg.
ZSNOW	snow depth, in.
IST	soil type: = 4 snow

a. Unit Conversion

```
PHI = PHI * π/180.
TANPHI = tan(PHI)
```

b. Obstacle Attenuation

```
if OBAA ≥ 0. (mound)
    then OBH = OBH - ZSNOW * $(\frac{GAMMA}{.8})$
else OBH remains the same
```

c. Surface Roughness Attenuation

```
if ZSNOW ≥ 2.*ACTRMS
    then ACTRMS = ACTRMS * $[1. - (1. - \frac{GAMMA}{.4})]$
else ACTRMS = ACTRMS * $[1.- (1. - \frac{GAMMA/.4}{2.})*(\frac{ZSNOW}{ACTRMS})]$
```

Snow Modified Terrain File (TERRN) Output (Modifications and Additions)

Areal Module

Variable	Routine	Meaning
COHES	3d.	cohesion, lb/in^2
GAMMA	3d.	snow specific gravity
TANPHI	3d.	tangent of internal friction angle
ZSNOW	3d.	snow depth, in.
IST	3d.	soil type: = 4 snow
OBH	1,16,17	obstacle height, in.
ACTRMS	10	surface roughness, in.

MODULE IV

AREAL

AREAL MODULE

The Areal Module calculates the maximum average speed across a patch that a vehicle can be expected to maintain. (A patch or terrain unit is an area within which mobility impediments are considered uniform.) As in the AMC '71 Mobility Model, the speed is chosen to be the maximum of those calculated for various obstacle and vegetation override and/or avoidance strategies. The new Areal Module takes the place of the FOIL, COIL, PATCH and MARSH subroutines of AMC '71 and of all the subroutines they call except OBSTCL.

An overview of the Areal Module is displayed in Figure 1. The main operating position of the module revolves around the sequentially executed stand-alone submodels. These submodels are fed vehicle, terrain and scenario data from the two preprocessors and the Input/Output Control module. Additionally, derived outputs (velocities, forces, flags and diagnostic indicators) from previously executed submodels are used as inputs to successive submodels. Each submodel provides the above mentioned derived outputs which in whole or part are used by an output processor. The output processor is external to the module and operates on the derived outputs per the user's scenario.

The major conceptual blocks of the Areal Module are displayed in Figure 2. In each block are listed the numerical designations of the routines described in this section. A more detailed data flow chart is also given (Figure 3). This is a sequential flow chart of execution which shows input and output variable names as defined in the glossary. The routines may be calculated in the order given with some rearrangement allowed to the individual program implementation.

In addition to the vehicle and terrain input files from modules II and III, the Areal Module requires the list of scenario variables given on pages IV-5 to IV-7.

A description of each submodel follows. The following information is furnished for each:

1. Descriptive name of submodel.

2. Brief description of what the submodel does.

3. Required inputs:

    a. Vehicle.

   b. Terrain.

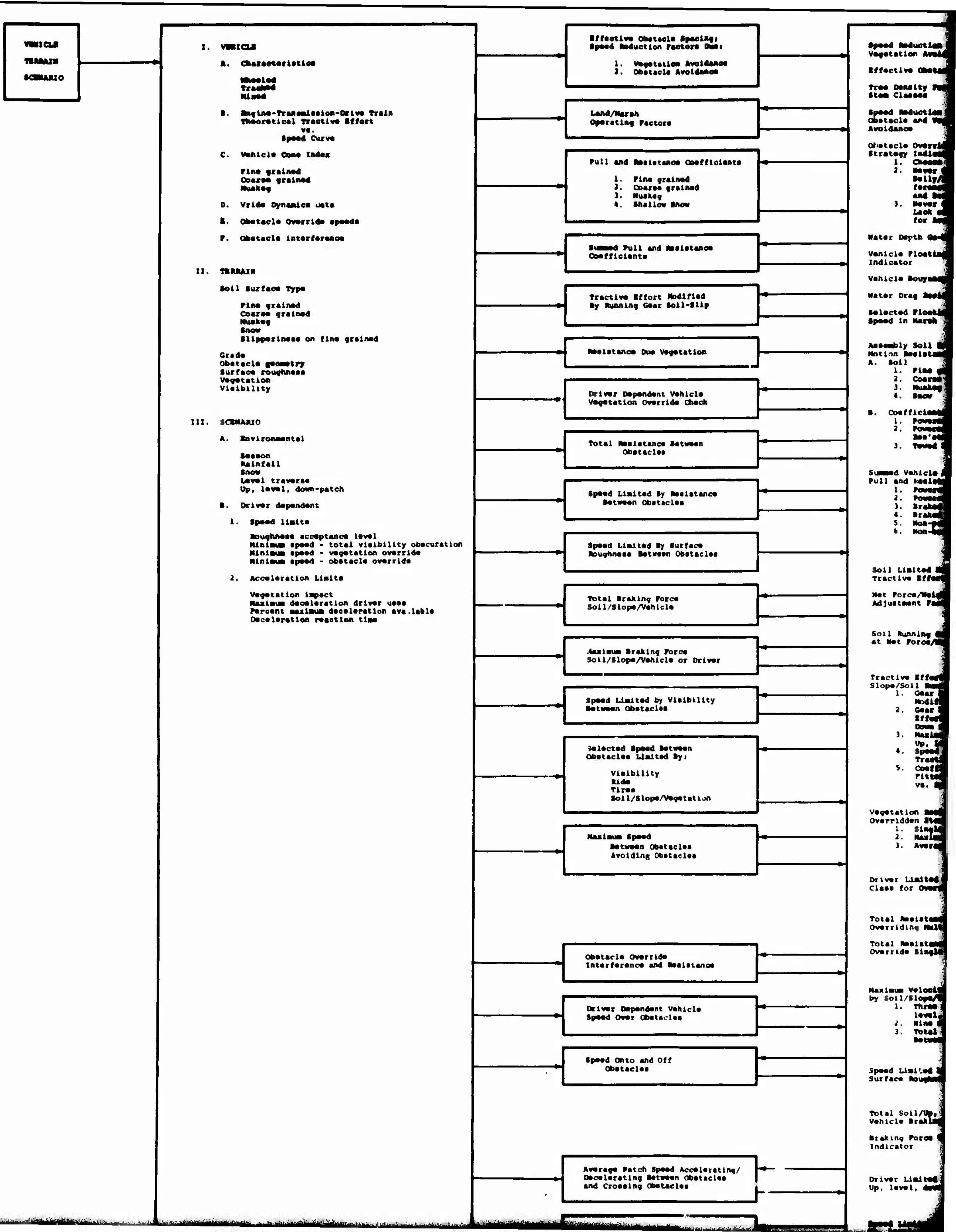
   c. Scenario.

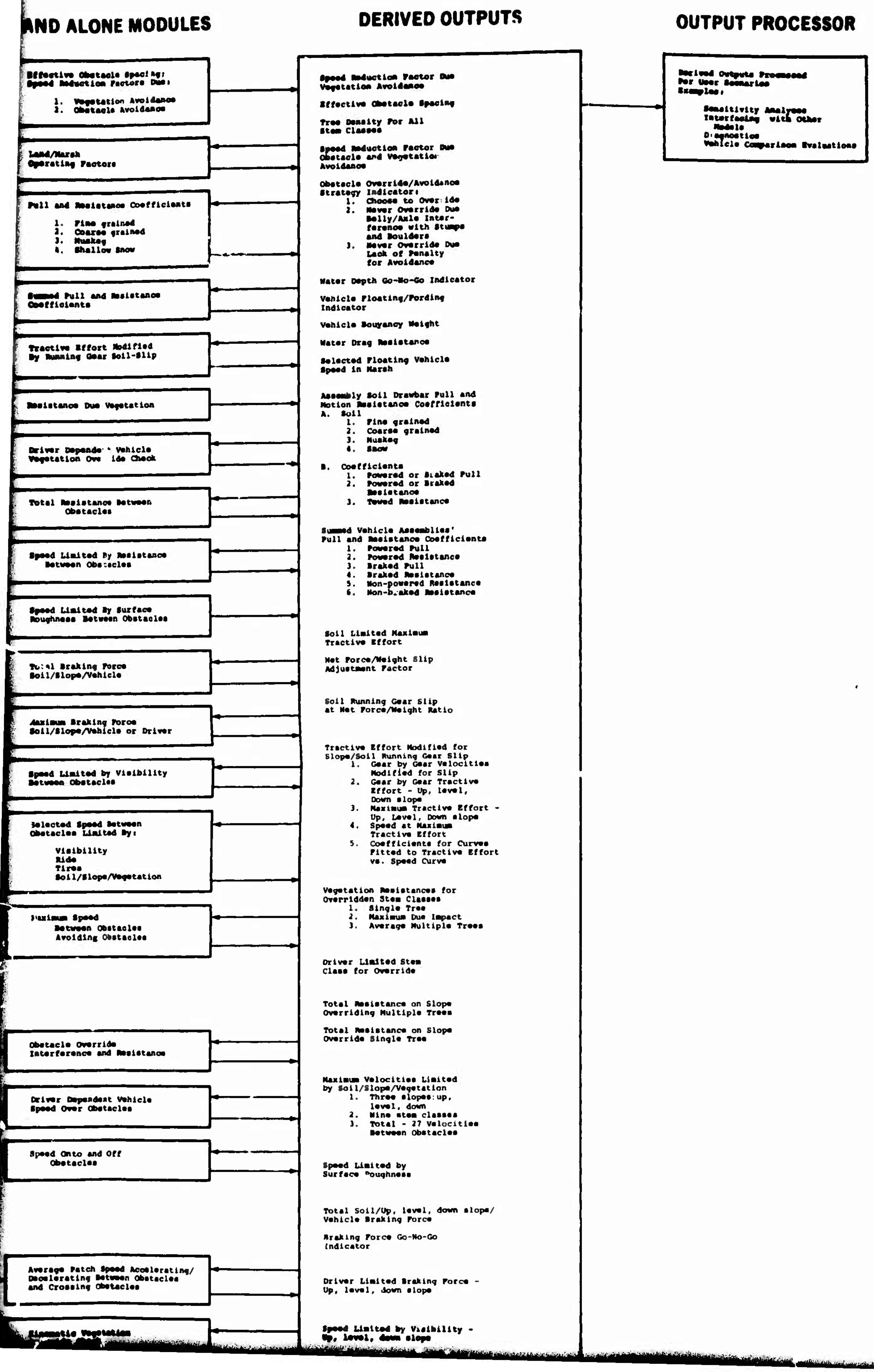
   d. Derived from previous submodels.

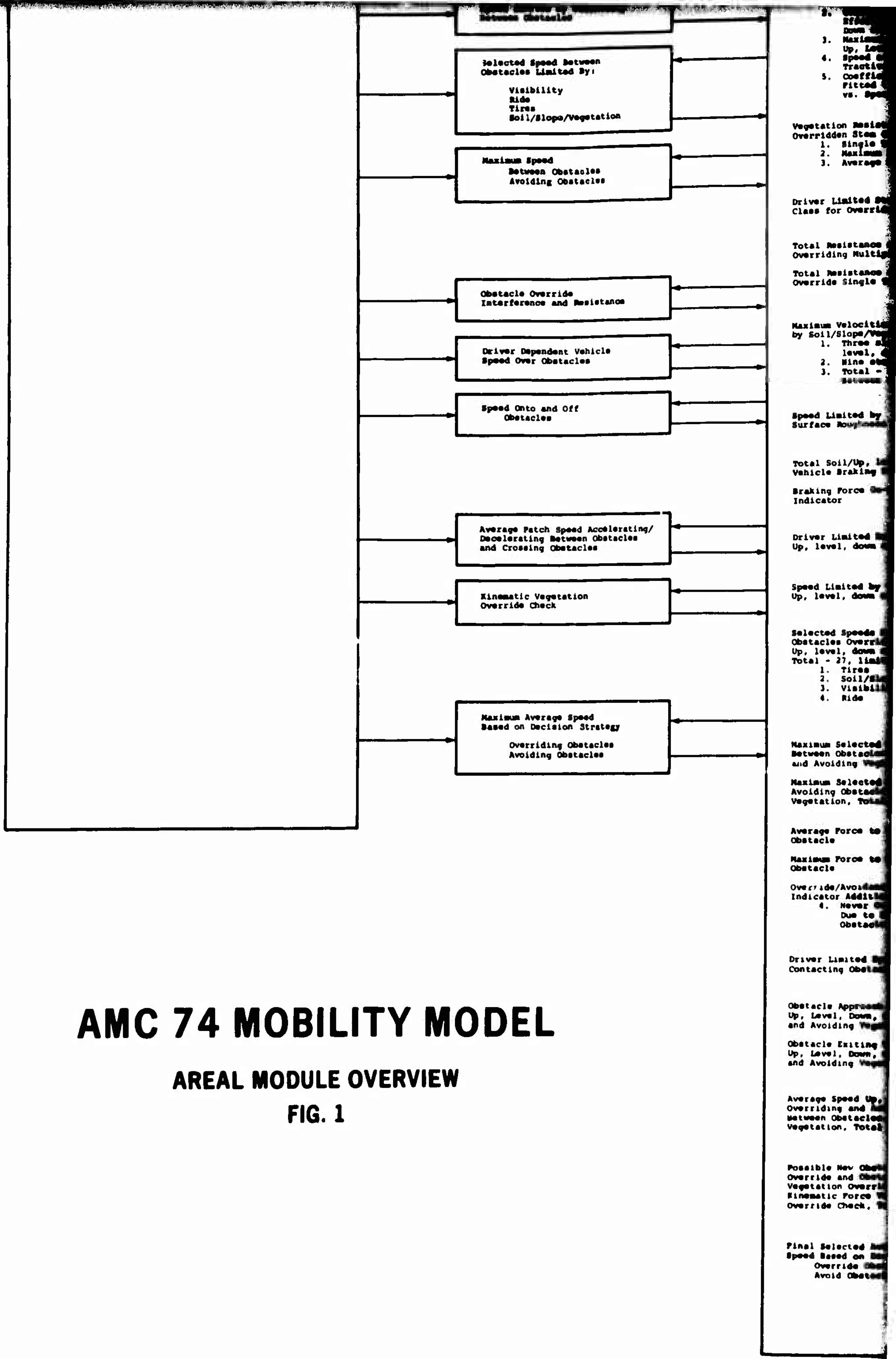
4. Derived outputs.

5. Algorithm

Although the Areal Module is so structured that each submodel is executed in succession, eliminating the need for programming the module as subroutines, there are instances where repetitive calculations are required within a submodel. In these cases, subroutines are used. These are identified in the submodels by the CALL statement, in which outputs of the subroutine are underlined in the CALL list. Such subroutines are specified immediately following the algorithm in the first submodel which uses each.


VEHICLE
TERRAIN
SCENARIO
I. VEHICLE
A. Characteristics
Wheeled
Tracked
Mixed
B. Engine-Transmission-Drive Train
Theoretical Tractive Effort
vs.
Speed Curve
C. Vehicle Cone Index
Fine grained
Coarse grained
Muskeg
D. Vride Dynamics data
E. Obstacle Override speeds
F. Obstacle interference
II. TERRAIN
Soil Surface Type
Fine grained
Coarse grained
Muskeg
Snow
Slipperiness on fine grained
Grade
Obstacle geometry
Surface roughness
Vegetation
Visibility
III. SCENARIO
A. Environmental
Season
Rainfall
Snow
Level traverse
Up, level, down-patch
B. Driver dependent
1. Speed limits
Roughness acceptance level
Minimum speed - total visibility obscuration
Minimum speed - vegetation override
Minimum speed - obstacle override
2. Acceleration Limits
Vegetation impact
Maximum deceleration driver uses
Percent maximum deceleration available
Deceleration reaction time
Effective Obstacle Spacing; Speed Reduction Factors Due:
1. Vegetation Avoidance
2. Obstacle Avoidance
Land/Marsh Operating Factors
Pull and Resistance Coefficients
1. Fine grained
2. Coarse grained
3. Muskeg
4. Shallow Snow
Summed Pull and Resistance Coefficients
Tractive Effort Modified By Running Gear Soil-Slip
Resistance Due Vegetation
Driver Dependent Vehicle Vegetation Override Check
Total Resistance Between Obstacles
Speed Limited By Resistance Between Obstacles
Speed Limited By Surface Roughness Between Obstacles
Total Braking Force Soil/Slope/Vehicle
Maximum Braking Force Soil/Slope/Vehicle or Driver
Speed Limited by Visibility Between Obstacles
Selected Speed Between Obstacles Limited By:
Visibility
Ride
Tires
Soil/Slope/Vegetation
Maximum Speed
Between Obstacles
Avoiding Obstacles
Obstacle Override Interference and Resistance
Driver Dependent Vehicle Speed Over Obstacles
Speed Onto and Off Obstacles
Average Patch Speed Accelerating/Decelerating Between Obstacles and Crossing Obstacles
Speed Reduction
Vegetation
Effective
Tree Density
Stem Classes
Speed Reduction
Obstacle and
Avoidance
Obstacle
Strategy
1.
2. Never
3. Never
Lack
for
Water Depth
Vehicle
Indicator
Vehicle
Water Drag
Selected
Speed in Marsh
Assembly Soil
Motion
A. Soil
1.
2.
3.
4. Snow
B.
1.
2.
3.
Summed Vehicle
Pull and
1.
2.
3.
4.
5.
6.
Soil Limited
Tractive
Net
Adjustment
Soil Running
at Net
Tractive
Slope/Soil
1. Gear
2. Gear
Down
3.
Up,
4.
5.
vs.
Vegetation
Overridden
1.
2.
3.
Driver Limited
Class for
Total
Overriding
Total
Override
Maximum
by
1. Three
level
2. Nine
3. Total
Speed Limited
Surface
Total
Vehicle
Braking Force
Indicator
Driver Limited
Up, level,

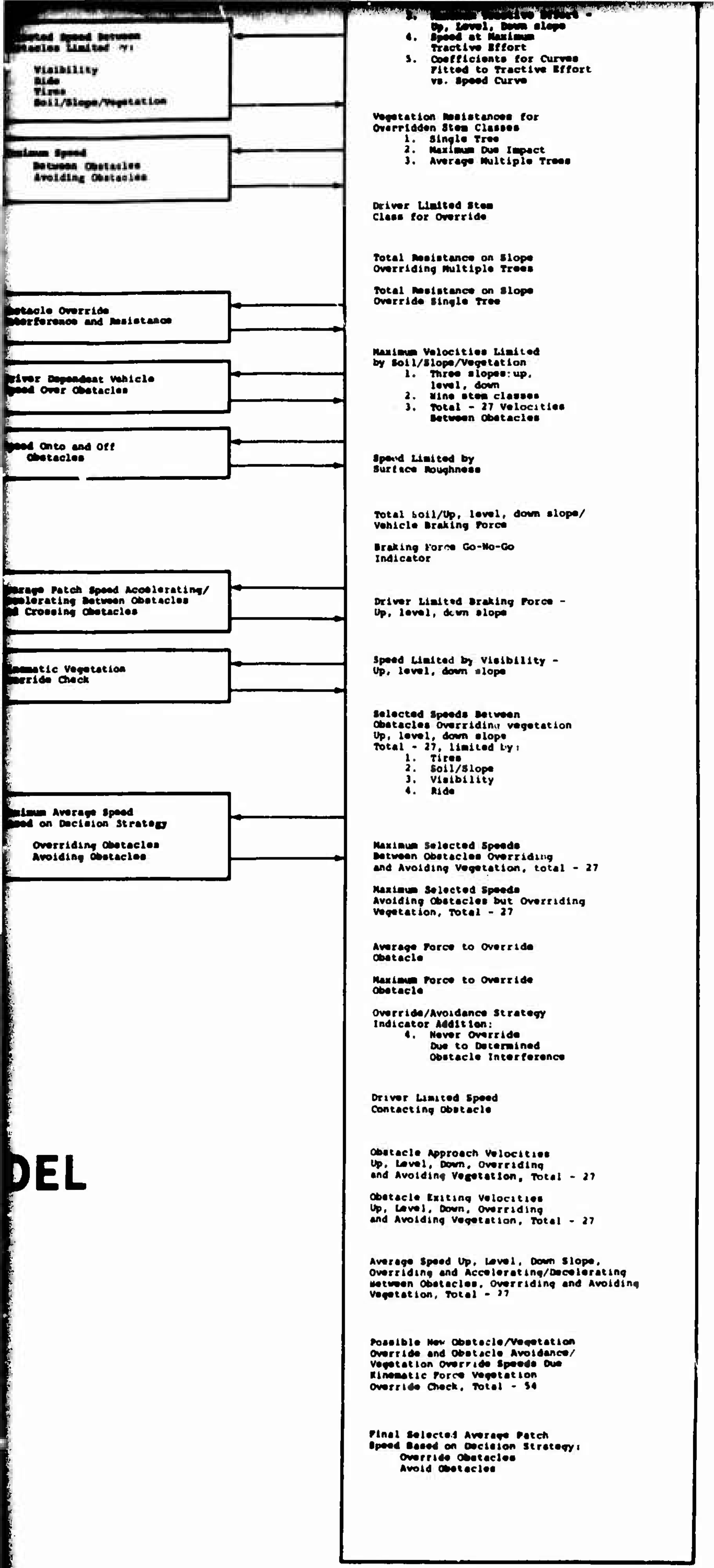

AND ALONE MODULES
DERIVED OUTPUTS
OUTPUT PROCESSOR
Effective Obstacle Spacing; Speed Reduction Factors Due:
1. Vegetation Avoidance
2. Obstacle Avoidance
Land/Marsh Operating Factors
Pull and Resistance Coefficients
1. Fine grained
2. Coarse grained
3. Muskeg
4. Shallow Snow
Summed Pull and Resistance Coefficients
Tractive Effort Modified By Running Gear Soil-Slip
Resistance Due Vegetation
Driver Dependent Vehicle Vegetation Override Check
Total Resistance Between Obstacles
Speed Limited By Resistance Between Obstacles
Speed Limited By Surface Roughness Between Obstacles
Total Braking Force Soil/Slope/Vehicle
Maximum Braking Force Soil/Slope/Vehicle or Driver
Speed Limited by Visibility Between Obstacles
Selected Speed Between Obstacles Limited By:
Visibility
Ride
Tires
Soil/Slope/Vegetation
Maximum Speed
Between Obstacles
Avoiding Obstacles
Obstacle Override Interference and Resistance
Driver Dependent Vehicle Speed Over Obstacles
Speed Onto and Off Obstacles
Average Patch Speed Accelerating/Decelerating Between Obstacles and Crossing Obstacles
Kinematic Vegetation
Speed Reduction Factor Due Vegetation Avoidance
Effective Obstacle Spacing
Tree Density For All Stem Classes
Speed Reduction Factor Due Obstacle and Vegetation Avoidance
Obstacle Override/Avoidance Strategy Indicator:
1. Choose to Override
2. Never Override Due Belly/Axle Interference with Stumps and Boulders
3. Never Override Due Lack of Penalty for Avoidance
Water Depth Go-No-Go Indicator
Vehicle Floating/Fording Indicator
Vehicle Bouyancy Weight
Water Drag Resistance
Selected Floating Vehicle Speed in Marsh
Assembly Soil Drawbar Pull and Motion Resistance Coefficients
A. Soil
1. Fine grained
2. Coarse grained
3. Muskeg
4. Snow
B. Coefficients
1. Powered or Braked Pull
2. Powered or Braked Resistance
3. Towed Resistance
Summed Vehicle Assemblies' Pull and Resistance Coefficients
1. Powered Pull
2. Powered Resistance
3. Braked Pull
4. Braked Resistance
5. Non-powered Resistance
6. Non-braked Resistance
Soil Limited Maximum Tractive Effort
Net Force/Weight Slip Adjustment Factor
Soil Running Gear Slip at Net Force/Weight Ratio
Tractive Effort Modified for Slope/Soil Running Gear Slip
1. Gear by Gear Velocities Modified for Slip
2. Gear by Gear Tractive Effort - Up, level, Down slope
3. Maximum Tractive Effort - Up, Level, Down slope
4. Speed at Maximum Tractive Effort
5. Coefficients for Curves Fitted to Tractive Effort vs. Speed Curve
Vegetation Resistances for Overridden Stem Classes
1. Single Tree
2. Maximum Due Impact
3. Average Multiple Trees
Driver Limited Stem Class for Override
Total Resistance on Slope Overriding Multiple Trees
Total Resistance on Slope Override Single Tree
Maximum Velocities Limited by Soil/Slope/Vegetation
1. Three slopes: up, level, down
2. Nine stem classes
3. Total - 27 Velocities Between Obstacles
Speed Limited by Surface Roughness
Total Soil/Up, level, down slope/Vehicle Braking Force
Braking Force Go-No-Go Indicator
Driver Limited Braking Force - Up, level, down slope
Speed Limited by Visibility - Up, level, down slope
Derived Outputs Processed For User Scenarios
Examples:
Sensitivity Analyses
Interfacing with Other Models
Diagnostics
Vehicle Comparison Evaluations



AMC 74 MOBILITY MODEL

AREAL MODULE OVERVIEW

FIG. 1


3. [illegible] -
Up, Level, Down slope
4. Speed at Maximum
Tractive Effort
5. Coefficients for Curves
Fitted to Tractive Effort
vs. Speed Curve
ted Speed Between
tacles Limited By:
Visibility
Ride
Tires
Soil/Slope/Vegetation
Vegetation Resistances for
Overridden Stem Classes
1. Single Tree
2. Maximum Due Impact
3. Average Multiple Trees
imum Speed
Between Obstacles
Avoiding Obstacles
Driver Limited Stem
Class for Override
Total Resistance on Slope
Overriding Multiple Trees
Total Resistance on Slope
Override Single Tree
stacle Override
terference and Resistance
Maximum Velocities Limited
by Soil/Slope/Vegetation
1. Three slopes: up,
level, down
2. Nine stem classes
3. Total - 27 Velocities
Between Obstacles
iver Dependent Vehicle
peed Over Obstacles
peed Onto and Off
Obstacles
Speed Limited by
Surface Roughness
Total Soil/Up, level, down slope/
Vehicle Braking Force
Braking Force Go-No-Go
Indicator
erage Patch Speed Accelerating/
celerating Between Obstacles
d Crossing Obstacles
Driver Limited Braking Force -
Up, level, down slope
nematic Vegetation
erride Check
Speed Limited by Visibility -
Up, level, down slope
Selected Speeds Between
Obstacles Overriding vegetation
Up, level, down slope
Total - 27, limited by:
1. Tires
2. Soil/Slope
3. Visibility
4. Ride
ximum Average Speed
sed on Decision Strategy
Overriding Obstacles
Avoiding Obstacles
Maximum Selected Speeds
Between Obstacles Overriding
and Avoiding Vegetation, total - 27
Maximum Selected Speeds
Avoiding Obstacles but Overriding
Vegetation, Total - 27
Average Force to Override
Obstacle
Maximum Force to Override
Obstacle
Override/Avoidance Strategy
Indicator Addition:
4. Never Override
Due to Determined
Obstacle Interference
Driver Limited Speed
Contacting Obstacle
Obstacle Approach Velocities
Up, Level, Down, Overriding
and Avoiding Vegetation, Total - 27
Obstacle Exiting Velocities
Up, Level, Down, Overriding
and Avoiding Vegetation, Total - 27
Average Speed Up, Level, Down Slope,
Overriding and Accelerating/Decelerating
Between Obstacles, Overriding and Avoiding
Vegetation, Total - 27
Possible New Obstacle/Vegetation
Override and Obstacle Avoidance/
Vegetation Override Speeds Due
Kinematic Force Vegetation
Override Check, Total - 54
Final Selected Average Patch
Speed Based on Decision Strategy:
Override Obstacles
Avoid Obstacles

DEL

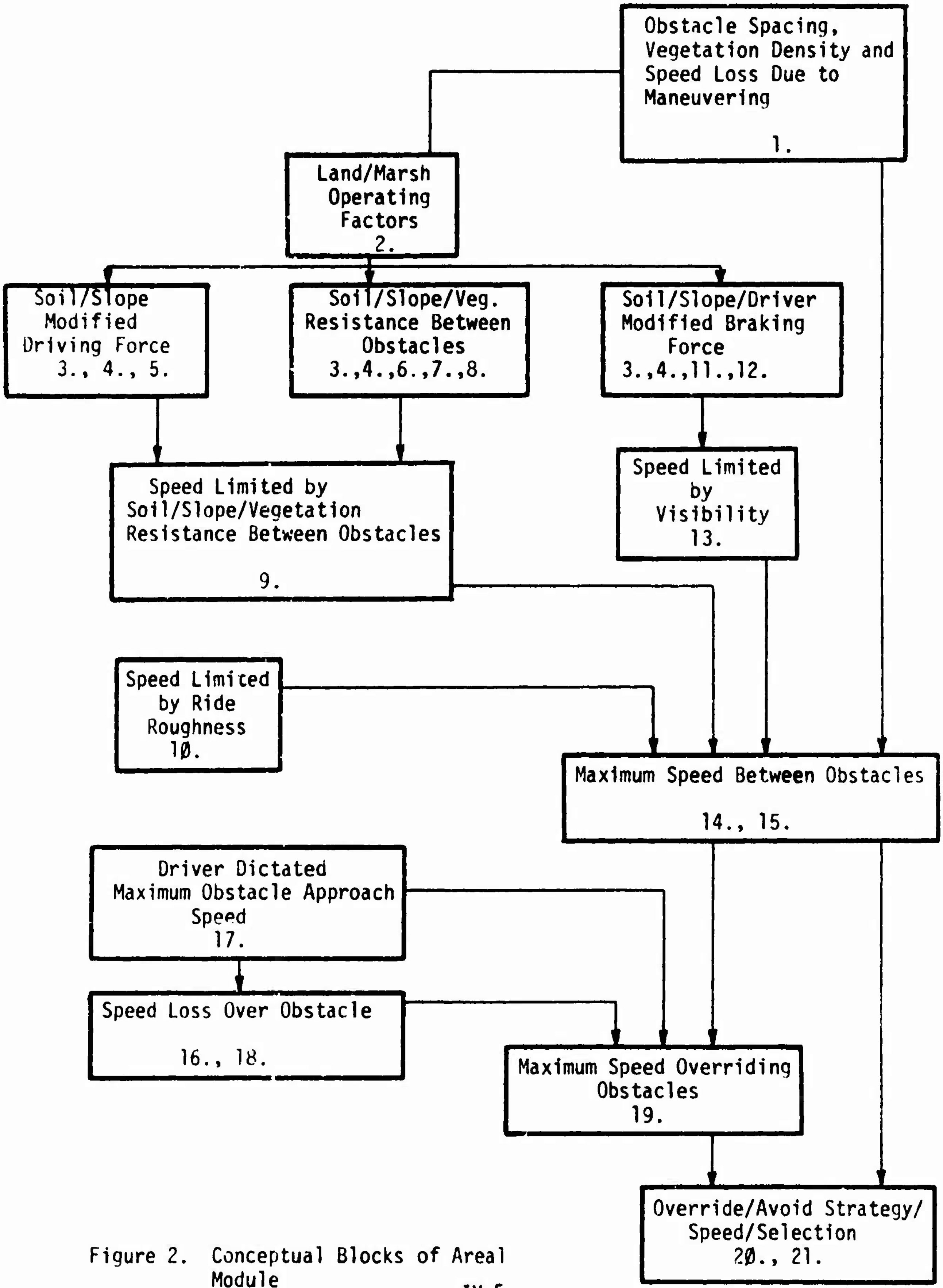
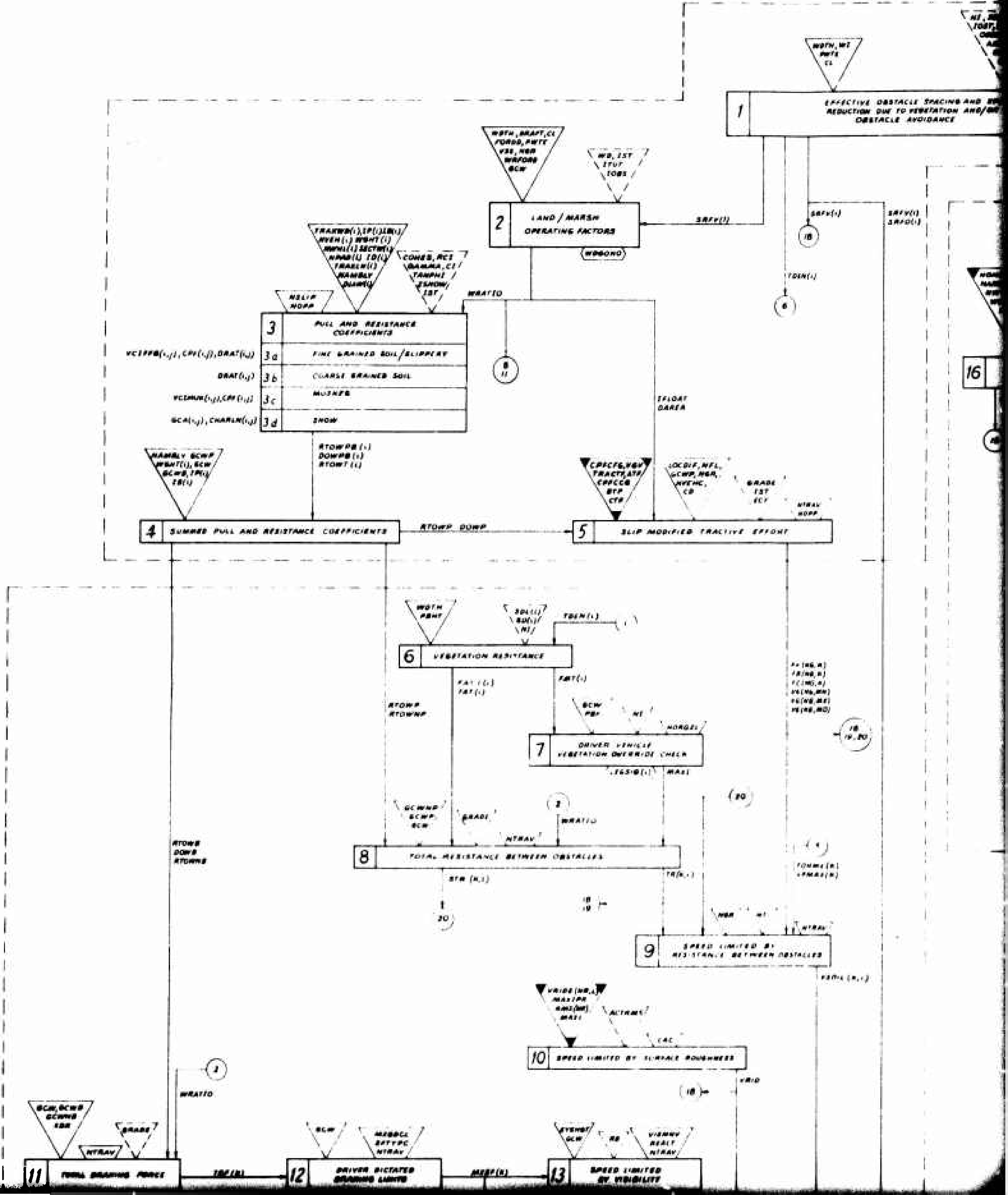
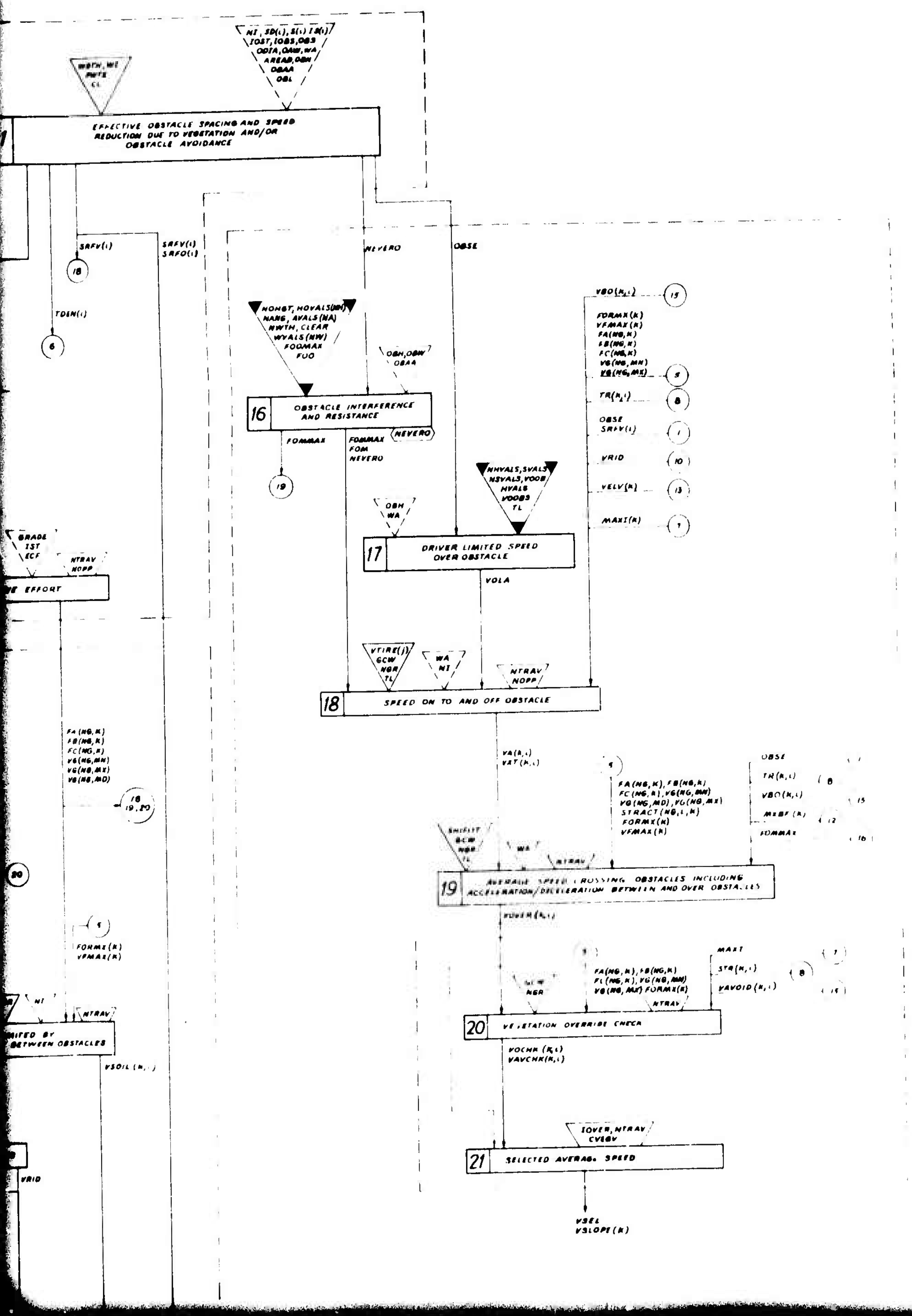
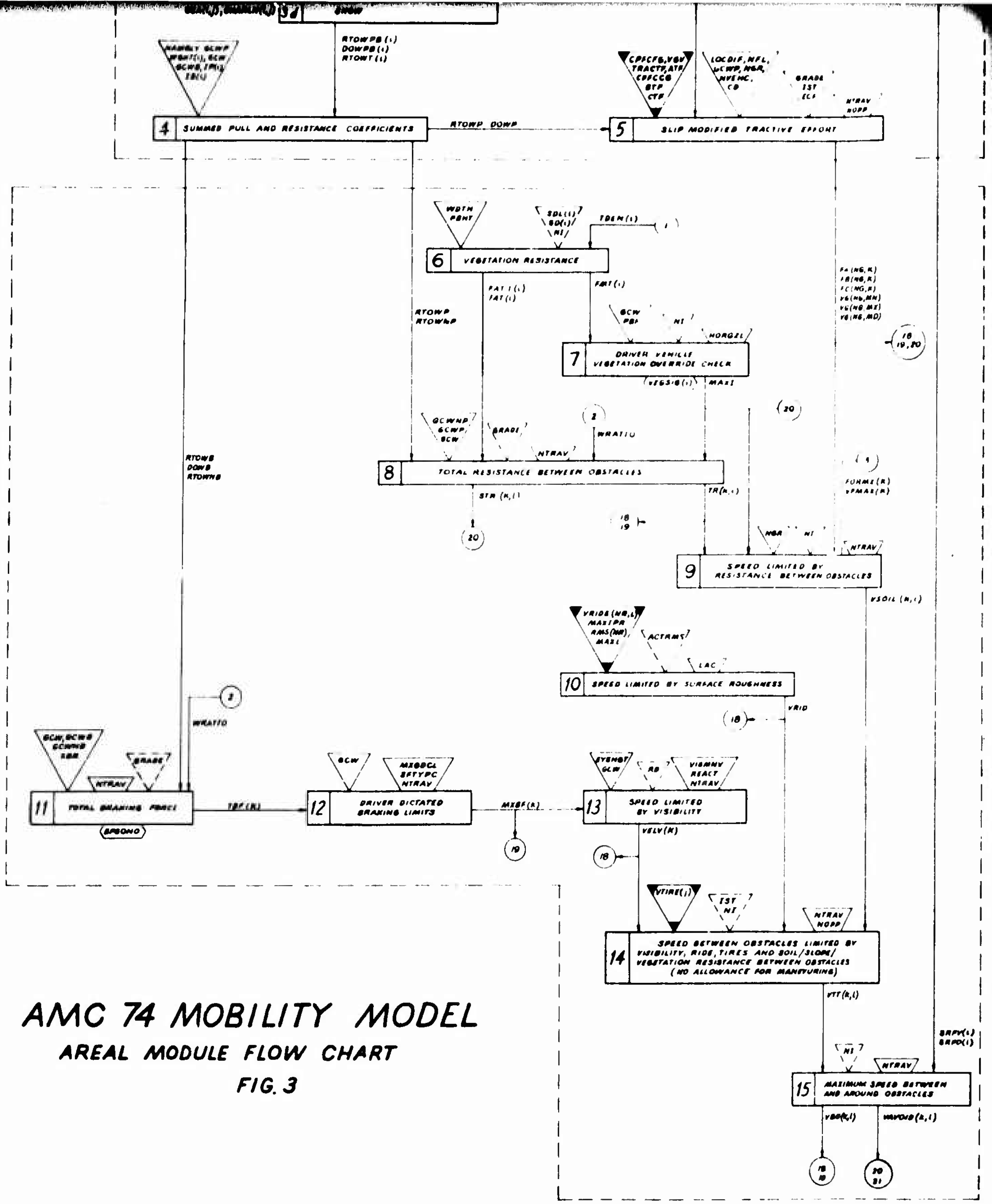


Figure 2. Conceptual Blocks of Areal Module


WDTH, WT
PWTS
CL
1
EFFECTIVE OBSTACLE SPACING AND
REDUCTION DUE TO VEGETATION AND/OR
OBSTACLE AVOIDANCE
WDTH, DRAFT, CL
FORDD, PWTS
VSS, NGR
WRFORD
GCW
WB, IST
ITUT
IOBS
2
LAND / MARSH
OPERATING FACTORS
SRFV(I)
WDBOND
SRFV(I)
18
SRFV(I)
SRFO(I)
TDEN(I)
6
TRAKWB(I), IP(I), LB(I)
NVEH(I), WGHT(I)
NWHL(I), SECTW(I)
NPAD(I), ID(I)
TRAKLN(I)
NAMBLY
DIAM(I)
COHES, RCI
GAMMA, CI
TANPHI
ISNOW
IST
NSLIP
NOPP
WRATIO
3
PULL AND RESISTANCE
COEFFICIENTS
VCIFFB(I,J), CPF(I,J), DRAT(I,J)
3a
FINE GRAINED SOIL/SLIPPERY
DRAT(I,J)
3b
COARSE GRAINED SOIL
VCIMUK(I,J), CPF(I,J)
3c
MUSKEG
GCA(I,J), CHARLN(I,J)
3d
SNOW
8
11
IFLOAT
DAREA
RTOWPB(I)
DOWPB(I)
RTOWT(I)
NAMBLY GCWP
WGHT(I), GCW
GCWB, IP(I)
IB(I)
CPFCFG, NGV
TRACTT, ATF
CPFCCG
BTF
CTF
LOCDIF, NFL,
GCWP, NGR,
NVEHC,
CD
GRADE
IST
ICY
NTRAV
NOPP
4
SUMMED PULL AND RESISTANCE COEFFICIENTS
RTOWP DOWP
5
SLIP MODIFIED TRACTIVE EFFORT
16
WDTH
PBHT
SDL(I)
SD(I)
NI
TDEN(I)
1
6
VEGETATION RESISTANCE
FAT(I)
FBT(I)
FBT(I)
RTOWP
RTOWNP
FN(NG,N)
FB(NG,N)
FC(NG,N)
VN(NG,MN)
VB(NG,MB)
VC(NG,MC)
18
19, 20
GCW
PBF
NI
NORGEL
7
DRIVER VEHICLE
VEGETATION OVERRIDE CHECK
LEGSIG(I)
MAXI
20
GCWNP
GCWP
GCW
GRADE
2
WRATIO
NTRAV
4
TORMAX(N)
VFMAX(N)
RTOWB
DOWB
RTOWNB
8
TOTAL RESISTANCE BETWEEN OBSTACLES
STR(N,I)
TR(N,I)
20
18
19
NGR
NI
NTRAV
9
SPEED LIMITED BY
RESISTANCE BETWEEN OBSTACLES
VSTOL(N,I)
VRIDE(NR,I)
MAXIPR
RMS(NR)
MAXI
ACTRMS
CAC
10
SPEED LIMITED BY SURFACE ROUGHNESS
VRID
18
2
WRATIO
GCW, GCWB
GCWNB
XBR
NTRAV
GRADE
11
TOTAL BRAKING FORCE
TBF(N)
GCW
MESBCL
ESTYPC
NTRAV
12
DRIVER DICTATED
BRAKING LIMITS
MESF(N)
EYEHGT
GCW
RB
VISMNV
REALT
NTRAV
13
SPEED LIMITED
BY VISIBILITY

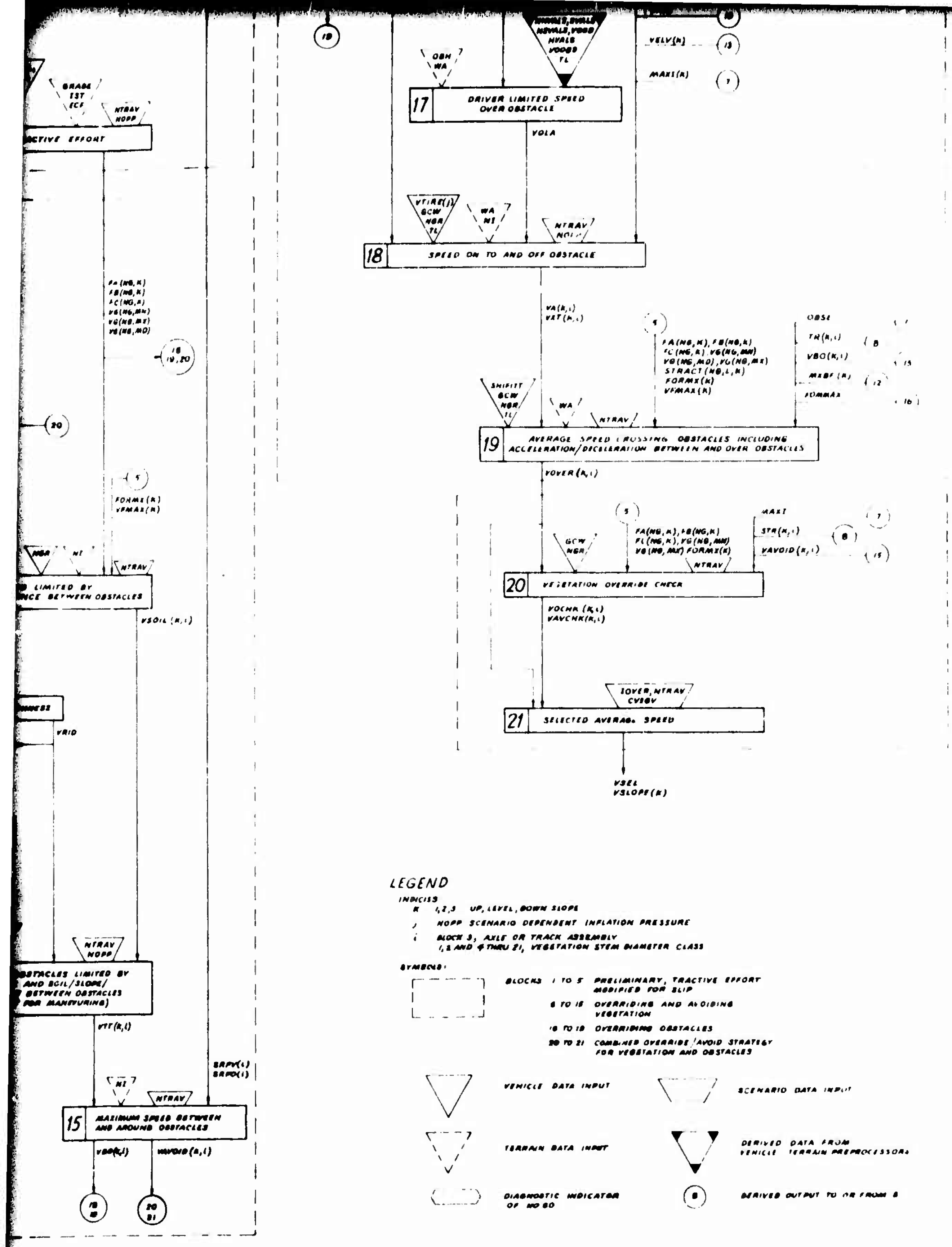

WBTH, WT
RWTS
CL
NI, SD(I), S(I) TS(I)
IOST, IOBS, OBS
ODTA, OAW, WA
AREAB, OBH
OBAA
OBL
EFFECTIVE OBSTACLE SPACING AND SPEED REDUCTION DUE TO VEGETATION AND/OR OBSTACLE AVOIDANCE
SRFV(I)
18
SRFV(I)
SRFO(I)
TDEN(I)
6
NEVERO
OBSE
NOHGT, HOVALS(NH)
NANG, AVALS(NA)
NWTH, CLEAR
WVALS(NW)
FOOMAX
FUO
OBH, OBW
OBAA
16
OBSTACLE INTERFERENCE AND RESISTANCE
NEVERO
FOMMAX
19
FOMMAX
FOM
NEVERO
VBO(K,I)
15
FORMX(K)
VFMAX(K)
FA(NG,K)
FB(NG,K)
FC(NG,K)
VG(NG,MN)
VG(NG,MX)
5
TR(K,I)
8
OBSE
SRFV(I)
1
VRID
10
VELV(K)
13
MAXI(K)
7
NHVALS, SVALS
NSVALS, VOOB
HVALS
VOOBS
TL
OBH
WA
17
DRIVER LIMITED SPEED OVER OBSTACLE
VOLA
GRADE
IST
ECF
NTRAV
NOPP
VE EFFORT
VTIRE(J)
GCW
NGR
TL
WA
NI
NTRAV
NOPP
18
SPEED ON TO AND OFF OBSTACLE
VA(K,I)
VAT(K,I)
5
FA(NG,K), FB(NG,K)
FC(NG,K), VG(NG,MN)
VG(NG,MD), VG(NG,MX)
STRACT(NG,I,K)
FORMX(K)
VFMAX(K)
OBSE
1
TR(K,I)
8
VBO(K,I)
15
MXBF(K)
12
FOMMAX
16
SHIFIT
GCW
NGR
TL
WA
NTRAV
19
AVERAGE SPEED CROSSING OBSTACLES INCLUDING ACCELERATION/DECELERATION BETWEEN AND OVER OBSTACLES
VOVER(K,I)
FA(NG,K)
FB(NG,K)
FC(NG,K)
VG(NG,MN)
VG(NG,MD)
VG(NG,MX)
18
19, 20
20
5
FORMX(K)
VFMAX(K)
NI
NTRAV
MITED BY
BETWEEN OBSTACLES
VSOIL(K,I)
VRID
5
FA(NG,K), FB(NG,K)
FC(NG,K), VG(NG,MN)
VG(NG,MX) FORMX(K)
NTRAV
MAXI
7
STR(K,I)
8
VAVOID(K,I)
15
GCW
NGR
20
VEGETATION OVERRIDE CHECK
VOCHK(K,I)
VAVCHK(K,I)
IOVER, NTRAV
CVEGV
21
SELECTED AVERAGE SPEED
VSEL
VSLOPE(K)



AMC 74 MOBILITY MODEL

AREAL MODULE FLOW CHART

FIG. 3



LEGEND

INDICISS
K 1,2,3 UP, LEVEL, DOWN SLOPE
J NOPP SCENARIO DEPENDENT INFLATION PRESSURE
I BLOCK 3, AXLE OR TRACK ASSEMBLY
1, 2 AND 4 THRU 21, VEGETATION STEM DIAMETER CLASS

SYMBOLS:

⬚	BLOCKS 1 TO 5	PRELIMINARY, TRACTIVE EFFORT MODIFIED FOR SLIP
	6 TO 15	OVERRIDING AND AVOIDING VEGETATION
	16 TO 19	OVERRIDING OBSTACLES
	20 TO 21	COMBINED OVERRIDE/AVOID STRATEGY FOR VEGETATION AND OBSTACLES

▽	VEHICLE DATA INPUT	⏢	SCENARIO DATA INPUT
▽	TERRAIN DATA INPUT	▼	DERIVED DATA FROM VEHICLE TERRAIN PREPROCESSORS
⬭	DIAGNOSTIC INDICATOR OF NO GO	⑧	DERIVED OUTPUT TO OR FROM 8

AREAL MODULE

SCENARIO VARIABLES

AND

ROUTINE SPECIFICATIONS

Scenario Values Required by Areal Module

Variable Name	Routine Used	Meaning
CVEGV	21.	= critical vegetation speed, in/sec
NSLIP	3a.	= 0 if no moisture to make surface slippery
		= 1 if < 1 in. of rain with no free surface water
		= 2 if < 6 hrs. flooding with no free surface water
		= 3 if ≥ 6 hrs. flooding with no free surface water
		= 4 if < 1 in. rain with free surface water
		= 5 if < 6 hrs. flooding with free surface water
		= 6 if ≥ 6 hrs. flooding with free surface water
HORZGL	7.	= maximum horizontal acceleration driver will tolerate when impacting tree, g's
LAC	10.	= roughness acceptance level
MXGDCL	12.	= maximum deceleration the driver will actually use, g's
NTRAV	5.,8.,9.,11.,12., 13.,14.,15.,18., 19.,20.,21.	= 1 for traverse
		= 3 for average up, level and down travel

NOPP	3.,5.,14., 18.	= operating tire pressure indicator: = 0 tire pressure soil dependent = 1 if always use fine grained soil dependent tire pressure = 2 if always use coarse grained soil dependent tire pressure = 3 if always use highway dependent tire pressure
SFTYPC	12.	= percent of maximum deceleration available that the driver will actually use, percent
VISMNV	13.	= speed at which vehicle will proceed if visibility is entirely obscured (walking speed), in/sec
REACT	13.	driver reaction time from steady vehicle running to initialization of deceleration, sec.
IOVER	21.	one greater than the index of the maximum stem diameter class to be overridden if speed to do so is greater than 2 times walking speed

VEHICLE INPUT DATA REQUIRED BY AREAL MODULE

Variable	Routine	Meaning
ATF(NG)	5	Constant of quadratic fitted to vehicle tractive effort curve in gear NG, lb.
AVALS(NA)	16	Value of NAth approach angle, radians
BTF(NG)	5	Coefficient of linear term of quadratic fitted to vehicle tractive effort curve in gear NG, lb(in/sec)
CHARLN(i)	3d	Characteristic length of tire element or track on running gear assembly i, in.
CD	5	Water drag coefficient
CL	1,2	Minimum ground clearance of combination, in.
CPFCCG(j)	5	Maximum contact pressure factor of all running gear assemblies of the type specified by NVEHC for coarse grained soil, lb/in^2, at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway
CPFCFG(j)	5	Maximum contact pressure factor of all running gear assemblies of the type specified by NVEHC for fine grained soil, lb/in^2, at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway
CPFFG(i,j)	3a,3c	Contact pressure factor of running gear assembly i, lb/in^2, fine grained soil at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway

Variable	Routine	Meaning
CTF(NG)	5	Coefficient of quadratic term of quadratic fitted to vehicle tractive effort in gear NG, lb/(in/sec)^2
DIAW(i)	3a,3b,3d	Outside wheel diameter of unloaded tires on running gear assembly i, in.
DRAFT	2	Combination draft when fully floating, in. = 0 if combination cannot float
DRAT(i,j)	3a,3b	Deflection ratio of each tire on running gear assembly i under load WGHT(i)/NWHL(i) at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway
EYEHGT	13	Height of driver's eyes above ground, in.
FORDD	2	Maximum water depth combination can ford, in. (FORDD = DRAFT if DRAFT ≠ 0)
GCA(i,j)	3d	Nominal ground contact area per tire element or track pair on running gear assembly i, in^2, at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway
GCW	2,4,7,8, 11,12,13, 18,19,20	Gross combination weight, lb.
GCWB	4,11	Gross combined weight on all braked running gear assemblies, lb.
GCWNB	11	Gross combined weight on all non-braked running gear assemblies, lb.

Variable	Routine	Meaning
GCWNP	8	Gross combined weight on all non-powered running gear assemblies, lb.
GCWP	4,5,8	Gross combined weight on all powered running gear assemblies, lb.
HOVALS(NH)	17	Value of NHth obstacle height, in.
IB(i)	3a,3b,3c, 3d,4	= 1 if running gear assembly i is braked = 0 otherwise
ID(i)	3b	= 0 if wheels are singles = 1 if duals
IP(i)	3a,3b,3c, 3d,4	= 1 if running gear assembly i is powered = 0 otherwise
LOCDIF	5	= 1 if all powered running gear assemblies have locking differentials = 0 otherwise
MAXIPR	10	Number of surface roughness values per tolerance level
MAXL	10	Number of roughness tolerance levels specified
NAMBLY	3a,3b,3c, 3d,4	Total number of running gear assemblies of the combination
MD	5,9,18, 19	Midpoint index of tractive effort versus speed curve
MN	5,9,18, 19	Minimum index of tractive effort versus speed curve

Variable	Routine	Meaning
MX	5,9,18, 19, 20	Maximum index of tractive effort versus speed curve
NANG	16	Number of obstacle approach angle values for which force to override obstacles is given
NFL	5,9,18, 19,20	= 0 if track is rigid = 1 otherwise
NGR	5,9,18, 19,20	Number of gears
NHVALS	17	Number of obstacles height values used in VOOB and HVALS
NPAD(i)	3a	=1 if track element has pads =0 otherwise
NSVALS	17	Number of obstacle spacing values used in VOOBS and SVALS
NVEH(i)	3a,3b, 3c,3d	= 0 if running gear assembly i is tracked ≠ 0 if wheeled
NVEHC	5	= 0 if one or more of the powered running gear assemblies is tracked ≠ 0 otherwise
NOHGT	16	Number of obstacle height values for which force to override obstacles is given
NWHL(i)	3a,3d	Number of tires on wheeled assembly i
NWR	2	Number of water depths between 0 and FORDD for which weight ratios are given

Variable	Routine	Meaning
NWTH	16	Number of obstacle widths values for which force to override obstacles is given
PBF	7	Maximum force pushbar can tolerate, lb.
PBHT	6	Unit pushbar height, in.
PWTE	1,2	Maximum path width of traction elements for one side of combination, in.
RMS(NR)	10	NRth surface roughness value, in.
SECTW(i)	3a,3b,3d	Section width of tires on running gear assembly i, in.
SHIFTT	19	Gear shift time, sec.
TL	17,18,19	Distance from front of first running gear assembly to rear of last, in.
TRACTF(NG,MD)	5	Tractive force available from drive train at mid-range speed index MD in gear NG, lb.
TRACTF(NG,MN)	5	Tractive force available from drive train at minimum speed index MN in gear NG, lb.
TRACTF(NG,MX)	5	Tractive force available from drive train at maximum speed index MX in gear NG, lb.
TRAKLN(i)	3b	Ground length of track on running gear assembly i, in.
TRAKWD(i)	3b	Track width of track assembly i, in.
VCIFG(i,j)	3a	One pass vehicle cone index in fine grained soil applied to running gear assembly i, lb/in^2, at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway

Variable	Routine	Meaning
VCIMUK(i)	3c	One pass vehicle cone index in muskeg applied to running gear assembly i, lb/in^2
VGV(NG,MD)	5	Mid-range speed in gear NG, in/sec
VGV(NG,MN)	5	Minimum speed in gear NG, in/sec
VGV(NG,MX)	5	Maximum speed in gear NG, in/sec
VOOB(NH)	17	Maximum driver limited speed at which vehicle can cross an obstacle of height HVALS(NH) if obstacles are spaced further than two vehicle lengths apart, in/sec
VOOBS(NS)	17	Maximum driver limited speed at which vehicle can cross successive obstacles spaced SVALS(NS) apart, in/sec
VRIDE(NR,L)	10	Maximum speed over ground for a surface roughness class NR and roughness tolerance level index L, in/sec
VSS	1	Maximum vehicle combination swimming speed, in/sec
VTIRE(j)	3	Maximum steady state speed allowed beyond which structural damage will occur to tires, in/sec at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway

Variable	Routine	Meaning
WDTH	1,2,6	Maximum combination width, in.
WDPTH(n)	2	n^{th} water depth, in.
WTMAX	1	Minimum width between combination running gear elements, in.
WRAT(n)	2	Weight ratio on ground at water depth WDPTH(n)
WRFORD	2	Proportion of combination weight supported by ground when combination is operating at maximum fording depth
XBR	11	Maximum braking effort vehicle can develop, lb.
WI	1	Minimum width between running gear elements, in.
WGHT(i)	3a,3b, 3d, 4	Weight on running gear assembly i, lb.
WVALS(NW)	16	Value of NW^{th} obstacle width, in.

1. Effective Obstacle Spacing and Speed Reduction Factors due to Vegetation and/or Obstacle Avoidance

Description This routine combines the calculations of area denied by vegetation and obstacles and the resulting speed reduction factors, all of which are done separately in AMC '71.

A new feature incorporated in AMC '74 is the calculation of an effective vehicle width EWDTH for round obstacles (stumps, boulders and holes). EWDTH depends on whether the round obstacle fits between the traction elements (a2) or not (a1). If it fits, a check is made for sufficient axle clearance. The density of obstacles then yields an effective obstacle spacing depending on the above effective vehicle width. This routine also sets a flag, NEVERO, indicating to the other routines that under certain circumstances obstacles should never be overridden.

Inputs

Vehicle: WDTH = maximum combination width, in.

PWTE = maximum patch width of traction elements for one side of combination, in.

WI = minimum width between running gear elements, in.

CL = minimum ground clearance of combination, in.

Terrain: NI = number of stem diameter classes

IS(i) = 1 if patch is bare of vegetation in stem class i and greater;

≠ 1 otherwise

SD(i) = mean stem diameter of vegetation in stem diameter class i, in.

S(i) = mean spacing of stems in stem diameter class i and larger, in.

IOBS = 1 if patch is bare of obstacles

≠ 1 otherwise

IOST = obstacle spacing type

= 1 for potentially avoidable orientation

= 2 for unavoidable orientation

OBS = obstacle spacing, in.

ODIA = maximum extent across obstacle, in.

OAW = mean obstacle approach width, in.

AREAO = patch area per obstacle, in^2

OBAA = obstacle approach angle, radians

OBH = obstacle height, in.

OBL = obstacle length, in.

WA = ground level width of obstacle, in.

Outputs

SRFV(i) = speed reduction factor due to avoiding vegetation in stem diameter class i and greater

OBSE = effective obstacle spacing, in.

TDEN(i) = density of vegetation in stem diameter class i, stems/in^2

SRFO(i) = speed reduction factor due to avoiding obstacles and vegetation in stem diameter class i or greater

NEVERO = 0 if override/avoidance strategy may choose obstacle override

= 1 if override/avoidance strategy will never choose obstacle override due to belly/axle interference with stumps or boulders

= 2 if override/avoidance strategy will never choose obstacle override due to lack of penalty for obstacle avoidance

Algorithm

a. Obstacle spacing and check for stump/boulder interference

```
if IOBS = 1
   then NEVERO = 2
   ADO = 0.
   do c.
else CLRNCE = CL-OBH
     NEVERO = 0
if IOST = 2
   then OBSE = OBS
   ADO = 100.
   do c.
else obstacles are potentially avoidable
```

```
a1. if ODIA $\geq$ WI then obstacle is long
       EWDTH = WDTH+OAW
       OBSE = AREAO/EWDTH
       do b.
a2. else obstacle is round
    EWDTH = PWTE+OAW
    OBSE = AREAO/EWDTH
    If OBAA $\leq$ 0. then obstacle is a hole
       do b.
    else obstacle is a boulder or stump
       if CLRNCE $\leq$ 0. then NEVERO = 1
                                   EWDTH = WDTH+OAW
                                   OBSE = AREAO/EWDTH
       else do b.
b.  Percent area denied due to avoiding obstacles, ADO
    $ADO = (OBL*WA+(OBL+WA)*WDTH+WDTH^2*\pi/4)*100/(OBSE^2*\pi/4)$
c.  Percent area denied due to avoiding vegetation (PAV), total
    percent area denied (ADT), and speed reduction factors
    do for i = 1 to NI -1
          if IS(i) = 1
             then TDEN(i) = 0.
          else
             $TDEN(i) = \frac{4}{\pi} * \left[ \frac{1}{S(i)^2} - \frac{1}{S(i+1)^2} \right]$
             next i
```

```
if IS(NI) = 1
   then TDEN(NI) = 0.
   do routine c1.
else TDEN(NI)= $4/[\pi*S(NI)^2]$

c1. Calculate percent area denied due vegetation, PAV
    do for i = 1 to NI
    SUMDEN = $\sum_{k=i}^{NI}$ TDEN(K)
    if SUMDEN = 0.
       then PAV(i) = 0.
       do routine c2.
    else
       PAV(i) = $\frac{100.}{S(i)^2} * \left[ \frac{\sum_{K=i}^{NI} SD(K)*TDEN(K)}{\sum_{K=i}^{NI} TDEN(K)} + WDTH \right]^2$
c2. ADT = ADO+PAV(i)*[100.-ADO]/100
    if PAV(i) < 10.
       then SRFV(i) = 1
    else if PAV(i) $\leq$ 50.
            then SRFV(i) = 1.-[PAV(i)-10.]/40.
         else SRFV(i) = 0.
```

```
    if ADT < 10.
       then SRFO(i) = 1
       next i
    else if ADT ≤ 50.
            then SRFO(i) = 1.-[ADT-10.]/40.
            next i
         else SRFO(i) = 0.
              next i
d.  After all i
    if SRFV(i) = SRFO(i) for all i then NEVERO = 2.
    exit
```

2. Land/Marsh Operating Factors

Description

This routine calculates the weight reduction factors [WRATIO] and the frontal area under water and water speed in a marsh as defined by maneuvering requirements. The weight reduction factors are calculated in (b1.) and (b2.) from the actual water depth (WD) and the known ratios given for various submerged depths (WDPTH(n)) of the vehicle. The weight reduction factor modifies the traction in subsequent submodels. The frontal area is used for calculating drag which also modifies traction. A return to the control module may take place if the vehicle is not a swimmer and the water is too deep to ford. If the vehicle is fully floating, the water speed is reduced by the vegetation maneuvering factor calculated in 1. and an exit is made to the control module. If there is no water, the factors are set to values which eliminate water effects in subsequent routines.

This routine tests the soil type and transfers control to the appropriate pull and resistance coefficient routine.

This routine replaces a section of MAIN and all of MARSH in AMC '71.

Inputs

Vehicle: WDTH = maximum combination width, in.

DRAFT = combination draft when fully floating, in. (= 0 if combination cannot float)

FORDD = maximum water depth combination can ford, in. (FORDD = DRAFT if DRAFT ≠ 0.)

CL = minimum ground clearance of combination, in.

PWTE = path width of traction elements on one side of combination, in.

VSS = maximum combination swimming speed, in/sec

NWR = number of water depths from 0 to FORDD for which weight ratios are given

WDPTH(n) = n^{th} water depth, in.

WRAT(n) = weight ratio on ground at water depth WDPTH(n)

WRFORD = proportion of combination weight supported by ground to combination weight when combination is operating at maximum fording depth

GCW = gross combination weight, lb.

Terrain: WD = water depth, in.

IST = soil type

ITUT = 1 if normally dry patch

= 2 if marsh

IOBS = 1 if patch is bare of obstacles

≠ 1 otherwise

Derived: SRFV(1) = speed reduction factor due to avoiding all vegetation

Outputs

WDGONO = 1 if water too deep for operation

= 0 if otherwise

IFLOAT = 0 if no standing water

= 1 if vehicle is fording

= 2 if vehicle is fully floating

WRATIO = ratio of combination weight supported by ground to combination weight

DAREA = frontal area under water, in.^{2}

VSEL = selected average speed, in./sec.

Algorithm

```
a.  Set operation type

    WDGONO = 0.

    if ITUT = 1 or IST = 4 (snow) then land operation

                    IFLOAT = 0.

                    WRATIO = 1.

                    DAREA = 0.

                    do c.

    else do b.


 b. IOBS = 1 (no obstacles)

    GRADE = 0.
```

```
if WD > FORDD
   then if DRAFT = 0
         then water too deep
              WDGONO = 1
              VSEL = 0.
              return to module I.  Control and I/O
         else vehicle fully floating
              IFLOAT = 2
              VSEL = VSS*SRFV(2)
              return to module I.  Control and I/O
b1. else (WD ≤ FORDD)
         IFLOAT = 1
         if WD ≤ WDPTH(1)
            then $WRATIO = 1. + WD*\frac{WRAT(1)-1.}{WDPTH(1)}$
           do b3.
b2.      else do for n = 2 to NWR
               if WD ≤ WDPTH(n)
                  then $WRATIO = WRAT(n-1)+[WRAT(n)-WRAT(n-1)]*\frac{WD-WDPTH(n-1)}{WDPTH(n)-WDPTH(n-1)}$
                  do b3.
               else next n
         after all n [WD > WDPTH(NWR)]
               $WRATIO = WRAT(NWR)+[WRFORD-WRAT(NWR)]*\frac{WD-WDPTH(NWR)}{FORDD-WDPTH(NWR)}$
```

```
b3.     if WD > CL then DAREA = WDTH*(WD-CL)+2.*PWTE*CL
        else DAREA = 2.*PWTE*WD
c.  if IST = 1 do 3a.
    if IST = 2 do 3b.
    if IST = 3 do 3c.
    if IST = 4 do 3d.
    if IST = 6 do 3a.
```

3a. Fine Grained Soil Pull and Resistance Coefficients

Description This routine calculates the pull and resistance coefficients for fine grained soils. A major new feature here is the addition of equations to calculate the effect on traction due to recent rainfall, flooding and/or standing water causing slippery soil surface conditions. Another is the application of the pull and resistance coefficient equations on an axle-by-axle basis, thereby more accurately reflecting the load distribution per axle and to accommodate unpowered axles. This approach enables one to handle mixed running gears such as a tracked vehicle pulling a wheeled trailer. An additional new feature is the possibility of using either a constant specified tire inflation pressure or to allow it to vary with the soil type. The variable inflation pressure determines three possible contact pressure factors CPF (i,j) where j is the indicator for inflation pressure used on fine grained, coarse grained soils or on the highway.

For the calculation of towed resistance, recent revisions by Turnage (4) were used instead of the mobility index which was used in AMC '71.

This routine corresponds to FOIL in AMC '71.

Since the analysis of vehicle performance on slippery soil has not been published before, a more detailed explanation is in order.

Slipperiness effects are included whenever soil surfaces are flooded or locally very wet. Separate relations are used for CH soils, which are impervious to water, and for other, more pervious fine grained soils. Where the soil is very soft, however, slipperiness is not a factor ($RCIX < 20$). If $RCIX \geq 20$, the drawbar coefficient (DOWS) is reduced in accordance with the equations in b and c. Note that when $RCIX > RCIS$, the reduction factor becomes constant indicating a "skating condition" on an extremely hard surface. The routine also takes into account the presence or absence of track pads (NPAD = 1 or NPAD = 0).

An additional factor is included in the analysis for tires (see paragraph c). This is DRAT(i,j) which accounts for the beneficial effect of high inflation pressure, which helps to maintain the "circular" shape of the tire and thereby improves the tire's ability to break through the slippery layer.

<u>Inputs</u> Vehicle: NAMBLY = number of running gear assemblies of the combination

IP(i) = 1 if running gear assembly i is powered

= 0 otherwise

IB(i) = 1 if running gear assembly i is braked

= 0 otherwise

VCIFG(i,j) = one pass vehicle cone index for fine grained soil applied to running gear assembly i, lb/in^2 at pressure specified for j = 1 fine grained, = 2 coarse grained, = 3 highway

NVEH(i) = 0 if running gear assembly i is tracked

≠ 0 if wheeled

WGHT(i) = weight on running gear assembly i, lb.

NWHL(i) = number of tires on running gear assembly i

SECTW(i) = section width of tires on running gear assembly i, in.

DIAW(i) = outside wheel diameter of unloaded tire on running gear assembly i, in.

DRAT(i,j) = deflection ratio of each tire on running gear assembly i under load WGHT(i)/NWHL(i) at pressure specified for j = 1 fine grained, = 2 coarse grained, = 3 highway

NPAD(i) = 1 if track element has pads

= 0 otherwise

CPFFG(i,j) = contact pressure factor of running gear assembly i, lbs/in^2 at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway

Terrain: RCI = rating cone index, lb/in^2

IST = soil type

= 1 for fine grained (except CH class) soils

= 6 for fine grained CH class soils, impervious to water

Derived: WRATIO = proportion of combination weight supported by ground

Scenario: NSLIP = 0 no slipperiness

= 1 if < 1 in. rain no free water

= 2 if < 6 hr. flooding no free water

= 3 if > 6 hr. flooding no free water

= 4 if < 1 in. rain free surface water

= 5 if < 6 hr. flooding free surface water

= 6 if > 6 hr. flooding free surface water

NOPP = operating tire pressure indicator:

= 0 tire pressure soil dependent

= 1 if always use fine grained soil dependent tire pressure

= 2 if always use coarse grained soil dependent tire pressure

= 3 if always use highway dependent tire pressure

Subroutine used: FGSPC

Outputs RTOWPB(i) = resistance coefficient of powered or braked assembly i due to soil

DOWPB(i) = pull coefficient of powered or braked assembly i due to soil

RTOWT(i) = resistance coefficient of towed assembly i due to soil

Algorithm

```
a.  If NOPP = 0

       then j = 1

    else j = NOPP

    do for i = 1 to NAMBLY

       RCIX = RCI -  VCIFG(i,j)

    if IP(i)+IB(i) = 0 then assembly i neither powered or braked

                      RTOWPB(i) = 0.

                      DOWPB(i) = 0.

                      do towed running gear resistance
                      routine e.

    else assembly is either powered and/or braked

    if NSLIP = 0 then no slipperiness

                 CALL FGSPC(D,RCIX,NEVH(i),CPFFG(i,j))

                 DOWPB(i) = D

                 Do resistance routines d. and e.

    else soil is slippery

        if NEVH(i) = 0 then do tracked slippery fine grained
                       soil routine b.

        else do wheeled slippery fine grained soil routine c.
```

b. Tracked slippery fine grained soil routine

```
    RCIO = 20.
    DOWCO = 0.55
    if RCIX ≤ 20.
      then CALL FGSPC(D,RCIX,i,NVEH(i),CPFFG(i,j))
             DOWPB(i) = D
             do resistance routine d. and e.
    else if IST = 6 then for NSLIP = 1; DOWCS = .50, RCIS = 200.
                             NSLIP = 2; DOWCS = .30, RCIS = 150.
                             NSLIP = 3; DOWCS = .30, RCIS = 200.
                             NSLIP = 4; DOWCS = .10, RCIS = 200.
                             NSLIP = 5; DOWCS = .10, RCIS = 300.
                             NSLIP = 6; DOWCS = .15, RCIS = 500.
                             do routine b1.
        else (IST = 1)
        then RCIS = 100.
        for:  NSLIP = 1; DOWCS = .45
              NSLIP = 2; DOWCS = .30
              NSLIP = 3; DOWCS = .20
              NSLIP = 4; DOWCS = .10
              NSLIP = 5; DOWCS = .10
              NSLIP = 6; DOWCS = .15
b1.  if 20.< RCIX < RCIS
       then XN = LOG (DOWCO/DOWCS)/LOG(RCIS/RCIO)
            $XK = DOWCS*(RCIS)^{XN}$
```

```
    DOWS = XK*$(\frac{1}{RCIX})^{XN}$
    if NPAD = 1
       then DOWPB(i) = DOWS
               do resistance routines d. and e.
    else CALL FGSPC(D,RCIX,NVEH(i),CPFFG(i,j))
                DOWPB(i) = .5*(D+DOWS)
                do resistance routines d. and e.
else (RCIX $\geq$ RCIS)
   if NPAD = 1 then DOWPB(i) = DOWCS
                    do resistance routines d. and e.
   else CALL FGSPC(D,RCIX,NVEH(i),CPFFG(i,j))
        DOWPB(i) = .5*(D+DOWS)
        do resistance routines d. and e.
```

c. Wheeled slippery fine grained soil routine

```
XKDELT = DRAT(i,j)/0.4-0.375
RCIO = 18.
DOWCO = 0.4
if RCIX $\leq$ 20.
   then RCIX = RCIX-2.
        CALL FGSPC(D,RCIX,NVEH(i),CPFFG(i,j))
        DOWPB(i) = D
        do resistance routines d. and e.
```

```
      else (RCIX > 20)
            if IST = 6 then for:
                  NSLIP = 1; DOWCS = .35, RCIS = 300
                  NSLIP = 2; DOWCS = .25 +XKDELT, RCIS = 150.
                  NSLIP = 3; DOWCS = .20 +XKDELT, RCIS = 200.
                  NSLIP = 4; DOWCS = .15 +XKDELT, RCIS = 150.
                  NSLIP = 5; DOWCS = .15 +XKDELT, RCIS = 150.
                  NSLIP = 6; DOWCS = .15, RCIS = 100.
                  do routine c1.
            else (IST = 1)
              RCIS = 80.
              for :  NSLIP ≠ 1 or ≠ 4; DOWCS = 0.10
                     NSLIP = 1; DOWCS = 0.30
                     NSLIP = 4; DOWCS = 0.10 + XKDELT
c1. if 20.< RCIX < RCIS
         then XN = LOG(DOWCO/DOWCS)/LOG(RCIS/RCIO)
              $XK = DOWCS*(RCIS)^{XN}$
               $DOWPB(i) = XK*(1./RCIX)^{XN}$
               do resistance routines d. and e.
    else (RCIX ≥ RCIS)
           DOWPB(i) = DOWCS
           do resistance routines d. and e.
d.  Powered running gear resistance
    if NVEH(i) = 0 then assembly is tracked
       if RCIX ≥ 0.
```

```
           then RTOWPB(i) = .045+2.3075/(RCIX+6.5)
       else if CPFFG(i,j) < 4.
                   then RTOWPB(i) = .4-.072*RCIX
                   do routine e.
               else (CPFFG(i,j) ≥ 4.)
                       RTOWPB(i) = .4-.052*RCIX
                       do routine e.
    else assembly is wheeled
                if RCIX ≥ 0.
                    then if CPFFG(i,j) < 4.
                               then RTOWPB(i) = .035+.861/(RCIX+3.249)
                               do routine e.
                           else (CPFFG(i,j) > 4.)
                                       RTOWPB(i) = .045+2.3075/(RCIX+6.5)
                                       do routine e.
                else (RCIX < 0.)
                        if CPFFG(i,j) < 4.
                            then RTOWPB(i) = .3-.043*RCIX
                            do routine e.
                        else RTOWPB(i) = .4-.029*RCIX
e.  Towed running gear routine
      if IB(i) and IP(i) ≠ 0 then assembly is never towed
                                              RTOWT(i) = 0.
                                              next assembly i
```

```
else if NVEH(i) $\neq$ 0 (running gear is a wheeled axle)
        then WPW = WGHT(i)*WRATIO/NWHL(i)
        $BETA = \frac{\overline{RCI*SECTW(i)*DIAW(i)*DRAT(i,j)}^{1/2}}{WPW*[1. + \frac{2\ SECTW(i)}{2.*DIAW(i)}]}$
        if BETA $\leq$ 2.
           then RTOWT(i) = 1. - .3412*BETA
                next assembly i
        else RTOWT(i) = .04 + .2/[BETA-1.35]
                         next assembly i
     else running gear assembly is a left/right pair of
          track elements - set error flag since towed or
          unbraked tracked assemblies not included in
          this model.  Return to Module I. Control and I/O.
```

Fine Grained Soil Pull Coefficient Subroutine

Description Subroutine FGSPC calculates the pull coefficient (traction/weight) in a fine grained soil. The computations are the same as in FOIL in AMC '71 with the exception that the excess RCI (RCIX) is allowed to be less than zero, the reason for this is to accommodate unpowered (but braked) axles.

Subroutine FGSPC(D,RCIX,NVEH,CPF)

Input Vehicle: NVEH = 0 if running gear assembly is tracked

$\neq 0$ if wheeled

CPF = contact pressure factor of running gear assembly, lb/in^2

Derived: RCIX = excess RCI, lb/in^2

Output D = pull coefficient

Algorithm

```
If NVEH = 0 then running gear assembly is tracked
    then if CPF < 4.
        then if RCIX $\geq$ 0.
            then D = $0.544+0.463*RCIX-[(0.544+0.0463*RCIX)^2-0.0702*RCIX]^{1/2}$
                exit
        else D = 0.076*RCIX
            exit
    else (CPF $\geq$ 4.)
        if RCIX $\geq$ 0.
            then D = $0.4554+0.0392*RCIX-[(0.4554+0.0392*RCIX)^2-0.0526*RCIX]^{1/2}$
                exit
        else D = 0.056*RCIX
            exit
else (NVEH $\neq$ 0) running gear assembly is wheeled
```

```
if $CPF < 4.$
    then if $RCIX \geq 0.$
            $D = 0.3885-0.0265*RCIX-[(0.3885+0.0265*RCIX)^2-0.0358*RCIX]^{1/2}$
            exit
        else ($RCIX < 0.$)
            $D = 0.046*RCIX$
            exit
else ($CPF \geq 4.$)
        if $RCIX \geq 0.$
            then $D = 0.379+0.0219*RCIX-[(0.379+0.0219*RCIX)^2-0.0257*RCIX]^{1/2}$
                exit
        else ($RCIX < 0.$)
            $D = 0.033*RCIX$
            exit
```

3b. Coarse Grained Soil Pull and Resistant Coefficient

Description In this routine, calculations for both drawbar and resistance coefficients are performed for coarse grained soils "axle-by-axle" for wheeled vehicles and track unit-by-track unit for tracked vehicles.

Dimensionless numerics developed by Turnage (4) are used instead of VCI. Numeric PIT is used in the calculation of the resistance coefficient and numeric PID is used for calculating the drawbar coefficient.

Input Vehicle: NAMBLY = total number of running gear assemblies of the combination

NVEH(i) = 0 if running gear assembly i is track

≠ 0 if wheeled

IP(i) = 1 if assembly i is powered, 0 if not

IB(i) = 1 if assembly i is braked, 0 if not

NWHL(i) = number of tires on wheeled assembly i

ID(i) = 1 if wheels on assembly i are duals

= 0 if singles

WGHT(i) = weight on running gear assembly i, lb.

SECTW(i) = section width of tires on running gear assembly i, in.

DIAW(i) = outside wheel diameter of unloaded tires on running gear assembly i, in.

DRAT(i,j) = deflection ratio of tires on running gear assembly i under load WGHT(i)/NWHL(i) at pressure specified for i=1 fine grained, =2 coarse grained, =3 highway

TRAKLN(i) = ground contact length of track on running gear assembly i, in.

TRAKWD(i) = track width of track assembly i, in.

Terrain: CI = cone index, lb/in.^{2}

Scenario: NOPP = operating tire pressure indicator:

= 0 tire pressure soil dependent

= 1 if always use fine grained soil dependent tire pressure

= 2 if always use coarse grained soil dependent tire pressure

= 3 if always use highway dependent tire pressure

Derived: WRATIO = proportion of combination weight supported by ground

Outputs

RTOWPB(i) = resistance coefficient of powered or braked assembly i due to soil

DOWPB(i) = pull coefficient of powered or braked assembly i due to soil

RTOWT(i) = resistance coefficient of towed assembly i due to soil

Algorithm

```
a. Common calculations and control decision

   G = CI*.8645/3.

   if NOPP = 0

      then j = 2

   else j = NOPP

   do for i = 1 to NAMBLY

   if NVEH(i) = 0 do tracked routine b.

   else do wheeled routine c.

b. Tracked element routine

   RTOWT(i) = 0.

   if IP(i)*IB(i) = 0

      then error:  towed or unbraked tracked elements not
                   included in this model.  Return to Module I.
                                            Control and I/O
```

```
        PIT = $.6*G*[TRAKWD(i)*TRAKLN(i)]^{1.5}/(WGHT(i)*WRATIO/2.)$
        if PIT $\leq$ 25. then DOWPB(i) = $.121 + .258*\log_{10}(PIT)$
        else if PIT $\leq$ 100. then DOWPB(i) = $.482 + .125*\log_{10}(PIT)$
            else if PIT $\leq$ 1000. then DOWPB(i) = $.555+.04*\log_{10}(PIT)$
                else DOWPB(i) = .595
        RTOWPB(i) = .6 - DOWPB(i)
        next i
    c.  Wheeled axle routine
        if IP(i)*IB(i) $\neq$ 0
           then RTOWT(i) = 0.
           do routine c1.
        else
           W = WGHT(i)*WRATIO/NWHL(i)
           PIT = $\frac{G*[SECTW(i)*DIAW(i)]^{3/2}*i^{1/3}}{W*[1.-DRAT(i,j)]^{3}*[1.+SECTW(i)/DIAW(i)]}$
           RTOWT(i) = $.44-.01*PIT+SQRT([.44-.01*PIT]^{2}+.0002*PIT+.08)$
    c1. if IP(i)+IB(i) = 0  then DOWPB(i) = 0.
                                 RTOWPB(i) = 0.
                                 next i
        else if ID(i) = 1 then B = 2*SECTW(i)
                               W = 2*WGHT(i)*WRATIO/NWHL(i)
                               do routine c2.
            else B = SECTW(i)
                W = WGHT(i)*WRATIO/NWHL(i)
```

```
c2.     $PID = G*[B*DIAW(i)]^{3/2}*DRAT(i,j)/[i^{1/2}*W]$
        DOWPB(i) = .53 - 4.5/(PID+3.7)
        RTOWPB(i) = .6 - DOWPB(i)
        next i
```

3c. Muskeg Pull and Resistance Coefficients

Description This routine is similar to the "fine grained soil pull and resistance coefficients" routine, with the exception that VCIMUK is used instead of VCIFG. The muskeg VCI is derived in the vehicle preprocessor.

Input Vehicle: NAMBLY = total number of running gear assemblies of the combination

NVEH(i) = 0 if running gear assembly i is tracked

≠ 0 if wheeled

IP(i) = 1 if running gear assembly is powered, 0 otherwise

IB(i) = 1 if running gear assembly is braked, 0 otherwise

CPFFG(i,j) = contact pressure factor for assembly i, fine grained soil, lb/in^2, at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway

VCIMUK(i) = one pass vehicle cone index in muskeg applied to running gear assembly i, lb/in^2

Terrain: RCI = rating cone index, lb/in^2

Scenario: NOPP = operating tire pressure indicator:

= 0 tire pressure soil dependent

= 1 if always use fine grained soil dependent tire pressure

= 2 if always use coarse grained soil dependent tire pressure

= 3 if always use highway dependent tire pressure

Output RTOWPB(i) = resistance coefficient of powered or braked assembly i due to soil

DOWPB(i) = pull coefficient of powered or braked assembly i due to soil

RTOWT(i) = resistance coefficient of towed assembly i due to soil

Algorithm

```
if NOPP = 0.
   then j = 1
else j = NOPP
do for i = 1 to NAMBLY
RCIX = RCI - VCIMUK(i)
```

a. Powered, braked and towed running gear resistance coefficient routine

```
if RCIX ≤ -100. then RT = 1.
else if -100.< RCIX ≤  0. then RT = 1. - .006*(RCIX+100.)
     else RT = .045 + 2.3075/(6.5+RCIX)
if IP(i)*IB(i) ≠ 0
   then RTOWT(i) = 0.
        RTOWPB(i) = RT
        do routine b.
else if IP(i)+IB(i) = 0
        then RTOWT(i) = RT
             RTOWPB(i) = 0.
             DOWPB(i) = 0.
             next i
     else RTOWT(i) = RTOWPB(i) = RT
```

b. Powered and braked pull coefficient routine

```
if RCIX ≤ -100 then DOWPB(i) = -1.
```

```
else if RCIX $\leq$ 0. then DOWPB(i) = -1.+.01*(RCIX+100.)
     else if NVEH(i) = 0 and CPFFG(i,j) < 4.
             then DOWPB(i) = $.5464+.1091*RCIX-[(.5464+.1091*RCIX)^2-.192*RCIX]^{1/2}$

             next i
          else DOWPB(i) = $.3537+.02258*RCIX-[(.3537+.02258*RCIX)^2-.03071*RCIX]^{1/2}$

          next i
          exit
```

3d. Shallow Snow Pull and Resistance Coefficients

Description Shallow snow is defined as snow covering frozen ground at a depth less than the characteristic length of the tire (CHARLN) or less than one third of the characteristic length of the track.

This submodel makes use of cohesion (COHES), internal friction coefficient (TANPHI) and specific weight (GAMMA) to calculate the drawbar and resistance coefficients.

For wheels the motion resistance is a function of snow depth (ZSNOW) and GAMMA. The empirical formula expresses the resistance coefficient (RT) as being directly proportional to the number of tires per axle, section width, specific weight and snow depth. It is inversely proportioned to the number of axles, undeflected tire diameter and characteristic length.

For tracks the resistance coefficient is defined in the equation for RT in section b.

The maximum traction is obtained from the well-known Coulomb equation (see TOWMAX) and the drawbar pull coefficient is the difference of TOWMAX and RT.

Input

Vehicle: NAMBLY = total number of running gear assemblies of the combination

NVEH(i) = 0 if running gear assembly i is tracked

$\neq$ 0 if wheeled

IP(i) = 1 if running gear assembly i is powered, 0 otherwise

IB(i) = 1 if running gear assembly i is braked, 0 otherwise

NWHL(i) = number of tires on wheeled assembly i

WGHT(i) = weight on running gear assembly i, lb.

SECTW(i) = section width of tires on running gear assembly i, in.

DIAW(i) = outside diameter of unloaded tires on running gear assembly i, in.

GCA(i,j) = nominal ground contact area per tire element or track pair on running gear assembly i, in.^{2} at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway

CHARLN(i,j) = characteristic length of tire or track on running gear assembly i, in. at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway

Terrain: GAMMA = snow specific weight

COHES = cohesion, lb/in.^{2}

TANPHI = tangent of internal friction angle

ZSNOW = snow depth, in.

Scenario: NOPP = operating tire pressure indicator:

= 0 tire pressure soil dependent

= 1 if always use fine grained soil dependent tire pressure

= 2 if always use coarse grained soil dependent tire pressure

= 3 if always use highway dependent tire pressure

Outputs

RTOWPB(i) = resistance coefficient of powered or braked assembly i due to soil

DOWPB(i) = pull coefficient of powered or braked assembly i due to soil

RTOWT(i) = resistance coefficient of towed assembly i due to soil

Algorithm

```
if NOPP = 0
   j = 1
else j = NOPP
do for i = 1 to NAMBLY
if NVEH(i) ≠ 0 then do wheel routine a.
else do track routine b.
```

a. Wheeled axle routine

```
RT = 10*[NWHL(i)*SECTW(i)/DIAW(i)]*[GAMMA*ZSNOW/CHARLN(i,j)]
if IP(i)*IB(i) ≠ 0 then RTOWT(i) = 0.
                        RTOWPB(i) = RT
                        do routine a1.
```

```
    else if IP(i)+IB(i) = 0 then RTOWT(i) = RT
                                 RTOWPB(i) = 0.
                                 DOWPB(i) = 0.
                                 next i
        else RTOWT(i) = RT
             RTOWPB(i) = RT
al.          TOWMAX = TANPHI+COHES*GCA(i,j)*NWHL(i)/WGHT(i)
             DOWPB(i) = TOWMAX-RT
             next i
```

b. Tracked element routine

```
    RT = (GAMMA/0.2)*(ZSNOW/CHARLN(i,j)-.15)
    if RT < 0. then RT = 0.
    else if IP(i)*IB(i) ≠ 0
            then RTOWT(i) = 0.
                 RTOWPB(i) = RT
                 do routine b1.
    if IP(i)+IB(i) = 0
        then RTOWT(i) = RT
             RTOWTPB(i) = 0.
             DOWPB(i) = 0.
             next i
    else RTOWT(i) = RT
         RTOWPB(i) = RT
```

```
b1.     TOWMAX = TANPHI+COHES*GCA(i,j)/WGHT(i)
        DOWPB(i) = TOWMAX-RT
        next i
        exit
```

4. Summed Pull and Resistance Coefficients

Description In this routine the pull and resistance coefficients calculated for each running gear assembly in either one of routines 3a, 3b, 3c or 3d are summed. Separate summations are made for all powered, braked, unpowered and unbraked assemblies.

Inputs

Vehicle:

NAMBLY = number of running gear assemblies of the combination

WGHT(i) = weight on running gear assembly i, lb.

GCWP = gross combined weight, on all powered running gear assemblies, lb.

GCWB = gross combined weight on all braked running gear assemblies, lb.

GCW = gross combination weight, lb.

IP(i) = 1 if running gear assembly i is powered, 0 otherwise

IB(i) = 1 if running gear assembly i is braked, 0 otherwise

Derived:

RTOWPB(i) = resistance coefficient of powered or braked assembly i due to soil

DOWPB(i) = pull coefficient of powered or braked assembly i due to soil

RTOWT(i) = resistance coefficient of towed assembly i due to soil

Outputs

RTOWP = combination resistance coefficient of powered running gear assemblies due to soil

DOWP = combination pull coefficient of powered running gear assemblies due to soil

RTOWB = combination resistance coefficient of braked running gear assemblies due to soil

DOWB = combination pull coefficient of braked running gear assemblies due to soil

RTOWNP = combination resistance coefficient of non-powered running gear assemblies due to soil

RTOWNB = combination resistance coefficient of non-braked running gear assemblies due to soil

Algorithm

$$\text{RTOWP} = \left[\sum_{i=1}^{\text{NAMBLY}} \text{IP(i)*RTOWPB(i)*WGHT(i)}\right] \text{/GCWP}$$

$$\text{DOWP} = \left[\sum_{i=1}^{\text{NAMBLY}} \text{IP(i)*DOWPB(i)*WGHT(i)}\right] \text{/GCWP}$$

$$\text{RTOWNP} = \left[\sum_{i=1}^{\text{NAMBLY}} \text{(1-IP(i))*RTOWT(i)*WGHT(i)}\right] \text{/(GCW-GCWP)}$$

$$\text{RTOWB} = \left[\sum_{i=1}^{\text{NAMBLY}} \text{IB(i)*RTOWPB(i)*WGHT(i)}\right] \text{/GCWB}$$

$$\text{DOWB} = \left[\sum_{i=1}^{\text{NAMBLY}} \text{IB(i)*DOWPB(i)*WGHT(i)}\right] \text{/GCWB}$$

$$\text{RTOWNB} = \left[\sum_{i=1}^{\text{NAMBLY}} \text{(1-IB(i))*RTOWT(i)*WGHT(i)}\right] \text{/(GCW-GCWB)}$$

5. Slip Modified Tractive Effort

Description

This routine modifies the tractive effort versus speed curve obtained from the vehicle power train or measured data for slippage of the running gear in the soil.

The first new feature in this submodel is scenario input NTRAV. If NTRAV=1 the model is executed for a single traverse and only one slope (θ_1) will enter from the processed Terrain File. If NTRAV=3 then the usual cases of up, level and down slope are computed for each patch. A second new feature is that the effect of elevation is now accounted for by means of factor ECF.

This submodel also accounts for water drag resistance while operating in a marsh.

<u>Inputs</u> Vehicle: NVEHC = 0 if one or more of the powered running gear assemblies is tracked

$\neq$ 0 otherwise

CPFCFG(j) = maximum contact pressure factor of all running gear assemblies of the type specified by NVEHC for fine grained soil, lb/in^2, at pressure specified for j = 1 fine grained, = 2 coarse grained, = 3 highway.

CPFCCG(j) = maximum contact pressure factor of all running gear assemblies of the type specified by NVEHC for coarse grained soil, lb/in^2, at pressure specified for j = 1 fine grained, = 2 coarse grained, = 3 highway.

NFL = 0 if track is rigid

= 1 otherwise

GCWP = gross combined weight on all powered running gear assemblies, lb.

NGR = number of gears

VGV(NG,MN) = minimum speed in gear NG, in/sec.

VGV(NG,MD) = mid-range speed in gear NG, in/sec.

VGV(NG,MX) = maximum speed in gear NG, in/sec.

TRACTF(NG,MN) = tractive force available from drive train at minimum speed in gear NG, lb.

TRACTF(NG,MD) = tractive force available from drive train at mid-range speed in gear NG, lb.

TRACTF(NG,MX) = tractive force available from drive train at maximum speed in gear NG, lb.

ATF(NG) = constant of quadratic fitted to vehicle tractive effort curve in gear NG, lb.

BTF(NG) = coefficient of linear term of quadratic fitted to vehicle tractive effort curve in gear NG, lb/(in/sec).

CTF(NG) = coefficient of quadratic term of quadratic fitted to vehicle tractive effort curve in gear NG, $\text{lb}/(\text{in/sec})^2$

CD = water drag coefficient.

LOCDIF = 1 if all powered running gear assemblies have locking differentials.

= 0 otherwise

Terrain: GRADE = grade, percent

IST = soil type

ECF = elevation correction factor for tractive effort

Derived: RTOWP = combination resistance coefficient of powered running gear assemblies.

DOWP = combination pull coefficient of powered running gear assemblies.

IFLOAT = 0 if no water drag

= 1 if vehicle fording

DAREA = frontal area under water, in^2

WRATIO = proportion of combination weight supported by ground

Subroutines used: TFORCF, SLIP

Scenario: NTRAV = 1 for traverse only; = 3 for average up, level and down travel.

NOPP = operating tire pressure indicator:

= 0 tire pressure soil dependent.

= 1 if always use fine grained soil dependent tire pressure.

= 2 if always use coarse grained soil dependent tire pressure.

= 3 if always use highway dependent tire pressure.

Outputs

VG(NG,MN) = minimum speed in gear NG modified by slip, in/sec.

VG(NG,MD) = mid-range speed in gear NG modified by slip, in/sec.

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec.

STRACT(NG,L,K) = slip modified tractive effort in gear NG at speed index L = MN, MD or MX and slope K = up, level and down, lb.

FA(NG,K) = constant term of quadratic fitted to tractive effort versus speed curve for gear NG and slope K, lb.

FB(NG,K) = linear term coefficient of quadratic fitted to tractive effort versus speed curve for gear NG and slope K, lb/(in/sec).

FC(NG,K) = quadratic term coefficient of quadratic fitted to tractive effort versus speed curve for gear NG and slope K, $\text{lb}/(\text{in}/\text{sec})^2$

FORMX(K) = maximum tractive effort available in soil for slope K, lb.

VFMAX(K) = speed at which maximum tractive effort on slope K = up, level and down, in/sec

Algorithm

```
a.  if NOPP = 0.
        then if IST = 1, 3 or 4
                then j = 1
             else j = 2
    else j = NOPP
    if IST = 2
        then CPFC = CPFCCG(j)
    else CPFC = CPFCFG(j)
    $\theta_1 = \frac{\pi}{4}$*(GRADE/100.)
    $\theta_2 = 0.$
    $\theta_3 = -\theta_1$
    if IST ≠ 4 (not snow)
        CALL TFORCF(TFOR,CF,GCWP,NVEHC,CPFC,NFL,IST,DOWP,RTOWP,WRATIO)
    else continue
    do for K = 1 to NTRAV
        if IST = 4 (snow)
            then TFOR = (DOWP+RTOWP)*GCWP*WRATIO*cos($\theta_K$)
        else continue
a1.     do for NG = 1 to NGR
```

```
b.  top speed in gear
    UX = VGV(NG,MX)
    TX = TRACTF(NG,MX)*ECF
    if IST = 4 (snow) then YX = TX/TFOR
    else YX = min{TFOR,TX}/[GCWP*WRATIO*cos($\theta_K$)]-CF
    CALL SLIP (SLIPX,YX,NVEHC,CPFC,IST,NFL,LOCDIF)
    if SLIPX = 1 then VG(NG,MX) = VG(NG,MD) = VG(NG,MN) = 0.
                      FA(NG,K) = TFOR
                      FB(NG,K) = FC(NG,K) = 0
                      STRACT(NG,MX,K) = STRACT(NG,MD,K) =
                                        STRACT(NG,MN,K) = TFOR
                      next gear NG
    else (SLIPX ≠ 1)
        VG(NG,MX) = VGV(NG,MX)*[1.-SLIPX]
        WDRAG = 0.5*.00111*CD*DAREA*VG(NG,MX)$^2$
        STRACT(NG,MX,K) = min{TFOR,TX}*cos($\theta_K$)-IFLOAT*WDRAG

c.  mid-range speed in gear
    UD = VGV(NG,MD)
    TD = TRACTF(NG,MD)*ECF
c1. if IST = 4 (snow) then YD = TD/TFOR
    else YD = min{TFOR,TD}/[GCWP*WRATIO*cos($\theta_K$)]-CF
    CALL SLIP (SLIPD,YD,NVEHC,CPFC,IST,NFL,COCDIF)
```

```
if SLIPD = 1 then UN = UD

                   UD = (UN+UX)*.5
                   TD = [CTF(NG)*UD+BTF(NG)]*UD+ATF(NG)
                   repeat c1.
else (SLIPD $\neq$1)
     VG(NG,MD) = VGV(NG,MD)*[1.-SLIPD]
     WDRAG = 0.5*.00111*CD*DAREA*$VG(NG,MD)^2$
     STRACT(NG,MD,K) = min{TFOR,TD}*$\cos(\theta_K)$-IFLOAT*WDRAG

d.  low speed in gear
    UN = VGV(NG,MN)
    TN = TRACTF(NG,MN)*ECF
    if IST = 4 (snow) then YN = TN/TFOR
    else YN = min{TFOR,TN}/[GCWP*WRATIO*$\cos(\theta_K)$]-CF
    CALL SLIP(SLIPN,YN,NVEHC,CPFC,IST,NFL,LOCDIF)
    if SLIPN $\neq$ 1
       then VG(NG,MN) = VGV(NG,MN)*[1.-SLIPN]
            WDRAG = .5*.00111*CD*DAREA*$VG(NG,MN)^2$
            STRACT(NG,MN,K) = min{TFOR,TN}*$\cos(\theta_K)$-IFLOAT*WDRAG
            do f.
    else (SLIPN = 1) do e.
```

e. interpolate to find lowest speed in gear

```
UH = UD
SLIPH = SLIPD
do for j = 1 to 4
UM = (UN+UH)*.5
TM = ([CTF(NG)*UM +BTF(NG)]*UM +ATF(NG))*ECF
if IST = 4 (snow) then YM = TM/TFOR
else YM = min{TFOR,TM}/[GCWP*WRATIO*cos($\theta_K$)]-CF
CALL SLIP (SLIPM,YM,NVEHC,CPFC,IST,NFL,LOCDIF)
if SLIPM = 1 then UN = UM
                  next j
else (SLIPM ≠ 1)  UH = UM
                  SLIPH = SLIPM
                  next j
after all j
UN = UH
TN = ([CTF(NG)*UN+BTF(NG)]*UN+ATF(NG))*ECF
VG(NG,MN) = UN*[1.-SLIPH]
WDRAG = 0.5*.00111*CD*DAREA*$VG(NG,MN)^2$
STRACT(NG,MN,K) = min{TFOR,TN}*cos($\theta_K$)-IFLOAT*WDRAG
```

```
f.  fit quadratic to new values of slip modified speed versus slope
    modified tractive effort

    CALL QUAD(FC(NG,K),FB(NG,K),FA(NG,K),

                        VG(NG,MN),STRACT(NG,MN,K),

                        VG(NG,MD),STRACT(NG,MD,K),

                        VG(NG,MX),STRACT(NG,MX,K))

    next NG  at statement a1.

    After all gears do g.

g.  FORMX(K) = max {STRACT(NG,L,K)}

    VFMAX(K) = VG(NG,L)  at above max

    next K

    exit
```

Soil Limited Tractive Effort Subroutine

Description This subroutine, TFORCF, is used in the submodel called "slip modified tractive effort". The drawbar pull and resistance coefficients calculated in submodels 3 and 4 are based on 20% wheel or track slip in the soil. Subroutine TFORCF calculates correction factors for the entire slip range up to 100% slip.

Subroutine TFORCF first calculates correction factor CF and then establishes the maximum soil limited tractive effort which occurs at 100% slip (TFOR).

Subroutine TFORCF(TFOR, CF, GCWP, NVEHC, CPFC, NFL, IST, DOWP, RTOWP, WRATIO)

Inputs

Vehicle: GCWP = gross combined weight on all powered running gear assemblies, lb.

NVEHC = 0 if one or more of the powered running gear assemblies is tracked

≠ 0 otherwise

CPFC = maximum contact pressure factor of all running gear assemblies of type specified by NVEHC, lb/in^2

NFL = 0 if track is rigid

= 1 otherwise

WRATIO = proportion of combination weight supported by ground to combination weight

Terrain: IST = soil type

Derived: DOWP = combination pull coefficient of powered running gear assemblies due to soil

RTOWP = combination resistance coefficient of powered running gear assemblies due to soil

Outputs

TFOR = soil limited maximum tractive effort, lb.

CF = net force/weight correction factor

Algorithm

```
if IST = 1 or 6 (fine grain soil)
   then if NVEHC = 0 (tracked)
           then if CPFC < 4.
                   then CF = (.758-DOWP)-RTOWP
                        TFOR = (.82-CF)*GCWP*WRATIO
                        exit
                else CF = (.671-DOWP)-RTOWP
                     TFOR = (.71-CF)*GCWP*WRATIO
                     exit
        else (NVEHC ≠ 0 wheeled)
             then if CPFC < 4.
                     then CF = (.674-DOWP)-RTOWP
                          TFOR = (.76-CF)*GCWP*WRATIO
                          exit
                  else CF = (.585-DOWP)-RTOWP
                       TFOR = (.655-CF)*GCWP*WRATIO
                       exit
```

```
if IST = 2 (coarse grain soil)
   if NVEHC = 0 (tracked)
      then if NFL = 0 (rigid track)
              then CF = .074
                   TFOR = (CF+.568)*GCWP*WRATIO
                   exit
           else (flexible track)
              CF = .1
              TFOR = (CF+.695)*GCWP*WRATIO
              exit
   else (wheeled)
        CF = RTOWP+DOWP-.56
        TFOR = (CF+.575)*GCWP*WRATIO
        exit
if IST = 3 (muskeg)
   then if NVEHC = 0 and CPFC < 4.
           then CF = RTOWP+DOWP-.88
                TFOR = (CF+.91)*GCWP*WRATIO
                exit
        else CF = RTOWP+DOWP-.68
             TFOR = (CF+.745)*GCWP*WRATIO
             exit
```

Slip Subroutine

Description Subroutine SLIP calculates the actual slip the vehicle would experience at the minimum, mid-point and maximum velocities in each gear that are used to obtain the quadratic fit coefficients of the tractive effort versus speed curve. The latter is the theoretical tractive effort versus speed curve derived in the vehicle preprocessor.

Subroutine SLIP(SLIP, Y, NVEHC, CPFC, IST, NFL, LOCDIF)

Input Vehicle: NVEHC = 0 if one or more of the powered running gear assemblies is tracked

≠ 0 otherwise

CPFC = maximum contact pressure factor of all running gear assemblies of type specified by NVEHC, lb/in^2

NFL = 0 if track is rigid

≠ 0 otherwise

LOCDIF = 1 if all powered running gear assemblies have locking differentials

= 0 otherwise

Terrain: IST = soil type

Dummy: Y = net force/weight ratio

Output SLIP = slip at net force/weight ratio

Algorithm

```
if IST = 1 or 6 (fine grain soil)
   then if NVEHC = 0 (tracked)
           then if CPFC < 4.
                   then SLIP = .0257*Y-.0161+.01519/(.8353-Y)
                        exit
              else (CPFC ≥ 4.)
                        SLIP = .0733*Y-.0063+.00734/(.7177-Y)
                        exit
```

```
          else (NVEHC ≠ 0, wheeled)
                if CPFC < 4.
                    then SLIP = .0621*Y-.021+.01888/(.7794-Y)
                    if LOCDIF = 1
                        SLIP = SLIP/1.1
                        exit
                    else exit
                else (CPFC ≥ 4.)
                        SLIP = .084*Y-.016+.01414/(.6697-Y)
                if LOCDIF = 1
                    SLIP = SLIP/1.1
                    exit
                else exit
if IST = 2 (coarse grained soil)
    then if NVEHC = 0 (tracked)
              then if NFL = 0 (rigid track)
                        then SLIP = -.0083+.005312/(.573-Y)
                              exit
                    else (NFL ≠ 0, flexible track)
                            YY = 1.074*Y-.72
                            SLIP = $YY+[YY^2+.09*Y+.009]^{1/2}$
                            exit
```

```
          else (wheeled)
                SLIP = .0074*Y-.0061+.00374/(.5785-Y)
                if LOCDIF = 1
                   SLIP = SLIP/1.1
                   exit
                else exit
if IST = 3 (muskeg)
   then if NVEHC = 0 and CPFC < 4. (tracked)
              then SLIP = .0585*Y-.0106+.01336/(.964-Y)
                   exit
          else (wheeled or tracked with CPF ≥ 4.)
                SLIP = .1024*Y-.00864+.01062/(.7564-Y)
                if NVEHC ≠ 0 and LOCDIF = 1
                   SLIP = SLIP/1.1
                   exit
                else exit
else IST = 4 (shallow snow)
          if Y ≥ 1. then SLIP = 1.
                         exit
          else $Y = .3*[1.-(1.-Y)^{1/2}]$
                exit
```

Quadratic Fit Through Three Points Subroutine

Description	This subroutine provides coefficients for a quadratic curve fitted exactly to 3 points. The subroutine is used to obtain new coefficients for tractive effort versus speed curve modified for soil slip. Dummy variables X and Y represent VG and STRACT defined in Submodel 5.

Subroutine QUAD(C,B,A,X1,Y1,X2,Y2,X3,Y3)

quadratic fitted is $y^2 = Cx^2 + Bx + A$

Inputs (X1,Y1), (X2,Y2), (X3,Y3) = points to be filled

Outputs A = constant term

B = coefficient of linear term

C = coefficient of quadratic term

Algorithm

$AA = (Y2-Y1)/(X2-X1)$

$BB = (Y3-Y1)/(X3-X1)$

$CC = (BB-AA)/(X3-X2)$

$A = Y1-AA*X1+CC*X1^2$

$B = A-(X1+X2)*CC$

$C = CC$

6. Vegetation Resistance

Description This routine calculates the forces necessary to override vegetation using the vegetation density calculations performed in routine 1. It is identical to subroutine VEGF in the AMC '71 Mobility Model. The equations for determining the output forces are explained in Reference 6.

Inputs

Vehicle: WDTH = maximum combination width, in.

PBHT = first unit pushbar height, in.

Terrain: SD(i) = mean stem diameter of vegetation in stem diameter class i, in.

SDL(i) = max stem diameter of vegetation in stem diameter class i, in.

NI = number of stem diameter classes

Derived: TDEN(i) = density of vegetation in stem diameter class i, stems/in.^{2}

Outputs

FAT1(i) = force required to override a single tree of stem diameter class i-1 during entire override, lb.

FMT(i) = max force at pushbar impact resulting from attempt to override a single tree of stem diameter class i-1, lb.

FAT(i) = average force to override trees of stem diameter class i-1 and smaller, lb.

Algorithm

```
FAT(1) = FAT1(1) = FMT(1) = 0.
for each i = 2 to NI + 1
    if TDEN(i) ≠ 0 then FAT1(i) = $(56/5.8)*SDL(i-1)^3$
                        FMT(i) = $(40-PBHT/2)*SDL(i-1)^3$
                        TFAT(i) = $\sum_{K=1}^{i-1} TDEN(K)*100.*SD(K)^3$
                        FAT(i) = 12.*TFAT(i)*WDTH
                        next i
                        exit
```

```
else FAT1(i) = 0.
     FMT(i) = 0.
     FAT(i) = FAT(i-1)
next i
exit
```

7. Driver/Vehicle Vegetation Override Check

Description	This routine uses the driver determined dynamic impact limit (HORZGL) and the maximum force the vehicle's pushbar can tolerate (PBF) to determine the maximum tree stem diameter which can be overridden. The diagnostic indicator VEGSIG is a new feature. It specifies the limiting factor in the event of a NO-GO.

Inputs

Vehicle: GCW = gross combination weight, lb.

PBF = max force vehicle pushbar can tolerate, lb.

Derived: FMT(i) = max force at pushbar impact resulting from attempting to override a single tree of stem diameter class i-1, lb.

Terrain: NI = number of stem diameter classes

Scenario: HORZGL = max horizontal acceleration driver will tolerate when impacting a tree, g's

Outputs

VEGSIG(i) = 0 if pushbar and driver can withstand impact to override a tree of stem diameter class i-1

= 1 if pushbar cannot withstand impact to override a tree of stem diameter class i-1

= 2 if driver cannot withstand impact to override a tree of stem diameter class i-1

= 3 if both driver and pushbar cannot withstand impact to override a tree of stem diameter class i-1

MAXI = one greater than the index of the maximum stem diameter class that can be overridden.

Algorithm

```
do for i = 1 to NI+1
   VEGSIG(i) = 0.
   if FMT(i) > PBF then VEGSIG(i) = 1.
   if FMT(i)/GCW > HORZGL
            then VEGSIG(i) = VEGSIG(i) +2.
   next i
MAXI = maximum i such that VEGSIG(i) = 0.
exit
```

8. Total Resistance Between Obstacles

Description This routine sums the soil, slope and vegetation resistance. In AMC '71 the average resistance to override obstacles was included, which is not done in this routine. Obstacle override is kept discrete from other operations in the patch to improve precision and clarity.

Inputs

Vehicle: GCW = gross combination weight, lb.

GCWP = gross combined weight on all powered running gear assemblies, lb.

GCWNP = gross combined weight on non-powered running gear assemblies, lb.

Terrain: GRADE = grade, percent

Derived: RTOWP = combination resistance coefficient of powered, running gear assemblies due to soil

RTOWNP = combination resistance coefficient on non-powered running gear assemblies due to soil

FAT1(i) = force required to override a single tree of stem diameter class i-1 during entire override, lb.

FAT(i) = average force to override trees of stem diameter class i-1 and smaller, lb.

MAXI = one greater than the index of the maximum stem diameter class which can be overridden

WRATIO = proportion of combination weight on ground

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

Outputs

TR(K,i) = total soil, slope and vegetation resistance between obstacles while overriding vegetation in stem diameter class i-1 and smaller, lb.

STR(K,i) = total resistance due to soil, slope and overriding a single tree in stem diameter class i-1, lb.

Algorithm

```
        $\theta_1 = \frac{\pi}{4} *(GRADE/100)$

        $\theta_2 = 0.$

        $\theta_3 = -\theta_1$

  do for K = 1 to NTRAV

     for i = 1 to MAXI

     $TR(K,i) = [GCW*\sin\theta_K+(RTOWP*GCWP+RTOWNP*GCWNP)*\cos\theta_K] * WRATIO+FAT(i)$

     $STR(K,i) = [GCW*\sin\theta_K+(RTOWP*GCWP+RTOWNP*GCWNP)*\cos\theta_K] * WRATIO+FAT1(i)$

     next i

     next K

    exit
```

9. Speed Limited by Resistance Between Obstacles (No reduction for avoidance.)

Description The routine determines the speed on up, level and down slope while overcoming soil, slope and vegetation resistances (VSOIL). (The soil resistance is already included in the modified tractive effort versus slip curve. See Submodel 5.) This routine computes the velocity for each stem diameter class that can be overridden on the three slopes. Additionally, the velocity VSOIL will be set equal to zero for larger stem diameters that cannot be overridden. This routine also accounts for a traverse (NTRAV) having only one slope value.

Inputs Vehicle: NGR = number of gears

Terrain: NI = number of stem diameter classes

Derived: FA(NG,K),FB(NG,K),FC(NG,K) = coefficients of the quadratic fit of slip modified tractive-effort versus speed curve for gear NG and slope K = up, level and down; lb, lb/(in/sec), $\text{lb}/(\text{in/sec})^2$

VG(NG,MN) = minimum speed in gear NG modified by slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec

TR(u,i) = total soil, slope and vegetation resistance between obstacles while overriding vegetation in stem diameter class i-1 and smaller, lb.

MAXI = one greater than the index of the maximum stem diameter class which can be overridden

FORMX(K) = maximum tractive effort available in soil on slope K = up, level and down; lb.

VFMAX(K) = speed at which maximum tractive effort on slope K = up, level and down is available, in/sec

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

Subroutines used: VELFOR

Outputs VSOIL(u,i),VSOIL(ℓ,i),VSOIL(d,i) = maximum velocity while overcoming soil, slope and vegetation resistance while overriding vegetation in stem diameter classes i-1 and smaller between obstacles without reduction for avoidance, in/sec

Algorithm

```
a.  NMAXI = MAXI
    do for i = 1 to NMAXI
    CALL VELFOR(TR(u,i),VSOIL(u,i),u,NGR,FA,FB,FC,VG)
    if VSOIL(u,i) = 0.
       then MAXI = i
       if NTRAV = 1
          do b.
       else CALL VELFOR(TR(ℓ,i),VSOIL(ℓ,i)ℓ,NGR,FA,FB,FC,VG)
            CALL VELFOR(TR(d,i),VSOIL(d,i),d,NGR,FA,FB,FC,VG)
            do b.
    else if NTRAV = 1
            next i
         else CALL VELFOR(TR(ℓ,i),VSOIL(ℓ,i),ℓ,NGR,FA,FB,FC,VG)
              CALL VELFOR(TR(d,i),VSOIL(d,i),d,NGR,FA,FB,FC,VG)
              next i
b.  do for i = MAXI + 1 to NI = 1
               VSOIL(u,i) = 0.
               if NTRAV = 1
                  then next i
                  exit
               else VSOIL(ℓ,i) = VSOIL(d,i) = 0.
               next i
               exit
```

Maximum Velocity Overcoming a Given Resistance Subroutine

Description This subroutine is used in submodel 9. Subroutine VELFOR examines the tractive effort versus speed curve segments for each gear (which are represented by quadratic equations of the form $y=FCx^2+FBx+FA$ (where y is traction, x is vehicle velocity) and establishes the intersection with the y = constant line representing the sum of the resistance due to grade and vegetation (TR). The abcissa of the intersection point is the maximum velocity that can be achieved while overcoming resistance TR. Several possibilities are investigated including parabolic segments with either positive or negative curvature (concave up and concave down respectively) and straight lines (FC = 0).

Subroutine VELFOR (F,VEL,K,NGR,FA,FB,FC,VG,FORMX,VFMAX)

Inputs

NGR = number of gears

F = resistance to be overcome, lb.

K = u: uphill; = l: level; = d: downhill

FA(NG,K) = constant term of quadratic fitted to tractive effort versus speed curve for gear NG and slope K, lb.

FB(NG,K) = linear term coefficient on quadratic fitted to tractive effort versus speed curve for gear NG and slope K, lb/(in/sec)

FC(NG,K) = quadratic term coefficient of quadratic fitted to tractive effort versus speed curve for gear NG and slope K, lb/(in/sec)^2

VG(NG,MN) = minimum speed in gear NG modified for slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified for slip, in/sec

FORMX(K) = maximum tractive effort available in soil on slope K = up, level and down; lb.

VFMAX(K) = speed at which maximum tractive effort on slope K = up, level and down is available, in/sec

Output

VEL = maximum velocity while overcoming F, in/sec

Algorithm

```
do for NG = NGR to 1 (from highest gear to lowest)
DSQ = $FB(NG,K)^2-4*FC(NG,K)*[FA(NG,K)-F]$
if DSQ < 0.
   then if FC(NG,K) > 0.
           then VEL = VG(NG,MX)
                exit
        else next lower gear NG
else if DSQ = 0.
        then if FC(NG,K) < 0.
                then next lower gear NG
             else if FC(NG,K) = 0.
                     then if FA(NG,K) ≥ F
                             then VEL = VG(NG,MX)
                                  exit
                                  else next lower gear NG
                  else VEL = VG(NG,MX)
                       exit
      else if DSQ > 0.
              then if FC(NG,K) = 0.
                      then R = -[FA(NG,K)-F]/FB(NG,K)
                           if R ≤ VG(NG,MN)
                              then if FB(NG,K) < 0.
```

```
            then next lower gear NG
          else VEL = VG(NG,MX)
             exit
     else if VG(NG,MN) < R < VG(NG,MX)
          then if FB(NG,K) < 0.
               then VEL = R
                  exit
             else next lower gear NG
        else if FB(NG,K) < 0.
             then VEL = VG(NG,MX)
           else next lower gear NG
else(FC(NG,K) ≠ 0.)
   if FB(NG,K) ≤ 0.
     then R2=[-FB(NG,K)+SQRT(DSQ)]/[2*FC(NG,K)]
        R1=[FA(NG,K)-F]/[R2*FC(NG,K)]
   else R1=[-FB(NG,K)-SQRT(DSQ)]/[2*FC(NG,K)]
      R2 = [FA(NG,K)-F]/[R1*FC(NG,K)]
RL = min{R1,R2}
RH = max{R1,R2}
if FC(NG,K) > 0.
  then if VG(NG,MN) ≤ RL
       then if VG(NG,MX)≤ RL
            then VEL = VG(NG,MX)
               exit
```

```
                                   else VEL = RL
                                        exit
                           else if RL < VG(NG,MN) < RH
                                   then next lower gear NG
                                be else VEL = VG(NG,MX)
                                     exit
                   else(FC(NG,K) < 0)
                   if VG(NG,MN) ≤ RL
                      then next lower gear NG
                   else if RL < VG(NG,MN) ≤ RH
                           then if VG(NG,MX) ≤ RH
                                   then VEL = VG(NG,MX)
                                        exit
                                else VEL = RH
                                     exit
                        else next lower gear NG
after all gears if FORMX(K) ≥ F
                    then VEL = VFMAX(K)
                         exit
                 else VEL = 0.
                      exit
```

10. Speed Limited by Surface Roughness

Description This routine determines the vehicle speed limited by the driver's tolerance to traveling over rough terrain. A table of vehicle speed versus surface roughness values obtained from either measured field data or the Ride Dynamics Module (VII) is interpolated for the actual terrain roughness (ACTRMS) of the particular patch. (This was not necessary in AMC '71 because AMC '71 could not accept actual terrain RMS values. It only operated with fixed classes of RMS.)

To allow latitude of having more than one roughness tolerance level, different tables may be used for different motivational levels of the driver. Field experience shows that the 6 watts tolerance level is often exceeded in an emergency situation.

Inputs

Vehicle:

MAXL = number of roughness tolerance levels specified

MAXIPR = number of surface roughness values per tolerance level

RMS(NR) = NRth surface roughness value, in.

VRIDE(NR,L) = maximum speed over ground for surface roughness class NR at roughness tolerance level L, in/sec

Terrain:

ACTRMS = surface roughness, in.

Scenario:

LAC = surface roughness tolerance level value

Outputs

VRID = speed between obstacles limited by surface roughness, in/sec

Algorithm

```
do for NR = 2 to MAXIPR
    if ACTRMS < RMS(NR)
        then VRID = VRIDE(NR-1,LAC)+
            $\frac{ACTRMS-RMS(NR-1)}{RMS(NR)-RMS(NR-1)} * [VRIDE(NR,LAC) - VRIDE(NR-1,LAC)]$
        exit
    else next NR
    after all NR's VRID = VRIDE(MAXIPR,LAC)
    exit
```

11. Total Braking Force

Description This routine assigns the maximum available braking force by examining the braking forces which can be generated by the soil and grade and compares this braking force with the maximum braking force which can be developed by the vehicle's braking system (XBR). One of the possible outputs is a NO-GO indicating inadequate braking of the vehicle on a down slope (BFGONO = 1).

Inputs

Vehicle: GCW = gross combination weight, lb.

GCWB = gross combined weight on all braked running gear assemblies, lb.

GCWNB = gross combined weight on all non-braked running gear assemblies, lb.

XBR = maximum braking effort vehicle can develop, lb.

Terrain: GRADE = grade, percent

Derived: RTOWB = combination resistance coefficient of braked running gear assemblies due to soil

DOWB = combination pull coefficient of braked running gear assemblies due to soil

RTOWNB = combination resistance coefficients of non-braked running gear assemblies due to soil

WRATIO = proportion of combination weight supported by ground

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

Outputs

TBF(u),TBF(ℓ),TBF(d) = total soil/slope/vehicle derived braking force, up, level, down slope, lb.

BFGONO = 1 if vehicle braking is inadequate for downslope operation

= 0 otherwise

Algorithm

```
            $\theta_1 = \frac{\pi}{4} *(GRADE/100)$

            $\theta_3 = -\theta_1$

$TBF(u) = [GCW*\sin\theta_1+(RTOWB*GCWB+RTOWNB*GCWNB)*\cos\theta_1]*WRATIO+$
              $\min\{XBR,(DOWB+RTOWB)*GCWB*WRATIO*\cos\theta_1\}$

if NTRAV = 1  then  if $TBF(u) < 0.$  then BFGONO = 1
                                            return to module I. Control and I/O

                    else BFGONO = 0.
                         exit

else
$TBF(\ell) = [RTOWB*GCWB+RTOWNB*GCWNB]*WRATIO +$
                 $\min\{XBR,(DOWB+RTOWB)*GCWB*WRATIO\}$

$TBF(d) = [GCW*\sin\theta_3+(RTOWB*GCWB+RTOWNB*GCWNB)*\cos\theta_3]*WRATIO +$
              $\min\{XBR,(DOWB+RTOWB)*GCWB*WRATIO*\cos\theta_3\}$

if $TBF(d) < 0.$  then  BFGONO = 1
                        return to module I.  Control and I/O

else BFGONO = 0.
    exit
```

12. Driver Dictated Braking Limits

Description	This is a new routine. It incorporates two driver dependent scenario inputs. The first establishes the maximum deceleration (MXGDCL) the driver is willing to use depending on comfort, cargo or perhaps emergencies. The second factor (SFTYPC) indicates that under certain circumstances the driver will not utilize the total maximum braking force available because, for example, he does not want to skid the vehicle.

Input Vehicle: GCW = gross combination weight, lb.

Scenario: MXGDCL = max deceleration (in g's) the driver will actually use

SFTYPC = percent of max deceleration available that the driver will actually use, as compared TBF, percent

NTRAV = 1 for traverse

= 3 for average up, level and down travel

Derived: TBF(K) = total soil/slope/vehicle derived braking force, K = u, ℓ, and d, up, level, down slope, lb.

Outputs MXBF(u), MXBF(ℓ), MXBF(d) = max braking force, up, level, down slope, lb.

Algorithm

```
MXBF(u) = min{MXGDCL*GCW, TBF(u)*SFTYPC/100}
if NTRAV = 1  then exit
else
MXBF(ℓ) = min{MXGDCL*GCW, TBF(ℓ)*SFTYPC/100}
MXBF(d) = min{MXGDCL*GCW, TBF(d)*SFTYPC/100}
exit
```

13. Speed Limited by Visibility

Description This routine takes the place of VISION of AMC '71. A new feature is the inclusion of the eye height of the driver as an input variable and not a constant. This height influences the recognition distance (RECD) which in turn, affects the speed limited by visibility (VELV). A new scenario input (VISMNV) is also included which is the minimum speed at which the driver would proceed for zero visibility. This speed (VISMNV) is assumed to be equal to a man's walking speed in most cases.

Input

Vehicle: GCW = gross combination weight, lb.

EYEHGT = height of driver's eyes above ground, in.

Terrain: RD = recognition distance for braking, in.

Scenario: VISMNV = speed at which vehicle will proceed if visibility is entirely obscured, in/sec

REACT = driver reaction time, sec.

NTRAV = 1 for traverse

= 3 for average up, level and down travel

Derived: MXBF(K) = max braking force on slope K = up, level and down, lb.

Output

VELV(K) = speed limited by visibility on slope K = up, level and down, in/sec

Algorithm

```
do for K = 1 to NTRAV
   RECD = RD*EYEHGT/60.
   ACC = MXBF(K)*385.9/GCW
   D = (REACT*ACC)$^2$+2*RECD*ACC
   C = -ACC*REACT
   VELV(K) = -RECD/[C-SQRT(D)]
   if VELV(K) < VISMNV
      then VELV(K) = VISMNV
           next K
   else next K
   exit
```

14. Speed Between Obstacles Limited by Visibility, Ride, Tires and Soil/Slope/Vegetation Resistance Between Obstacles (No allowance for maneuvering)

Description This routine selects the minimum of the previously calculated speeds. A new feature for AMC '74 is the inclusion of a speed which depends essentially on tire pressure. This forces low speed limits to guard against structural damage to tires on vehicles which cannot re-inflate their tires after operating with reduced pressures on marginal terrain.

Inputs

Vehicle: VTIRE(j) = max steady state speed allowed beyond which structural damage will occur to tires at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway, in/sec

Terrain: NI = number of stem diameter classes

IST = soil type

Derived: VSOIL(u,i), VSOIL(ℓ,i), VSOIL(d,i) = max speed while overcoming soil, slope and vegetation resistance of stem diameter class i-1 and smaller between obstacles, without reduction for avoidance, in/sec

VRID = speed limited by surface roughness, in/sec

VELV(K) = speed limited by visibility on slope K = up, level and down, in/sec

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

NOPP = operating tire pressure indicator:

= 0 tire pressure soil dependent

= 1 if always use fine grained soil dependent tire pressure

= 2 if always use coarse grained soil dependent tire pressure

= 3 if always use highway dependent tire pressure

Outputs

VTT(u,i),VTT(ℓ,i),VTT(d,i) = speed between obstacles (without allowance for maneuvering) overriding vegetation in stem diameter class i-1 and smaller, up, level and down slope, in/sec

Algorithm

```
if NOPP = 0
   then if IST = 1, 3 or 4
           then j = 1
        else j = 2
else j = NOPP
for K = 1 to NTRAV
for i = 1 to NI + 1
           VTT(K,i) = min{VTIRE(j),VSOIL(K,i),VRID,VELV(K)}
next i
next K
exit
```

15. Maximum Speed Between and Around Obstacles

Description In this routine the speeds obtained in submodel 14 are further modified. The speed reduction factors, calculated in submodel 1, are applied to account for maneuvering around trees having stem diameters greater than i and obstacles, (SRFO) as well as SRFV which accounts for maneuvering around trees only.

The output velocities VBO are used later to determine vehicle velocity both while crossing obstacles and accelerating and decelerating between them. (Submodels 18 and 19.) The output velocities VAVOID are used in the final selection of the obstacle avoidance/override strategy in submodel 21.

Inputs

Derived: VTT(u,i),VTT(ℓ,i),VTT(d,i) = speed between obstacles (without allowance for maneuvering) overriding vegetation in stem diameter class i-1 and smaller, up, level and down slope, in/sec

SRFV(i) = speed reduction factor due to avoiding vegetation in stem diameter class i and greater

SRFO(i) = speed reduction factor due to avoiding obstacles and vegetation in stem diameter class i and greater

Terrain: NI = number of stem diameter classes

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

Output

VBO(u,i), VBO(ℓ,i), VBO(d,i) = speed on slope K = up, level and down between obstacles overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

VAVOID(u,i), VAVOID(ℓ,i), VAVOID(d,i) = speed on slope K = up, level and down avoiding obstacles but overriding vegetation in stem diameter class i-1 and smaller, and avoiding vegetation in stem diameter class i and greater, in/sec

Algorithm

```
for K = 1 to NTRAV

for i = 1 to NI + 1

    VBO(K,i) = VTT(K,i)*SRFV(i)

    VAVOID(K,i) = VTT(K,i)*SRFO(i)

    next i

    next K

    exit
```

16. Obstacle Interference and Resistance

Description This routine determines whether the vehicle can override the obstacles of the current patch, and if so, determines the average force (FOM) and the maximum force (FOMMAX) to do so. This is done by using subroutine D3LINC to interpolate in tables which give minimum clearance (CLRMIN), average force (FOO), and maximum force (FOOMAX) to overcome obstacles for the obstacle height (HOVALS), approach angle (AVALS), and width (WVALS). These tables are generated by Module VIII., Obstacle Override.

Inputs

Vehicle:

NOHGT = number of obstacle height values for which force to override obstacles is given

HOVALS(NH) = value of NHth height of obstacle, in.

NANG = number of obstacle approach angle values for which force to override obstacles is given

AVALS(NA) = value of NAth approach angle, radians

NWTH = number of obstacle widths values for which force to override obstacles is given

WVALS(NW) = value of NWth width, in.

CLEAR(NH,NA,NW) = minimum clearance (negative if interference) during override for obstacle of height HOVALS(NH), approach angle AVALS(NA), and width WVALS(NW), in.

FOOMAX(NH,NA,NW) = maximum force required during obstacle override for obstacle of height HOVALS(NH), approach angle AVALS(NA), and width WVALS(NW), lb.

FOO(NH,NA,NW) = average force required to override obstacle of height HOVALS(NH), approach angle AVALS(NA), and width WVALS(NW), lb.

Terrain:

OBH = obstacle height, in.

OBAA = obstacle approach angle, radians

OBW = obstacle width, in.

Subroutine used: D3LINC

Derived: NEVERO = 0 if override/avoidance strategy may choose obstacle override

$\neq$ 0 otherwise

Outputs FOM = average force required during obstacle override, lb.

FOMMAX = maximum force required during obstacle override, lb.

NEVERO = 0 if override/avoidance strategy may choose obstacle override

= 1, 2 if input as such

= 3 if detailed obstacle override determined interference

Algorithm

```
a.  if NEVERO $\neq$ 0 then exit

    else

b.  find height index

    if NOHGT = 1 or OBH $\le$ HOVALS(1) then I = 1
                                             II = 1
                                             do c.

    else do for NH = 2 to NOHGT

        if OBH $\le$ HOVALS(NH) then I = NH - 1
                                     II = NH
                                     do c.

        else next NH

        after all NH:  I = NOHGT
                      II = NOHGT
```

```
c.  find approach angle index
    if NANG = 1 or OBAA ≤ AVALS(1) then J = 1
                                        JJ = 1
                                        do d.
    else do for NA = 2 to NANG
        if OBAA ≤ AVALS(NA) then J = NA - 1
                                 JJ = NA
                                 do d.
        else next NA
        after all NA:  J = NANG
                      JJ = NANG
d.  find width index
    if NWTH = 1 or OBW ≤ WVALS(1) then K = 1
                                       KK = 1
                                       do e.
    else do for NW = 2 to NWTH
        if OBW ≤ WVALS(NW) then K = NW-1
                                KK = NW
                                do e.
        else next NW
        after all NW:  K = NWTH
                      KK = NWTH
```

e. call interpolation

```
CALL D3LINC(CLR,CLEAR,I,II,J,JJ,K,KK,OBH,OBAA, OBW,
                                 HOVALS,AVALS,WVALS)

if CLR < 0 then NEVERO = 3

                exit

else

CALL D3LINC(FOMMAX,FOOMAX,I,II,J,JJ,K,KK,OBH,OBAA,OBW
                                 HOVALS, AVALS,WVALS)

CALL D3LINC(FOM,FOO,I,II,J,JJ,K,KK,OBH,OBAA,OBW,HOVALS,
                                     AVALS,WVALS)

exit
```

Three-Dimensioanl Linear Interpolation Subroutine Extrapolation at Constant Level Beyond Elements of Array

Description

This subroutine is used in submodel 16 to obtain the minimum clearance (CLR) and the maximum and average forces (FOMMAX and FOM) for the vehicle overriding the specific obstacle in the patch.

It provides interpolation in a three-dimensional array by successive interpolation of one dimension at a time. Extrapolation beyond the boundaries of the data included in the array is made by assuming constant values equal to the first or last element in the array.

Subroutine D3LINC (D,A,I,II,J,JJ,K,KK,VI,VJ,VK,VALI,VALJ,VALK)

Inputs

A(i,j,k) = three dimensional dependent variable array to be interpolated

I,II = low and high values of index i

J,JJ = low and high values of the index j

K,KK = low and high values of the index k

VI,VJ,VK = actual values of the independent variables at which the value of the dependent variable is to be found

VALI(i),VALJ(j),VALK(k) = arrays of independent variables at which values of the dependent variable are given

Outputs

D = value of dependent variable at VI,VJ and VK

Algorithm

```
a.  set plane through VI
    if I = II then ALL = A(I,J,K)
                   ALH = A(I,J,KK)
                   AHL = A(I,JJ,K)
                   AHH = A(I,JJ,KK)
    else ALL = $A(I,J,K) + \frac{VI-VALI(I)}{VALI(II)-VALI(I)} * [A(II,J,K)-A(I,J,K)]$
         ALH = $A(I,J,KK) + \frac{VI-VALI(I)}{VALI(II)-VALI(I)} * [A(II,J,KK)-A(I,J,KK)]$
         AHL = $A(I,JJ,K) + \frac{VI-VALI(I)}{VALI(II)-VALI(I)} * [A(II,JJ,K)-A(I,JJ,K)]$
         AHH = $A(I,JJ,KK) + \frac{VI-VALI(I)}{VALI(II)-VALI(I)} * [A(II,JJ,KK)-A(I,JJ,KK)]$
```

```
b.  set line through VI and VJ
    if J = JJ then AL = ALL
                   AH = ALH
    else
       $AL = ALL + \frac{VJ-VALJ(J)}{VALJ(JJ)-VALJ(J)} * [AHL-ALL]$
       $AH = ALH + \frac{VJ-VALJ(J)}{VALJ(JJ)-VALJ(J)} * [AHH-ALH]$
c.  set point at VI, VJ and VK
    if K = KK then D = AL
    else
       $D = AL + \frac{VK-VALK(K)}{VALK(KK)-VALK(K)} * [AH-AL]$
    exit
```

17. Driver Limited Speed Over Obstacles

Description This routine determines the maximum speed (VOLA) at which the vehicle will impact a single obstacle or a series of spaced obstacles in order to limit acceleration at the driver's station, or on the cargo, to pre-determined maximum values. This speed is obtained by interpolating in tables, produced by Module VII (Vehicle Ride Dynamics) which relate impact speed limit to obstacle height (HVALS).

In AMC '74 two tables of speed versus obstacle height or spacing are provided, one for impacts with single obstacles (VOOB), and the other (VOOBS), for the situation where obstacles are so closely spaced that the dynamic effects from one obstacle are not completely damped before the next obstacle is encountered. The second table of speeds (VOOBS) is used for obstacles spaced closer than two vehicle lengths apart.

Input

Vehicle: TL = distance from front of first running gear assembly to rear of last, in.

NHVALS = number of obstacle height values used in VOOB and HVALS

HVALS(NH) = value of NH^{th} obstacle height, in.

VOOB(NH) = maximum driver limited speed at which vehicle can contact an obstacle of height HVALS(NH) if obstacles are spaced further than two vehicle lengths apart, in/sec

NSVALS = number of obstacle spacing values used in VOOBS and SVALS

SVALS(NS) = value of NS^{th} obstacle spacing, in.

VOOBS(NS) = maximum driver limited speed at which vehicle can contact successive obstacles spaced SVALS(NS) apart, in/sec

Terrain: OBH = obstacle height, in.

WA = ground level width of obstacle in.

Derived: OBSE = effective obstacle spacing, in.

Output

VOLA = maximum speed with which vehicle may contact obstacle limited by driver or cargo, in/sec

Algorithm

```
a.  if $TL \geq OBSE-WA$
        then do for $NH = 2$ to NHVALS
            if $OBH \leq HVALS(NH)$
                then
```

```
          $VOLAB = VOOB(NH-1) + \frac{OBH-HVALS(NH-1)}{HVALS(NH)-HVALS(NH-1)} *[VOOB(NH)-VOOB(NH-1)]$
          do b.
        else next NH
        if no more NH's then VOLAB = VOOB(NHVALS)
        do b.
    else do b.
b.  if 2*TL $\geq$ OBSE-WA  then VOLA = VOLAB
                                  exit
    else do for NS = 2 to NSVALS
         if OBSE $\leq$ SVALS(NS)
           then
           $VOLAS = VOOBS(NS-1) + \frac{OBSE-SVALS(NS-1)}{SVALS(NS)-SVALS(NS-1)} *[VOOBS(NS)-VOOBS(NS-1)]$
           do c.
         else next NS
         if no more NS's then VOLAS = VOOBS(NSVALS)
         do c.
c.  if TL < OBSE-WA then VOLA = VOLAS
                               exit
    else VOLA = min {VOLAB,VOLAS}
    exit
```

18. Speed Onto and Off Obstacles

Description This routine calculates the speed lost in crossing an obstacle.

The reserve force available (maximum force available less resistance between obstacles) at the speed (VA) with which the vehicle encounters the obstacle is calculated using subroutine FORVEL. If there is sufficient reserve force to overcome the obstacle resistance (FOM) then no speed loss occurs in crossing the obstacle. If not enough reserve force is available (FORDEF ≥ 0), the extra force needed is taken from the vehicle's kinetic energy (MASS*VA^2), resulting in a speed loss. If there is insufficient kinetic energy, then the obstacle resistance (TR+FOMMAX) is compared to the maximum tractive effort (FORMX) the vehicle can produce. If that force is sufficient then the vehicle proceeds at the speed determined by the maximum tractive effort that can be produced. If the maximum tractive effort (FORMX) is insufficient to overcome the obstacle resistance (FOM), the crossing speed is set to zero.

This routine addresses both the single obstacle crossing case and the case where the vehicle is crossing obstacles spaced closer than the vehicle's length. When the obstacles are spaced closer than the vehicle's length then the velocities VSOIL, VTT, VBO defined for soil/slope/vegetation resistance between obstacles are not applicable. However, to avoid creating a new set of velocity variable names which depend on the same resistances (soil/slope/vegetation), the velocities VSOIL, VTT, and VBO are recalculated including the average force to override an obstacle (FOM).

Inputs

Vehicle: GCW = gross combination weight, lb.

TL = distance from front of first running gear assembly to rear of last, in.

VTIRE(j) = maximum steady state speed allowed beyond which structural damage will occur to tires at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway, in/sec

NGR = number of gears

Terrain: WA = ground level width of obstacle, in.

NI = number of stem diameter classes

IST = soil type

Derived: VBO(K,i) = speed on slope K = up, level and down between obstacles overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

VOLA = maximum speed with which vehicle may contact obstacle limited by driver or cargo, in/sec

NEVERO = 0 if override/avoid strategy may choose obstacle override

≠ 0 otherwise

FOMMAX = maximum force required during obstacle override, lb.

FOM = average force required to override obstacle, lb.

FORMX(K) = maximum tractive effort available in soil on slope K, lb.

VFMAX(K) = speed at which maximum tractive effort on slope K = up, level and down is available, in/sec

FA(NG,K),FB(NG,K),FC(NG,K) = coefficients of quadratic fitted to tractive effort versus speed curve for gear NG and slope K = up, level and down; lb, lb/(in/sec), $lb/(in/sec)^2$

VG(NG,MN) = minimum speed in gear NG modified by slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec

TR(K,i) = total soil, slope and vegetation resistance between obstacles while overriding vegetation in stem diameter class i-1 and smaller, lb.

OBSE = effective obstacle spacing, in.

MAXI = one greater than the index of the maximum stem diameter class that can be overridden

VRID = speed between obstacles limited by surface roughness, in/sec

VELV(K) = speed limited by visibility on slope K = up, level and down, in/sec

SRFV(i) = speed reduction factor due to avoiding vegetation in stem diameter class i and greater

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

NOPP = operating tire pressure indicator:

= 0 tire pressure soil dependent

= 1 if always use fine grained soil dependent tire pressure

= 2 if always use coarse grained soil dependent tire pressure

= 3 if always use highway dependent tire pressure

Subroutines Used: FORVEL, VELFOR

<u>Outputs</u>

VA(K,i) = obstacle approach velocity on slope K = up, level and down while overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

VXT(K,i) = obstacle exit velocity on slope K = up, level and down while overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

<u>Algorithm</u>

```
if NEVERO ≠ 0
   then VBO(K,i) = VA(K,i) = VXT(K,i) = 0 for all K,i
   exit
else if TL > OBSE-WA
        then do single obstacle routine b.
     else do multiple obstacle routine a.
```

```
a.  multiple obstacle routine
    if NOPP = 0
       then if IST = 1, 3 or 4
               then j = 1
            else j = 2
    else j = NOPP
    do for K = 1 to NTRAV
       do for i = 1 to MAXI
             RESIST = TR(K,i)+FOM
             CALL VELFOR(RESIST,VSOIL(k,i),K,NGR,FA,FB,FC,
                                VG,FORMX(K),VFMAX(K))
             VTT(K,i) = min { VSOIL(K,i),VRID,VELV(K),
                                   VTIRE(j), VOLA }
             VBO(K,i) = SRFV(i)*VTT(K,i)
             VA(K,i) = VXT(K,i) = VBO(K,i)
             next i
    do for i = MAXI+1 to NI+1
          VA(K,i) = VXT(K,i) = VBO(K,i) = 0.
    next i,K
    exit
b.  single obstacle routine
    do for K = 1 to NTRAV
       do for i = 1 to MAXI
             VA(K,i) = min { VBO(K,i),VOLA }
             CALL FORVEL(VA(K,i),F,K,NGR,FA,FB,FC,VG,FORMX(K))
```

```
        FORRQ(K) = TR(K,1)+FOM
        FORDEF = FORRQ(K)-F
        if FORDEF $\leq$ 0.
           then VXT(K,i) = VA(K,i)
                next i
        else
           VBSQ = VA(K,i)$^2$-FORDEF*(WA+TL)*385.9/GCW
           if VBSQ $\leq$ 0.
              then if FORMX(K) < TR(K,1)+FOMMAX
                      then VXT(K,i) = VA(K,i) = 0.
                           next i
                   else calculate velocity to overcome
                        max resistance over obstacle
                   CALL VELFOR(TR(K,1)+FOMMAX,VXT(K,i),
                        NGR,FA,FB,FC,VG,FORMX(K),VGMAX(K))
                   VA(K,i) = VXT(K,i)
                   next i
           else VXT(K,i) = SQRT(VBSQ)
           next i
do for i = MAXI+1 to NI+1
      VXT(K,i) = VA(K,i) = VBO(K,i) = 0.
next i
next K
exit
```

Force Available at a Given Velocity

Description This subroutine (FORVEL) calculates the force available to the vehicle while it is traveling at a given speed in a given gear. It is used in submodels 18 and 20. The coefficients (FA,FB,FC) specifying the quadratic curve of speed versus tractive effort in the given gear (see subroutine QUAD) are used to directly evaluate the force available at the given speed.

Subroutine FORVEL (V,F,K,NGR,FA,FB,FC,VG,FORMX)

Inputs

NGR = number of gears

V = velocity, in/sec

K = u: uphill; = ℓ: uphill; = d: downhill

FA(NG,K) = constant term of quadratic fitted to tractive effort versus speed curve for gear NG and slope K, lb.

FB(NG,K) = linear term coefficient of quadratic fitted to tractive effort versus speed curve for gear NG and slope K, lb/(in/sec)

FC(NG,K) = quadratic term coefficient of quadratic fitted to tractive effort versus speed curve for gear NG and slope K, $\text{lb}/(\text{in/sec})^2$

VG(NG,MN) = minimum speed in gear NG, modified by slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec

FORMX(K) = maximum tractive effort available in soil on slope K = up, level and down; lb.

Output

F = force available at velocity V, lb.

Algorithm

```
if V < VG(1,MN)
   then F = FORMX(K)
        exit
else if V > VG(NGR,MX)
        then F = 0.
             exit
```

```
else do for NG = 1 to NGR
     if V > VG(NG,MX)
        then next NG
     else F = (FC(NG,K)*V+FB(NG,K))*V+FA(NG,K)
          exit
```

19. Average Patch Speed Crossing Obstacles Including Acceleration/Deceleration Between and Over Obstacles

Description This routine calculates the average patch speed as affected by acceleration and deceleration between obstacles. It first calculates the time and distance required to accelerate from the obstacle exit speed (VXT) to the maximum feasible speed between obstacles as determined by resistances or other limits (VBO), or some lower speed governed by the distance at which deceleration must begin in order to reach the obstacle approach speed (VA) at contact with the next obstacle. Vehicle acceleration is computed in subroutine ACCEL, which accounts for shift time (SHIFTT) between gears where appropriate. Average speed (VOVER) is obtained by summing acceleration time (TA), deceleration time (TB), time (TBO) spent at maximum steady speed (VBO), and time crossing the obstacle (TOO), and dividing by effective obstacle spacing (OBSE).

Inputs Vehicle: GCW = gross combination weight, lb.

TL = distance from front of first running gear assembly to rear of last, in.

NGR = number of gears

SHIFTT = gear shift time, sec.

Terrain: WA = ground level width of obstacles, in.

Derived: OBSE = effective obstacle spacing, in.

FOMMAX = maximum force required during obstacle override, lb.

TR(K,i) = total soil, slope and vegetation resistance between obstacles overriding vegetation in stem diameter class i-1 and smaller, lb.

FA(NG,K),FB(NG,K),FC(NG,K) = coefficients of quadratic fitted to tractive effort versus speed curve for gear NG and slope K = up, level and down, lb, lb/(in/sec), lb(in/sec)^{2}

VG(NG,MN) = minimum speed in gear NG modified by slip, in/sec

VG(NG,MD) = mid-range speed in gear NG modified by slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec

VBO(K,i) = speed on slope K = up, level and down between obstacles when overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

VA(K,i) = obstacle approach velocity on slope K = up, level and down while overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

STRACT(NG,L,K) = slip modified tractive effort in gear NG at speed index L = MN, MD and MX and slope K = up, level and down, lb.

VXT(K,i) = obstacle exit velocity on slope K = up, level and down while overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

FORMX(K) = maximum tractive effort available in soil on slope K = up, level and down, lb.

VFMAX(K) = speed at which maximum tractive effort on slope K = up, level and down is available, in/sec

MXBF(K) = maximum braking force on slope K = up, level and down, lb.

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

Subroutines used: TXGEAR, ACCEL

<u>Output</u> VOVER(K,i) = average speed on slope K = up, level and down while overriding obstacles and vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

Algorithm

```
VM = GCW/385.9

do for K = 1 to NTRAV

       i = 1 to NI+1

a.  determine if obstacle exit speed is between obstacles,
    if so it is VOVER

    if VBO(K,i) = VXT(K,i) then VOVER(K,i) = VXT(K,i)

                                next i

                                next K

    else

b.  determine if there is enough distance between obstacles
    to accelerate to obstacle approach speed

    if VXT(K,i) < VA(K,i)  then

       CALL ACCEL(VXT(K,i),VA(K,i),TA,XA,NV2FLG,K,i,NGR,
              FA,FB,FC,VG,STRACT,TR,GCW,SHIFTT,NGF,V2F)

       if XA > OBSE - (WA+TL) and/or NV2FLG ≠ 0

          then not enough distance so

               if FORMX(K) ≥ TR(K,1)+FOMMAX

                  then CALL VELFOR(TR(K,1)+FOMMAX,VOVER(K,i),
                         K,NGR,FA,FB,FC,VG,FORMX(K),VFMAX(K))

                           next i

                           next K

               else VOVER(K,i) = 0

               next i

               next K
               exit

       else (XA < OBSE-(WA+TL) and NEVERO = 0) do c.

    else (VXT(K,i) ≥ VA(K,i)) continue
```

c. acceleration/deceleration required; determine if VBO can be reached in time to decelerate to VA

```
CALL ACCEL(VXT(K,i),VBO(K,i),TA,XA,NV2FLG,K,i,NGR,FA
           FB,FC,VG,STRACT,TR,GCW,SHIFTT,NGF,V2F)

if NV2FLG = 2 then VBO cannot be reached

                  do d.

else

  TB = VM*[VBO(K,i)-VA(K,i)]/MXBF(K)

  XB = .5*[VBO(K,i)+VA(K,i)]*TB

if XA+XB > OBSE-WA-TL then not enough space between
                                              obstacles

                     do d.

else

  TOO = 2*(WA+TL)/[VA(K,i)+VXT(K,i)]

  TBO = (OBSE-WA-TL-XA-XB)/VBO(K,i)

  VOVER(K,i) = OBSE/(TA+TBO+TB+TOO)

  next i

  next K
```

d. acceleration/deceleration required; determine velocity which can be reached before deceleration required and time between and over obstacles

```
VLOW = VA(K,i)

VHGH = VBO(K,i)

do for J = 1 to 5

VMID = .5*(VLOW+VHGH)
```

```
CALL ACCEL(VXT(K,i),VMID,TA,XA,NV2FLG,K,i,NGR,FA,FB,
        FC,VG,STRACT,TR,GCW,SHIFTT,NGF,V2F)

if NV2FLG = 1

   then VHGH = VLOW

        VLOW = VA(K,i)

        next J

else if NV2FLG = 2

        then VHGH = VMID

             next J

      else TB = VM*[VMID-VA(K,i)]/MXBF(K)

           XB = .5*[VMID+VA(K,i)]*TB

      if XA+XB ≤ OBSE - (TL+WA)

         then VLOW = VMID

              next J

      else VHGH = VMID

           next J

      after all J

      TOO = 2*(WA+TL)/(VA(K,i)+VXT(K,i))

      VOVER(K,i) = OBSE/(TA+TB+TOO)

      next i

      next K

      exit
```

Time and Distance in a Gear Subroutine

Description

Subroutine TXGEAR calculates the time and distance required for the vehicle to accelerate from one speed (V1) to another (V2) in a fixed gear.

Checks are made to determine if the initial speed (V1) is in the stall range for the given gear; if so, the flag NV2FLG is set to 1. Another check is made to determine if the final speed (V2) is beyond the capability of the vehicle in the given gear; if so, the flag NV2FLG is set to 2.

The new feature of this routine is the use of a closed form integration for calculating times and distances.

This closed form integration is made possible by representing the tractive effort versus speed curve by a quadratic curve for each gear.

Subroutine TXGEAR(V1,V2,NG,T,X,NV2FLG,K,i,FA,FB,FC,VG,STRACT, TR,GCW)

Inputs

Vehicle: GCW = gross combination weight, lb.

Derived: FA(NG,K),FB(NG,K),FC(NG,K) = coefficient of quadratic fitted to tractive effort versus speed curve for gear NG and slope K = up, level and down; lb, lb/(in/sec),lb/(in/sec)^2

VG(NG,MN) = minimum speed in gear NG modified by slip, in/sec

VG(NG,MD) = mid-range speed in gear NG modified by slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec

STRACT(NG,L,K) = slope modified tractive effort in gear NG at speed index L = MN, MD or MX and slope K = up, level and down, lb.

TR(K,i) = total soil, slope and vegetation resistance between obstacles while overriding vegetation in stem diameter class i-1 and smaller, lb.

Dummy: V1 = initial speed before acceleration, in/sec

V2 = final speed after acceleration, in/sec

NG = gear

K = slope

i = one greater than the index of the stem diameter class being overridden

Outputs

T = time to accelerate from V1 to V2, sec

X = distance required to accelerate from V1 to V2, in.

NV2FLG = 0 if vehicle can accelerate from V1 to V2

= 1 if vehicle cannot increase speed above V1

= 2 if vehicle cannot reach speed V2

Algorithm

```
a.  set common values
    VM = GCW/385.9
    A = FA(NG,K)
    B = FB(NG,K)
    C = FC(NG,K)
    F = TR(K,i)
    $DSQ = B^2 - 4*(A-F)*C$
    NV2FLG = 0
b.  curvature test; C:  0
    if C > 0 then do c.
    else if C = 0 then do d.
         else do e.
c.  positive curvature - test slope at V = 0; B:0
    if B < 0 then do c1.
    else if B = 0 then do c2.
         else do c3.
```

```
c.1  positive curvature, negative slope at V = 0 - test
     intercept; A-F:0

     if A-F ≤ 0 then R2 = [-B+SQRT(DSQ)]/(2*C)

                     R1 = (A-F)/(C*R2)

                     if V1 ≤ R2 then NV2FLG = 1

                                     exit

                     else do x.

     else if DSQ < 0 then do z.

          else (DSQ) ≥ 0)

               R2 = [-B+SQRT(DSQ)]/(2*C)

               R1 = (A-F)/(C*R2)

               if DSQ > 0 then if V2 ≤ R1 or V1 ≥ R2 then do x.

                                else if V1 > R1 then NV2FLG = 1

                                     else NV2FLG = 2

                                          exit

               else (DSQ = 0) if V1 > R1 or V2 < R1 then do y.

                              else if V1 = R1 then NV2FLG = 1

                                                   exit

                                   else NV2FLG = 2

                                        exit

c.2  positive curvature, zero slope at V = 0 - test intercept;
     A-F:0

     if A-F > 0 then do z.
```

```
    else if A-F = 0 then T = VM*(1./V1-1./V2)/C
                         X = (VM/C)*ln(VM/[VM-V1*C*T])
                         exit
         else (A-F<0)    R2 = SQRT(DSQ)/(2*C)
                         R1 = (A-F)/(C*R2)
                         if V1 ≤ R2 then NV2FLG = 1
                         else do x.
c.3  positive curvature, positive slope at V=0 - test intercept;
     A-F:0
     if A-F ≤ 0 then R1 = [-B-SQRT(DSQ)]/(2*C)
                     R2 = (A-F)/(C*R1)
                     if V1 ≤ R2 then NV2FLG = 1
                                     exit
                     else do x.
     else if DSQ > 0 then do x.
          else if DSQ = 0 then do y.
               else do z.
d.   zero curvature, test slope at V=0; B:0
    if B < 0 then if A-F ≤ 0 then NV2FLG = 1
                                exit
                  else R1 = -(A-F)/B
                       if V1 ≥ R1 then NV2FLG = 1
                                     exit
                       else if V2 ≥ R1 then NV2FLG = 2
                                            exit
                            else do w.
```

```
if B = 0 then if A-F ≤ 0 then NV2FLG = 1
                          exit
              else T = VM*(V2-V1)/(A-F)
                   X = [(A-F)*T/(2*VM)+V1]*T
                   exit
else (B > 0) if A-F < 0 then R1 = -(A-F)/B
                             if V1 ≤ R1 then NV2FLG = 1
                                             exit
                             else (V1 > R1) do w.
             else (A-F ≥ 0) do w.
```

e. negative curvature

```
if B < 0 then if A-F ≤ 0 then NV2FLG = 1
                          exit
              else (A-F > 0) R1 = [-B+SQRT(DSQ)]/(2*C)
                             R2 = (A-F)/(C*R1)
                             if V1 ≥ R2 then NV2FLG = 1
                                             exit
                             else (V1 < R2) if V2 > R2 then
                                                NV2FLG = 2
                                                exit
                                            else do x.
else (B ≥ 0) if A-F < 0 then if DSQ ≤ 0 then NV2FLG = 1
                                             exit
                             else (DSQ > 0) do e1.
             else (A-F ≥ 0) do e1.
```

```
el. R2 = [-B-SQRT(DSQ)]/(2*C)
    R1 = (A-F)/(C*R2)
    if V1 ≤ R1 then NV2FLG = 1
                    exit
    else if V1 ≥ R2 then NV2FLG = 1
                         exit
         else if V2 > R2 then NV2FLG = 2
                              exit
              else do x.
w.  T = (VM/B*)*ℓn[(B*V2+A-F)/(B*V1+A-F)]
    X = -(A-F)*T/B+(VM/B^2)*(B*V1+A-F)*[EXP(T*B/VM)-1.]
    exit
x.  log routine - positive discriminant
        D = SQRT(DSQ)
        V1BAR = [2*C*V1+B-D]/[2*V1+B+D]
        V2BAR = [2*C*V2+B-D]/[2*C*V2+B+D]
        T = (VM/D)*ℓn(V2BAR/V1BAR)
        $X = \frac{1}{C}\left[.5*(D-B)*T - VM*\ \ell n\ \left(\frac{1-V1BAR*EXP(T*D/VM)}{1-V1BAR}\right)\right]$
        exit
```

y. reciprocal routine - zero discriminant

$$T = 2*VM*\left[\frac{1}{2*C*V1+B} - \frac{1}{2*C*V2+B}\right]$$

$$X = \frac{VM}{C}*\ln\left(\frac{2*VM}{2*VM-T*(2*C*V1+B)}\right) - .5*B*T/C$$

exit

z. negative discriminant - make two gears fitted by straight lines out of one fitted by a quadratic

$$SH = \frac{STRACT(NG,MX,K) - STRACT(NG,MD,K)}{VG(NG,MX) - VG(NG,MD)}$$

$$ZH = \frac{STRACT(NG,MX,K)*VG(NG,MX) - STRACT(NG,MD,K)*VG(NG,MD)}{VG(NG,MX) - VG(NG,MD)}$$

$$SL = \frac{STRACT(NG,MD,K) - STRACT(NG,MN,K)}{VG(NG,MD) - VG(NG,MN)}$$

$$ZL = \frac{STRACT(NG,MD,K)*VG(NG,MD) - STRACT(NG,MN,K)*VG(NG,MN)}{VG(NG,MD) - VG(NG,MN)}$$

```
if $V2 < VG(NG,MD)$ then $S = SL$
                         $Z = ZL$
                         do z'.
else if $V1 > VG(NG,MD)$ then $S = SH$
                              $Z = ZH$
                              do z'.
    else if $V2 > \min -(ZH-F)/SH , -(ZL-F)/SL )$
        then $NV2FLG = 2$
            exit
```

```
          else (V2 < min( -(ZH-F)/SH , -(ZL-F)/SL ))
      $TL = (VM/SL)*\ln\left(\frac{SL*VG(NG,MD)+ZL-F}{SL*V1+ZL-F}\right)$
      $TH = (VM/SH)*\ln\left(\frac{SH*V2+ZH-F}{SH*VG(NG,MD)+ZH-F}\right)$
      $X = \frac{SL*V1+ZL-F}{SL^2}*VM*[EXP(SL*TL/VM)-1]$
          $+ \frac{SH*VG(NG,MD)+ZH-F}{SH^2}*VM*[EXP(SH*TH/VM)-1]$
          $- (ZL-F)*TL/SL-(ZH-F)*TH/SH$
      T = TL+TH
      exit
2'. VZ = -(Z-F)/S
    if $V2 \geq VZ$ then NV2FLG = 0
                  exit
    else
    $T = (VM/S)*\ln\left(\frac{S*V2+Z-F}{S*V1+Z-F}\right)$
    $X = \{(S*V1+Z-F)*VM*[EXP(S*T/VM)-1]-(Z-F)*S*T\}/S^2$
    exit
```

Time and Distance to Accelerate from One Velocity to Another

Description Subroutine ACCEL calculates the time and distance required to accelerate from one speed (V1) to another (V2). The lowest gears in which V1 and V2 can be realized are used as the initial gears (NG1) and final gear (NG2).

The subroutine TXGEAR is used to determine the time and distance in each gear from lowest (NG1) to the highest (NG2). In addition to these times and distances, which are accumulated from gear to gear, ACCEL includes a time to shift gears (SHIFTT).

Whenever TXGEAR indicates that a final speed cannot be reached, an iterative routine determines the highest speed (V2F) and the corresponding gear (NGF) that can be achieved and a non-zero value for the flag NV2FLG is returned.

Subroutine ACCEL (V1,V2,T,X,NV2FLG,K,i,NGR,FA,FB,FC,VG,
STRACT,TR,GCW,SHIFTT,NGR,V2F

<u>Inputs</u> Vehicle: GCW = gross combination weight, lb.

SHIFTT = gear shift time, sec.

NGR = number of gears

Derived: FA(NG,K),FB(NG,K),FC(NG,K) = coefficients of the quadratic fitted to the tractive effort versus speed curve in gear NG for slope K = up, level and down; lb, lb/(in/sec), lb/(in/sec)^2

VG(NG,MN) = minimum speed in gear NG modified by slip, in/sec

VG(NG,MD) = mid-range speed in gear NG modified by slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec

STRACT(NG,L,K) = slope modified tractive effort in gear NG for speed index L = MN, MD or MX and slope K = up, level and down; lb.

TR(K,i) = total soil, slope and vegetation resistance between obstacles while overriding vegetation in stem diameter class i-1 and smaller, lb.

Dummy: V1 = initial speed before acceleration, in/sec

V2 = final speed after acceleration, in/sec

K = slope being traversed

i = one greater than the maximum stem diameter class being overridden

Output

T = time to accelerate from V1 to V2, sec.

X = distance required to accelerate from V1 to V2, in.

NV2FLG = 0 if vehicle can accelerate from V1 to V2
= 1 if vehicle cannot increase speed above V1
= 2 if vehicle cannot reach speed V2

NGF = final gear achieved while accelerating between obstacles

V2F = final speed achieved while accelerating between obstacles, in/sec

Algorithm

```
a.  determine gears NG1 and NG2, of initial and final velocity

    VM = GCW/385.9

    do for NG = 1 to NGR

          if V1 ≤ VG(NG,MX) then NG1 = NG

          else next gear NG

    do for NG = NG1 to NGR

          if V2 < VG(NG,MX) then NG2 = NG

          else next gear NG

    if NG1 = NG2 then do single gear routine b.

    else do multiple gear routine c.

b.  single gear routine

    VL = V1

    T = 0.

    X = 0.
```

```
   VH = V2
   NG = NG1
   CALL TXGEAR(VL,VH,NG,TT,XX,NV2FLG,K,i,FA,FB,FC,VG,STRACT,
                                                    TR,GCW)
   if NV2FLG = 0 then T = TT, X = XX, exit
   else if NV2FLG = 1 then exit
        else (NV2FLG = 2) do z.
c. multiple gear routine
   T = 0.
   X = 0.
   VL = V1
   VH = VG(NG1,MX)
   NG = NG1
   CALL TXGEAR(VL,VH,NG,TT,XX,NV2FLG,K,i,FA,FB,FC,VG,STRACT,
                                                    TR,GCW)
   if NV2FLG = 1 then exit
   else if NV2FLG = 2 then do z.
        else T = TT+SHIFTT
             VS = VG(NG1,MX)-SHIFTT*TR(K,i)/VM
             X = XX+SHIFTT*[VG(NG1,MX)-.5*SHIFTT*TR(K,i)/VM]
             if NG2 > NG1+1 then do d.
             else VL = VS
                  VH = V2
                  NG = NG2
                  CALL  TXGEAR(VL,VH,NG,TT,XX,NV2FLG,K,i,FA,
                               FB,FC,VG,STRACT,TR,GCW)
```

```
            if NV2FLG = 1
               then T = T-SHIFTT
                    V2F = VG(NG1,MX)
                    NGF = NG1
                    X = X-SHIFTT*[VG(NGF,MX)-.5*SHIFTT*TR(K,i)/VM]
                    NV2FLG = 2
                    exit
            else (NV2FLG ≠ 1)  if NV2FLG = 2 then do z.
                               else (NV2FLG = 0.)
                               T = T+TT
                               X = X+XX
                               exit
d.  accelerate through intermediate gears
    do for NG = NG1+1 to NG2-1
    VL = VS
    VH = VG(NG,MX)
    CALL TXGEAR (VL,VH,NG,TT,XX,NV2FLG,K,i,FA,FB,FC,VG,STRACT,
                                                      TR,GCW)
    if NV2FLG = 1 then T = T-SHIFTT
                       NGF = NG-1
                       V2F = VG(NGF,MX)
                       X=X+SHIFTT*[VG(NGF,MX)-.5*SHIFTT*TR(K,i)/VM]
                       NV2FLG = 2
                       exit
```

```
else if NV2FLG = 2 then do z.

     else T = T+TT+SHIFTT

          VS = VG(NG,MX)-SHIFTT*TR(K,i)/VM

          X = X+XX+SHIFTT*[VG(NG,MX)-.5*SHIFTT*TR(K,i)/VM]

          next NG

after all NG

NG = NG2

VL = VS

VH = V2

CALL TXGEAR(VL,VH,NG,TT,XX,NV2FLG,K,i,FA,FB,FC,VG,STRACT,
                                            TR,GCW)

if NV2FLG = 1 then T = T-SHIFTT

                   NGF = NG-1

                   V2F = VG(NGF,MX)

                   X = X+SHIFTT*[VG(NGF,MX)-.5*SHIFTT*TR(K,i)/VM]

                   NV2FLG = 2

                   exit

else if NV2FLG = 2 then do z.

     else T = T+TT

          X = X+XX

          exit
```

z. error routine

```
VAV = (VL+VH)/2

do for j = 1 to 4

CALL TXGEAR(VL,VAV,NG,TT,XX,NV2FLG,K,i,FA,FB,FC,VG,STRACT,
                                              TR,GCW)

if NV2FLG = 0 then VAV = (VAV+VH)/2

                    next j

else VH = VAV

     VAV = (VL+VH)/2

     next j

after last j: V2F = VAV

              NGF = NG

              NV2FLG = 2

              T = T+TT

              X = X+XX

              exit
```

20. Vegetation Override Check

Description This routine determines whether a single stem of the largest stem diameter class to be overridden in a given strategy can actually be overridden at the average vehicle speed in the patch (VOVER calculated in submodel 19 or VAVOID calculated in submodel 15). As in AMC '71 the vegetation resistance (calculated in submodel 6) is averaged over the vegetation spacing, which for sparse vegetation can result in a low average resistance. The vegetation override check is made to determine whether peak resistance force requirements can be met.

The sum of the tractive effort force calculated in subroutine FORVEL at speed VOVER or VAVOID, as appropriate, and the force available from kinetic energy is compared to the resistance due soil, slope and overriding a single tree of the largest stem diameter class to be overridden. If the available force is adequate a flag VOCHK(K,i) or VAVCHK(K,i) is set equal to 1. Otherwise the flag is set equal to zero.

The products VOVER*VOCHK and VAVOID*VAVCHK are used in making final speed selections (Submodel 21).

Inputs Vehicle: GCW = gross combination weight, lb.

NGR = number of gears

Derived: STR(K,i) = total resistance due to soil, slope and overriding a single tree in stem diameter class i-1, lb.

VOVER(K,i) = average speed on slope K = up, level and down while overriding obstacles and vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

VAVOID(K,i) = speed on slope K =up, level and down avoiding obstacles but overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

FA(NG,K),FB(NG,K),FC(NG,K) = coefficients of quadratic fitted to tractive effort versus speed curve in gear NG on slope K = up, level and down, lb, lb/(in/sec), $\text{lb}/(\text{in/sec})^2$

FORMX(K) = maximum tractive effort available in soil on slope K = up, level and down; lb.

VG(NG,MN) = minimum speed in gear NG modified by slip, in/sec

VG(NG,MX) = maximum speed in gear NG modified by slip, in/sec

MAXI = one greater than the index of the maximum stem diameter class that can be overridden

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

Subroutines used: FORVEL

Outputs VOCHK(K,i) = 1 if combination can override a single tree of stem diameter class i-1 at speed VOVER(K,i)

= 0 otherwise

VAVCHK(K,i) = 1 if combination can override a single tree of stem diameter class i-1 at speed VAVOID(K,i)

= 0 otherwise

Algorithm

```
do for K = 1 to NTRAV
do for i = 1 to MAXI
    CALL FORVEL (VOVER(K,i),F,K,NGR,FA,FB,FC,VG,FORMX(K))
    if $F+.5*GCW*VOVER(K,i)^2/385.9 \le STR(K,i)$
        then VOCHK(K,i) = 0.
    else VOCHK(K,i) = 1.
    CALL FORVEL (VAVOID(K,i),F,K,NGR,FA,FB,FC,VG,FORMX(K))
    if $F+.5*GCW*VAVOID(K,i)^2/385.9 \le STR(K,i)$
        then VAVCHK(K,i) = 0.
    else VAVCHK(K,i) = 1.
    next i
    next K
    exit
```

21. Maximum Average Speed

Description This routine assigns the maximum average speed in the patch (VSEL). For each direction of travel relative to the slope (up, level and down), the speed assigned is the maximum achievable among the 18 possible obstacle and vegetation avoid/override options computed, (VOCHK*VOVER, VAVCHK*VAVOID), subject to the following possible condition. It has been found that in many situations, if a vehicle will travel at a reasonable speed without overriding large trees, the driver will accept that speed rather than override more trees, even though by further overriding his average speed could be increased. This reasonable speed is entered as a scenario variable CVEGV.

When a traverse prediction is being made (NTRAV = 1) the speed determined for the single slope direction specified is output as VSEL. When a non-directional area speed prediction is specified (NTRAV = 3) VSEL is computed on the assumption that 1/3 of the distance traveled in the patch is uphill, 1/3 downhill and 1/3 on level ground. This assumption produces a prediction which is directly applicable to operations in rolling country for which the slope specified for the patch is the characteristic maximum slope. In patches with a prevailing slope, VSEL is considered an omni-directional average speed, and the 1/3 of distance on level ground is interpreted as 1/3 of distance along the slope contours at a fixed elevation, is side slope operation. Because the average is based upon 1/3 distance in each direction (up, level and down), the maximum average, VSEL, is, in this case, the harmonic average of the maxima selected for each direction.

Input

Derived: VOVER(K,i) = average velocity on slope K = up, level and down while overriding obstacles and vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

VAVOID(K,i) = speed on slope K = up, level and down avoiding obstacles but overriding vegetation in stem diameter class i-1 and smaller and avoiding vegetation in stem diameter class i and greater, in/sec

VOCHK(K,i) = 1 if combination can override a single tree of stem diameter class i-1 at speed VOVER(K,i)

= 0 otherwise

VAVCHK(K,i) = 1 if combination can override a single tree of stem diameter class i-1 at speed VAVOID(K,i)

= 0 otherwise

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

CVEGV = critical vegetation speed, in/sec

IOVER = one greater than the index of the maximum stem diameter class to be overridden if speed to do so is greater than the critical vegetation speed

Outputs

VSEL = selected average speed in patch, in/sec

ISLCT(K) = one greater than the stem diameter class actually being overridden on slope K

VSLOPE(K) = final selected average speed on slope K = up, level, down

Algorithm

```
do for K = 1 to NTRAV
      i = 1 to NI+1
  V(K,i) = maximum {VOCHK(K,i)*VOVER(K,i),VAVCHK(K,i)*VAVOID(K,i)}
  next i
  ISLCT(K) = minimum {i $\geq$ IOVER such that V(K,i) $\geq$ CVEGV}
  if there is such an ISLCT(K) then VSLOPE(K) = V(K,ISLCT(K))
  else VSLOPE(K) = maximum {V(K,i)}
  ISLCT(K) = i at which above maximum occurred
  next K
  if NTRAV = 1 then VSEL = VSLOPE(1)
  else VSEL = $3/\left[\frac{1}{VSLOPE(u)} + \frac{1}{VSLOPE(\ell)} + \frac{1}{VSLOPE(d)}\right]$
  return to Module I. Control and I/O
```

MODULE V

HASTY RIVER AND DRY LINEAR FEATURES CROSSING

HASTY RIVER AND DRY LINEAR FEATURES CROSSING MODULE

This module is intended to improve and generalize the RIVER subroutine of AMC '71. A report in progress (Reference 7) contains the detailed rationale behind the specifications, equations, and logic of this module.

In the Mobility Model terminology a "linear feature" is any geographic feature represented by a line on a topographic map; such as streams, natural drainage ditches, man-made ditches, and highway embankments. These features require special treatment since the vehicle does not negotiate a linear feature in the same manner as an areal feature (excepting obstacle override). For example, negotiating a linear feature may require that the vehicle remain "on" or "in" the feature until a route is found to exit from it. Linear features of significance are those shown on a 1:50,000 scale topographic map which cause a decrease in vehicle speed or require the vehicle to detour the feature.

The impediments due to linear features on vehicle cross-country movement can be represented by:

- GO or NO-GO across the feature.
- A speed reduction while crossing the feature.
- A time required to cross the feature.

The representation used may be scenario dependent. For example, when a specific vehicle terrain and scenario are given, the interaction between areal patches and linear features can be melded together. In this type of analysis the path of the vehicle is specified either by the scenario or the best route in the areal patches. The terrain input data may have both areal and linear features arranged in the order that the vehicle would encounter them, as specified by the scenario.

Identification of linear features on a topographic map is a straight-forward process. Normally an overlay is prepared and each significant linear feature is traced. In this manner the location and type (i.e., wet, dry, river, canal, slope, railroad, embankment, etc.) is shown. The features are differentiated by the type of line on the overlay and by code numbers.

Assignment of specific geometric properties and physical dimensions to the linear features can be done by a number of different methods. These include:

- Use of "ground truth" data
- Measurements from airphotos and airphoto stereopairs.
- Terrain analogues.
- Estimates based on classifications of feature type.
- Intelligence data.
- Measurements from topographic maps.

The AMC '74 Hasty River and Dry Linear Features Crossing Module first determines if the feature can be crossed on the basis of upslope bank height and bank angles. If crossing is considered possible, bank interference and traction versus resistance are calculated either for the bank as presented or a deformed bank. A deformed bank is a bank formed from a natural bank by action of the vehicle's running gear. If the calculation is made for a deformed bank, allowance is made for modifying the bank by the vehicle in its attempt to negotiate the slope.

Regardless of whether crossing is possible or not, time and distance to alternate crossing sites (bridges and/or exit windows) are calculated from bridge spacings and the natural river meanders which depend on gross topography.

The outputs, GO/NO-GO and time to cross or find other crossing sites, are returned to the user with no further analysis. How they are used to calculate traverse times or average speeds depends on the scenario of the user. The model does not postulate a scenario.

Two specific assumptions are made:

- downslopes can always be negotiated with no time penalty if the upslope negotiation is possible
- alternate crossing sites will always allow a crossing. No time penalty is assessed other than the time to arrive at this alternate site.

The vehicle is assumed to approach the linear feature from the left bank and to exit it from the right bank.

SCENARIO VALUES REQUIRED BY LINEAR FEATURE MODULE

Variable Name	Routine Used	Meaning
NOPP	2	= operating tire pressure indicator = 0 tire pressure soil dependent = 1 if always use fine grained soil dependent tire pressure = 2 if always use coarse grained soil dependent tire pressure = 3 if always use highway dependent tire pressure

VEHICLE INPUT DATA REQUIRED BY HASTY RIVER AND DRY LINEAR FEATURES MODULE

Variable	Routine	Meaning
CGH	3,4	loaded height of CG above ground, in.
CGR	4	loaded horizontal distance of CG to rear most running gear assembly center line, in.
DIAW(i)	3	outside wheel diameter of unloaded tires on running gear assembly i, in.
DRAFT	1	combination draft when fully floating, in. (= 0 if combination cannot float)
FEC	3	front end clearance, in.
FORDD	1,5	maximum water depth combination can ford, in. (FORDD = DRAFT if DRAFT ≠ 0.)
GCA(i,j)	2	nominal ground contact area per track pair or per tire element at pressure specified for j=1 fine grained soil, =2 coarse grained, =3 highway on running gear assembly i, in^2
GCW	2,4	gross combination weight, lb.
IP(i)	2,4	=1 if running gear assembly i is powered = 0 otherwise
NAMBLY	2	total number of running gear assemblies

Variable	Routine	Meaning
NVEH(i)	2,3	= 0 if running gear assembly i is tracked ≠ 0 otherwise
NVEHC	2,4	= 0 if one or more of the powered running gear assemblies is tracked ≠ 0 otherwise
NWHL(i)	2	number of tires on wheeled assembly i
SHF	3	front sprocket (or idler) height, in.
TL	4	distance from center line of first running gear assembly to center line of last, in.
V	6	average travel speed adjacent to river or dry feature, in/sec
VAA	3	front end approach angle, rad.
VFS	5	vehicle fording speed, in/sec
VSS	5,6	maximum combination swimming speed, in/sec
WGHT(i)	2	weight on running gear assembly i, lb.

1. Initial GO/NO-GO Screen

Description This routine makes simple checks of bank heights (RBH) and angles (RBA) to distinguish linear features which are so severe that they pose a NO-GO to any vehicle. This routine also indicates a NO-GO when a non-swimmer (DRAFT = 0) encounters a deep waterway.

Inputs

Vehicle: DRAFT = combination draft when fully floating, in. (= 0.if combination cannot float)

FORDD = maximum water depth combination can ford, in. (FORDD = DRAFT if DRAFT ≠ 0.)

Terrain: RBA = right bank angle, radians

LBA = left bank angle, radians

WD = water depth, in.

RBH = right bank height, in.

LBH = left bank height, in.

C = bank soil cohesion, lb/in^2

TANP = tangent of internal friction angle

RCI = bank rating cone index, lb/in^2

ITUT = terrain unit type code:

= 4 man-made ditch

= 5 natural ditch (river or trench)

= 6 mound

<u>Outputs</u> NOGO = GO/NO-GO type indicator:

= 0 potential GO

= 1 NO-GO due to water depth greater then fording depth

= 2 NO-GO due to bank slope and height

Algorithm

```
a.  feature type test
    if $WD = 0$.  then feature is dry
                  if $ITUT = 6$ then do mound routine d.
                  else do ditch routine c.
    else do river routine b.
b.  river routine
    if $FORDD < WD$ and $DRAFT = 0$.
        then $NOGO = 1$
            do routine 6.  Exit and Crossing Search
    else if $RBA > \pi/6.43$ and $RBH \geq 167.32$
            then $NOGO = 2$
                do routine 6.  Exit and Crossing Search
        else $NOGO = 0$
            exit
c.  dry ditch routine
    if $RBA \geq \pi/5.14$ and $RBH \geq 167.32$
        then $NOGO = 2$
            do routine 6.  Exit and Crossing Search
    else $NOGO = 0$
        exit
```

d. mound routine

```
if LBA > $\pi/3.79$ and LBH $\geq$ 167.32
   then NOGO = 2
        do routine 6. Exit and Crossing Search
else NOGO = 0
     exit
```

2. Initial Traction/Resistance Screen

Description This routine makes an initial check to determine if the vehicle can operate at all in the soil type (IST) of the linear feature slopes. Soil type and strength (C, TANP) are used to calculate a traction (TFL) and resistance (RTOWL*GCW) for the vehicle operating on level ground for the soil type and strength found on the banks. If no excess traction exists, a NOGO is assigned.

Inputs Vehicle: GCW = gross combination weight, lb.

NAMBLY = total number of running gear assemblies

NVEH(i) = 0 if running gear assembly i is tracked

$\neq$ 0 otherwise

NVEHC = 0 if one or more of the powered running gear assemblies is tracked

$\neq$ 0 otherwise

IP(i) = 1 if running gear assembly i is powered

= 0 otherwise

GCA(i,j) = nominal ground contact area per track pair or per tire element at pressure specified for j=1 fine grained soil, =2 coarse grained, = 3 highway on running gear assembly i, in^2

WGHT(i) = weight on running gear assembly i, lb.

NWHL(i) = number of tires on wheeled assembly i

Terrain: ITUT = terrain unit type:

= 4 for man-made ditch

= 5 natural ditch (river or trench)

= 6 mound

WD = water depth, in.

RCI = bank rating cone index, lb/in^2

RBA = right bank angle, radians

LBA = left bank angle, radians

IST = soil type:

= 1 fine grained not CH impervious to water

= 2 coarse grained

= 6 CH impervious to water

= 7 gravel

= 12 clay/sand

= 17 clay/gravel

= 27 sand/gravel

C = bank soil cohesion, lb/in^2

TANP = tangent of internal friction angle

Scenario: NOPP = operating tire pressure indicator:

= 0 tire pressure soil dependent

= 1 if always use fine grained soil dependent tire pressure

= 2 if always use coarse grained soil dependent tire pressure

= 3 if always use highway dependent tire pressure

Outputs RTOWL = level resistance coefficient on bank soil type

RTOW = resistance coefficient on bank

TFL = level tractive force on bank soil type, lb.

NOGO = 0 if potential GO

=3 NO-GO due to insufficient level traction on bank soil type

GAREA(i) = ground contact area of running gear assembly i, in^2

Algorithm

```
a. feature type test
   if WD = 0. then feature is dry
               if ITUT = 0 then do mound routine d.
               else do ditch routine c.
   else do river routine b.
b. river routine
   if NVEHC = 0 (wheeled vehicle)
      then $RTOWL = \frac{28. - 6.35 * \log_{10}(RCI)}{100.}$
           $RTOW = RTOWL - \frac{RBA}{\pi/4.} * \frac{100.}{1500.}$
   else (tracked vehicle)
           $RTOWL = .14$
           $RTOW = RTOWL - \frac{RBA}{\pi/4.} * \frac{100.}{3000.}$
   do routine e.
c. dry ditch routine
   if NVEHC ≠ 0 (wheeled Vehicle)
      then $RTOWL = \frac{28. - 6.35 * \log_{10}(RCI)}{100.}$
           $RTOW = RTOWL - \frac{RBA}{\pi/4.} * \frac{100.}{1200.}$
   else (tracked vehicle)
           $RTOWL = .12$
           $RTOW = RTOWL - \frac{RBA}{\pi/4.} * \frac{100.}{2500.}$
   do routine e.
```

```
d.  mound
    if NVEHC ≠ 0 (wheeled vehicle)
        then RTOWL = $\frac{28. -6.35*\log_{10}(RCI)}{100.}$
            RTOW = RTOWL/1000.
    else (tracked vehicle)
            RTOWL = .1
            RTOW = RTOWL - $\frac{LBA}{45.} * \frac{100.}{2000.}$
    do routine e.
e.  traction on level
    if NOPP = 0 then if IST = 1 or 12 or 17 or 27
                         then j = 1
                     else j = 2
    else j = NOPP
    do for i = 1 to NAMBLY
        if NVEH(i) = 0
            then GAREA(i) = GCA(i,j)
        else GAREA(i) = GCA(i,j) * NWHL(i)
        next i
    TFL = $C*\sum_{i=1}^{NAMBLY} IP(i)*GAREA(i)+TANP*\sum_{i=1}^{NAMBLY} IP(i)*WGHT(i)$
    TFLNET = TFL - RTOWL * GCW
    if TFLNET ≤ -20. then NOGO = 3
                          do routine 6. Exit and Crossing Search
    else exit
```

3. Interference Check

Description This routine determines if there is interference between the vehicle front end and the upslope (right) bank. If there is an interference, a check is made to determine whether the bank surface is soft enough (RCI < 200.) to be deformed by the vehicle to create a bank slope which the vehicle can negotiate without interference. If not, a NO-GO is indicated.

Inputs

Vehicle:

NVEH(i) = 0 if running gear assembly i is tracked

≠ 0 otherwise

SHF = front sprocket (or idler) height, in.

DIAW(i) = outside wheel diameter of unloaded tires on running gear assembly i, in.

FEC = front end clearance, in.

VAA = front end approach angle, rad.

CGH = **loaded height of CG above ground, in.**

Terrain:

RBA = right bank angle, rad.

LBA = left bank angle, rad.

RCI = rating cone index of bank, lb/in^2

Outputs

NOGO = 0 if potential GO

= 4 if NO-GO due to vehicle front end too low

= 5 if NO-GO over step

= 9 if NO-GO due to front end angle too shallow

Algorithm

```
if RBA > LBA then OBAA = RBA
                     H = RBH
else OBAA = LBA
        H = LBH
```

```
if RCI $\geq$ 200. (hard bank)
    then if OBAA $\geq \frac{\pi}{2}$ (steep, hard bank)
            then if NVEH(1) = 0 (first running gear assembly
                                   is tracked)
                    then if H $\geq$ SHF
                            then NOGO = 5
                            do routine 6. Exit and Crossing Search
                         else continue
                 else (first running gear assembly is wheeled)
                      if H $\geq$ DIAW(1)
                         then NOGO = 5
                              do routine 6. Exit and Crossing
                                                  Search
                      else continue
         else if OBAA < $\pi/2$  (shallow, hard bank)
                 then if H $\geq$ FEC
                         then if OBAA $\geq$ VAA
                                 then NOGO = 4
                                 do routine 6.  Exit and
                                               Crossing Search
                              else exit
                      else exit
else (RCI < 200. - soft bank)
```

```
if VAA $\geq$ OBAA - $\frac{200.-RCI}{20.}$
   then vehicle can modify bank sufficiently
        exit
else (vehicle cannot modify bank sufficiently)
    if H $\geq$ CGH * (.75 + .25 *$\frac{RCI}{300.}$)
       then NOGO = 9
            do routine 6.  Exit and Crossing Search
    else exit
```

4. Traction/Resistance on Slope

Description This routine calculates the traction (TSNET) and resistance (RFS) on the upslope (right) bank of the linear feature and specifies a NOGO if there is insufficient traction. When the bank is shorter than the distance between the first and last running gear assembly (TL) the traction is reduced by an amount specified by the bank height (LBH or RBH) and running gear distance (TL). These checks are made for both actual and deformed slope conditions.

Inputs

Vehicle:

GCW = gross combination weight, lb.

NVEHC = 0 if one or more powered running gear assemblies is tracked

≠ 0 otherwise

CGH = loaded height of CG above ground, in.

CGR = loaded horizontal distance of CG to rear most running gear assembly center line, in.

TL = distance from center line of first running gear assembly to center line of last, in.

IP(i) = 1 if running gear assembly i is powered

= 0 otherwise

Terrain:

ITUT = terrain unit type:

= 4 man made ditch

= 5 natural ditch (river or trench)

= 6 mound

RBH = right bank height, in.

LBH = left bank height, in.

RBA = right bank angle, rad.

LBA = left bank angle, rad.

C = bank soil cohesion, lb/in^2

TANP = tangent of internal friction angle

Derived:

GAREA(i) = ground contact area of running gear assembly i, in.^{2}

RTOW = resistance coefficient on bank

Outputs NOGO = 0 if potential GO

=6 if NO-GO due to lack of traction on deformed slope

=7 if NO-GO due to lack of traction on natural slope

= 8 if NO-GO on deformed slope

TSNET = net traction on bank slope, lb.

Algorithm

```
a.  if ITUT = 6 then (mound) H = LBH
                              OBAA = LBA
    else (ditch) H = RBH
                 OBAA = RBA
    if NVEHC = 0 (tracked) then do routine b.
    else do routine c.
b.  tracked vehicle
    if OBAA $\geq \pi/4$ and CGH $\geq$ H  or
       if $\frac{H}{\sin(OBAA)} < CGR-CGH*\tan(OBAA)$
       then (deformed slope)
           if OBAA $\geq \pi/3$ then COBR = .8
           else COBR = cos (OBAA)
           TFS = $C* \sum_{i=1}^{NAMBLY} IP(i)*GAREA(i)+GCW*COBR*TANP$
           RFS = $GCW*(COBR*RTOW)+ \frac{H}{TL})$
           TSNET = TFS-RFS
```

```
        if TSNET < -20. then NOGO = 7

                            do routine 6. Exit and Crossing
                                                     Search

        else NOGO = 8

              exit

    else TFS = C* $\sum_{i=1}^{NAMBLY}$ IP(i)*GAREA(i)+TANP*GCW*Cos(OBAA)

    if H ≤ 1.3*CGH

       then RFS = GCW*(cos(OBAA)*RTOW+H/TL)

    else RFS = GCW*cos(OBAA)*(RTOW+sin(OBAA))

    TSNET = TFS-RFS

    if TSNET < - 20. then NOGO = 6

                      do routine 6. Exit and Crossing Search

    else exit

c.  wheeled vehicle

    TFSC = C* $\sum_{i=1}^{NAMBLY}$ IP(i)*GAREA(i)

    TFSP=TANP*GCW*cos(OBAA)*
            [IP(i)*(CGR-CGH*tan(OBAA))+TL-CGR+CGH*tan(OBAA)]/TL

    if TL ≥ H/sin(OBAA) then SOBR = H/TL

                                  ISDEF = 1

    else SOBR = sin(OBAA)

          ISDEF = 0
```

```
if H < 2. * DIAW(i) or OBAA < π/12
    then RFS = GCW*(SOBR+COBR*RTOW+CGR*tan(OBAA)/TL)
else RFS = GCW*(SOBR+COBR*RTOW)
      TSNET = TFSC+TFSP-RFS
if TSNET <-20.
    then if ISDEF = 1 then NOGO = 7
         else (ISDEF = 0) NOGO = 6
              do routine 6.  Exit and Crossing Search
else if ISDEF = 1 then NOGO = 8
      else exit
```

5. Crossing Time

Description This routine calculates an average crossing speed (VSEL) from the excess traction and a crossing time (TCROS) which depend on the size of the linear feature. The speed on the banks is obtained by interpolating between an assumed maximum crossing speed of 15 ft/sec at an excess traction of 50 lbs. or more to a minimum speed of .5 ft/sec at a traction deficit of 20 lbs.

Inputs Vehicle: VSS = maximum combination swimming speed, in/sec

VFS = vehicle fording speed, in/sec

FORDD = maximum water depth combination can ford, in. (FORDD = DRAFT if DRAFT ≠ 0)

Terrain: LBA = left bank angle, rad.

RBA = right bank angle, rad.

LBH = left bank height, in.

RBH = right bank height, in.

FWDTH = trench bottom, water or mound top, in.

WD = water depth, in.

Derived: TSNET = net traction on bank slope, lb.

Outputs VSEL = average speed across feature, in/sec

TCROS = time required to cross feature, sec.

Algorithm

```
if WD > FORDD then vehicle must swim
                    $CVEL = VSS$
else vehicle fords
     $CVEL = VFS$
$LBL = LBH/\sin(LBA)$
$RBL = RBH/\sin(RBA)$
if $TSNET \leq 50.$ then $VBANK = 6.+(TSNET+20.)*\frac{174.}{70.}$
else $VBANK = 180.$
```

```
TCROS = LBL/VBANK + FWDTH/CVEL + RBL/VBANK
VSEL = (LBL +  OBW  + RBL)/TCROS
exit
```

6. Exit and Crossing Search

Description This routine estimates the distance and time (T) a vehicle would have to travel to reach a natural or man-made crossing of the linear feature. The natural crossings are assumed to be at the apex of each meander; the meander spacing is a function of topographic slope. Bridge spacing is assumed given. The distance to each of these crossing points (DX) or (DB) is calculated from the assumption that the vehicle encounters the linear feature anywhere between the crossings with equal probability.

Inputs Vehicle: V = average travel speed adjacent to river or dry feature, in/sec

VSS = maximum combination swimming speed, in/sec (= 0. for non-swimmers)

Terrain: BRIDGS = mean bridge spacing along feature, ft.

SLOPE = nominal terrain slope, percent

Outputs DB = mean distance to nearest bridge, ft.

DX = mean distance to nearest exit site, ft.

T = mean travel time to nearest crossing site, min.

Algorithm

```
a.  calculate average distance to nearest bridge and exit

    DB = .5*BRIDGS

    DX = 5280./[8.3 - 1.1 * SLOPE]

b.  calculate land travel time to nearest exit

    if VSS = 0. then non-swimmer

                    T = DB*12./(V*60.)

    else swimmer

         T = 12./[(1/DB+1/DX)*V*60.)

    return to Module I.  Control and I/O.
```

MODULE VI

ROAD

ROAD MODULE

The Road Module computes a maximum speed that a wheeled vehicle is expected to maintain on a road segment. No provisions are currently included for tracked vehicles. The term road is intended to include both prepared and unprepared trails and all types of maintained and/or paved (oiled, stabilized, etc.) roads. Generally, roads are classified into primary and secondary roads and trails. These are characterized by a surface/wheel interaction involving:

1. No sinkage.

2. Soil shear properties replaced by a coefficient of friction.

3. Resistance depending on a surface micro-roughness level.

Roads may have slope and curvature along the direction of travel and superelevation normal to it. A visibility distance similar to that in the Areal Module is also included.

Calculation of resistance to motion is based on a standard SAE procedure (Reference 8) modified by certain relationships found in Reference 9 by Smith.

Included are resistance and performance effects due to altitude, atmospheric pressure, temperature and wind.

The speed limited by these resistance factors (road surface, aerodynamics, grades) may be further reduced to a final maximum speed due to:

1. Ride effects caused by roughness.

2. Curvature and superelevation of the roadway.

3. Visibility restrictions due to roadside factors.

4. Tire pressure/construction factors.

Scenario variables allow:

1. Adjustment of weather factors including ambient temperature, wind, and dry, wet or ice covered roads.

2. Human tolerance factors for ride roughness, deceleration and reaction time.

The individual routines of the Road Module are described below. Due to similarity between the Areal Module and the Road Module several routines and subroutines from the Areal Module are used without modification.

Scenario Values Required by Road Model

Variable Name	Routine Used	Meaning
AMBT	1	Ambient temperature, °F
ISURF	1,3,5	= 1 if roadway is dry
		= 2 if roadway is wet
		= 3 if roadway is ice covered
LAC	2	Roughness acceptance level
MXGDCL	6	Maximum deceleration driver will actually use, g's
NTRAV	1,5,6,7,8	= 1 for traverse
		= 3 for average up, level and down travel
REACT	7	Driver reaction time, sec.
SFTYPC	6	Percent of maximum deceleration available that driver will actually use, percent
VISMNV	7	Speed at which driver will proceed if visibility is entirely obscured, in/sec
WINDV	1	Head wind speed, in/sec.
NOPP	8	Operating tire pressure indicator:
		= 0 if tire pressure soil dependent
		= 1 if always use fine grained soil dependent tire pressure
		= 2 if always use coarse grained soil dependent tire pressure
		= 3 if always use highway dependent tire pressure

VEHICLE INPUT DATA REQUIRED BY ROAD MODULE

Variable	Routine	Meaning
ACD	1	Aerodynamic drag coefficient
AVGC	1	Average cornering stiffness of tires, lb/deg.
AXLSP(i)	1	Distance from running gear assembly i to next (inter-axle distance), in.
GCW	1,5,6,7	Gross combination weight, lb.
GCWB	1,5	Gross combination weight on all powered running gear assemblies, lb.
CGH	4	Height of CG, in.
IT(i)	1	$= 0$ if running gear assembly i is not part of a tandem axle $j \neq 0$ if running gear assembly is the j^{th} of a tandem axle
MAXIPR	2	Number of surface roughness values per level
MAXL	2	Number of roughness levels specified
NAMBLY	1	Number of running gear assemblies
NGR	1	Number of gears
NWHL(i)	1	Number of wheels on assembly i
PFA	1	Projected frontal area, in^2
RMS(NR)	2	NR^{th} surface roughness value, in.
TRACTF(NG,MD)	1	Tractive effort available from drive train at mid-range speed in gear NG, lb.

Variable	Routine	Meaning
TRACTF(NG,MN)	1	Tractive effort available from drive train at minimum speed in gear NG, lb.
TRACTF(NG,MX)	1	Tractive effort available from drive train at maximum speed in gear NG, lb
VGV(NG,MD)	1	Mid-range speed in gear NG, in/sec.
VGV(NG,MN)	1	Minimum speed in gear NG, in/sec.
VGV(NG,MX)	1	Maximum speed in gear NG, in/sec.
VRIDE(NR,L)	2	Maximum speed over ground with roughness level RMS(NR) at roughness acceptance level L, in/sec.
VTIRE(j)	8	Maximum steady state speed beyond which structural damage will occur to tires, in/sec. at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway
WGHT(i)	1	Weight on running gear assembly i, lb.
WTMAX	4	Maximum lateral distance from CG to outer wheels, in.
XBR	5	Maximum braking effort vehicle can develop, lb.

1. Speed Limited by Aerodynamic, Rolling, Cornering and Grade Resistance

Description: This routine calculates resistances due to aerodynamic drag, rolling, cornering and grades. The rolling resistance due to tandem axle alignment (FTC) and grade resistance (FG) are independent of velocity (Reference 7). The velocity dependent resistances; i.e., aerodynamic drag (FA), rolling resistance (FR) and drag resulting from tire cornering forces (FCC) are calculated for the minimum, mid-range and maximum speed in each gear (VGV(NG, MN), VGV(NG,MD), VGV(NG,MX)). These total velocity dependent resistances (FV) are then subtracted from the net available tractive effort on the road at these respective speeds.

To obtain the net available tractive effort on the road (STRACT) the rim pull tractive effort calculated in the Vehicle Preprocessor (TRACTF) is compared to the friction available on the road (FMU). Whichever is less is chosen and the total speed resistance (FV) is subtracted to obtain the net available tractive effort (STRACT).

Subroutines QUAD and VELFOR (described in the Areal Module) are used to fit quadratics to the net available tractive effort versus speed values and to determine the maximum speed which can be maintained while overcoming these resistances.

Input Vehicle: ACD = aerodynamic drag coefficient

PFA = projected frontal area, in^2

GCW = gross combination weight, lb.

GCWP = gross combined weight on all powered running gear assemblies, lb.

NAMBLY = number of running gear assemblies

IT(i) = 0 if running gear assembly i is not part of a tandem axle

= $j \neq 0$ if running gear assembly is the jth of a tandem axle

WGHT(i) = weight on running gear assembly i, lb.

AXLSP(i) = distance from running gear assembly i to next (inter-axle distance), in.

NWHL(i) = number of tires on wheeled assembly i

AVGC = average cornering stiffness of tires, lb/deg.

NGR = number of gears

VGV(NG,MN) = minimum speed in gear NG, in/sec.

VGV(NG,MD) = mid-range speed in gear NG, in/sec.

VGV(NG,MX) = maximum speed in gear NG, in/sec.

TRACTF(NG,MN) = tractive effort available from drive train at minimum speed in gear NG, lb.

TRACTF(NG,MD) = tractive effort available from drive train at mid-range speed in gear NG, lb.

TRACTF(NG,MX) = tractive effort available from drive train at maximum speed in gear NG, lb.

Roadway: ECF = elevation correction factor for tractive effort

HG = atmospheric pressure, inches of H_g

SURFF = 1 if highway

> 1 if rougher

RADC = radius of curvature, in.

EANG = superelevation angle, radians positive for vehicle lean into curve

GRADE = grade, percent

FMU(i) = roadway coefficient of sliding friction for i = 1 if dry, = 2 if wet, = 3 if ice covered.

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

AMBT = ambient temperature, ^{o}F

WINDV = head wind speed, in/sec.

ISURF = 1 if roadway surface is dry

= 2 if roadway surface is wet

= 3 if roadway surface is ice covered

Output

VRSIST(K) = speed limited by aerodynamic rolling, cornering and grade resistance for K = up, level and down, in/sec.

Algorithm

a. $\theta_1 = \frac{\pi}{4} *(\text{GRADE}/100.)$

$\theta_2 = 0.$

$\theta_3 = -\theta_1$

$$\text{NWHLS} = \sum_{1}^{\text{NAMBLY}} \text{NWHL}(i)$$

b. Superelevation effect factor

FE = 1.-.5*14.95*[RADC/12.]*EANG

c. Drag from tandem aligning forces

```
WTSPA = 0.
do for NA = 1 to NAMBLY
if IT(NA) $\neq$ 1 then next running gear assembly NA
else WTSPA = WTSPA + [WGHT(NA)+WGHT(NA+1)]*AXLSP(NA)
     next NA
after all NA
FTC = FE*[.5*FMU(ISURF)*WTSPA/RADC]
```

d. Do for K = 1 to NTRAV in steps of 2

$FG = GCW*\sin\theta_K$

e. Do for NG = 1 to NGR

do for L = MN,MD,MX

f. Aerodynamic drag

$$FAD = .044258*\left[\frac{3600}{12.*5280.} * \frac{1}{12.}\right]^2 * ACD * \frac{HG}{460.+AMBT} *PFA*[VGV(NG,L)+WINDV]^2$$

g. Rolling resistance

if GCW < 10.000.

then $$FR = GCW*\cos\theta_K*\left[.0116+.000228*VGV(NG,L)*\frac{3600.}{12.*5280.}\right]*SURFF$$

else (GCW $\geq$ 10,000.)

$$FR=GCW*\cos\theta_K*\left[.0068+.000074*VGV(NG,L)*\frac{3600.}{12.*5280.}\right]*SURFF$$

h. Drag resulting from tire cornering forces

$$FCC = FE*\left[\frac{GCW*\cos\theta * \left[VGV(NG,L)*\frac{3600.}{12.*5280.}\right]^2}{111.*RADC/12.}\right]^2 *\frac{1}{NWHLS*AVGC}$$

i. Total speed dependent resistance

$FV = FAD+FR+FCC$

j. Net tractive effort

$$STRACT(NG,L,K) = \min\{ECF*TRACTF(NG,L),FMU(ISURF)*GCWP*\cos\theta_K\}-FV$$

```
    next L

    after all L

k.  Fit quadratic to gear and find resistance speed

    CALL QUAD(FC(NG,K),FB(NG,K),FA(NG,K),
               VGV(NG,MN),STRACT(NG,MN,K),
               VGV(NG,MD),STRACT(NG,MD,K),
               VGV(NG,MX),STRACT(NG,MX,K))

    next NG

    after all gears

    FORMX(K) = max {STRACT(NG,L,K)}

    VFMAX(K) = VGV(NG,L) at above max

    CALL VELFOR(FTC+FG,VRSIST(K),K,NGR,FA,FB,FC,VGV,FORMX,
         VFMAX)

l.  If NTRAV = 1

       then exit

    else next K
```

2. Speed Limited by Road Roughness

Description: This routine determines the maximum allowable road speed based on driver tolerance to rough ride. It is identical to Submodel 10 of the Areal Module.

Output: VRID = speed limited by roughness, in/sec.

3. Speed Limited by Sliding in Curves

Description: This routine calculates the maximum road speed in a curve limited by sliding (VSLID). The centrifugal force relationship used includes road curvature (RADC), superelevation angle (EANG) and road coefficient of sliding friction (FMU) (Reference 10). The constant 385.9 is the acceleration of gravity in in/sec^2.

Input Roadway: RADC = radius of curvature, in.

EANG = superelevation angle, radians positive for vehicle lean into turn

FMU(i) = roadway coefficient of sliding friction for i=1 if dry, =2 if wet, =3 if ice covered

Scenario: ISURF = 1 if roadway surface is dry

= 2 if roadway surface is wet

= 3 if roadway surface is ice covered

Output VSLID = speed limited by sliding on curves, in/sec.

Algorithm

$$\text{VSLID} = \text{SQRT}(385.9*\frac{\text{RADC}*[\tan(\text{EANG})+\text{FMU}(\text{ISURF})]}{1-\text{FMU}(\text{ISURF})*\tan(\text{EANG})})$$

4. Speed Limited by Tipping While Negotiating a Curve

Description This routine calculates the maximum road speed which can be maintained in a curve limited by tipping of the vehicle (VTIP) (see Reference 10). The relationship for VTIP is obtained from the equation expressing the equilibrium of moments around the outer tire/pavement contact point. The forces involved are the centrifugal force and the weight of the vehicle. Constant 385.9 (in/sec^2) is the gravitational acceleration g.

Input Vehicle: CGH = height of CG, in.

WTMAX = controlling lateral distance from CG to outer wheels, in.

Roadway: RADC = radius of curvature, in.

EANG = superelevation angle, radians positive for vehicle lean into turn

Output VTIP = speed limited by tipping on curves, in/sec.

Algorithm

$$\text{VTIP} = \text{SQRT}\left(385.9*\frac{\text{RADC}*[\text{WTMAX}+\text{CGH}*\tan(\text{EANG})]}{\text{CGH}-\text{WTMAX}*\tan(\text{EANG})}\right)$$

5. Total Braking Force

Description: This routine calculates the total maximum braking force (TBF) available on a grade. The braking force due to the grade is added to the minimum of the braking force from the vehicle (XBR) or the road surface to produce the total maximum braking force (TBF). If the total maximum braking force is negative, then the final average speed on this road segment is set to zero and a braking NO-GO flag is set (BFGONO). This flag is set with the apriori notion that the vehicle could not be slowed down to a safe speed to negotiate curves.

Input

Vehicle: GCW = total combination weight, lb.

GCWB = combination vehicle weight on braked wheels, lb.

XBR = maximum braking effort vehicle can develop, lb.

Roadway: GRADE = grade, percent

FMU(i) = coefficient of sliding friction for i=1 if dry, i=2 if wet, i=3 if ice covered

Scenario: NTRAV = 1 for traverse

= 3 for average up, level and down travel

ISURF = 1 if roadway is dry

= 2 if roadway is wet

= 3 if roadway is ice covered

Output

TBF(K) = total roadway/slope/vehicle braking force for K = up, level and down, lb.

BFGONO = 1 if vehicle braking is inadequate for downslope operation

= 0 otherwise

VSEL = average speed, in/sec.

= 0 if inadequate braking

Algorithm

$$\theta_1 = \frac{\pi}{4} * GRADE/100.$$

$$\theta_3 = -\theta_1$$

```
TBF(u) = GCW*sin$\theta_1$+min{XBR,FMU(ISURF)*GCWB*cos$\theta_1$}
if NTRAV = 1
    then if TBF(u) < 0.
            then VSEL = 0
            BFGONO = 1
            return to module I. Control and I/O
        else BFGONO = 0
        exit
else

TBF(d) = GCW*sin$\theta_3$ + min{XBR,FMU(ISURF)*GCWB*cos$\theta_3$}
if TBF(d) < 0.
    then BFGONO = 1.
        VSEL = 0.
    return to module I.  Control and I/O
else BFGONO = 0.
exit
```

6. Driver Dictated Braking Limits

Description: This routine calculates the maximum braking that the driver will use based on comfort limits of the driver. It is identical to Submodel 12 of the Areal Module.

Output: MXBF(K) = maximum braking force for slope
K = up, and down, lb.

7 Speed Limited by Visibility

Description: This routine calculates the maximum road speed limited by visibility (VELV). It is identical to Submodel 13 of the Areal Module with the exception that the height of the driver's eyes above ground is not considered.

Inputs

Vehicle: GCW = gross combination weight, lb.

Roadway: RECD = recognition distance, in.

Scenario: VISMNV = speed at which vehicle will proceed if visibility is entirely obscured, in/sec

REACT = driver reaction time, sec

NTRAV = 1 for traverse

= 3 for average up, level and down travel

Derived: MXBF(K) = maximum braking force for slope K = up, level and down, lb.

Output VELV(K) = speed limited by visibility, in/sec

Algorithm

```
do for K = 1 to NTRAV  in steps of 2

       ACC = MXBF(K)*385.9/GCW

       D = $(REACT*ACC)^2$+2*RECD*ACC

       C = ACC*REACT

       VELV(K) = -RECD/[C-SQRT(D)]

       if VELV(K) < VISMNV

          then VELV(K) = VISMNV

          next K

       else next K

       exit
```

8. Maximum Road Speed

Description: This routine selects the average allowable road speed (VSEL) on the given road segment. The selection is made by choosing the minimum of all previously calculated speeds due to resistances, driver comfort limits and safety limits. Included in the safety speed limits is the speed limited by tire inflation pressure to prevent structural damage to the tire (VTIRE).

The final selected average speed is calculated in the same manner and using the same rationale as that used in selecting the average speed in Submodel 21 of the Areal Module; i.e., a harmonic average of the up, level and down slope speeds is taken to obtain the average selected road segment speed.

Input

Vehicle:

VTIRE(j) = maximum steady state speed beyond which structural damage will occur to tires, in/sec, at pressure specified for j=1 fine grained, =2 coarse grained, =3 highway

Derived:

VRSIST(K) = speed limited by aerodynamic rolling, cornering and grade resistance for slope K = up, level and down, in/sec

VRID = speed limited by roadway roughness, in/sec

VSLID = speed limited by sliding off curves, in/sec

VTIP = speed limited by tipping in curves, in/sec

VELV(K) = speed limited by visibility, in/sec

Scenario:

NTRAV = 1 for traverse

= 3 for average up, level and down travel

NOPP = Operating tire pressure indicator:

= 0 if tire pressure soil dependent

= 1 if always use fine grained soil tire pressure

= 2 if always use coarse grained soil dependent tire pressure

= 3 if always use highway dependent tire pressure

Outputs

VSEL = average speed, in/sec

VSLOPE(K) = final selected average speed on slope K = 1 up, =3 down, in/sec

Algorithm

```
a.  if NOPP ≠ 0.
        then j = NOPP
        do b.
    else j = 3
b.  do for K = 1 to NTRAV in steps of 2
    VSLOPE(K) = min{VRSIST(K),VRID,VSLID,VTIP,VELV(K),VTIRE(j)}
    if NTRAV = 1
        then VSEL = VSLOPE(1)
        return to Module I.  Control and I/O
    else next K
    after all K  VSEL = $2/\left[\frac{1}{VSLOPE(u)} + \frac{1}{VSLOPE(d)}\right]$
                 return to Module I. Control and I/O
```

MODULE VII

RIDE DYNAMICS

RIDE DYNAMICS MODULE

The Ride Dynamics Module of AMC '74 (Reference 3) provides the driver dictated speed limits due to vibration and shock while traveling over rough terrain or discrete obstacles. AMC '74 includes provisions for more than one tolerance level to rough ride. Potential tolerance levels for short and medium range duration of vibration input to the driver, other occupants or cargo are foreseen as outcomes of ongoing dynamics research. The Ride Dynamics Module described in Reference 3 provides the speed versus surface roughness values tables at specified tolerance levels and also the speed versus obstacle heights for single or multiple obstacle crossings.

MODULE VIII

OBSTACLE CROSSING

OBSTACLE CROSSING MODULE

Background

The Obstacle Crossing Module of AMC '74 is an externally executed module which solves the static equations of equilibrium for a vehicle negotiating an arbitrarily shaped obstacle. The solution of these equations produces the maximum force required to cross an obstacle, the average force required during the entire obstacle override and a geometric interference history between the critical clearance points on the vehicle and the obstacle profile. This module replaces the subroutines OBSTCL and OBSF in AMC '71.

The features of the Obstacle Crossing Module which set it apart from the methods used in AMC '71 are:

1. Inclusion of suspension compliance within the equations of equilibrium.
2. A single degree of pitch articulation for multiple unit vehicles.
3. Arbitrarily shaped obstacles.
4. Average and maximum forces required during override.
5. Permanent file of vehicle's obstacle crossing performance.

The Obstacle Crossing Module may be executed for a single obstacle or several obstacles of varying sizes. If several obstacles are examined then a permanent file of obstacle performance can be generated for a given vehicle. This file is used in the Areal Module to determine the vehicle approach and exit velocities while crossing a specific obstacle in the patch.

Multiple unit vehicles which have a single degree of pitch articulation can be examined in this module. Thus, tractor/trailer combinations are more accurately addressed in AMC '74 than was possible in AMC '71.

The Obstacle Crossing Module described herein is formulated for wheeled vehicles only. A tracked vehicle version is currently being developed and will be published at a later date as a revision to the current write-up.

Methodology

The forces and interference history are obtained by a stepwise movement of the vehicle over the obstacle. The vehicle's orientation (attitude and position with respect to the obstacle), and the tangential tire-obstacle forces are calculated by solving the static equations of equilibrium at each step. The vehicle is represented as a rigid beam on springs which are located at the vehicle's upper suspension supports. The beam springs represent either independent or bogie type suspensions. The lower ends of these springs are located at the wheel hubs. Each suspension support has an initial load which is the curb weight (no payload) of the vehicle on that support. The payload of the vehicle is represented as a concentrated load located at the center of gravity of the actual payload.

The obstacle profile must be modified to obtain the geometric interference history. The path that the wheel hubs follow over the obstacle is calculated and defined as the modified profile. The vehicle is moved across the modified obstacle profile and the clearances between the actual obstacle profile and the reference line on the vehicle are found for the entire length of the vehicle.

The clearance data that are compiled represent the minimum clearance between a point on the obstacle profile grid and the entire vehicle. These values can be positive or negative. At each step, the wheel travel and/or bogie swing angle are checked to determine if the suspension bump stops have been contacted. If a bump stop limit is reached, zero suspension travel is defined in the equations.

The tangential force at the tire-obstacle interface is also calculated at each step. The inclination angle of the tire contact patch is determined and the tangential tire-obstacle interface force in turn is calculated. The tangential forces are summed to obtain a total tractive force for the vehicle.

SCENARIO VALUES REQUIRED BY OBSTACLE CROSSING MODULE

Variable Name	Routine	Meaning
LOBST	1	= type of obstacle terrain input data:
		= 0 if class interval numbers for OBH, OBAA, OBW
		= 1 if arbitrary obstacle contour
		= 2 if values for height (HOVALS), angle (AVALS), and width (WVALS)

VEHICLE INPUT DATA REQUIRED BY OBSTACLE CROSSING MODULE

Variable	Routine	Meaning
ANGLIM(SUP)	6	angle limit of bogie suspension for support SUP, (= 0 if no bogie), deg.
BWIDTH(SUP)	6	bogie swing arm width for support SUP, (= 0 if no bogie), in.
CPLEN(SUP)	6	length of tire contact patch at support SUP, in.
DEE1	2,6	distance from the front of the vehicle to the CG of the payload of the first unit, in.
DEE2	2,6	distance from the front of the vehicle to the CG of the payload of the second unit (= 0 if single unit vehicle), in.
DELTW1	6	weight of payload on first unit, lb.
DELTW2	6	weight of payload for second unit (= 0 if single unit vehicle), lb.
DJOINT	2,4,6	length of the first unit to nearest inch, in.
DLIMDN(SUP)	6	downward suspension travel limit in wheel plane for support SUP, in.
DLIMUP(SUP)	6	upward suspension travel limit in wheel plane for support SUP, in.
EFFRAD(SUP)	4,6	effective radius of tire at support SUP, in.

Variable	Routine	Meaning
EJOINT	4,6	length of the second unit to nearest inch (= 0 if single unit vehicle), in.
ELL(SUP)	1,2,6	distance to each suspension support from front of first unit to support SUP, in.
EQUILF(SUP)	6	equilibrium load on one side of vehicle at suspension support SUP, lb.
JFLAG	2,5,6	= 1 if single unit vehicle = 2 if two unit vehicle
KAY(SUP)	2,6	spring constant in the wheel plane at suspension support SUP, lb/in.
NPTSC1	5	number of points that describe the clearance contour of the first unit above ground, at equilibrium with no payload
NPTSC2	5	number of points that describe the clearance contour of the second unit above ground, at equilibrium with no payload (= 0 if single unit vehicle)
NSUSP	2,4,6	total number of suspension supports for entire vehicle
NSUSP1	6	number of suspension supports for the first unit (= 0 if single unit vehicle)
REFHT1	5,6	height above the ground of a horizontal reference line located on or near the upper suspension supports of the first unit (vehicle with no payload), in.

Variable	Routine	Meaning
REFHT2	5,6	height above ground of a horizontal reference line located on or near the upper suspension supports of the second unit (= 0 if the vehicle has only one unit), in.
SFLAG(SUP)	6	suspension type at support SUP: 0 = independent 1 = bogie
VL	1	total length of vehicle, in.
XCLC1	5	x coordinate of the clearance contour of the first unit above ground at equilibrium with no payload at contour station POINT, in.
XCLC2	5	x coordinate of clearance contour of the second unit above ground at equilibrium with no payload at contour station POINT, in. (= 0 if single unit vehicle)
YCLC1	5	y coordinate of the clearance contour of the first unit above ground at equilibrium with no payload at contour station POINT, in.
YCLC2	5	y coordinate of clearance contour above ground at equilibrium with no payload at contour station POINT, in. (= 0 if single unit vehicle)

1. Calculation of Obstacle Breakpoints

Description This routine calculates the obstacle breakpoints that will be used to make an array of the obstacle contour. The user may choose one of three ways (LOBST) to input obstacle data:

a. Obstacle class numbers as used in AMC '71 may be entered and the obstacle breakpoints calculated.

b. Values for the obstacle height, approach angle and width are entered and the obstacle coordinates calculated.

c. The (x,y) coordinates that describe an obstacle of arbitrary size can be entered using the following procedure:

(1) The first point is (0,0)

(2) The second point must have a "y" coordinate of zero and an "x" coordinate greater than the radius of the first tire on the vehicle.

(3) The last two coordinates must be selected to allow the vehicle to be completely clear of the obstacle, i.e., the distance between the last two coordinates must be greater than the total length of the vehicle.

<u>Inputs</u>

Vehicle:

ELL(1) = distance from front of vehicle to first suspension support, in.

VL = total length of vehicle, in.

Terrain:

OBAA = obstacle approach angle, rad.

OBH = obstacle height, in.

OBW = obstacle base width, in.

NPTSPR = number of point pairs in arrays XPRF(PT), YPRF(PT)

XPRF(PT) = x coordinate of obstacle contour at grid point PT, in.

YPRF(PT) = y coordinate of obstacle contour at grid point PT, in.

NOHGT = number of obstacle height values for which force to override obstacles is given

HOVALS(NH) = value of NH^{th} height, in.

NANG = number of obstacle approach angle values for which force to override obstacles is given

AVALS(NA) = value of NA^{th} approach angle, rad.

NWTH = number of obstacle widths values for which force to override obstacles is given

WVALS(NW) = value of NW^{th} width, in.

Scenario: LOBST = type of obstacle terrain input data:

= 0 if class interval numbers for OBH, OBAA, OBW

= 1 if arbitrary obstacle contour

= 2 if values for height (HOVALS), angle (AVALS), and width (WVALS)

Outputs

NPTSPR = number of points that describe the obstacle contour

XPRF(PT) = x coordinate of obstacle contour at grid point PT, in.

YPRF(PT) = y coordinate of obstacle contour at grid point PT, in.

NOTE: XPRF(PT) and YPRF(PT) are outputs when LOBST = 0 or 2

Algorithm

```
a.  determine type of terrain input data that has been
    selected

    if LOBST = 0 then do b.

    else if LOBST = 1 then exit

         else (LOBST = 2)

         OBH = HOVALS(NH)

         OBAA = AVALS(NA)

         OBW = WVALS(NW)

b.  obtain obstacle dimensions OBAA, OBH, OBW

    XPRF(1) = YPRF(1) = YPRF(2) = 0.
```

```
XPRF(2) = ELL(1) + 2.
if OBAA > $\pi$   (trench)
   then OBH = - OBH
         A = (OBAA - $\pi$ )
else (OBAA < $\pi$ )
      A = ( $\pi$ - OBAA)
XPRF(3) = XPRF(2) + (OBH/tan(A))
YPRF(3) = OBH
XPRF(4) = XPRF(3) + OBW
YPRF(4) = OBH
XPRF(5) = XPRF(4) + (OBH/tan(A))
YPRF(5) = 0.
XPRF(6) = XPRF(5) + VL
YPRF(6) = 0.
```

2. Static Equilibrium Equation Coefficients

Description This routine calculates the coefficients [A] of the equilibrium equations which are solved for the vertical displacement of the payload (Z) and vehicle inclination angle (θ).

The vehicle is represented as a beam with arbitrary supports (See Figure VIII-1). The equations of static equilibrium are:

$$[\sum_{i=1}^{N} K_i]Z + [\sum_{i=1}^{N} K_i(d-\ell_i)]\theta = -\Delta W+\sum_{i=1}^{N} K_i x_i \quad . . . (1)$$

$$[\sum_{i=1}^{N} K_i(d-\ell_i)]Z + [\sum_{i=1}^{N} K_i(d-\ell_i)^2]\theta = \sum_{i=1}^{N} K_i(d-\ell_i)x_i \quad . . (2)$$

where:

N = number of suspension supports

K_i = spring constant at each suspension support i

ΔW = payload vector

d = location of payload vector, ΔW

ℓ_i = location of each support i

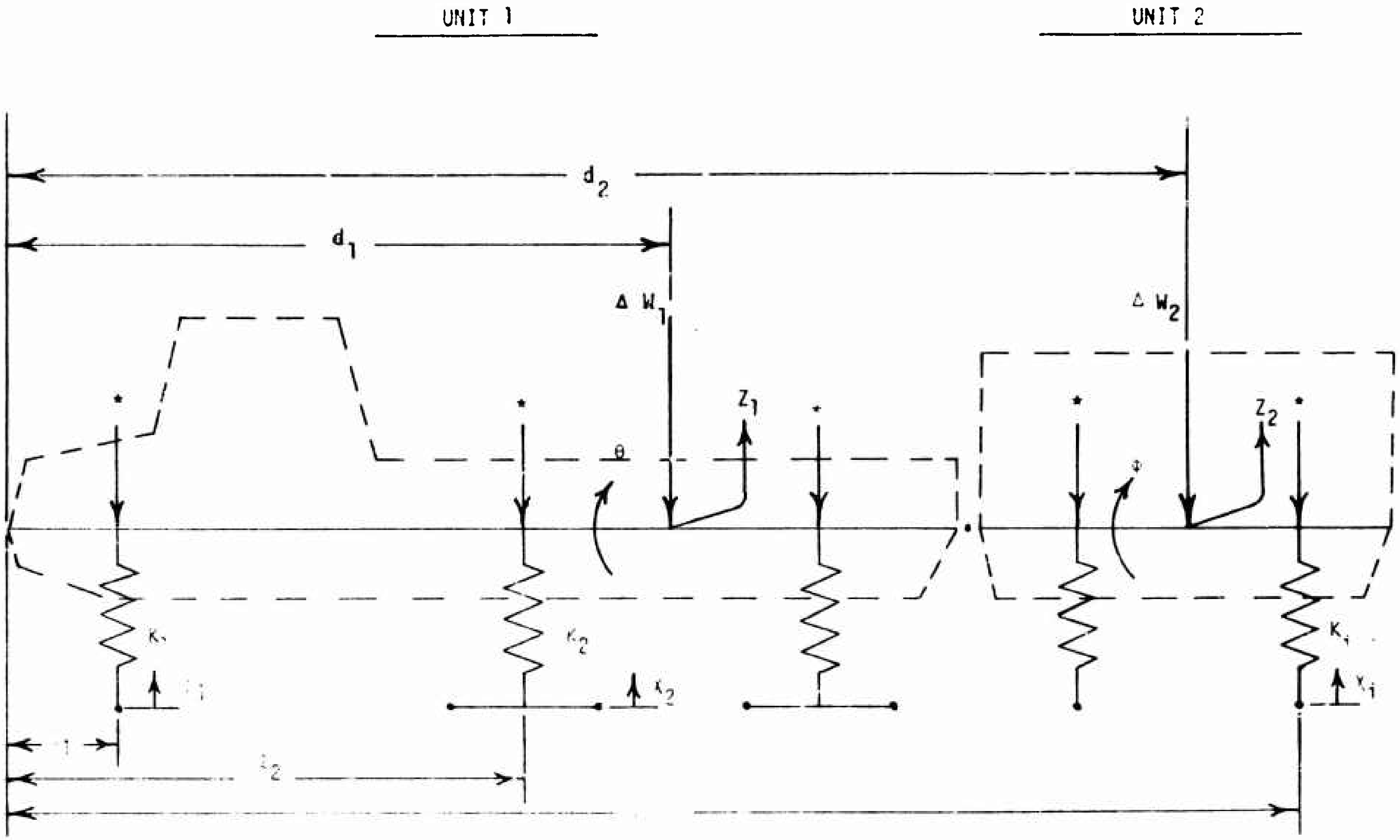
x_i = lower support deflection of suspension support i

Z = vertical displacement of reference line at point of application of payload vector

θ = inclination angle of 1st unit reference line

The static equations of equilibrium have been linearized for the inclination angle θ. This assumption is valid for the combined range of military vehicle wheel bases and obstacle heights which appear in the areal features terrain data. These coefficients are used in the Routine 6, Minimum Clearance and Tangential Forces.

FIGURE VIII-1 VEHICLE REPRESENTATION FOR AMC 74 OBSTACLE MODULE



*Equilibrium load of vehicle with no payload at each support.

Inputs Vehicle: JFLAG = 1 if single unit vehicle

= 2 if two unit vehicle

NSUSP = total number of suspension supports for entire vehicle

KAY(SUP) = spring constant in the wheel plane at suspension support SUP, lb/in

DEE1 = distance from the front of the vehicle to the CG of the payload of the first unit, in.

DEE2 = distance from the front of the vehicle to the CG of the payload of the second unit, in. (= 0 if single unit vehicle)

ELL(SUP) = distance to each suspension support from front of first unit to support SUP, in.

DJOINT = length of the first unit to nearest inch

Outputs A(i,j) = coefficients of static equations of equilibrium, i x j = 2 x 2, single unit vehicle; i x j = 3 x 3, two unit vehicle

Algorithm

```
a.  A11 = A12 = A22 = A13 = A23 = A33 = 0.

    if JFLAG = 2 (two unit vehicle)

       then do b.

    else (JFLAG = 1, single unit vehicle)

    do for SUP = 1 to NSUSP
```

```
    A11 = A11 + KAY(SUP)
    A12 = A12 + KAY(SUP)*(DEE1-ELL(SUP))
    A22 = A22+KAY(SUP)*$[(DEE1-ELL(SUP))^2]$
    next SUP
    A11 = 2. * A11
    A12 = 2. * A12
    A21 = A12
    A22 = 2. * A22
    exit
b.  calculation of coefficients for a 2-unit vehicle
b1. coefficients for first unit
    do for SUP = 1 to NSUSP1
    A11 = A11 + KAY(SUP)
    A12 = A12 + KAY(SUP) * (DEE1-ELL(SUP))
    A22 = A22 + KAY(SUP) * $[(DEE1-ELL(SUP))^2]$
    next SUP
b2. coefficients for 2nd unit
    do for SUP = NSUSP1+1 to NSUSP
    A11 = A11 + KAY(SUP)
    A12 = A12 + KAY(SUP) * (DEE1-DJOINT)
    A13 = A13 + KAY(SUP) * (ELL(SUP)-DJOINT)
    A22 = A22 + KAY(SUP) * $[(DEE1-DJOINT)^2]$
    A23 = A23 + KAY(SUP) * (ELL(SUP)-DJOINT)*(DEE1-DJOINT)
```

```
A33 = A33 + KAY(SUP) * $[(ELL(SUP)-DJOINT)^2]$
next SUP
A11 = 2. * A11
A12 = 2. * A12
A13 = 2. * A13
A21 = A12
A22 = 2. * A22
A23 = 2. * A23
A31 = A13
A32 = A23
A33 = 2. * A33
```

3. Obstacle Profile Contour

Description This routine creates the array (PRF) which describes the obstacle profile at each inch along the ground reference line. The profile is described for any shape obstacle.

Inputs Derived: NPTSPR = number of points that describe the obstacle contour

XPRF(PT) = x coordinate of obstacle contour at grid point PT, in.

YPRF(PT) = y coordinate of obstacle contour at grid point PT, in.

Outputs PRF(INCH) = the y coordinate of the obstacle profile at each inch along the profile, in.

Algorithm

```
do for PT = 1 to NPTSPR - 1

SLOPE = $\frac{YPRF(PT+1) - YPRF(PT)}{XPRF(PT+1) - XPRF(PT)}$

do for INCH = XPRF(PT) + 1 to XPRF(PT+1) - 1

        PRF(INCH) = YPRF(PT)+SLOPE*[ INCH-(XPRF(PT) + 1]

next INCH

next PT

exit
```

4. Wheel Hub Contour

Description This routine builds the array (HUBPRF) of the path that is followed by the wheel hubs as the vehicle moves over the obstacle. Figure VIII-2 shows the obstacle profile as modified by the wheel. The hub profile is built by testing the clearance between points on the tire periphery (THR) and the obstacle profile (PRF) across the entire lower semi-circle of the tire at each inch x coordinate along the obstacle. The minimum clearance between the obstacle and tire periphery establishes the vertical coordinate of the wheel hub at the specific inch x coordinate along the obstacle.

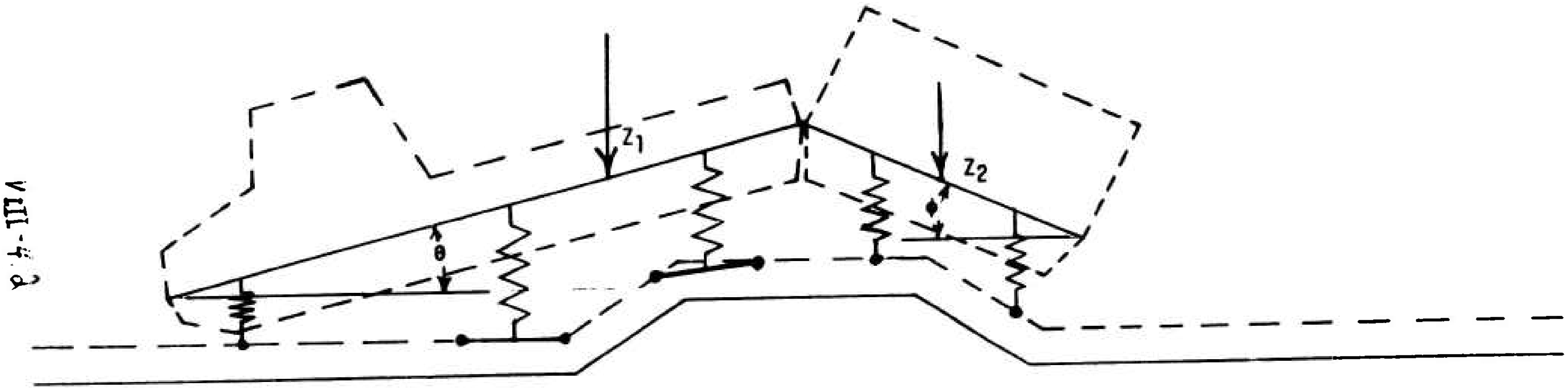


FIGURE VIII-2. REPRESENTATION OF MODIFIED OBSTACLE PROFILE

Inputs

Vehicle: NSUSP = total number of suspension supports for entire vehicle

EFFRAD(SUP) = effective radius of tire at support SUP, in.

DJOINT = length of first unit to nearest inch

EJOINT = length of second unit to nearest inch

Derived: XPRF(NPTSPR) = this is the value for the total length of the obstacle profile

PRF(INCH) = y coordinate of the obstacle at the INCHth x coordinate along the obstacle

Outputs

HUBPRF(SUP,INCH) = the y coordinate of the SUPth suspension support at each inch along the obstacle

NPTSOB = the total number of points in the obstacle and hub profile arrays

Algorithm

a. build hub profile array to reflect modification of obstacle profile by wheel

```
NPTSOB = XPRF(NPTSPR)

do for SUP = 1 to NSUSP

    NINT(SUP) = integer { EFFRAD(SUP) }

    THR(1) = 0.

do for K = 2 to NINT(SUP)+1

    $THR(K) = EFFRAD(SUP) - [(EFFRAD(SUP))^2 - (K-1)^2]^{1/2}$

    next K
```

```
      do for j = NINT(SUP)+1 to NPTSOB-NINT(SUP)
      TEMP = 1000.
      TEMP0 = 2000.
      TEMP2 = 1000.
b.    foreward tire quarter circle
      K = NINT(SUP)+2
      do for INCH = j-NINT(SUP) to j-1
      K = K-1
         TEMP1 = THR(K)-PRF(INCH)
         if TEMP1 - TEMP2 ≥ 0.
            then do b1.
         else TEMP = TEMP1
              continue
b1.           TEMP2 = TEMP1
         if TEMP - TEMP0 < 0.
            then do b2.
         else TEMP = TEMP0
              continue
b2.           TEMP0 = TEMP
      next INCH
      tire centerline
      TEMP1 = THR(1)-PRF(j)
      if TEMP1 - TEMP2 ≥ 0.
         then do b3.
      else TEMP = TEMP1
```

```
b3.    TEMP2 = TEMP1
    if TEMP - TEMP0 < 0.
       then do b4.
    else TEMP = TEMP0
b4.     TEMP0 = TEMP
    rearward tire quarter circle
    K = 1
    do for INCH = j+1 to j+NINT(SUP)
    K = K+1
    TEMP1 = THR(K)-PRF(INCH)
    if TEMP1 - TEMP2 ≥ 0.
       then do b5.
    else TEMP = TEMP1
b5.     TEMP2 = TEMP1
    if TEMP - TEMP0 < 0.
       then do b6.
    else TEMP = TEMP0
b6.     TEMP0 = TEMP
    next INCH
    HUBPRF(SUP,j) = EFFRAD(SUP)-TEMP
    next j
c.  complete hub profile along level approach and exit stations
    do for j = 1 to NINT(SUP)
       HUBPRF(SUP,j) = EFFRAD(SUP)
    next j
```

```
do for j = NPTSOB - NINT(SUP)+1 to NPTSOB
   HUBPRF(SUP,j) - HUBPRF(SUP,(NPTSOB-NINT(SUP)))
next j
next SUP
exit
```

5. Vehicle Clearance Contour

Description This routine creates the array (REFCLC) which is the difference between the vehicle reference lines (REFHT1, REFHT2) and the vehicle ground clearance contours at equilibrium ((XCLC1,YCLC1), (XCLC2,YCLC2)).

Inputs Vehicle: JFLAG = 1 if single unit vehicle

= 2 if two unit vehicle

REFHT1 = height above the ground of a horizontal reference line located on or near the upper suspension supports of the first unit (vehicle with no payload), in.

REFHT2 = height above ground of a horizontal reference line located on or near the upper suspension supports of the second unit (= 0 if the vehicle has only one unit), in.

NPTSC1 = number of points that describe the clearance contour of the first unit above ground, at equilibrium with no payload

NPTSC2 = number of points that describe the clearance contour of the second unit above ground, at equilibrium with no payload (= 0. if single unit vehicle)

XCLC1(POINT) = x coordinate of the clearance contour of the first unit above ground at equilibrium with no payload at contour station POINT, in.

YCLC1(POINT) = y coordinate of the clearance contour of the first unit above ground at equilibrium with no payload at contour station POINT, in.

XCLC2(POINT) = x coordinate of clearance contour of the second unit above ground at equilibrium with no payload at contour station POINT, in. (= 0. if single unit vehicle)

YCLC2(POINT) = y coordinate of clearance contour above ground at equilibrium with no payload at contour station POINT, in. (= 0. if single unit vehicle)

NOTE: The coordinate system for these points has the origin (0,0) on the ground at the front of the first unit. The x coordinates are in the horizontal direction and the y coordinates are in the vertical direction.

Outputs

REFCLC(1,INCH) = the difference between the height of the vehicle clearance contour of the first unit and the reference line height REFHT1 at each inch along the clearance contour, in.

REFCLC(2,INCH) = the difference between the height of the vehicle clearance contour of the second unit and the reference line height REFHT2 at each inch along the clearance contour, in.

Algorithm

```
make array of differences between reference lines and
clearance contours

do for POINT = 1 to NPTSC1

NTEMP(POINT) = integer { XCLC1(POINT)} + 1

    next POINT

do for POINT = 1 to NPTSC1-1

SLOPE = $\frac{(YCLC1(POINT+1)-YCLC1(POINT))}{XCLC1(POINT+1)-XCLC1(POINT)}$
```

```
do for INCH = NTEMP(POINT) to NTEMP(POINT+1)-1
REFCLC(1,INCH) = YCLC1(POINT)+SLOPE*(INCH-NTEMP(POINT))-REFHT1
next INCH
next POINT
if JFLAG = 1 (single unit vehicle)
   then exit
else (two unit vehicle)
do for POINT = 1 to NPTSC2
NTEMP(POINT) = integer { XCLC2(POINT) } + 1
next POINT
do for POINT = 1 to NPTSC2-1
SLOPE = $\frac{YCLC2(POINT-1)-YCLC2(POINT)}{XCLC2(POINT+1)-XCLC2(POINT)}$
do for INCH = NTEMP(POINT) to NTEMP(POINT+1)-1
REFCLC(2,INCH) = YCLC2(POINT)+SLOPE*(INCH-NTEMP(POINT))-REFHT2
next INCH
next POINT
exit
```

6. Minimum Clearance and Tangential Force

Description This routine calculates the minimum clearances (CLRMIN) between points on the vehicle underbody and points along the obstacle profile, and also the summed tangential forces (TFSUM) at the tire-obstacle interface for all tires along the obstacle profile. The clearances and forces are found by determining the vehicle's position and orientation (inclination angle) with respect to the obstacle at each step along the obstacle. In solving the static equations of equilibrium, the jounce and rebound positions of the vehicle's suspension system are examined for the extent of suspension travel. If travel limits are encountered, then deflection expressions are altered accordingly.

Inputs Vehicle: JFLAG = 1 if single unit vehicle

= 2 if two unit vehicle

REFHT1 = height above the ground of a horizontal reference line located on or near the upper suspension supports of the first unit (vehicle with no payload), in.

REFHT2 = height above ground of a horizontal reference line located on or near the upper suspension supports of the second unit (= 0 if the vehicle has only one unit), in.

NOTE: These reference lines are horizontal with the ground and should be chosen as close as possible to all the upper suspension supports. This is for the vehicle with no payload.

DJOINT = length of the first unit to nearest inch, in.

EJOINT = length of the second unit to nearest inch (= 0 if single unit vehicle), in.

NSUSP = total number of suspension supports for entire vehicle

NSUSP1 = number of suspension supports for the first unit (= 0 if single unit vehicle)

DEE1 = distance from the front of the vehicle to the CG of the payload of the first unit, in.

SFLAG(SUP) = suspension type at support SUP.

0 = independent

1 = bogie

EFFRAD(SUP) = effective radius of tire at support SUP, in.

ELL(SUP) = distance to each suspension support from front of first unit to support SUP, in.

ANGLIM(SUP) = angle limit of bogie suspension for support SUP, (= 0 if no bogie), deg.

DLIMUP(SUP) = upward suspension travel limit in wheel plane for support SUP, in.

DLIMDN(SUP) = downward suspension travel limit in wheel plane for support SUP, in.

BWIDTH(SUP) = bogie swing arm width for support SUP, (= 0 if no bogie), in.

EQUILF(SUP) = equilibrium load on one side of vehicle at suspension support SUP, lb.

CPLEN(SUP) = length of tire contact patch at support SUP, in.

DEE2 = distance from the front of the vehicle to the CG of the payload of the second unit (= 0 if single unit vehicle), in.

DELTW1 = weight of payload on first unit, lb.

KAY(SUP) = spring constant in the wheel plane at suspension support SUP, lb/in

DELTW2 = weight of payload for second unit (= 0 if single unit vehicle), lb.

Dervied: PRF(INCH) = the y coordinate of the obstacle profile at each inch along the profile, in.

HUBPRF(SUP,INCH) = the y coordinate of the SUPth suspension support at each inch along the obstacle, in.

REFCLC(1,INCH) = the difference between the height of the vehicle clearance contour of the first unit and the reference line height REFHT1, at each inch along the clearance contour, in.

REFCLC(2,INCH) = the difference between the height of the vehicle clearance contour of the second unit and the reference line height REFHT2, at each inch along the clearance contour, in.

A(i,j) = coefficients of equations of static equilibrium

Scenario: JGRID = vehicle movement step size, in.

<u>Outputs</u> CLRMIN(NH,NA,NW) = minimum clearance (negative if interference) during override for obstacle of height (HOVALS(NH), approach angle AVALS(NA), and width WVALS(NW), in.

LOCA(NH,NA,NW) = the distance from the front of the vehicle to CLRMIN(NH,NA,NW)

TFSUM(INCH) = the total tangential force at the tire-obstacle interface at each inch location along the obstacle profile, lb.

Algorithm

```
a.  NJOINT = integer { DJOINT } + 1
    NPTSGR = NJOINT + integer { EJOINT } + 1

    do for SUP = 1 to NSUSP
        NGRID(SUP) = integer { ELL(SUP) } + 1
    next SUP
    THETA = 0.
    PHI = 0.
  Initialize main sequence counter; clear working profile arrays
    IGRID = -JGRID+1
    do for SUP = 1 to NSUSP
        do for INCH = 1 to NPTSOB
            WPRF(INCH) = 0.
            WHUB(SUP,INCH) = EFFRAD(SUP)
        next INCH
    next SUP
b.  main loop:  advance obstacle and hub working profiles by,
    JGRID, grid points
    IGRID = IGRID+JGRID
    do for INCH = 1 to IGRID
        WPRF(INCH) = PRF(IGRID-INCH+1)
    next INCH
```

```
    do for SUP = 1 to NSUSP

    do for INCH = 1 to IGRID

    WHUB(SUP,INCH) = HUBPRF(SUP,(IGRID-1+1))

    next INCH

    next SUP

    set control index for wheel plane spring rate modification
    loop

    LOOP = 0.

    determine lower support displacements

    do for SUP = 1 to NSUSP

    check suspension type

    if SFLAG(SUP) = 1

        then do b1.

    else continue

    independent suspension

    LWRSUP(SUP) = WHUB(SUP,NGRID(SUP))

        next SUP

    do c.

b1. bogied suspension:  find bogie angle

    TEMP1 = WHUB(SUP,NGRID(SUP)+ integer { BWIDTH(SUP)/2 }

    TEMP2 = WHUB(SUP,NGRID(SUP) - integer {BWIDTH(SUP)/2}

    $TEMP = \frac{(TEMP1 - TEMP2)}{integer \{ BWIDTH(SUP)/2 \} * 2}$

    ANGLE = $\tan^{-1}$ (TEMP)
```

```
      include previous hull angle in check of bogie angle
      ANGLIM(SUP) = ANGLIM(SUP) * π/180.
      check for second unit
      if SUP > NSUSP1
         then THETA = PHI
      else there is no change in THETA
      if [ANGLE+THETA] - ANGLIM(SUP) > 0.
         then do b2.
      else bogie angle within limit of stop
         LWRSUP(SUP) = (TEMP1+TEMP2)/2.
         BFLAG(SUP) = 1
         next SUP
b2. bogie angle beyond limit of stop
      if TEMP1 - TEMP2 > 0.
         then do b3.
      bogie inclined upward toward front
      else LWRSUP(SUP) = TEMP2 - $\frac{BWIDTH(SUP)}{2}$ * tan(ANGLIM(SUP))
      BFLAG(SUP) = 2.
      go to b4.
b3. bogie inclined upward toward rear
      LWRSUP(SUP) = TEMP1 - $\frac{BWIDTH(SUP)}{2}$ * tan(ANGLIM(SUP))
      BFLAG(SUP) = 3.
```

```
b4. next SUP
c.  after all SUP compute position and inclination of ref lines
    B1 = B2 = B3 = 0.
    if JFLAG = 2
       then do c2.
    else do c1.
c1. one reference line
    do for SUP = 1 to NSUSP
    B1 = B1+KAY(SUP)*WHUB(SUP,NGRID(SUP))
    B2 = B2+KAY(SUP)*(DEE1-ELL(SUP))*WHUB(SUP,NGRID(SUP))
    next SUP
    B1 = -DELTWT+2.*B1
    B2 = 2.*B2
    TEMP1 = A11*A22-A12*A21
    TEMP2 = A11*B2-B1*A21
    THETA = $\frac{TEMP2}{TEMP1}$
    TEMP2 = B1*A22-A12*B2
    ZEE = $\frac{TEMP2}{TEMP1}$
    do d.
c2. do for SUP = 1 to NSUSP1
    B1 = B1+KAY(SUP)*LWRSUP(SUP)
```

```
B2 = B2+KAY(SUP)*(DEE1-ELL(SUP))*LWRSUP(SUP)
next SUP
do for SUP = NSUSP1+1 to NSUSP
B1 = B1+KAY(SUP)*LWRSUP(SUP)
B2 = B2+KAY(SUP)*(DEE1-DJOINT)*LWRSUP(SUP)
B3 = B3+KAY(SUP)*(ELL(SUP)-DJOINT)*LWRSUP(SUP)
next SUP
B1 = 2.*B1-DELTW1-DELTW2
B2 - 2.*B2-DELTW1*(DEE1-DJOINT)
B3 = 2.*B3-DELTW2*(DEE2-DJOINT)
TEMP1 = (A11*A22*A33)+(A12*A23*A31)+(A13*A21*A31)-
                      (A12*A21*A33)-(A11*A23*A32)-(A13*A22*A31)
TEMP2 = (B1*A22*A33)+(A12*A23*B3)+(A13*B2*A32)-
                     (A13*A22*B3)-(A12*B2*A33)-(B1*A23*A32)
ZEE = $\frac{TEMP2}{TEMP1}$
TEMP2 = (A11*B2*A33)+(B1*A23*A31)+(A13*A21*B3)-
                 (A13*B2*A31)-(B1*A21*A33)-(A11*A23*B3)
THETA = $\frac{TEMP2}{TEMP1}$
TEMP2 = (A11*A22*B3)+(A12*B2*A31)+(B1*A21*A32)-
                 (B1*A22*A31)-(A12*A21*B3)-(A11*B2*A32)
PHI = $\frac{TEMP2}{TEMP1}$
```

```
d.  complete computation of upper suspension support
    displacements, suspension incremental deflections,
    incremental and total forces

    one reference line

    do for SUP = 1 to NSUSP1

    UPRSUP(SUP) = ZEE+(DEE1-ELL(SUP))*THETA

    DELDEF(SUP) = LWRSUP(SUP)-UPRSUP(SUP)

    DELFRC(SUP) = 2 *KAY(SUP)*DELDEF(SUP)

    TOTFRC(SUP) = 2.*EQUILF(SUP)+DELFRC(SUP)

    next SUP

    if JFLAG = 1 (single unit vehicle)

       then do d2.

    else (two unit vehicle, second reference line)

d1. do for SUP = NSUSP1+1 to NSUSP

    UPRSUP(SUP) = ZEE+(DEE1-DJOINT)*THETA+(REFHT2-REFHT1)+
                           (ELL(SUP)-DJOINT)*PHI

    DELDEF(SUP) = LWRSUP(SUP)-UPRSUP(SUP)

    DELFRC(SUP) = 2.*KAY(SUP)*DELDEF(SUP)

    TOTFRC(SUP) = 2.*EQUILF(SUP)+DELFRC(SUP)

    next SUP

d2. check deflections against suspension travel limits

    if LOOP = 1

       then do f.

    else do for SUP = 1 to NSUSP

    NTEMP(SUP) = 0

    next SUP
```

```
d3. do for SUP = 1 to NSUSP
    if DELDEF(SUP) > 0.
       then do d5.
    else do d4.
d4. deflection negative:  check for downward suspension
    travel limit
    if (-DELDEF(SUP)-DLIMDN(SUP)) $\le$ 0.
       then next SUP
    else KAYTMP(SUP) = KAY(SUP)
         NTEMP(SUP) = 1
         KAY(SUP) = absolute { $\frac{DELFRC(SUP)/DLIMDN(SUP)}{2.}$ }
         LOOP = 1
         next SUP
d5. deflection positive:  check for upward suspension
    travel limit
    if DELDEF(SUP) - DLIMUP(SUP) $\le$ 0.
       then next SUP
    else KAYTMP(SUP) = KAY(SUP)
    after all SUP, check suspension travel limit stops
    NTEMP(SUP) = 1
    KAY(SUP) = absolute { $\frac{DELFRC(SUP)/DLIMUP(SUP)}{2.}$ }
    LOOP = 1
    next SUP
```

```
e.  if LOOP = 0

        then do f.

    else reprocessing of coefficient matrix [A] if any wheel
    plane spring rates have been changed in travel limits
    check

        C11 = C12 = C13 = C21 = C22 = C23 = C31 = C32 = C33 = 0.

    if JFLAG = 2 (two unit vehicle)

        then do e1.

    else (single unit vehicle)

        do for SUP = 1 to NSUSP

        C11 = C11+KAY(SUP)

        C12 = C12+KAY(SUP)*(DEE1-ELL(SUP))

        C22 = C22+KAY(SUP)*[$(DEE1-ELL(SUP))^2$]

        next SUP

    C11 = 2.*C11

    C12 = 2.*C12

    C21 = C12

    C22 = 2.*C22

    do e3.

e1. two unit vehicle:  calculation of coefficients for 1st unit

    do for SUP = 1 to NSUSP1

    C11 = C11*KAY(SUP)

    C12 = C12+KAY(SUP)*(DEE1-ELL(SUP))

    C22 = C22*KAY(SUP)*[$(DEE1-ELL(SUP))^2$]

    next SUP
```

```
    calculation of coefficients for 2nd unit

    do for SUP = NSUSP1+1 to NSUSP

    C11 = C11+KAY(SUP)

    C12 = C12+KAY(SUP)*(DEE1-DJOINT)

    C13 = C13+KAY(SUP)*(ELL(SUP)-DJOINT)

    C22 = C22+KAY(SUP)*[(DEE1-DJOINT)$^{2}$]

    C23 = C23+KAY(SUP)*(ELL(SUP)-DJOINT)*(DEE1-DJOINT)

    C33 = C33+KAY(SUP)*[(ELL(SUP)-DJOINT)$^{2}$]

    next SUP

    C11 = 2.*C11

    C12 = 2.*C12

    C13 = 2.*C13

    C21 = C12

    C22 = 2.*C22

    C23 = 2.*C23

    C31 = C13

    C32 = C23

    C33 = 2.*C33

e2. recompute position and inclination of reference lines
    for wheel plane spring rate changes due to travel
    limit stops being reached

    D1 = D2 = D3 = 0.

    if JFLAG = 2 (two unit vehicle)

       then do e3.

    else (single unit vehicle)
```

```
    do for SUP = 1 to NSUSP
        D1 = D1+KAY(SUP)*LWRSUP(SUP)
        D2 = D2+KAY(SUP)*(DEE1-ELL(SUP))*LWRSUP(SUP)
    next SUP
D1 = 2.*D1 - DELTW1
D2 = 2.*D2
TEMP1 = C11*C22-C12*C21
TEMP2 = C11*D2-D1*C21
THETA = $\frac{TEMP2}{TEMP1}$
TEMP2 = D1*C22- C12*D2
ZEE = $\frac{TEMP2}{TEMP1}$
do d.
e3. for two unit vehicle
    do for SUP = 1 to NSUSP1
        D1 = D1+KAY(SUP)*LWRSUP(SUP)
        D2 = D2+KAY(SUP)*(DEE1-ELL(SUP))*LWRSUP(SUP)
    next SUP
    do for SUP = NSUSP1+1 to NSUSP
        D1 = D1 + KAY(SUP) * LWRSUP(SUP)
        D2 = D2 + KAY(SUP) * (DEE1-DJOINT) * LWRSUP(SUP)
        D3 = D3 + KAY(SUP) * (ELL(SUP)-DJOINT) * LWRSUP(SUP)
    next SUP
```

```
 D1 = 2.*D1-DELTW1-DELTW2

 D2 = 2.*D2-DELTW1*(DEE1-DJOINT)

 D3 = 2.*D3-DELTW2*(DEE2-DJOINT)

 TEMP1 = (C11*C22*C33)+(C12*C23*C31)+(C13*C21*C32)-
                 (C13*C22*C31)-(C12*C21*C33)-(C11*C23*C32)

 TEMP2 = (D1*C22*C33)+(C12*C23*D3)+(C13*D2*C32)-
                 (C13*C22*D3)-(C12*D2*C33)-(D1*C23*C32)

 $ZEE = \frac{TEMP2}{TEMP1}$

 TEMP2 = (C11*D2*C33)+(D1*C23*C31)+(C13*C21*D3)-
                 (C13*D2*C31)-(D1*C21*C33)-(C11*C23*D3)

 $THETA = \frac{TEMP2}{TEMP1}$

 TEMP2 = (C11*C22*D3)+(C12*D2*C31)+(D1*C21*C32)-
                 (D1*C22*C31)-(C12*C21*D3)-(C11*D2*C32)

 $PHI = \frac{TEMP2}{TEMP1}$

   do d.

f. restore wheel plane spring constants

   do for SUP = 1 to NSUSP

   if NTEMP(SUP) ≠ 0

      then KAY(SUP) = KAYTMP(SUP)

   else next SUP
```

```
g.  determine tire contact patch inclination at tire obstacle
    interface points:  compute total tangential force

    do for SUP = 1 to NSUSP

    if SFLAG(SUP) = 1

       then do g2.

    else do g1.

g1. independent suspension:  check obstacle profile inclination
    across wheel contact patch

    $TEMP1 = WHUB(SUP,NGRID(SUP) + integer \{ \frac{CPLEN(SUP)}{2.} \})$

    $TEMP2 = WHUB(SUP,NGRID(SUP) - integer \{ \frac{CPLEN(SUP)}{2.} \})$

    $TEMP = \frac{(TEMP1-TEMP2)}{integer \{ CPLEN(SUP)/2. \} *2}$

    $ANGLE = \tan^{-1} (TEMP)$

    tangential force

    $TFORCE(SUP) = TOTFRC(SUP)*\sin(ANGLE)$

    do g3.

g2. bogie suspension:  check bogie flag to determine contact
    status of bogie wheels

    if BFLAG(SUP) = 1

       then do g3.

    else if BFLAG(SUP) = 2

           then do g4.

         else if BFLAG(SUP) = 3

                then do g5.

              else error. Return to Module I. Control and I/O.
```

g3. both wheels in contact

$$\text{TEMP1} = \text{WHUB}(\text{SUP}, \text{NGRID}(\text{SUP}) - \text{integer}\ \{\ \text{BWIDTH}(\text{SUP})/2\ \} + \text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \}\ )$$

$$\text{TEMP2} = \text{WHUB}(\text{SUP}, \text{NGRID}(\text{SUP}) - \text{integer}\ \{\ \text{BWIDTH}(\text{SUP})/2\ \} - \text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \}\ )$$

$$\text{TEMP} = \frac{(\text{TEMP1} - \text{TEMP2})}{\text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \} * 2}$$

$$\text{ANGLE} = \tan^{-1}(\text{TEMP})$$

tangential force, forward wheel of bogie

$$\text{TFORCE}(\text{SUP}) = \text{TOTFRC}(\text{SUP}) * \frac{\sin(\text{ANGLE})}{2}$$

compute and add tangential force of rearward wheel

$$\text{TEMP1} = \text{WHUB}(\text{SUP}, \text{NGRID}(\text{SUP}) + \text{integer}\ \{\ \text{BWIDTH}(\text{SUP})/2\ \} + \text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \}\ )$$

$$\text{TEMP2} = \text{WHUB}(\text{SUP}, \text{NGRID}(\text{SUP}) + \text{integer}\ \{\ \text{BWIDTH}(\text{SUP})/2\ \} - \text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \}\ )$$

$$\text{TEMP} = \frac{(\text{TEMP1} - \text{TEMP2})}{\text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \}}$$

$$\text{ANGLE} = \tan^{-1}(\text{TEMP})$$

tangential force, both wheels of bogie

$$\text{TFORCE}(\text{SUP}) = \text{TFORCE}(\text{SUP}) + \text{TOTFRC}(\text{SUP}) * \sin(\text{ANGLE})/2$$

next SUP: **after all SUP, do h.**

g4. forward bogie wheel in contact only

$$\text{TEMP1} = \text{WHUB}(\text{SUP}, \text{NGRID}(\text{SUP}) - \text{integer}\ \{\ \text{BWIDTH}(\text{SUP})/2\ \} + \text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \}\ )$$

$$\text{TEMP2} = \text{WHUB}(\text{SUP}, \text{NGRID}(\text{SUP}) - \text{integer}\ \{\ \text{BWIDTH}(\text{SUP})/2\ \} - \text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \}\ )$$

$$\text{TEMP} = \frac{(\text{TEMP1} - \text{TEMP2})}{\text{integer}\ \{\ \text{CPLEN}(\text{SUP})/2\ \} * 2}$$

```
         ANGLE = tan^-1(TEMP)

         TFORCE(SUP) = TOTFRC(SUP) * sin(ANGLE)

         next SUP:  after all SUP, do h.

     g5. rearward bogie wheel in contact only

         TEMP1 = WHUB(SUP, NGRID(SUP) + integer { BWIDTH(SUP)/2 } +
                                        integer { CPLEN(SUP)/2 } )

         TEMP2 = WHUB(SUP, NGRID(SUP) + integer { BWIDTH(SUP)/2 } -
                                        integer { CPLEN(SUP)/2 } )

         TEMP =        (TEMP1 - TEMP2)
                 ----------------------------
                 integer { CPLEN(SUP)/2 }  *2

         ANGLE = tan^-1(TEMP)

         TFORCE(SUP) = TOTFRC(SUP) * sin(ANGLE)

         next SUP

     h.  sum the tangential forces over all the suspension supports
         for the present orientation of the vehicle and obstacle

         TEMP = 0.

         do for SUP = 1 to NSUSP

         TEMP = TEMP+TFORCE(SUP)

         next SUP

         TFSUM(IGRID) = TEMP

     i.  compare present clearance contour with the obstacle
         profile:  retain algebraically the minimum clearance
         at each point along the vehicle contour

         F1 = F2 = 0.

         do for SUP = 1 to NSUSP1

         F1 = F1 + EFFRAD(SUP)

         next SUP
```

```
F2 = F1/NSUSP1

do for INCH = 1 to NJOINT in steps of JGRID

TEMP = ZEE+REFHT1-F2(DEE1-(INCH-1))*THETA+REFCLC(1,INCH)-
                                        WPRF(INCH)

if TEMP - MINCLR(INCH) < 0.

   then MINCLR(INCH) = TEMP

        LOC(INCH) = IGRID

        ITEMP = INCH

        next INCH

else ITEMP = INCH

     next INCH

if JFLAG = 1 (single unit vehicle)

   then do j

else (JFLAG = 2, two unit vehicle)

   F3 = F4 = 0.

   do for SUP = NSUSP1+1 to NSUSP

   F3 = F3 + EFFRAD(SUP)

   next SUP

   F4 = F3/(NSUSP-NSUSP1)

   do for INCH = ITEMP+JGRID to NPTSGR in steps of JGRID

   TEMP = ZEE+REFHT2-F4+(DEE1-DJOINT)*THETA+(INCH-1-DJOINT)*
                              PHI+REFCLC(2,INCH)-WPRF(INCH)

   if TEMP - MINCLR(INCH) < 0.

      then MINCLR(INCH) = TEMP

      LOC(INCH) = IGRID

         next INCH

   else next INCH
```

```
j.  check end of obstacle override position
    if IGRID < NPTSOB
       then do b.
    else do k.
k.  find CLRMIN and LOCA
    do for INCH = 1 to NPTSGR in steps of JGRID
    if CLRMIN(NH,NA,NW) < MINCLR(INCH)
       then next INCH
    else CLRMIN(NH,NA,NW) = MINCLR(INCH)
         LOCA(NH,NA,NW) = LOC(INCH)
         next INCH
```

7. Maximum and Average Force to Override an Obstacle

Description This routine determines the average (FOO) and maximum (FOOMAX) forces required during the entire override of an obstacle. In previous routines, obstacle negotiation has been addressed via the solution of the static equations of equilibrium formulated using an energy approach, specifically, the Lagrangian. Since this energy method presupposes a conservative system, energy losses due to viscous and frictional elements in the vehicle suspension and elsewhere are not treated analytically in the equations thus formed. To accommodate for these energy losses an estimate is made for the amount of recoverable energy in the system for complete negotiation of the obstacle. Truly, this rebound attenuation factor (RAF) is a ball park estimate based on the Model Designers' best attempts at estimating without resorting to a time consuming dynamics solution. The positive valued tire-obstacle tangential forces are attenuated for the energy losses. A value of 1/2 is used for RAF.

Inputs

Terrain: NH = index of height value used, HOVALS(NH)

NOHGT = number of height values for which force to override obstacles is calculated

NA = index of approach angle value used, AVALS(NA)

NANG = number of obstacle approach angle values for which force to override obstacles is calculated

NW = index of width value used, WVALS(NW)

NWTH = number of obstacle width values for which force to override obstacles is calculated

RAF = rebound attenuation factor

Outputs

TFSUM(INCH) = total tangential force at tire-obstacle interface at each inch location INCH, lb.

FOOMAX(NH,NA,NW) = maximum force required during obstacle override for obstacle of height HOVALS(NH), approach angle AVALS(NA), and width WVALS(NW), lb.

FOO(MH,NA,NW) = average force required to override obstacles of height HOVALS(NH), approach angle AVALS(NA), and width WVALS(NW), lb.

Algorithm

a. attenuate tangential force for energy losses

```
do for INCH = 1 to NPTSOB in steps of JGRID

if TFSUM(INCH) > 0.

   then TFSUM(INCH) = RAF*TFSUM(INCH)

        next INCH

else next INCH
```

b. find peak resistance force

```
PEAKRF = 1000.

do for INCH = 1 to NPTSOB in steps of JGRID

if TFSUM(INCH) - PEAKRF < 0.

   then PEAKRF = TFSUM(INCH)

        then next INCH

else next INCH
```

c. find average force to override obstacle: discard leading and trailing zeros, include intervening zeros

```
INDEX1 = INDEX2 = 0.

find the number of leading zeros in the tangential force array

do for INCH = 1 to NPTSOB in steps of JGRID

if TFSUM(INCH) = 0.

   then INDEX1 = INDEX1+1

        next INCH

else next INCH
```

```
find the number of trailing zeros in the tangential
force array

do for INCH = 1 to NPTSOB in steps of JGRID

if TFSUM(NPTSOB-INCH+1) = 0.

   then INDEX2 = INDEX2+1

        next INCH

else next INCH

find average force to override

SUM = 0.

do for KSUM = INDEX1+1 to NPTSOB- INDEX2

SUM = SUM+TFSUM(KSUM)

next KSUM

after all KSUM

$SUM = \frac{SUM}{(NPTSOB-INDEX1-INDEX2)/JGRID}$

FOO(NH,NA,NW) = absolute { SUM }

FOOMAX(NH,NA,NW) = absolute { PEAKRF }
```

IX. REFERENCES

1. The Staffs of the Mobility & Environmental Division, U.S. Army Engineer Waterways Experiment Station, and The Surface Mobility Laboratory, U.S. Army Tank-Automotive Command: "The AMC '71 Mobility Model", Volumes I and II, Technical Report No. 11789 (LL 143), Warren, Michigan (July 1973)

2. USATACOM and WES: "Vehicle Mobility Assessment for Project WHEELS Study Group" (September 1972)

3. N. R. Murphy: "AMC '74 Ride Dynamics Model", WES In Progress Report

4. G. W. Turnage: "Performance of Soils Under Tire Loads, Report 8, Application of Test Results to Tire Selection for Off-Road Vehicles", Technical Report No. 3-666, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi (September 1972)

5. "WES-VCI Relations Organic Soils", Unpublished WES Research Effort, Circa 1968

6. A. A. Rula, C, J. Nuttall, Jr.: "An Analysis of Ground Mobility Models (ANAMOB)", Technical Report No. M-71-4. U.S Army Engineer Waterways Experiment Station, Vicksburg. Mississippi (July 1971)

7. L. A. Martin, D. A. Sloss, Jr.: "The Linear Feature Crossing Model of AMC '74", TACOM In Progress Report

8. "Truck Ability Prediction Procedure", SAE Recommended Practice J 588 (1963)

9. G. Smith: "Commercial Vehicle Performance and Fuel Economy", SAE SP-355 (1970)

10. J. J. Taborek: "Mechanics of Vehicles", Penton Publications, Cleveland, Ohio (1957)

APPENDIX

VEHICLE DATA

SHEETS

VEHICLE DATA SHEET INSTRUCTIONS

The vehicle data sheets for AMC '74 have been revised to provide for greater clarity and convenience to the user in filling them out. Most vehicle component and/or overall vehicle data appearing on the data sheets can be located from standard vehicle characteristic sheets or catalogues (e.g., Tire and Rim Association, Inc. Yearbook) using the nomenclature found in these sources. With the exception of the water characteristics, Item 5., little or no computation is necessary on the part of the user.

The data sheets are structured to minimize human blunders in both filling out the sheets and transcribing the data from these sheets to a computer file. Line items are right justified where necessary and double spaced.

Prior to filling out the data sheets, a user is requested to read the introductory write-up in Module II, Vehicle Preprocessor, to acquaint him with the vehicle nomenclature used throughout AMC '74. Also, it is recommended that the user review the Vehicle Data Cross Index to assure that all data required are entered. At this writing, some of the vehicle data appearing on the sheets are not required but will be used at a later date. However, if these data are available, it is advised that they be provided (e.g., horsepower loss curves, auxiliary transmissions in the final drive).

Item 8, Input From Ride Dynamics Module, is included since these data could be obtained from experimental tests. The experimental data are preferred over the data obtained from the simulation performed in Module VII, Ride Dynamics.

The buoyancy characteristics in Item 5 require a knowledge of the vehicle density distribution with vehicle height. This form of data would be extremely difficult to build in the vehicle preprocessor for an arbitrary vehicle and is, therefore, left to the user to provide.

VEHICLE DATA CROSS INDEX

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
i	Axle or track pair assembly number
NAMBLY	Number of axle assemblies plus Number of track pair assemblies
NVEH(i)	Running gear assembly type
WGHT(i)	Operating load on axle or operating load on track pair
IP(i)	Powered axle or track; Yes = 1; No = 0
IB(i)	Braked axle or track; Yes = 1; No = 0
RDIAM(i)	Rim diameter
RIMW(i)	Rim width
ICONST(i)	Tire Construction: Radials = 0; Bias Ply = 1
TPLY(i)	Tire ply rating
REVM(i)	Tire: Nominal revolutions/mile
DIAW(i)	Tire: Nominal O.A. diameter
SECTW(i)	Tire: Nominal section width
SECTH(i)	Tire: Nominal section height
TPSI(i,2)	Tire: Sand Inflation Pressure
DFLCT(i,2)	Tire: Deflection under operating load and sand inflation pressure
TPSI(i,1)	Tire: Cross-country inflation pressure
DFLCT(i,1)	Tire deflection under operating load and cross-country inflation pressure

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
TPSI(i,3)	Tire: Highway inflation Pressure
DFLCT(i,3)	Tire deflection under operating load and highway inflation pressure
NWHL(i)	Number of tires on axle
ID(i)	Dual tires
CLRMIN(i)	Minimum ground clearance (from running gear data)
WTE(i)	Minimum width between left-right tires of axle assembly or Minimum width between left-right tracks
WT(i)	Vehicle axle tread (center plane to center plane if duals) or Vehicle track tread (center line to center line)
NCHAIN(i)	Presence of tire chains
TRAKWD(i)	O.A. track width
GROUSH(i)	Grouser height
NPAD(i)	Road pads
ASHOE(i)	Area of one road pad
TRAKLN(i)	Track length on ground
NBOGIE(i)	No. of road wheels
NFL(i)	Flexible tracks = 1 Girderized tracks = 0
RW(i)	Track thickness plus bogie rolling radius

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
IAPG	Tractive force - speed; Yes = 2; No = 1 or Power train characteristics; Yes = 1; No = 2 or Both = 0
POWER(FORCE,N)	Tractive force (tractive force versus speed curve)
POWER(SPEED,N)	Speed (tractive force versus speed curve)
IPOWER	Number of point pairs (tractive force versus speed curve)
NETHP	Maximum net HP
ENGINE(RPM,N)	RPM (engine RPM versus torque curve)
ENGINE(TORQUE,N)	Torque (engine RPM versus torque curve)
IENGIN	Number of point pairs (engine RPM versus torque curve)
ITCASE	Engine to transmission transfer gear box gear; Yes = 1; No = 0
TCASE(GR)	Gear ratio (engine to transmission transfer gear box; = 1 if no such gear)
TCASE(EFF)	Efficiency (engine to transmission transfer gear box; = 1 if no such gear)
ITRAN	Torque converter: Yes = 1; No = 0
TQIND	Converter characteristics measure at a constant ______ lb-ft input torque
CONV2(SR,N)	Speed ratio (torque converter versus speed ratio curve)
CONV2(TR,N)	Torque ratio (torque converter versus speed ratio curve)

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
ICONV2	Number of data point pairs (torque ratio versus speed ratio curve)
CONV1(RPM,N)	Input RPM (input RPM versus speed ratio curve)
CONV1(SR,N)	Speed ratio (input RPM versus speed ratio curve)
ICONV1	Number of data points (input RPM versus speed ratio curve)
LOCKUP	Lockup: Yes = 1; No = 0
TRANS(GR,NG)	Gear ratio (transmission gear ratios versus efficiency in each gear)
TRANS(EFF,NG)	Efficiency (transmission gear ratios versus efficiency in each gear)
NGR	Number of gears (transmission gear ratios versus efficiency in each gear)
FD(GR)	Gear ratio (final drive)
FD(EFF)	Efficiency (final drive)
XBRCOF	Maximum vehicle braking coefficient per axle _____ lb/lb of load carried
TL	Distance from centerline of first assembly to centerline of last assembly
WDTH	Maximum vehicle width
CL	Minimum vehicle ground clearance
VAA	Vehicle approach angle
VDA	Vehicle departure angle
SHF	Height of front sprocket or idler wheel above ground, in.

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
CGH	Loaded height of CG above ground
CGR	Loaded horizontal distance of CG to rear most assembly centerline - prime mover
CGLAT	Lateral distance of CG measured from vehicle centerline
PBHT	Height of pushbar above ground
EYEHGT	Eye height of driver's eyes above ground
FORDD	Fording depth
VFS	Vehicle fording speed
DRAFT	Draft height (=0 if non-floater)
SAI	Vehicle ingress swamp angle
SAE	Vehicle egress swamp angle
VSS	Maximum still water speed without auxiliary propulsion
VSSAXP	Maximum still water speed with auxiliary propulsion
WWAXP	Minimum water width required to use auxiliary propulsion
WDAXP	Minimum water depth required to use auxiliary propulsion
CD	Water drag coefficient
WRAT(NWR)	Ratio of vehicle weight supported by ground to total vehicle weight at maximum fording depth

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
WRAT(N)	Ratio of vehicle weight on ground to total vehicle weight (weight ratio versus water depth curve)
WDPTH(N)	Water depth (weight ratio versus water depth curve)
NWR	Number of point pairs (weight ratio versus water depth curve)
ACD	Aerodynamic drag coefficient
AVGC	Average cornering stiffness of tires
PFA	Vehicle projected frontal area
IT(i)	Is axle assembly part of a tandem axle: No = 0; Yes = j^{th} axle of the tandem
AXLSP(i)	Interaxle distance
WC	Winch capacity
PBF	Pushbar/bumper capacity
MAXL	Number of absorbed power acceptance levels
MAXIPR	Number of point pairs for each absorbed power level
RMS(NR)	Terrain rms (ride limited speed versus surface roughness)
VRIDE(NR,L)	Velocity (ride limited speed versus surface roughness)
NHVALS	Number of point pairs (maximum driver ride limited speed at which vehicle can cross an obstacle (for obstacles spaced farther than two vehicle lengths apart) versus height of obstacle table)

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
VOOB(NH)	Vehicle velocity (maximum driver limited speed versus obstacle height table for single obstacle crossing)
HVALS(NH)	Obstacle height (maximum driver limited speed versus obstacle height table for single obstacle crossing)
NSVALS	Number of point pairs (maximum driver limited speed at which vehicle can cross successive obstacles versus obstacle spacing table)
VOOBS(NS)	Vehicle velocity (maximum driver limited speed versus obstacle spacing table for successive obstacle crossing)
SVALS(NS)	Obstacle spacing (maximum driver limited speed versus obstacle spacing table for successive obstacle crossing)
SHIFTT	Manual Transmission Shift time per gear
JFLAG	Does vehicle have 1 or 2 units: = 1 for single unit = 2 for two unit
REFHT1	Height above the ground of a horizontal reference line taken on or near the upper suspension supports for the first unit
REFHT2	Reference line for second unit
TEMP	Length of second unit
DELTW1	Weight of payload on first unit
DELTW2	Weight of payload on second unit
DEE1	Distance from front of first unit to CG of payload of first unit
DEE2	Distance from front of first unit to CG of payload of second unit

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
NSUSP	Total number of suspension supports
NSUSP1	Total number of suspension supports for first unit
SUP	Suspension support number
ELL(SUP)	Distance to each support from front of vehicle
EQUILF(SUP)	Equilibrium load at each suspension support
SFLAG(SUP)	Suspension type for each support = 0 if independent = 1 if bogie
EFFRAD(SUP)	Rolling radius of tires at suspension support SUP
DLIMUP(SUP)	Upward suspension limit in wheel plane for support SUP
DLIMDN(SUP)	Downward suspension limit in wheel plane for support SUP
KAY(SUP)	Spring constant in wheel plane at suspension support SUP
CPLEN(SUP)	Length of tire contact patch at suspension support SUP
ANGLIM(SUP)	Angle limit of bogie suspension at support SUP, 0 = no bogie
BWIDTH(SUP)	Bogie swing arm width at suspension support SUP, 0 = no bogie
XCLC1	Coordinate for first unit Vehicle Clearance contour. This is for the vehicle without the payload

Variable Name Used in Model	Vehicle Data Sheet Nomenclature
NPTSC1	Number of point pairs (Vehicle Clearance Contour table for first unit)
XCLC2	Coordinate for second unit clearance contour. This is for vehicle with no payload
NPTSC2	Number of point pairs (Vehicle Clearance Contour table for second unit)
YCLC1	Coordinate for first unit Vehicle Clearance Contour. This is for the vehicle without the payload
YCLC2	Coordinate for second unit Clearance Contour. This is for the vehicle without the payload

VEHICLE DATA FOR AMC '74 MOBILITY MODEL

1. VEHICLE IDENTIFICATION

Vehicle/Tractor Description . . . . ______________________________

Payload Description . . . . ______________________________

2. RUNNING GEAR

Number of Axle Assemblies ______________

Number of Track Pair Assemblies ________

RUNNING GEAR DATA

Axle or Track Pair Assembly Number								
Running Gear Assembly Type: Wheeled = 1; Tracked = 0								
Operating Load on Axle (lb)								
Powered Axle = 1; Unpowered Axle = 0								
Braked Axle = 1; Unbraked Axle = 0								
Rim Description (Reference)								
Rim Diameter (in)								
Rim Width (in)								
Tire Size (Reference)								
Tire Tread (Reference)								
Tire Construction (Reference)								
Tire Ply Rating								
Tire: Nominal Revolutions/Mile								

2. RUNNING GEAR (Cont'd)

RUNNING GEAR DATA

Axle or Track Pair Assembly Number				
Tire: Nominal O.A. Diameter (in)				
Tire: Nominal O.A. Width (in)				
Tire: Nominal Section Height (in)				
Tire: Nominal Section Width (in)				
Tire: Sand Inflation Pressure (psi)				
Tire Deflection Under Operating Load and Sand Inflation Pressure (in)				
Tire: Cross-Country Inflation Pressure (psi)				
Tire Deflection Under Operating Load and Cross-Country Inflation Pressure (in)				
Tire: Highway Inflation Pressure (psi)				
Tire Deflection Under Operating Load and Highway Inflation Pressure (in)				
Number of Tires on Axle				
Dual Tires: Yes = 1; No = 0				
Central Tire Inflation System: Yes = 1; No = 0				
Minimum Ground Clearance (in)				
Minimum Width Between Left-Right Tires of Axle Assembly (in)				
Vehicle Axle Tread (Center Plane to Center Plane if Duals) (in)				

2. RUNNING GEAR (cont'd)

RUNNING GEAR DATA

Axle or Track Pair Assembly Number								
Presence of Tire Chains: Yes = 1; No = 0								

2. RUNNING GEAR (Cont'd)

Number of Track Pair Assemblies ____________

Number of Axle Assemblies ______________

RUNNING GEAR DATA

Axle or Track Pair Assembly Number								
Running Gear Assembly Type: Wheeled = 1; Tracked = 0								
Operating Load on Tracks (lb)								
Powered Track = 1; Unpowered Track = 0								
Braked Track = 1; Unbraked Track = 0								
Track Type (Reference)								
Suspension Type (Reference)								
O.A. Track Width (in)								
Track Pitch (in)								
Grouser Height (in)								
Road Pads: Yes = 1; No = 0								
Area of One Road Pad (sq in)								
Track Length on Ground (in)								
No. of Road Wheels								

2. RUNNING GEAR (Cont'd)

RUNNING GEAR DATA

Axle or Track Pair Assembly Number								
Flexible Tracks = 1; Girderized Tracks = 0								
Track Tnickness Plus Bogie Rolling Radius (in)								
Bogie Wheel Radius (in)								
Minimum width between left-right tracks (in)								
Vehicle Track Tread (centerline to centerline) (in)								

3. POWER TRAIN

Data Supplied:

Road Load Resistance (lb/ton) . . . . ____________________

Tractive Force-Speed . . . . Yes = 2; No = 1 . . . ____________

and/or or both = 0 . . . . . ____________

Power Train Characteristics . . . . Yes = 1 No = 2 . . . ____________

a. Tractive Force (lb) Versus Speed (mph) Curve

Number of Point Pairs ____________

Note: Provide at least (4) point pairs per gear.

3. POWER TRAIN (Cont'd)

Tractive Force							
Speed							

3. POWER TRAIN (Cont'd)

b. Engine Description . . . . ____________________

Maximum Gross HP . . . . ____________hp @ ____________rpm

Maximum Gross Torque . . . . ____________lb-ft @ ____________rpm

Maximum Net HP . . . . ____________hp @ ____________rpm

Maximum Net Torque . . . . ____________lb-ft @ ____________rpm

c. Engine RPM Versus Torque Curve . . . Number of Point Pairs ____________

RPM							
Torque							

3. POWER TRAIN (Cont'd)

d. Engine to Transmission Transfer Gear Box . . . . Yes = 1; No = 0 . . . ____________

Gear Ratio ____________:1 ; Efficiency 0.____________
(=1 if no such gear) (=1 if no such gear)

e. Torque Converter . . . . Yes = 1; No = 0 . . . ____________

Torque Converter Description . . . . . ____________

Converter Characteristics Measured at a Constant ____________ lb-ft Input Torque

Torque Ratio Versus Speed Ratio Curve . . . . Number of Data Point Pairs ____________

Torque Ratio							
Speed Ratio							

3. POWER TRAIN (Cont'd)

Input RPM Versus Speed Ratio Curve . . . . Number of Data Point Pairs ____________

Input RPM							
Speed Ratio							

Converter Accessory Losses . . . . Yes = 1; No = 0 ____________

Input RPM Versus Horsepower Loss Curve . . . . Number of Data Point Pairs ____________

3. POWER TRAIN (Cont'd)

Input RPM							
HP Loss							

Lockup . . . . Yes = 1; No = 0 . . . ______

f. Transmission Description . . . . ______

Transmission Gear Ratios Versus Efficiency in Each Gear . . . . . . .Number of Gears ______

3. POWER TRAIN (Cont'd)

Gear Ratio							
Efficiency							

g. Transmission to Final Drive Transfer Gear Case . . . . Yes = 1; No = 0 ____________

Transfer Gear Case Description . . . . ____________________________

Transfer Gear Case Gear Ratios Versus Efficiency in Each Gear . . . Number of Gears ____________

3. POWER TRAIN (Cont'd)

Gear Ratio :1							
Efficiency							

h. Final Drive Description . . . . ______________________________

Gear Ratio ________________:1 ; Efficiency 0.________________

i. Maximum Vehicle Braking Force Coefficient Per Axle 0.______________lb/lb of Load Carried
(Function of Brake Performance Only)

j. Manual Transmission Shift Time Per Gear (Sec.) ______________________________

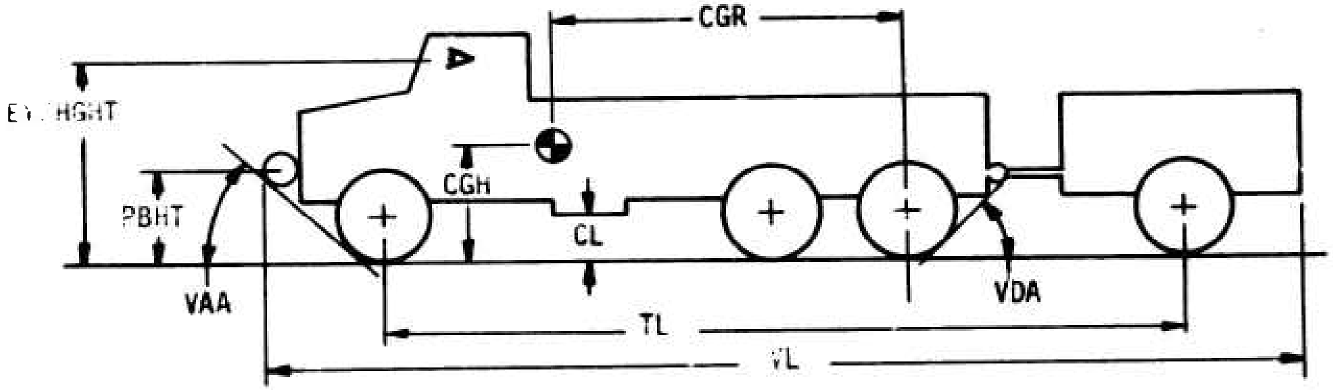
4. VEHICLE GEOMETRY

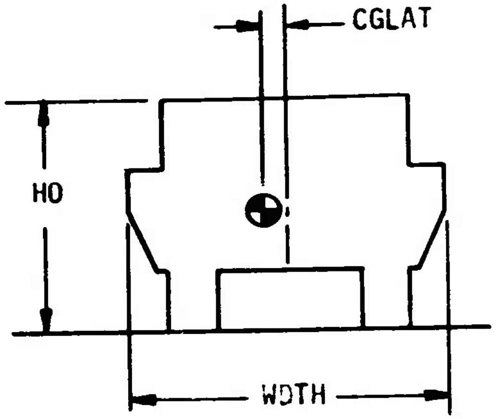
	Reference Figure	
Overall Dimensions		
Overall vehicle length (in.)	VL	____
Distance from centerline of first assembly to centerline of last assembly (in.)	TL	____
Maximum vehicle width (in.)	WDTH	____
Minimum vehicle ground clearance (in.)	CL	____
Maximum vehicle height (in.)	HO	____
Vehicle approach angle (deg.)	VAA	____
Vehicle departure angle (deg.)	VDA	____
Center of Gravity Location		
Loaded height of CG above ground (in.)	CGH	____
Loaded horizontal distance of CG to rear most assembly centerline - Prime Mover (in.)	CGR	____
Lateral distance of CG measured from vehicle centerline (in.)	CGLAT	____

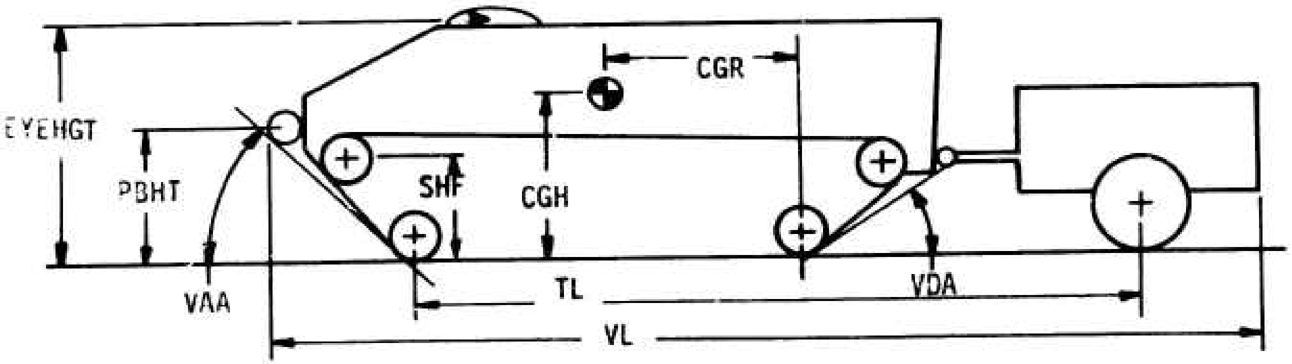
4. VEHICLE GEOMETRY (cont'd)

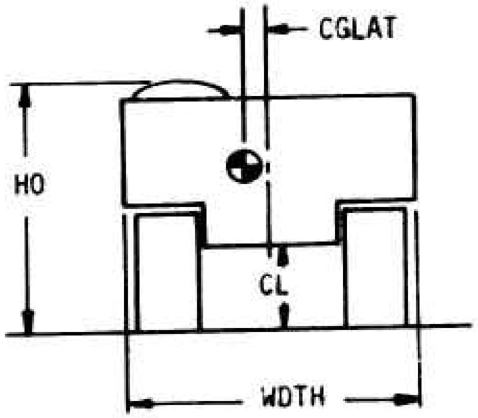
	Reference Figure	
Other		
Height of pushbar above ground (in.)	PBHT	________
Eyeheight of driver's eyes above ground (in.)	EYEHGT	________
Height of Front sprocket or idler wheel above ground (in.) (only for track vehicles)	SHF	________

4. VEHICLE GEOMETRY









5. WATER CHARACTERISTICS

Fording depth (in.) ____________

Vehicle fording speed (mph) ____________

Floater . . . . . . YES = 1; NO = 0 ____________

Hull type ____________

1 = Boat

2 = Barge

3 = Box

Water line length (in.) ____________

Beam (in.) ____________

Draft height (in.) ____________

Minimum free board (in.) ____________

5. WATER CHARACTERISTICS (cont'd)

Vehicle ingress swamp angle (deg.) ____________________

Vehicle egress swamp angle (deg.) ____________________

Water propulsion element type ____________________

0 = Normal tires or tracks

1 = Special water tracks

2 = Propellers

3 = Jet

4 = Kort nozzle

Maximum still water speed without auxiliary propulsion (mph) ____________________

Maximum still water speed with auxiliary propulsion (mph) ____________________

Minimum water width required to use auxiliary propulsion (in.) ____________________

Minimum water depth required to use auxiliary propulsion (in.) ____________________

Water drag coefficient ____________________

5. WATER CHARACTERISTICS (cont'd)

Buoyancy Characteristics:

Ratio of vehicle weight supported by ground to total vehicle weight at maximum fording depth ____________________

Ratio of vehicle weight on ground to total vehicle weight versus water depth (in.).... number of point pairs ____________________

NOTE: First water depth measured from ground surface to vehicle belly.

Wt. Ratio	1.0							
Water Depth	0.							

6. HIGHWAY CHARACTERISTICS (WHEELED VEHICLES ONLY)

Aerodynamic drag coefficient . . . . ____________

Average cornering stiffness of tires (lb/deg). . . . ____________

Vehicle projected frontal area (sq. in). . . . . . . ____________

<table>
<tr><td>Axle Assembly Number</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Is Axle Assembly Part of a Tandem Axle:
No = 0; Yes = jth axle of the tandem</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Interaxle Distance (in.)</td><td>▨</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td>▨</td></tr>
</table>

7. MOBILITY ASSIST SYSTEMS

Winch Capacity (lb.). . . . . ____________

Pushbar/Bumper Capacity (lb.) . . . ____________

8. INPUT FROM DYNAMICS MODULE

a. Ride Limited Speed (mph) Versus Surface Roughness, rms (in)

Number of Absorbed Power Acceptance Levels ____________________

Number of Point Pairs for Each Absorbed Power Level __________ __________ __________

8. INPUT FROM DYNAMICS MODULE (Cont'd)

Absorbed Power Limit	________(watts)	________(watts)	________(watts)
Terrain RMS (in)	Velocity (mph)	Velocity (mph)	Velocity (mph)

8. INPUT FROM DYNAMICS MODULE (Cont'd)

b. Maximum Driver Ride Limited Speed at Which Vehicle Can Cross an Obstacle (For Obstacles Spaced Further Than Two Vehicle Lengths Apart) Versus Height of Obstacle

Number of Point Pairs ____________

Vehicle Velocity (mph)							
Obstacle Height (in)							

8. INPUT FROM DYNAMICS MODULE (cont'd)

c. Maximum Driver Ride Limited Speed at Which Vehicle Can Cross Successive Obstacles Versus Obstacle Spacing

Number of Point Pairs ____________________

Vehicle Velocity (mph)						
Obstacle Spacing (in)						

9. OBSTACLE CROSSING INPUT DATA

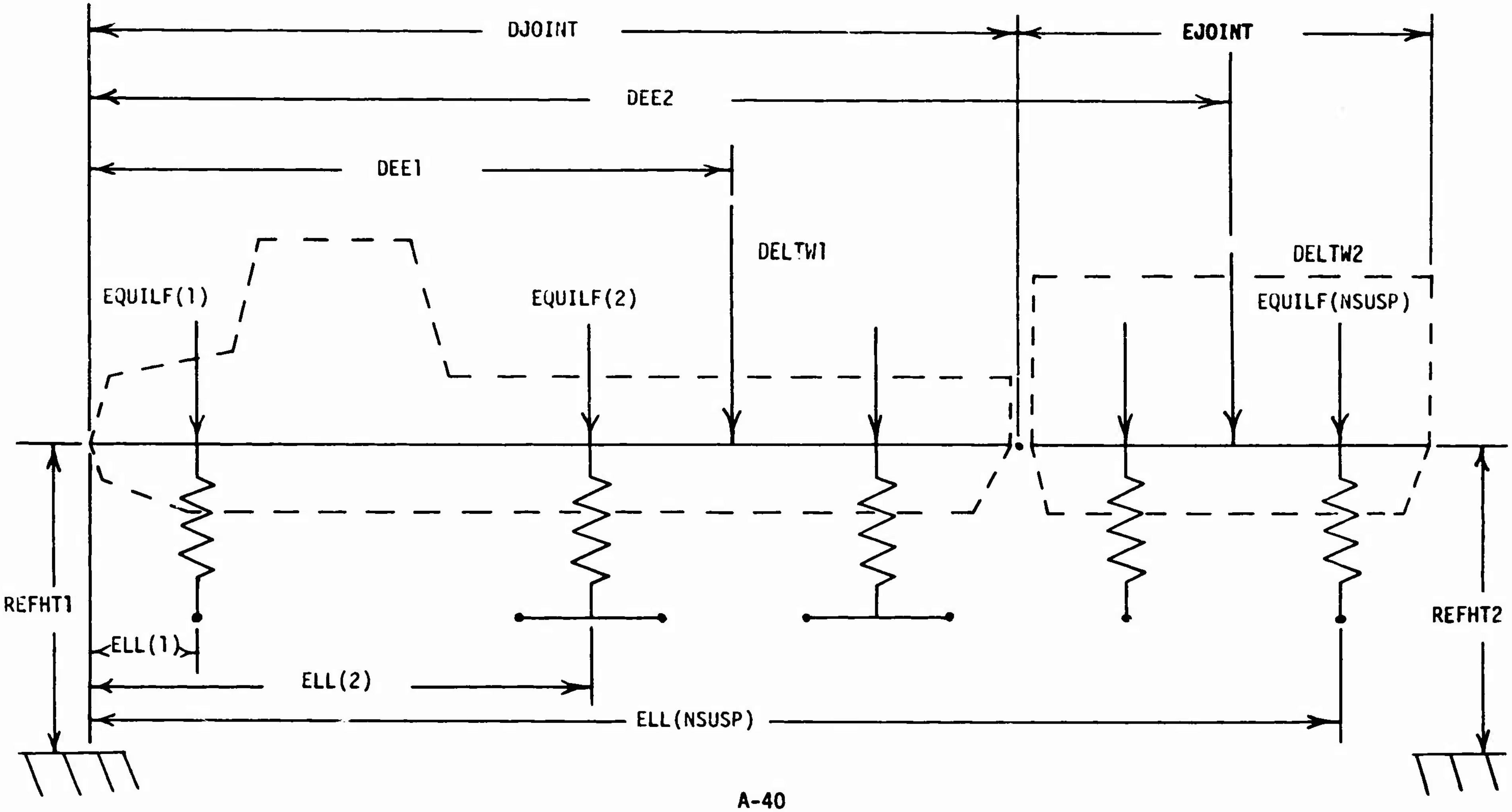
	Reference Figure A-1	
Does this vehicle have 1 or 2 units 1 unit JFLAG=1, 2 unit JFLAG=2	JFLAG	________
*Height above the ground of a horizontal reference line taken on or near the upper suspension supports for the first unit	REFHT1	________
*Reference line for second unit **	REFHT2	________
Length of first unit	DJOINT	________
**Length of second unit	EJOINT	________
Weight of payload on first unit	DELTW1	________
**Weight of payload on second unit	DELTW2	________
Distance from front of first unit to CG of payload of first unit	DEE1	________
**Distance from front of first unit to CG of payload of second unit	DEE2	________

*For the vehicle with no payload
** 0 entered if vehicle has only one unit

9. OBSTACLE CROSSING INPUT DATA (cont'd)

	Reference Figure A-1	
Total number of suspension supports	NSUSP	__________
**Total number of suspension supports for first unit	NSUSP1	__________

FIGURE A-1. OBSTACLE CROSSING INPUT DATA



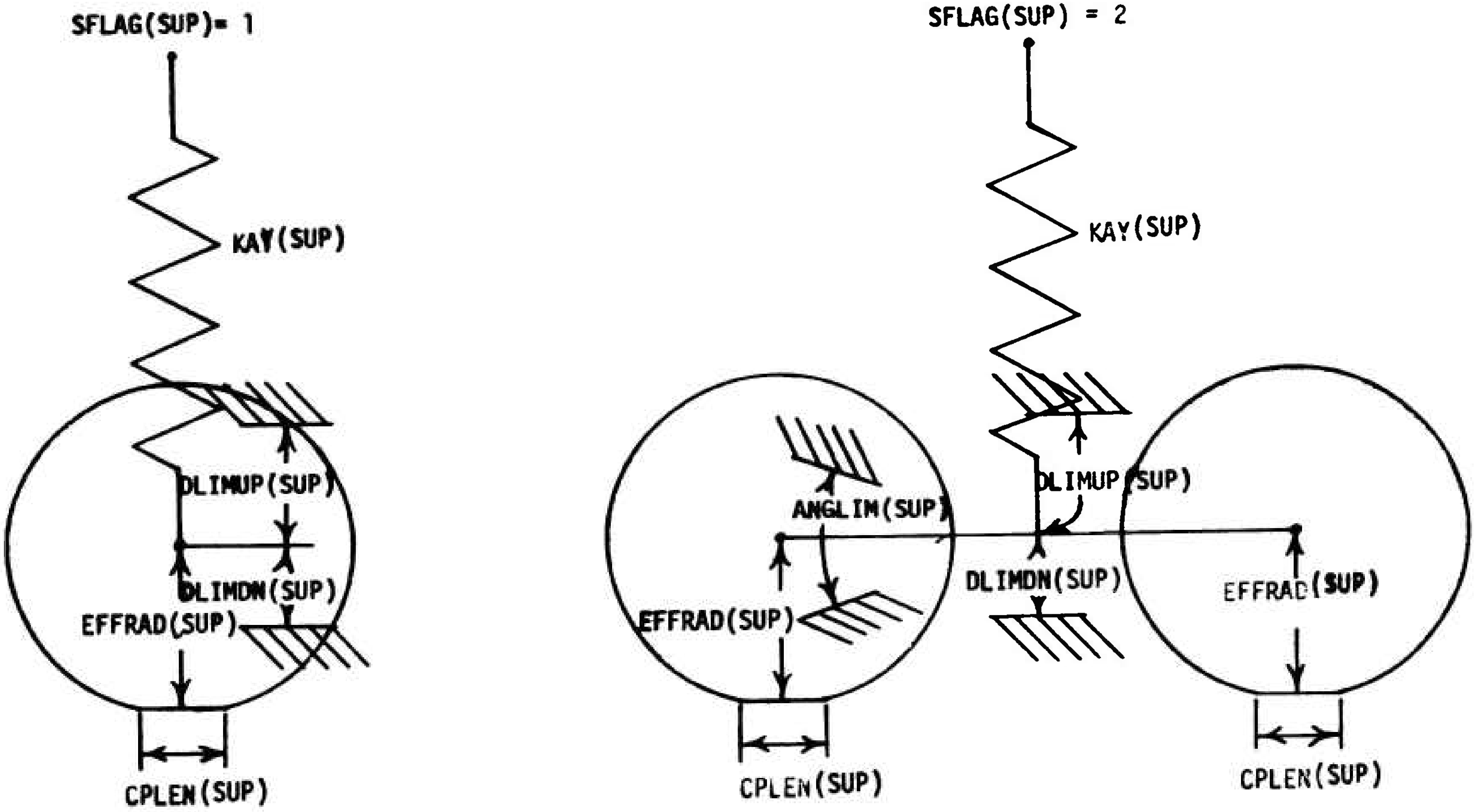
9. OBSTACLE CROSSING INPUT DATA (Cont'd)

	Reference Figure A-1									
Suspension support number	SUP									
Distance to each support from front of vehicle	ELL(SUP)									
Equilibrium load at each suspension support	EQUILF(SUP)									
	Reference Figure A-2									
Suspension type for each support 0=independent, 1=BOGIE	SFLAG(SUP)									
Rolling radius of tires at Suspension support SUP	EFFRAD(SUP)									
Upward suspension limit in wheel plane for support SUP	DLIMUP(SUP)									
Downward suspension limit in wheel plane for support SUP	DLIMDN(SUP)									
Spring constant in wheel plane at suspension support SUP	KAY(SUP)									

9. OBSTACLE CROSSING INPUT DATA (cont'd)

	Reference Figure A-2									
Length of tire contact patch at suspension support SUP	CPLEN(SUP)									
Angle limit of bogie suspension at support SUP, 0=no bogie	ANGLIM(SUP)									
Bogie swing arm width at suspension support SUP, 0=no bogie	BWIDTH(SUP)									

FIGURE A-2. OBSTACLE CROSSING INPUT DATA



9. OBSTACLE CROSSING INPUT DATA (cont'd)

(X,Y) Coordinates for first unit Vehicle Clearance Contour. This is for the vehicle without the payload. **(See Figure A-3)**

Number of Point Pairs (NPTSC1) ________________

X Coordinate XCLC1 (in)					
Y Coordinate YCLC1 (in)					

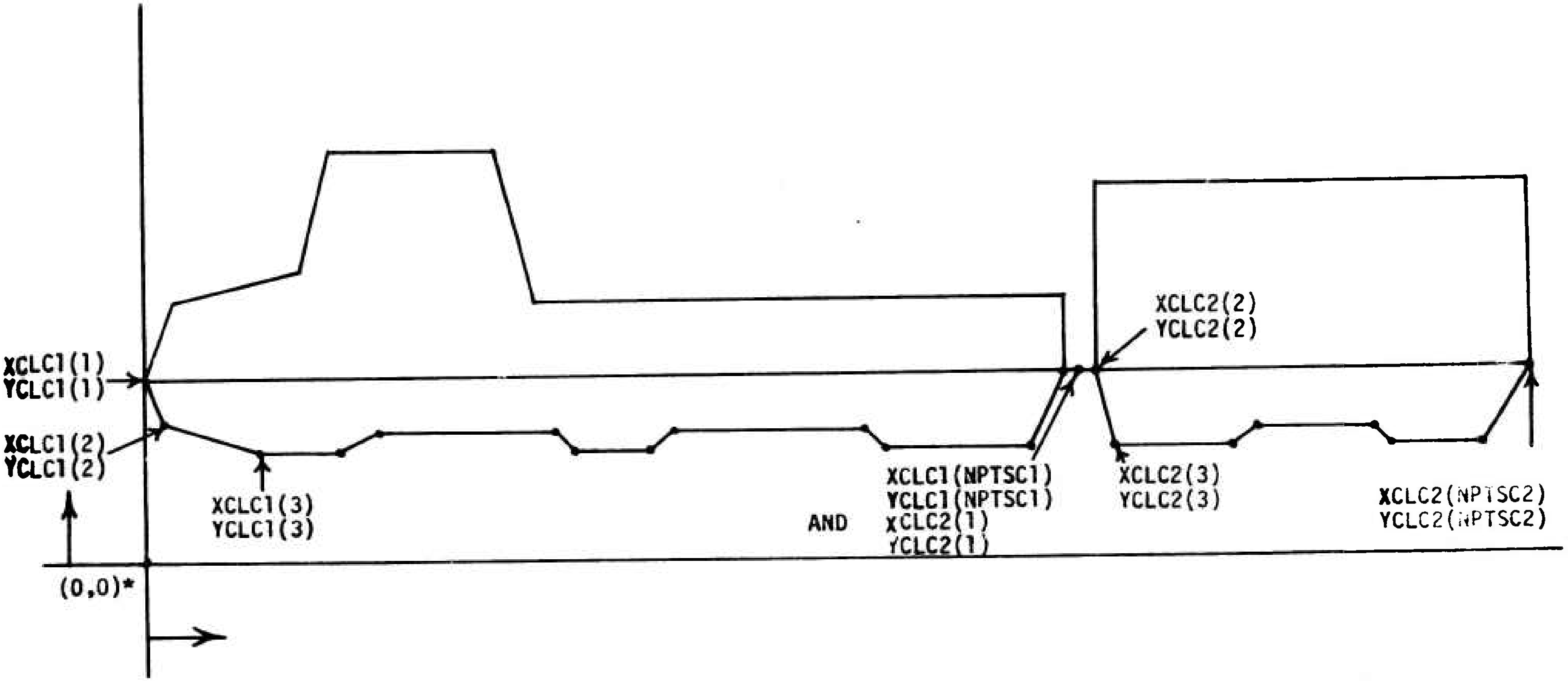
9. OBSTACLE CROSSING INPUT DATA (cont'd)

(X,Y) Coordinates for Second Unit Clearance Contour. This is for the vehicle with no payload. This entered only if there is a second unit. **(See Figure A-3)**

Number of Point Pairs (NPTSC2) ______________

X Coordinate XCLC2 (in)					
Y Coordinate YCLC2 (in)					

FIGURE A-3. OBSTACLE CROSSING INPUT DATA



*The location of this point is the front of the vehicle at ground level.

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