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TECHNICAL REPORT M-68-1

DYNAMICS OF WHEELED VEHICLES

Report 1

A MATHEMATICAL MODEL FOR THE TRAVERSAL OF
RIGID OBSTACLES BY A PNEUMATIC TIRE

APPENDIX B: DIGITAL IMPLEMENTATION OF
SEGMENTED TIRE MODEL

by

N. R. Murphy, Jr.



August 1969

Sponsored by

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station

CORPS OF ENGINEERS

Vicksburg, Mississippi

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Foreword

The digital implementation of the segmented tire model is an extension of the study reported in the basic report and was developed at the U. S. Army Engineer Waterways Experiment Station (WES) as a part of the vehicle mobility research program under DA Project 1TO62103A046, "Trafficability and Mobility Research," Task O3, "Mobility Fundamentals and Model Studies," sponsored by the Directorate of Development and Engineering, U. S. Army Materiel Command.

The study described herein was accomplished by personnel of the Vehicle Dynamics Section (VDS), Mobility Research Branch, Mobility and Environmental Division, under the general supervision of Messrs. W. G. Shockley and S. J. Knight, and under the direct supervision of Dr. D. R. Freitag and Mr. A. J. Green. Mr. N. R. Murphy, Jr., of the VDS and Mr. J. F. Smith of the Mathematics and Analysis Section, Electronic Computer Branch, wrote the computer programs. Mr. Murphy prepared this appendix.

COL Levi A. Brown, CE, was Director of WES during the preparation of this appendix. Mr. F. R. Brown was Technical Director.

Contents

	<u>Page</u>
Foreword	v
Conversion Factors, British to Metric Units of Measurement	ix
Summary.	xi
Program 1.	B1
Program 2.	B3
Computer calculations.	B3
Notation	B6
Summary.	B7
Damping.	B8
Figs. B1-B4	

Conversion Factors, British to Metric Units of Measurement

British units of measurement used in this report can be converted to metric units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
inches	2.54	centimeters
pounds	4.444	newtons
pounds per square inch	0.689476	newtons per square centimeter

Summary

This appendix presents the procedures for digital implementation of the segmented tire model, developed in the basic report for an analog computer. Two procedures are required: (a) determination of the segment spring coefficient from measured load-deflection test results, and (b) computation of the resultant force vector transmitted to the axle. Digital programs for both procedures were written in Fortran IV for a GE-420 system, and are included.

DYNAMICS OF WHEELED VEHICLES

A MATHEMATICAL MODEL FOR THE TRAVERSAL OF RIGID OBSTACLES BY A PNEUMATIC TIRE

APPENDIX B: DIGITAL IMPLEMENTATION OF SEGMENTED TIRE MODEL

1. For digital implementation of the segmented tire model, basically two procedures are required: (a) determination of the segment spring coefficient from measured load-deflection test results, and (b) computation of the resultant force vector transmitted to the axle. Therefore, two computer programs have been prepared.

Program 1

2. The first program (fig. B1) is used to compute the average deflection of each segment for a given vertical center-line deflection.* It is written in Fortran IV and programmed to run on a GE-420 system. The only input requirement is a card containing the tire radius in inches, the number of segments for 180 deg (current status of the program limits the maximum number of segments to 60), and the desired maximum vertical center-line deflection in inches multiplied by 10. This maximum deflection serves as a cutoff criterion for the computer and should be a number that does not exceed the tire section height. The actual maximum deflection is multiplied by 10 to ensure an integer value. This is a restriction imposed by the "DO-loop" that successively increments the center-line deflection.

3. A representative computer printout is shown in fig. B2 to illustrate the format of the output and to demonstrate, in conjunction with the following example, how the results are used to determine an appropriate segment spring coefficient:

* Appendix A to this report presents procedures for computing the necessary effective radial deflections.

- a. Problem. A 9.00-14, 2-PR tire with a 14-in.* radius is inflated to 30-psi pressure; at this pressure it deflects 1 in. under a 760-lb load. Divide the lower half (180 deg) of the tire into 18 equal segments and determine the segment spring coefficient.
- b. Solution. Prepare an input data card containing the tire radius in inches (14), the number of segments in 180 deg (18), and the maximum vertical center-line deflection in inches multiplied by 10 (say $3 \times 10 = 30$). Run, using the program in fig. B1. Since the coordinate (1.0, 760) was chosen from the load-deflection curve, examine the computer printout (fig. B2) and find the values of segment deflections for a center-line deflection of 1 in. Two segments on each side of the vertical center line are seen to be influenced at this particular deflection. Compute the segment spring coefficient K from the equation**

$$\begin{aligned}
 K &= \frac{F}{2 \sum_{i=1}^2 \Delta_i \cos \phi_i} \\
 &= \frac{760}{2(0.914 \cos 5^\circ + 0.384 \cos 15^\circ)} \\
 &= \frac{760}{2.56} \\
 &= 297 \text{ lb/in.}
 \end{aligned}$$

This value is assigned as the spring coefficient for each segment and will change only if the number of segments or the inflation pressure is changed. Choosing a small deflection, such as 0.2 or 0.4 in., as a basis for determining the spring coefficient would most likely yield a K-value somewhat different from one with a larger value of deflection as a basis. Comparisons of measured load-deflection curves with those computed for K-values obtained from the segmented tire model at various deflections revealed that greater accuracy and consistency were obtained when K was computed from a deflection of 1 in. This deflection is generally in the area of maximum curvature on the load-deflection curve.

* A table of factors for converting British units of measurement to metric units is presented on page ix.

** See equation development in paragraph 21 of the main report.

Program 2

4. The second program (fig. B3) is used to compute the vertical and horizontal components of the resultant force vector transmitted to the axle. It, too, is written in Fortran IV for the GE-420 system. It is a complete, self-contained program that was assembled from a section of a more comprehensive one that represented a multidegree-of-freedom vehicle. Taken out of context, it contains none of the dynamics of the problem, i.e. the influence of the coupled differential equations describing the dynamics of the sprung mass of the system has been removed. Certain modifications were made regarding the input requirements, so the program demonstrates, in a static sense, how the components of the resultant wheel spring force are computed with the segmented tire concept. With other slight modifications, this program can be adapted as a subprogram to describe the tire compliance in other vehicle dynamics programs.

5. The solution is based on a purely geometric approach that treats each discrete axle movement interval in terms of space-oriented coordinates of the terrain and wheel center with respect to a fixed reference frame. The current program will handle up to 100 terrain profile points and up to 24 tire segments equally divided about a vertical axis through the axle of each wheel. Experience has indicated that twelve 10-deg segments, six on each side of the vertical, are sufficient to describe the tire compliance for most terrain conditions and obstacle configurations. The angle to each segment center line is measured from the vertical and is considered positive in a counterclockwise direction.

Computer calculations

6. The following sequence of calculations is used in this second program:

- a. Dimension the appropriate space for segment angles, segment spring coefficients, terrain profile points, segment forces, etc.
- b. Provide a "degree-to-radian" converter = $\pi/180$.
- c. Read in: Coordinates of wheel center (X1,Y1), tire radius, number of tire segments, number of terrain points, number of positions to be calculated, and X and Y increments.

- d. Check for end of data; if no more data, exit computer.
- e. Read in and store all segment angles, spring coefficients, and terrain points.
- f. Print headings and terrain profile table.
- g. Designate a variable name for the number of tire segments; e.g. NNN = NSEG.
- h. Determine maximum horizontal projection of tire, i.e. $XRET = X1 - WRAD$, $XRET = X1 + WRAD$.
- i. Initialize ITR = 2.
- j. Change all segment angles from degrees to radians.
- k. Compute the coordinates of each (undeflected) tire segment (i) location with respect to the wheel axle:

$$CX(i) = SIN(DSEG(i) * WRAD)$$

$$CY(i) = -COS(DSEG(i) * WRAD)$$

(These then remain constant for a given wheel.)

- l. Set $VW(1) = 0$ $VW(2) = 0$.
- m. Now determine the coordinates of each (undeflected) segment with respect to the fixed reference system, e.g.

$$RXY(1,i) = X1 + CX(i)$$

$$RXY(2,i) = Y1 + CY(i)$$

- n. At this time compute intersections of the tire segment centers with terrain. For each tire segment:
 - (1) Set $DMIN = 1.E10$, i.e. some large number definitely greater than tire radius.
 - (2) Compute slope of tire segment (i), e.g. $SM = CY(i)/CX(i)$.
 - (3) $KTR = ITR$. This is a counter to account for terrain stations.
 - (4) Set $X2 = 0$, i.e. first terrain point begins at $X = 0$.
 - (5) Recall $Y2$ from proper storage location; now there is terrain coordinate $X2, Y2$.
 - (6) Recall $X3, Y3$, i.e. the next forward terrain coordinate.
 - (7) Obtain the slope of this line (terrain segment).
 - (8) Compare it with the slope of i^{th} tire segment.
 - (9) If slopes are not the same, the lines will intersect; use the point slope method to obtain coordinate of intersection, i.e. XX, YY for i^{th} tire segment. (This is

coordinate of deflected tire segment with respect to fixed reference system.)

- (10) Now determine whether this coordinate falls within the tire circumference.
- (11) If not, then increment the terrain segment and recheck as before until a coordinate is determined that falls within the tire circumference.
- (12) Compute the radial distance of this intersection from the wheel center and set this distance equal to the variable, DMIN. This represents a new "minimum" length.
- (13) Check this length against last minimum value.
- (14) If it is smaller, let the coordinates of this deflected tire segment be: $RXY(1,i) = XX$; $RXY(2,i) = YY$.
- (15) If, however, it is larger, check to see whether forward edge of tire is ahead of the terrain station.
- (16) If so, then advance the station by one. Go back to step (1).
- (17) If not, go to next tire segment and repeat the procedures described above until all intersections of tire segment centers with terrain segments have been computed.

This operation should locate the positions (with respect to the fixed and moving reference) of each deflected tire segment.

- o. Now compute the actual deflection of each tire segment beginning as follows:

$$\begin{aligned} RXY(1,i) &= X1 - RXY(1,i) \\ RXY(2,i) &= Y1 - RXY(2,i) \end{aligned}$$

These are vertical and horizontal components of new segment length.

- p. Store these values in a temporary storage $AA(1), AA(2)$.
- q. Compute the radial distance of each segment using the Pythagorean Theorem, i.e. $TMAG(i) = \text{square root of sum of squares of the respective components.}$
- r. Obtain the sin and cos of each segment angle as follows:

$$\begin{aligned} RXY(1,i) &= AA(1)/TMAG(i) = \sin \text{ of the segment angle} \\ RXY(2,i) &= AA(2)/TMAG(i) = \cos \text{ of the segment angle} \end{aligned}$$

- s. Compute the radial force in each segment, i.e.

$$TMAG(i) = (WRAD - TMAG(i)) * SEGK(i) = K\delta$$

where $\delta = WRAD - TMAG(i)$

- t. Compute the horizontal and vertical components of the resultant force vector, e.g.

$$VVV(1) = \sum TMAG(i) * RXY(1,i) \rightarrow \text{horizontal component}$$

$$VVV(2) = \sum TMAG(i) * RXY(2,i) \rightarrow \text{vertical component}$$

- u. Print results.

- v. Increment tire center position and repeat procedures.

7. Computation of resultant tire spring force vector is summarized as follows:

- a. The points where all tire segment centers (spring locations) intersect the undeflected tire circumference are located.
- b. The points where tire segment centers intersect the terrain are located.
- c. The radial reduction in length of each tire segment center intersecting the terrain is computed.
- d. The force vector for each segment is computed using the displacement of the segment center and the segment spring coefficient.
- e. The segment force vectors are summed to yield the vertical and horizontal components of the resultant spring force vector for the wheel.

Notation

8. Symbols used in the second program are defined below:

CX,CY	Coordinates (with respect to the wheel axle) of points where segment center lines intersect the undeflected tire circumference
DSEG	Segment angle in degrees; the angle measured from a vertical line through the wheel axle to center line of segment (positive value, counterclockwise)
DTR	Degree-to-radian conversion factor
HGT	Elevation of profile
NPOS	Number of wheel positions to be computed
NSEG,NNN	Number of tire segments
NTP	Number of terrain points to be used

RXY	Absolute coordinates (with respect to fixed X-Y reference) of the points where segment center lines intersect the undeflected tire circumference
SE GK	Segment spring coefficient (can vary with each segment)
ST	Slope of a terrain segment
STA	Horizontal distance of terrain profile
TMAG	Radial force of segment
VV(1)	Horizontal component of force
VV(2)	Vertical component of force
WRAD	Wheel radius
XX,YY	Absolute coordinates of the intersection points of the terrain with tire segment
X1,Y1	Coordinates of wheel center
X2,Y2	Absolute coordinates of the rear terrain station
X3,Y3	Absolute coordinates of the adjacent terrain station in increasing X-direction
XFET,XRET	Forward and rear extremes of tire (horizontal)
XINCR,YINCR	Increment of axle movement of wheel in X- and Y-directions

Summary

9. The required input information for the second program consists of (a) the coordinates of the tire center, (b) the undeflected tire radius, (c) the number of segments to be used, (d) the number of terrain coordinates, (e) the number of axle positions to be calculated, (f) the X- and Y-increments (i.e. the movements of the axle), (g) each segment angle in degrees, (h) each segment spring constant (may be different for each segment if desired), and (i) the terrain profile coordinates. The tire-center coordinates are the only inputs that do not remain constant. When the program is used in an appropriate vehicle dynamics program that describes the motions of the sprung masses, these coordinates are determined at each time step by the differential equations that describe the dynamics of the vehicle system. The coordinates (X1,Y1) of the tire center are used to compute forward and rear extremes of the tire for each increment of movement. This is accomplished by subtracting or adding the tire radius (WRAD) to the coordinate X1. (See fig. B4.) The program can then be used to compute

the location of the points, relative to the axle, where each segment center intersects the tire circumference. These values never change and are stored in the computer under the identification $CX(i)$ and $CY(i)$.

10. Then for each increment of horizontal axle movement ($XINCR$), the program proceeds as follows:

The points of the wheel at each segment's center line are located relative to the fixed (X-Y) reference frame and stored as coordinates under the identification $RXY(1,i)$ and $RXY(2,i)$. This gives the complete orientation of each undeflected segment "spring." The program then proceeds into a loop that calculates the intersections of the segment center lines and the terrain profile segments, which are constructed from straight-line connections of the terrain profile points. These intersections are determined by the point-slope method, which compares the slopes of each segment center line (proceeding in a counterclockwise sequence beginning with the rear segment) with the slopes of each terrain segment within the forward extreme of the tire. A check is made in each instance to determine if the intersections occur within the periphery of the undeflected tire. This indicates whether a particular segment is influenced by the terrain and the amount that each segment deflects in a radial direction. The radial deflection that is computed for each segment spring is multiplied by the appropriate spring constant to yield a segment force vector whose magnitude and orientation are known. These individual vectors are summed to yield the vertical and horizontal components of the resultant force vector acting at the axle. The axle is then advanced to the next position and the process is repeated.

Damping

11. No provision has been made to incorporate segment damping forces at this time. The influence of tire damping is currently computed as a gross vertical force from the relative motion between the axle and a point directly beneath the axle.

06/13/69

MURPHY

THE GE-400 SERIES - FORTRAN ASA (DPS)

PAGE # 1 MURP FW39'8

```

C      A PROGRAM TO COMPUTE AVG DEFLECTIONS OF PNEUMATIC TIRE SEGMENTS
1      DIMENSION AVGDEL(60)
2      TANF(AZ) = SIN(AZ)/COS(AZ)
3      PI = 3.1416
4      1 READ 10, R, N, IDEFL
5      PRINT 155
6      40 PRINT 60

C      R IS TIRE RADIUS IN IN., N IS NO. OF SEGMENTS FOR 180 DEGREES
C      IDEFL IS MAX. VERTICAL DEFLECTION AT VRP IN IN. TIMES 10
7      THETA = PI/N
8      W = R * THETA
9      TTHETA = THETA * 180.0/PI
10     DO 15 J = 1, IDEFL
11     DELTA = J/10.
12     C      DELTA IS CENTERLINE DEFLECTION IN IN.
13     X = SQRT(2 * R * DELTA * DELTA)
14     PHI = ATAN2(X, R - DELTA)
15     C      ARC IS ARC OF CONTACT, W IS ARC OF ENTIRE SEGMENT
16     B = PHI/THETA
17     IF (B - 1.0) 5, 6, 6
18     5 W = 1
19     I = 1
20     ARC = R * PHI
21     C      W IS THE NO. OF SEGMENTS INFLUENCED BY DELTA DEFLECTION
22     AVGDEL(I) = R - SQRT((W - ARC)/W * R * R + R/W * ((R - DELTA)
23     1 ** 2) * (TANF(PHI)))
24     C      AVGDEL IS AVG DEFLECTION OF SEGMENT
25     GO TO 14
26     6 K = 3
27     C      NO. OF SEGMENTS FULLY DEPRESSED
28     IF (3 - K) 3, 8, 7
29     C      IS AN INTEGER
30     3 STOP 95
31     7 M = B + 1.0
32     GO TO 9
33     8 M = 8
34     9 DO 4 I = 1, K
35     4 AVGDEL(I) = R - SQRT(R/W * ((R - DELTA) ** 2) * (TANF(I * THETA)
36     1 - TANF((I - 1) * THETA)))
37     IF (M - B) 11, 13, 11
38     13 IF (I - 14) 14, 14, 17
39     11 I = M
40     ARC = R * PHI - (I - 1) * W
41     AVGDEL(I) = R - SQRT((W - ARC)/W * R * R + (R/W * ((R - DELTA)
42     1 ** 2) * (TANF(PHI) - TANF((I - 1) * THETA))))
43     IF (I - 14) 14, 14, 17
44     14 PRINT 185
45     PRINT 186
46     PRINT 187, DELTA, N, TTHETA, (AVGDEL(I), I = 1, M)
47     GO TO 15
48     17 PRINT 185
49     PRINT 186
50     PRINT 188, DELTA, N, TTHETA, (AVGDEL(I), I = 1, 14)
51     PRINT 189
52     PRINT 190, (AVGDEL(I), I = 15, M)
53     15 CONTINUE
54     GO TO 1
55     10 FORMAT (F10.2, 2I5)
56     155 FORMAT (1H1)
57     60 FORMAT (41X, 34HCOMPUTATION OF AVERAGE DEFLECTIONS//)

```

```

18      ARC = R * PHI
19      C M IS THE NO. OF SEGMENTS INFLUENCED BY DELTA DEFLECTION
      AVDEL(I) = R - SQRT ((W - ARC)/W * R * R + R/W * ((R - DELTA)
1          *2) * (TANF(PHI)))
20      C AVDEL IS AVG DEFLECTION OF SEGMENT
      GO TO 14
21      6 K = 8
22      C NO. OF SEGMENTS FULLY DEPRESSED
      IF (8 - K) 3,8,7
23      C IS R AN INTEGER
      3 STOP 55
24      7 M = B + 1.0
25      GO TO 9
26      8 M = 8
27      9 DO 4 I = 1, K
28      4 AVDEL(I) = R - SQRT (R/W * ((R - DELTA) *2) * (TANF(I * THETA)
1          *2) * (TANF(PHI) - TANF((I - 1) * THETA)))
29      1 - TANF((I - 1) * THETA))
      IF (M - B) 11, 13, 11
30      13 IF (I - 14) 14, 14, 17
31      11 I = M
32      ARC = R * PHI - (I - 1) * W
33      AVDEL(I) = R - SQRT ((W - ARC)/W * R * R + (R/W * ((R - DELTA)
1          *2) * (TANF(PHI) - TANF((I - 1) * THETA)))
      IF (I - 14) 14, 14, 17
34      14 PRINT 185
35      PRINT 186
36      PRINT 187, DELTA, N, THETA, (AVDEL(I), I=1, M)
37      GO TO 15
38      17 PRINT 185
39      PRINT 186
40      PRINT 188, DELTA, N, THETA, (AVDEL(I), I=1, 14)
41      PRINT 189
42      PRINT 190, (AVDEL(I), I=15, M)
43      15 CONTINUE
44      GO TO 1
45      10 FORMAT (F10.2, 2I5)
46      155 FORMAT (1H1)
47      60 FORMAT (41X, 34HCOMPUTATION OF AVERAGE DEFLECTIONS//)
48      185 FORMAT (3X, 2HCL, 3X, 2HNO, 3X, 5HTHETA, 18X, 7H AVERAGE, 2X
1          7HSEGMENT, 2X, 10HDEFLECTION, 2X, 2HIN, 2X, 6HINCHES)
49      186 FORMAT (2X, 4HDEFL, 2X, 3HSEG, 3X, 3HDEG, 3X, 4HSEG1, 3X, 4HSEG2,
1          3X, 4HSEG3, 3X, 4HSEG4, 3X, 4HSEG5, 3X, 4HSEG6, 3X, 4HSEG7,
1          3X, 4HSEG8, 3X, 4HSEG9, 2X, 5HSEG10, 2X, 5HSEG11, 2X, 5HSEG12,
1          2X, 5HSEG13, 2X, 5HSEG14)
50      187 FORMAT (F6.2, 15, F6.2, 14F7.3/)
51      188 FORMAT (F6.2, 15, F6.2, 14F7.3/)
52      189 FORMAT (19X, 5HSEG15, 2X, 5HSEG16, 2X, 5HSEG17, 2X, 5HSEG18,
1          2X, 5HSEG19, 2X, 5HSEG20, 2X, 5HSEG21, 2X, 5HSEG22, 2X, 5HSEG23,
1          2X, 5HSEG24, 2X, 5HSEG25, 2X, 5HSEG26, 2X, 5HSEG27, 2X, 5HSEG28)
53      190 FORMAT (17X, 14F7.3/)
54      END
55

```

Fig. B1. Program for computing average deflections
of pneumatic tire segments

B

A

[illegible]

CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
1.30	18	10.00	1.216	0.692	0.025											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
1.40	18	10.00	1.316	0.796	0.052											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
1.50	18	10.00	1.417	0.900	0.087											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
1.60	18	10.00	1.517	1.003	0.131											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
1.70	18	10.00	1.618	1.107	0.183											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
1.80	18	10.00	1.718	1.211	0.243											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
1.90	18	10.00	1.819	1.314	0.312											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.00	18	10.00	1.919	1.418	0.389											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.10	18	10.00	2.020	1.522	0.474											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.20	18	10.00	2.120	1.625	0.566											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.30	18	10.00	2.221	1.729	0.666											
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.40	18	10.00	2.321	1.833	0.774	0.000										
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.50	18	10.00	2.422	1.936	0.885	0.005										
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.60	18	10.00	2.522	2.040	0.995	0.017										
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.70	18	10.00	2.623	2.144	1.106	0.037										
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.80	18	10.00	2.723	2.248	1.217	0.063										
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
2.90	18	10.00	2.824	2.351	1.327	0.097										
CL	NO	THETA	AVERAGE SEGMENT DEFLECTION IN INCHES													
DEFL	SEG	DEG	SEG1	SEG2	SEG3	SEG4	SEG5	SEG6	SEG7	SEG8	SEG9	SEG10	SEG11	SEG12	SEG13	SEG14
3.00	18	10.00	2.924	2.455	1.438	0.137										

Fig. B2. Printout of computations of average reflections

B

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INGRAM

INGRAM

TC1 04-G2-R0-010 7 FEBRUARY 1969

PAGE # 1

INGR SDL6

3 TITLE INGRAM TC1 04-G2-R0-010 7 FEBRUARY 1969
C THIS CODE WAS TAKEN FROM A VEHICLE DYNAMICS PROGRAM WHICH IS NOW
C BEING USED AT WES,
C THE PROGRAM PRESENTED HERE CONTAINS NONE OF THE DYNAMICS OF THE
C PROBLEM, BUT IS INTENDED ONLY TO DEMONSTRATE STATISTICALLY HOW THE
C RESULTANT WHEEL SPRING FORCE IS COMPUTED USING THE SEGMENTED WHEEL
C CONCEPT.

1 DIMENSION DSEG(24), SEGK(24), STA(100), HGT(100), TMAG(24), RXY(2,24)
2 DIMENSION VVV(2), AA(2), CX(24), CY(24)
3 1 FORMAT (8F10.0)

4 DTR = 3.141592653 / 180.
C THE ANGLE, DSEG(I), TO EACH SEGMENT CENTER IS MEASURED FROM THE

C VERTICAL, POSITIVE COUNTERCLOCKWISE IN DEGREES.
C UNITS FOR OTHER VARIABLES ARE ARBITRARY, BUT SHOULD BE CONSISTENT.

5 100 READ 1, X1, Y1, WRAD, NSEG, NTP, NPOS, XINCR, YINCR
6 CALL EOFTST(50, ITEST)
7 GO TO(120, 110), ITEST

8 110 CALL EXIT
9 120 READ 1, (DSEG(I), SEGK(I), I = 1, NSEG)
10 READ 1, (STA(I), HGT(I), I = 1, NTP)

11 PRINT 3, WRAD, NSEG
12 3 FORMAT(
115W1WHEEL RADIUS = F8.2, //
221H NUMBER OF SEGMENTS = 15//)

13 PRINT 4, (1, DSEG(I), SEGK(I), I = 1, NSEG)
14 4 FORMAT (34H SEGMENT ANGLE TO SPRING
36H NUMBER CENTERLINE CONSTANT //

1 15, F14.2)
2 (15, F15.2)
PRINT 5, (STA(I), HGT(I), I = 1, NTP)
5 FORMAT (16H0TERRAIN PROFILE /

1 16H X Y /
2 (2F8.2))
NNN = NSEG
XFET = X1 - WF.D
XFET = X1 + WRAD
1TR = 2

DO 1065 I = 1, NSEG
DSEG(I) = DSEG(I) * DTR
CX(I) = SIN(DSEG(I)) * WRAD
CY(I) = COS(DSEG(I)) * WRAD

25 1065 CONTINUE
26 PRINT 10

10 FORMAT(50H0LOCATION OF WHEEL CENTER
1 7X, 1HX, 9X, 1HY, 17X, 4HF(X), 6X, 4HF(Y),)

DO 200 I = 1, NPOS
VVV(I) = 0.
VVV(2) = 0.
.. LOCATE ALL POINTS ALONG TIRE CIRCUMFERENCE

DO 5325 I = 1, NNN
RXY(1, I) = X1 + CX(I)
RXY(2, I) = Y1 + CY(I)

5325 CONTINUE
C .. INTERSECT SEGMENT CENTERS WITH TERRAIN

DO 5350 I = 1, NNN
DMIN = 1.E10
SM = CY(I) / CX(I)

37 38
36 39
35 40

7372
7373
765
766
769
770
771

33	33	XY(2,1) = Y1 + CY(1)		
34	34	5325 CONTINUE		769
	C	..INTERSECT SEGMENT CENTERS WITH TERRAIN		770
35		DO 5350 I=1,NNN		771
36		DMIN=1.E10		
37		SM=CY(1) / CX(1)		
38		KTR=1TR		773
39		X2=0.		774
40		Y2=HGT(KTR-1)		775
41	5329	CONTINUE		776
42		X3=STA(KTR)- STA(1TR-1)		777
43		Y3=HGT(KTR)		778
44		ST=(Y2-Y3)/(X2-X3)		779
45		IF(SM-ST)5331,5330,5331		780
46	5330	XX=1.E35		781
47		GO TO 5333		782
48	5331	XX=(Y2-Y1+SM*X1-ST*X2)/(SM-ST)		783
49	5333	YY=ST*(XX-X2)+Y2		784
50		KERR=KBTWN(X2,XX,X3)		785
51		GO TO (5332,5336),KERR		786
52	5332	KERS=KBTWN(Y2,YY,Y3)		787
53		GO TO (5334,5336),KERS		7871
54	5334	KERT=KBTWN(X1,XX,XY(1,1))		7872
55		GO TO (5335,5336),KERT		7873
56	5335	KERU=KBTWN(Y1,YY,XY(2,1))		7874
57		GO TO (5340,5336),KERU		7875
58	5336	IF(XFET-STA(KTR))5350,5338		7876
59	5338	KTR=KTR+1		7877
60		X2=X3		788
61		Y2=Y3		789
62		GO TO 5329		790
63	5340	DMIN1=SQRT((XX-X1)**2+(YY-Y1)**2)		
64		IF(DMIN1-DMIN)5341,5341,5336		
65	5341	DMIN=DMIN1		
66		XY(1,1)=XX		792
67		XY(2,1)=YY		
68		GO TO 5336		793
69	5350	CONTINUE		794
70	5355	CONTINUE		795
	C			796
71		DO 5356 I=1,NNN		
72		XY(1,1)=X1-XY(1,1)		
73		XY(2,1)=Y1-XY(2,1)		
74	5356	CONTINUE		799
	C	..NORMALIZE RXY AND LET TMAG BE MAGNITUDE		800
75		DO 5357 I=1,NNN		801
76		AA(1)=RXY(1,1)		802
77		AA(2)=RXY(2,1)		803
78		TMAG(I)=SQRT(AA(1)*AA(1)+AA(2)*AA(2))		804
79		XY(1,1)=AA(1)/TMAG(I)		805
80		XY(2,1)=AA(2)/TMAG(I)		806
81	5357	CONTINUE		807
	C	..COMPUTE FORCE FOR EACH SEGMENT		808
82		DO 5358 I=1,NNN		809
83		TMAG(I)=(HRAD-TMAG(I))*SEK(I)		
84	5358	CONTINUE		811
	C	..COMPUTE COMPOSITE FORCE VECTOR		812
85		DO 5359 I=1,NNN		813
86		VVV(1)=VVV(1)+TMAG(I)*RXY(1,1)		
87		VVV(2)=VVV(2)+TMAG(I)*RXY(2,1)		
88	5359	CONTINUE		
89		PRINT 2,X1,Y1,VVV		
90	2	FORMAT(2F10.2,10X,2F10.2)		
91		Y1=Y1+YINCR		
92		X1=X1+XINCR		
93	200	CONTINUE		
94		GO TO 100		
95		END		

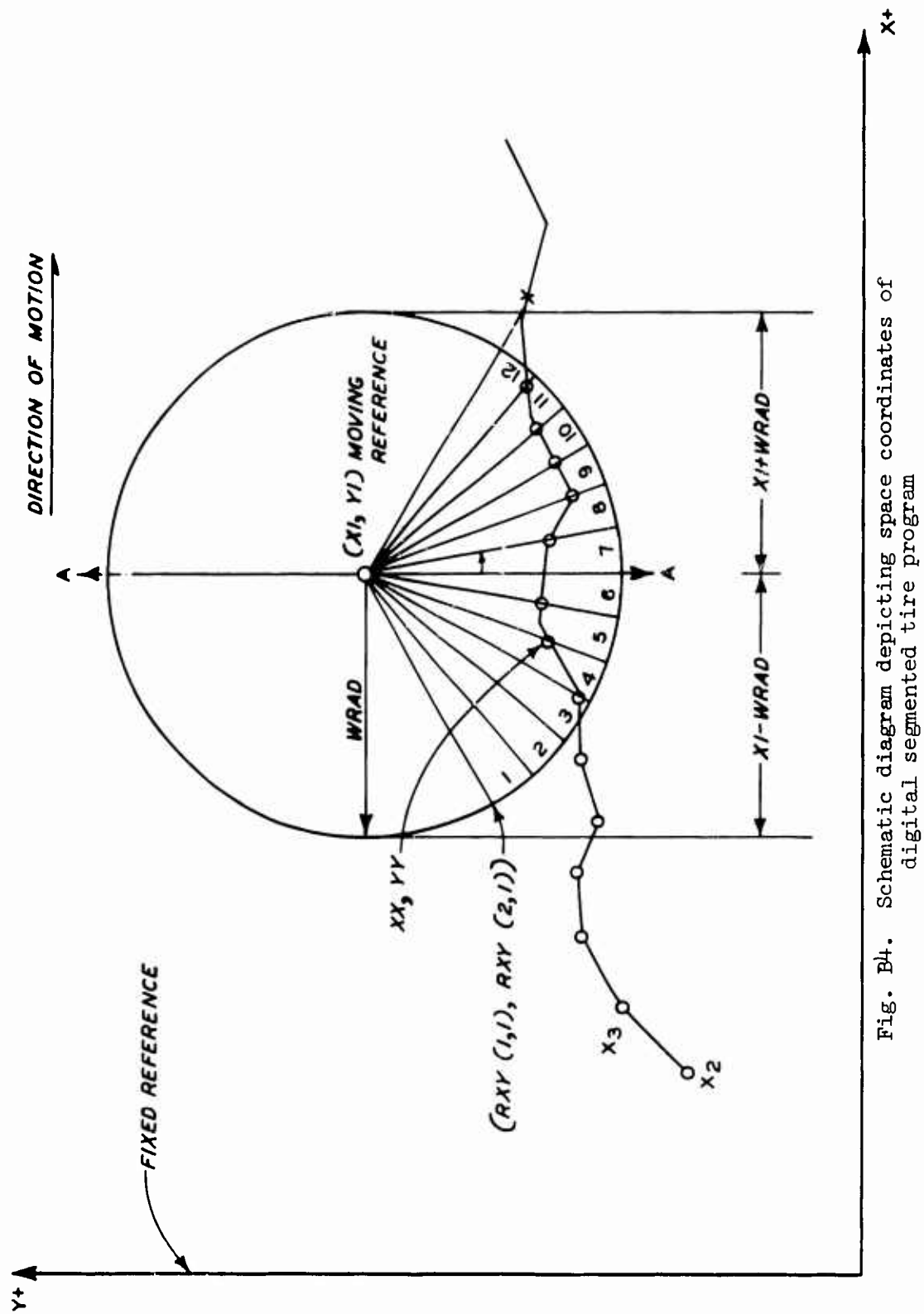


Fig. B4. Schematic diagram depicting space coordinates of digital segmented tire program

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13. ABSTRACT This appendix presents the procedures for digital implementation of the segmented tire model, developed in the basic report for an analog computer. Two procedures are required: (a) determination of the segment spring coefficient from measured load-deflection test results, and (b) computation of the resultant force vector transmitted to the axle. Digital programs for both procedures were written in Fortran IV for a GE-420 system, and are included. ()		

DD FORM 1473

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14.	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
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	Obstacles						
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