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RETARDERS FOR HEAVY VEHICLES: PHASE III EXPERIMENTATION AND ANALYSIS; PERFORMANCE, BRAKE SAVINGS, AND VEHICLE STABILITY

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16. Abstract

This report discusses the influences of retarder torque and power on downhill speed control, brake wear, and directional control on slippery surfaces. It presents (1) a "Retardation Prediction Procedure" for calculating the equilibrium speeds (control speeds) attainable by vehicle-retarder combinations when operating on various levels of downgrade, (2) a methodology for predicting the savings in brake wear occurring in service on specified vehicle routes, when a retarder is employed, and (3) a simplified method for estimating those operating conditions that can cause directional control problems, if retarder torque is applied while the vehicle is travelling on a slippery surface.

In support of the analytical methods described herein, the report contains descriptions of (a) dynamometer testing performed to investigate brake wear and (b) vehicle tests performed to assess a driver's ability to maintain directional control during retardation on wet and icy surfaces.

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1. INTRODUCTION

This document presents the results and findings from the third phase of a research project entitled "Retarders for Heavy Vehicles: Evaluation of Performance Characteristics and In-Service Costs" conducted by The University of Michigan Transportation Research Institute (UMTRI) for the National Highway Traffic Safety Administration (NHTSA).

The first phase of this study produced a report [1] that described the potential benefits to be derived from retarder use in various heavy truck applications. The benefits examined in Phase I were (1) safety enhancement due to reduced probability of a runaway accident, (2) cost savings due to decreased brake wear and maintenance, and (3) productivity gains due to decreased trip time.

In Phase II [2], two types of field evaluations were conducted. A survey of heavy trucks operating on severe grades near Cumberland, Maryland produced findings indicating that (1) average brake temperatures were approximately 60°C lower on retarder-equipped vehicles than on non-retarder-equipped vehicles and (2) the maintenance of truck brakes was generally poor with no evidence suggesting that vehicles equipped with retarders have foundation brakes that are better adjusted than those installed on non-retarder-equipped vehicles. In addition to the field survey, a "mobile retardation dynamometer" [2,3] was constructed and used to measure retardation forces deriving from engine drag, rolling resistance plus aerodynamic drag, and retarder systems. On a steep grade, retardation measurements were performed on two tractors and three retarders. The field information gathered in Phase II confirmed the general validity of the benefits predicted in Phase I and provided the basis for further research on methods for estimating retarder performance with respect to downhill speed control, reduced brake wear, and directional instability on slippery surfaces.

Issues associated with downhill speed control, reduced brake wear, and directional stability are addressed in this report. With regard to brake wear and directional stability, Phase III included both analytical and experimental work. The Vehicle Research and Test Center (VRTC) of NHTSA performed (1) vehicle tests to study directional control matters and (2) inertia dynamometer tests to examine the influence of temperature on brake wear. This report combines theoretical and analytical work with the experimental results obtained by VRTC to provide preliminary methods for predicting (a) brake savings due to retarder use and (b) bounds of stable vehicle operation during retarder application on slippery surfaces. (See Sections 3 and 4, respectively.) The next section of this report describes a method for predicting the downhill speed control provided by retarders and discusses the influence of retarder characteristics on a grade severity rating system [4,5,6].

2. RETARDER PERFORMANCE IN CONTROLLING THE SPEED OF SPECIFIC VEHICLES

2.1 Information Needed to Predict Retardation

A major goal of this project has been to develop a calculation procedure for predicting the retardation performance of specified vehicle/retarder combinations. A preliminary format for a proposed recommended practice for estimating equilibrium speeds on downgrades was presented in the Phase II technical report [2]. During Phase III, the approach outlined in Phase II was refined and modified to represent industry practice to the extent that we understood it. (Appendix A presents a computer code and examples of calculated results for the current version of the prediction procedure.)

The revised prediction procedure provides a uniform method for calculating the control (equilibrium) speeds maintainable by either engine, driveline, or trailer-axle retarders. This calculation procedure balances the power demand associated with descending a grade at constant velocity against the available retarding power. The power demand depends upon the weight of the vehicle, its velocity, and the sine of the angle of the downgrade. The available retarding power is developed through (1) natural retardation (that is, aerodynamic drag and rolling resistance), (2) engine drag, and (3) retarder operation. Table 1 presents the symbols, definitions, variables, and equations used in the calculation procedure.

In addition to information describing the vehicle (i.e., its weight, tires, aerodynamic factors, and drive system), the procedure requires measured data describing the power versus rotational speed characteristics of the installed retarder. In the case of an engine speed retarder, the power capability of the retarder, over and above that supplied by the engine operating without a retarder, is the appropriate input information. If the retarder is temperature sensitive, graphs or tables of power capability versus speed for the temperature range applicable to the anticipated service conditions are needed. Currently,

Table 1

Calculation Procedure: Retardation Performance

For each gear, the calculation procedure determines maximum grades for four values of control speed ranging from the vehicle velocity (V_{1i}) corresponding to maximum engine RPM to the vehicle velocity (V_{4i}) corresponding to the engine RPM at the minimum speed of interest.

Symbols and Definitions

Weight Factors

W total vehicle weight (lbs)

Vehicle Dimensions

A vehicle frontal area (ft^2)

R_M number of tire revolutions per mile of travel (establishes the rolling radius of the tires)

Dimensionless Coefficients

C_A air resistance coefficient

C_{AL} altitude correction factor

C_R road surface coefficient

C_T rolling resistance coefficient

Subscripts

i subscript used to denote gears, $i=1$ corresponding to low gear

Velocities

V_e engine speed in revolutions per minute (rpm)

V_{er} maximum engine speed (rpm)

V_{ep} minimum engine speed (rpm)

V vehicle velocity (mph)

V_{1i} vehicle velocity corresponding to maximum engine speed, gear i (mph)

V_{4i} vehicle velocity corresponding to minimum engine speed, gear i (mph)

V_{2i} $V_{2i} = V_{4i} + 2/3(V_{1i}-V_{4i})$ (mph)

V_{3i} $V_{3i} = V_{4i} + 1/3(V_{1i}-V_{4i})$ (mph)

V_d driveline speed (rpm)

V_t trailer retarder speed (rpm)

Table 1 (Cont.)

V_C control speed (equilibrium speed on a downgrade (mph)

Gear Ratios

G_i transmission gear ratio, i^{th} gear

A_R drive axle gear ratio

A_{RT} trailer axle ratio (for retarder installed on a trailer axle)

Efficiencies

n_D drive axle efficiency

n_T trailer axle efficiency

n_o overall drive system efficiency

Power

P_N natural retardation in horsepower

P_E engine retarding power (hp)

P_{RE} retarder power from an engine-speed retarder (hp)

P_{RD} retarder power from a driveline-speed retarder (hp)

P_{RT} retarder power from a trailer axle retarder (hp)

P_S total retarding power available (hp)

P_G grade power demand (hp)

Table 1 (Cont.)

Retardation Numerics

G grade of the hill used in determining P_G

G_M maximum grade allowable for a given set of values for P_S, W, and V_C

Vehicle Speeds

For each gear (denoted by the subscript i)

V_{1i} = Vehicle velocity corresponding to rated speed = $V_{er}60/R_M A_R G_i$

V_{4i} = Vehicle velocity corresponding to the engine RPM at minimum speed = $V_{ep}60/R_M A_R G_i$

$V_{2i} = V_{4i} + 2/3(V_{1i}-V_{4i})$

$V_{3i} = V_{4i} + 1/3(V_{1i}-V_{4i})$

The calculations are done at each of these speeds, but the basic equations are the same regardless of the speed used. Hence, the symbol V is used to represent vehicle velocity in the following equations.

Rotational Speeds

a) V_e = engine speed in RPM

$$V_e = V\ R_M A_R G_i/60 \quad (1)$$

where

V = vehicle velocity in mph

R_M = tire revolutions per mile

A_R = rear (drive) axle ratio

G_i = ratio for the i^{th} gear

b) V_d = driveline speed in RPM

$$V_d = V\ R_M A_R/60 \quad (2)$$

c) V_t = trailer retarder speed in RPM

$$V_t = V\ R_M A_{RT}/60 \quad (3)$$

where

A_{RT} = trailer axle ratio

Retardation Variables

a) P_N = natural retardation in horsepower

Table 1 (Cont.)

$$P_N = W\ C_R C_T V/375 + A\ 0.0024\ C_A C_{AL} V^3/375 \quad (4)$$

where

W = weight in lbs

C_R = road surface coefficient

C_T = tire rolling resistance coefficient

V = vehicle velocity in mph

C_A = air resistance coefficient

C_{AL} = altitude correction factor

In the following, $f_E(V_e)$, $f_{RE}(V_e)$, $f_{RD}(V)$, and $f_{RT}(V_t)$ are tabular functions.

b) P_E = engine retarding power in horsepower

$$P_E = f_E(V_e) \quad (5)$$

c) P_{RE} = retarder power from an engine speed retarder

$$P_{RE} = f_{RE}(V_e) \quad (6)$$

d) P_{RD} = retarder power for a driveline retarder (horsepower)

$$P_{RD} = f_{RD}(V_d) \quad (7)$$

e) P_{RT} = retarder power from a trailer axle retarder (horsepower)

$$P_{RT} = f_{RT}(V_t) \quad (8)$$

f)* P_S = total retarding power available

$$P_S = P_E/n_o + P_{RE}/n_o + P_{RD}/n_D + P_{RT}/n_T + P_N \quad (9)$$

where

n_o = overall drive system efficiency

n_D = rear (drive) axle efficiency

n_T = trailer axle efficiency

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*See footnote on next page.

Table 1 (Cont.)

Grade vs. Control Speed

P_G = grade power demand

$$P_G = W\ G\ V/375 \tag{10}$$

where G is the grade (G is the sine of the angle of the hill).

By equating P_G and P_S and solving for the maximum grade, G_M, at which V is the control speed, one obtains:

$$G_M = P_S 375/(W\ V_c) \tag{11}$$

where V_c is the selected control speed.

Note: The program calculates G_M for the speeds V_{1i} through V_{4i} for each gear. These speeds are control speeds for the grades determined by Eq. (11).

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*This applies to all mechanical transmissions and converter-type transmissions when in lockup. For converter operation, it is necessary to compensate for the feedback (slip) characteristics of the converter. A reasonable approximation for converter braking can be obtained by adjusting the P_S formulation as follows:

Braking Device	Factor (Converter Braking)
None	$P_E/n_o * 0.80$
Transmission Input Retarder	$(P_E/n_o + P_{RE}/n_o) * 0.90$
Transmission Output or Driveline Retarder	$(P_E/n_o + P_{RD}/n_o) * 0.95$

input information on the power absorption capabilities of retarders is available from most of the manufacturers of retarders.

Parametric data describing rolling resistance, aerodynamic drag, and driveline properties are sometimes available from vehicle, transmission, and engine manufacturers who use these data in predicting the acceleration and fuel economy performance of heavy trucks. Suggested values for these parameters are listed in Tables 2-8, should values for these variables not be readily available. Parametric data, describing how the closed-throttle drag of the engine varies as a function of engine speed, are more difficult to obtain. Example values of this function were measured in Phase II for two 350-hp engines [2,3], however, engine features, accessories, and other factors may cause variations in retardation horsepower capabilities that could be deemed important in close comparisons (involving horsepower differences on the order of approximately 35 hp). Clearly, specific information on the engine and accessories involved in a particular evaluation is desirable, but (if nothing else is readily available) representative values of engine drag, as shown in Table 9, may be used in making relative comparisons.

2.2 Equilibrium Control Speeds on Various Grades

The total retarding power available depends upon vehicle speed and the gear ratio involved. For each gear, retarding power is a continuous function of vehicle speed (see Figure 1, for example). Although the total power available for retardation increases with speed (and gear ratio), the power demand associated with maintaining speed on a grade also increases with speed. In addition, the power demand is proportional to grade such that on steep grades, the power demand will exceed the retarding power available at high speeds (see the dashed lines superimposed on Figure 1). The intersection of a line of power demand on a fixed grade with the retarding power available in a particular gear represents a power balance between demanded and available power. This point of power balance is described by (1) the speed at which it occurs (called the "control speed"), (2) the grade specified, and (3) the power level involved. Amongst these three quantities the vehicle operator is

Table 2

Suggested Values for Tire Revolutions Per Mile (RM)

by Truck Tire Size

Size	Rev/Mile
6.50-20	602
7.00-15	710
7.00-16	685
7.00-17	628
7.00-17.5	685
7.00-20	602
7.00-22.5	602
7.15-17	628
7.50-15	670
7.50-16	670
7.50-20	561
8.00-17.5	670
8.00-19.5	628
8.00-22.5	561
8.25-20	542
9.00-20	520
9.00-22.5	542
10.00-20	504
10.00-22	482

Table 2 - Continued

Size	Rev/Mile
10.00-22.5	520
11.00-20	492
11.00-22	470
11.00-24	457
11.00-22.5	504
11.00-24.5	482
12.00-20	482
12.00-24	443
12.00-22.5	492
12.00-24.5	470
13.00-20	457
14.75-17.5	581
14.00-20	439
14.00-24	403
15.00-19.5	521
15.00-22.5	481
16.5-19.5	504
16.5-22.5	467
18.00-19.5	491
18.00-22.5	456
19.50-19.5	467

Table 3

Suggested Values for Truck Aerodynamic Drag Coefficients (C_A)

0.80 for a power unit not equipped with aerodynamic aids on its roof
0.64 for a power unit equipped with aerodynamic aids

Table 4

Suggested Values for Highway Surface Coefficients (C_R)

Road Type	C_R
Smooth Concrete	1.0
Worn Concrete, Brick, Cold Blacktop	1.2
Hot Blacktop	1.5

Table 5

Suggested Values for Rolling Resistance Coefficient (C_T)

Tire Type	C_T
Bias Ply	0.0066 + 0.000046V
Radial Ply	0.0041 + 0.000041V
	where V is in mph

Table 6

Suggested Values for Altitude Correction Coefficients (C_{AL})

Altitude (ft)	C_{AL}
0	1.00
1000	0.97
2000	0.94
3000	0.91
4000	0.89
5000	0.86
6000	0.83
7000	0.81
8000	0.78
9000	0.76
10000	0.74
11000	0.71
12000	0.69
13000	0.67
14000	0.65
15000	0.63

Table 7

Suggested Values for Drivetrain Efficiencies (n_D, n_o, n_{TR})

Vehicle	n_D	n_o
4x2 tractor, manual transmission	.94	.92
4x2 tractor, automatic transmission	.94	.90
6x4 tractor, manual transmission	.90	.88
6x4 tractor, automatic transmission	.90	.86
retarder-equipped trailer axle n_{TR} = .95		

Table 8

Vehicle Frontal Areas

Vehicle	ft^2
Van	108
Tankers	
Conventional	75
Cab-Over	85
Buses	
Transit	84
School	64
10-Wheel Dump	73

Table 9

Typical Four-Cycle Engine Friction HP

	Engine Speed, RPM			
Engine HP	1200	1600	1900	2100
201-250	20	35	49	58
251-300	19	32	45	56
301-350	20	38	55	70
351-400	23	37	50	65
401-450	25	45	65	75

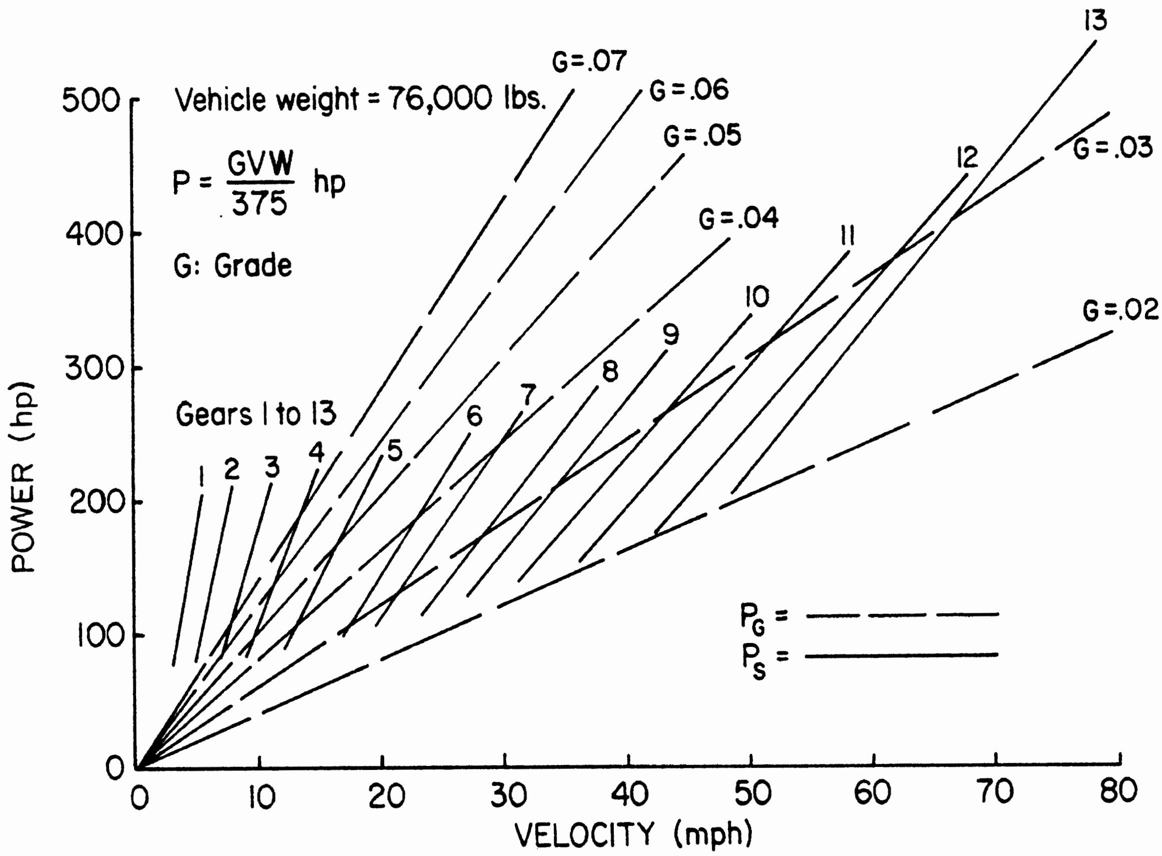


Figure 1. Retarding power, P_S, versus velocity with superimposed lines of power required on constant grades, P_G.

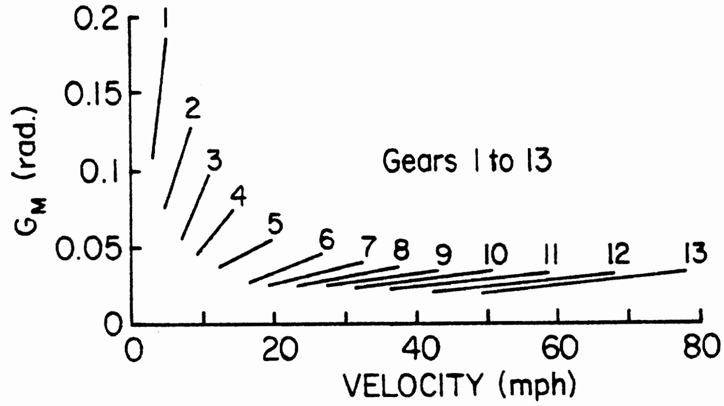


Figure 2. Maximum grades, G_M, over the range of control speeds applicable to each grade.

interested in the control speed applicable to a particular grade. Hence, a primary output of the calculation procedure is a set of curves (one for each gear) showing equilibrium conditions in terms of maximum grade versus control speed (see Figure 2).

By examining graphs of maximum grade versus control speed, a vehicle operator can determine the speeds and gear selections appropriate to the grades that a vehicle/retarder combination is likely to encounter in service.

(In this case, the results reflect the capability of the retarder to maintain control speeds on grades without using the foundation brakes at all. Combined use of both retarders and foundation brakes in order to minimize trip time is discussed in Section 2.3.)

The maximum power absorption capability of a retarder is clearly a primary factor in determining control speed on downgrades. If predictions for a particular retarder/vehicle combination indicate an unacceptably low control speed on downgrades encountered in service, a more powerful retarder is probably required.

Given comparable power capabilities, the installed performance characteristics of retarders differ due to where they are located on the vehicle. Engine speed retarders can produce high torque at low forward velocities because retarder speed (that is, engine speed) will be high if the proper gear is selected. In contrast, at low forward velocities, retarders installed on the driveline or the trailer axles will produce less than their maximum torque capability because their rotational speeds will be lower than those speeds associated with normal highway travel. These differences are readily illustrated by example calculations (see Figures 3 and 4). The engine speed retarder (Fig. 3) and the driveline retarder (Fig. 4) have comparable power capabilities at approximately 2100 rpm but, as can be seen by comparing Figures 3 and 4, the engine speed retarder has much greater grade capability at velocities less than 40 mph than the grade capability of the driveline retarder chosen for this example.

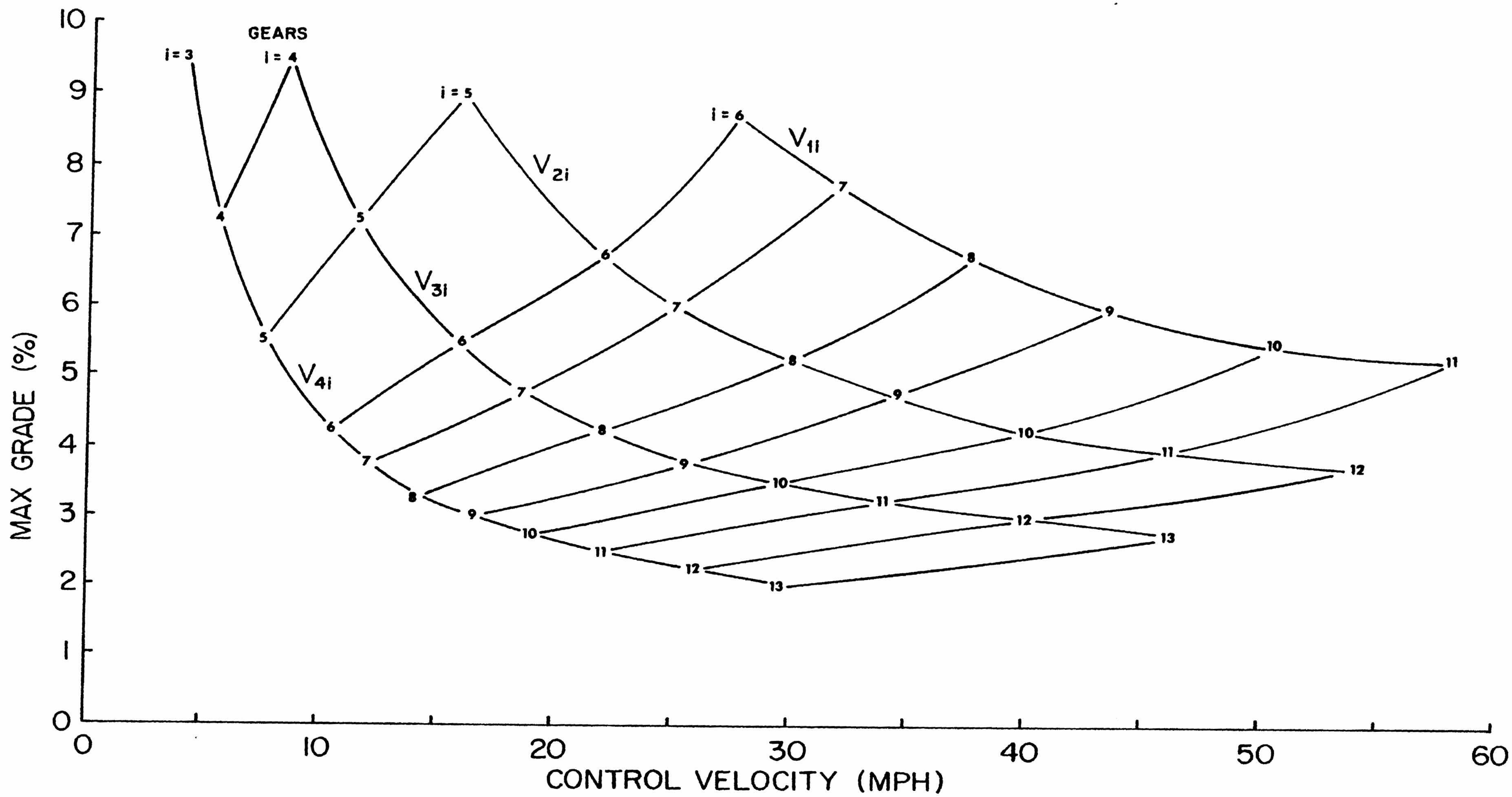


Figure 3. Maximum grade versus control velocity, engine speed retarder

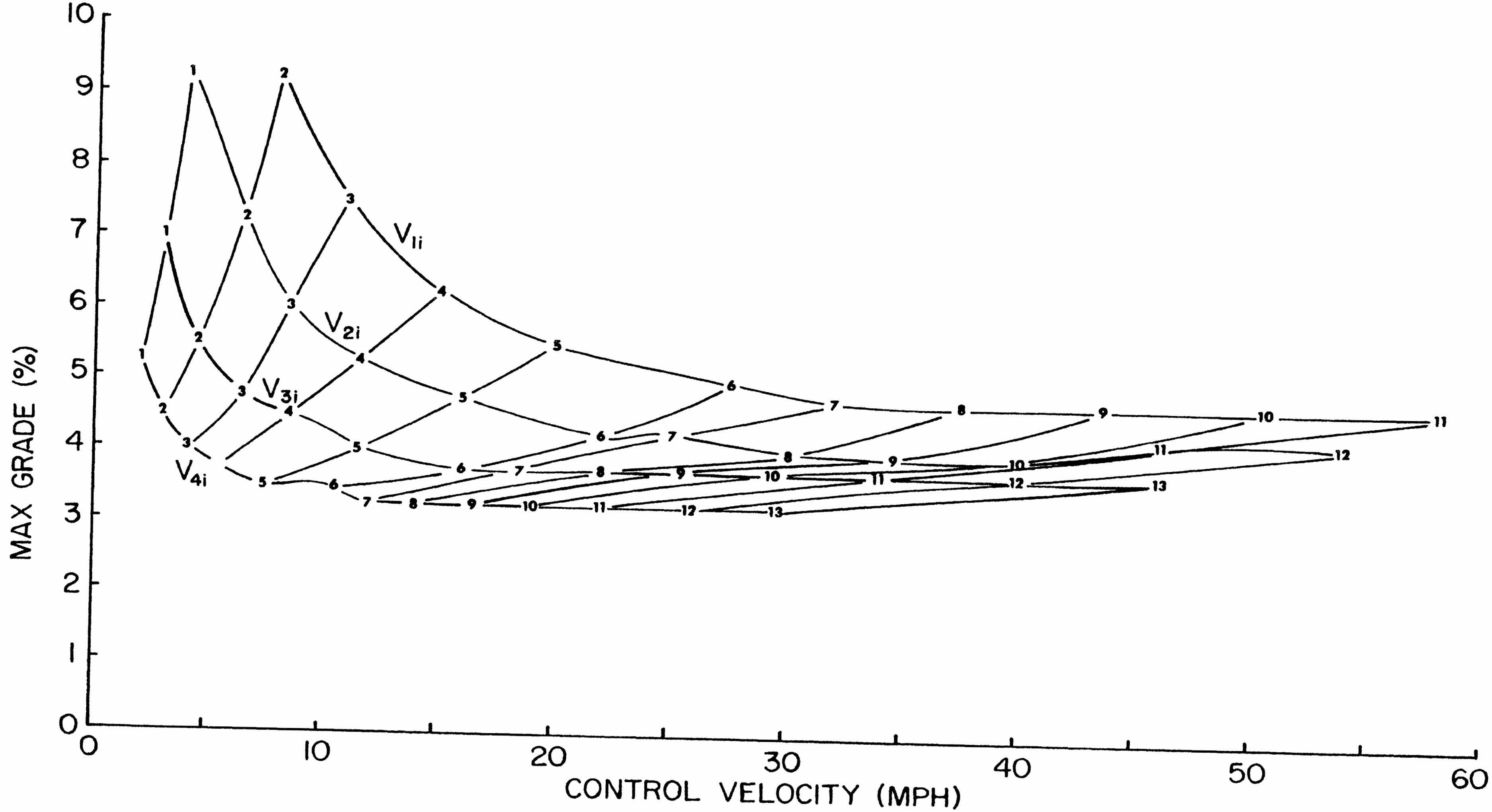


Figure 4. Maximum grade versus control velocity, driveline retarder.

In practice, a number of options are available to achieve desired performance. Models of driveline and trailer axle retarders with high power capability are available. High values of drive axle, and particularly trailer axle, ratios (on the order of 5 or 6) may be chosen to cause the driveline or trailer axle retarder to operate at high speeds, thereby absorbing more power at lower forward speeds than would have been possible with lower axle ratios. Clearly, the prospective buyer of a retarder needs to consider these factors plus concerns with shifting gears and using automatic transmissions. Nevertheless, the calculation procedure is applicable to all types of retarders and the results can be used to aid in selecting an acceptable level of performance.

2.3 Adoption of a Grade Severity Rating System for Retarder-Equipped Trucks

A grade severity rating system has been developed for advising truck drivers of appropriate speeds for descending mountains [3,4]. This system is based on setting a safe upper bound on brake temperature and then calculating the maximum speed of descent that will cause the vehicle's brakes to reach, but not exceed, the temperature limit. In this sense, the procedure provides an optimum time solution with a brake temperature constraint.

In the prototype grade severity rating system recommended in [5], truck drivers receive driving instructions via signs displaying appropriate speeds for the weight classes of their vehicles. These signs, referred to as weight specific speed signs (see Figure 5), are placed at the top of severe downgrades. The entries in each sign are based on the slope and length of the particular grade involved. The slope of the downgrade influences the power that has to be absorbed by the braking system in order to maintain a constant velocity, and the length of the grade determines the time period during which the brakes are heated. Essentially, the slope and length of grade, along with the weight of the vehicle, determine the potential energy that needs to be dissipated by the braking system and other sources of retardation.

The entries in the weight specific speed signs are determined by a bulk temperature calculation in which the heat flow process for all of

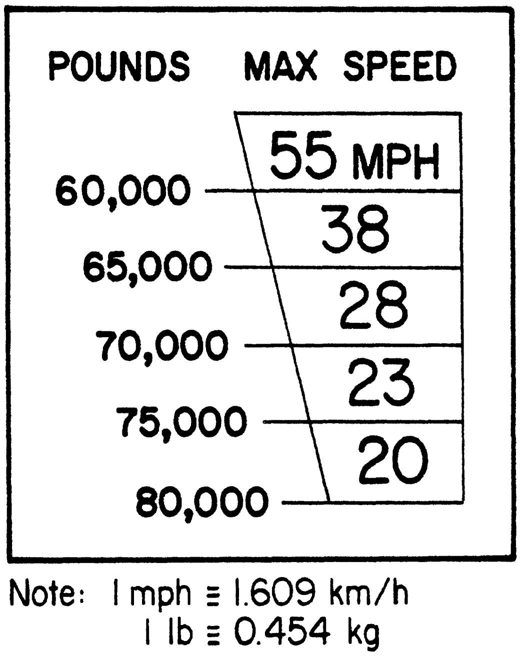


Figure 5. Example of a weight specific speed (WSS) sign [5].

of the foundation brakes is represented by the equations, variables, and parametric factors presented in Table 10. The severity of a given grade is rated in terms of the velocity at which the temperature-constrained power absorption capability of the vehicle's brakes equals the power demanded of the vehicle's brakes. This is the same conceptual notion, involving a power balance, as that used in explaining the truck retardation prediction procedure. However, in this case, the basic calculations are performed for vehicles without retarders. The entries in a typical weight specific speed sign assume that the foundation brakes are absorbing an amount of power equal to the power needed to maintain a constant control speed on the grade less the power absorbed by rolling resistance, aerodynamic drag, and engine drag.

The minimum-time constrained-brake-temperature approach may be extended to retarder-equipped vehicles by reducing the power absorbed by the foundation brakes by an amount equal to the power absorbed by the retarder. To minimize trip time, the driver of a retarder-equipped vehicle may be expected to travel faster than the driver of a comparable vehicle without a retarder because both the retarder and the foundation brakes may be used to control speed during mountain descents. Given that the weight specific speed signs are being developed for non-retarder-equipped vehicles, the information presented on these signs would be conservative relative to retarder-equipped vehicles.

On the surface, it might seem that a plausible solution would be to have two sets of signs—one set for retarder-equipped vehicles and the other set for other vehicles. This solution, besides appearing to be cumbersome and confusing, is not practical because various retarders have differing amounts of power absorption capability. The preferred approach has been to try to develop a method for operators of retarder-equipped vehicles to reinterpret the weight specific speed signs using knowledge of the horsepower capabilities of their retarders.

Two methods for reinterpreting the weight specific speed signs have been discussed [5,6]. Herein these methods are referred to as the "ΔV" and "ΔW" interpretations.

Table 10

Parameters, Equations, and Variables for Bulk Temperature Calculations

In a mountain descent, the rate at which potential energy is converted to heat is low enough that bulk temperature calculations may be used to study the thermal properties of braking systems. Equation (12) describes the heat flow process for the foundation brakes in terms of (a) the total energy storage capability of all the brakes, (b) the heat losses due to cooling (convection, radiation, etc.), and (c) the total braking power, P_B, applied to all the brakes, viz.:

$$(m_B C_p) \frac{d\theta}{dt} = P_B - h(V)(\theta - \theta_a) \tag{12}$$

where

$m_B C_p$ represents the product of the mass of the brakes multiplied by the specific heat of the brake material (nevertheless, it is an empirically determined coefficient in the application of Equation (13))

θ is the average or bulk temperature of the brakes

$h(V)$ is a cooling coefficient that depends upon velocity

θ_a is the ambient temperature

t is time

$\frac{d\theta}{dt}$ is the time rate of change of temperature

For an initial temperature, θ_o, the solution of (12) for a constant velocity, V_c, is

$$\theta(t) = \theta_o e^{-t/\tau} + \left(\frac{P_B}{h(V_c)}\right)\left(1 - e^{-t/\tau}\right) \tag{13}$$

where

$$\frac{1}{\tau} = \frac{h(V_c)}{m_B C_p}$$

Table 10 (Cont.)

Empirical results obtained in Reference [4] yield the following expressions for $1/\tau$ and $h(V)$ as functions of velocity:

$$\frac{1}{\tau} = 1.23 + 0.0256V \text{ mph, } 1/\text{hr} \tag{14}$$

and

$$h(V) = 0.1 + 0.00208V \text{ mph, hp/°F} \tag{15}$$

(These expressions, (14) and (15), are determined from measurements on a particular tractor-semitrailer vehicle equipped with ten S-cam brakes [4].)

For a fixed grade of length L being traveled at a constant velocity, V_c, the time required to descend the grade is L/V_c. Hence, using (13) the temperature, θ_f, at the bottom of the grade is:

$$\theta_f = \theta_o e^{-L/V_c\tau} + \left(\frac{P_B}{h(V_c)} + \theta_a\right)\left(1 - e^{-L/V_c\tau}\right) \tag{16}$$

For a given set of values for θ_f, θ_o, and θ_a, Equation (16) may be used to portray the influences of the length of grade and control velocity on the power that truck brakes can absorb without exceeding the temperature boundary, θ_f.

The power into the brake, P_B (hp), is described by the following equation:

$$P_B = \frac{WGV}{375} - P_N \tag{17}$$

where

W is the vehicle weight (lbs)

G is the slope of the grade (rad)

V is the velocity (mph)

and P_N is the "natural" retardation (hp)

The main components of P_N are rolling resistance, aerodynamic drag, and engine drag

In the ΔV method, the driver of a retarder-equipped vehicle would add a velocity increment (ΔV) to the speed given in the WSS sign. Ideally, the velocity increment would be based on the power of the retarder, P_R, the slope of the grade, G, and the weight of the vehicle, W, per the following equation:

$$\Delta V = \frac{P_R}{GW} 375 \tag{18}$$

Assuming that the above equation can be implemented by a chart or other suitable driver's aid, the driver would need to know the slope of the grade in addition to the current weight of the vehicle and the power of the retarder. Possibly the WSS sign could be augmented to give the slope of the grade or a preceding sign could be used to display grade information. In the absence of specific grade information, a conservative approach would be to use the maximum grade in the vehicle's region of service to determine a general speed increment for that region . In [6], it is shown that vehicle operation in accordance with Equation (18) and WSS signs will result in conservative operation with respect to the temperature predicted for the foundation brakes.

In the ΔW method, the driver of a retarder-equipped vehicle would reduce the weight category of his vehicle by an amount determined by the power of his retarder and, in an ideal arrangement, by the slope of the grade. Once the weight decrement (ΔW) is determined, the driver would use a higher speed associated with a lower weight as displayed on the WSS sign. Mathematically, the ΔW interpretation may be characterized by the following equation:

$$\Delta W = \frac{P_R}{GV} 375 \tag{19}$$

where

ΔW is the weight decrement (lbs)

P_R is the power of the retarder (hp)

G is the slope of the grade

and V is the velocity

As in the ΔV approach, information concerning the slope of the grade is involved, if not directly, at least in some implicit manner. Although the slope of the grade is used in determining the weight versus speed information displayed in the WSS sign, it is difficult to extract grade information from the sign because the length and the slope of the grade interact in a complex relationship pertaining to brake temperature. Again we suggest that, in addition to the grade severity rating system, grade information also be supplied or a maximum grade for the region be employed.

A disadvantage of the weight decrement method is that not only is grade information needed, but also a velocity needs to be chosen to calculate ΔW. In [5], a velocity, based on results from the grade severity rating system applied to a non-retarder-equipped vehicle, is employed in an example calculation. Since the velocity obtained by the GSRS procedure may be low, the computed value of ΔW may be high (see Equation (19)) leading to a nonconservative estimate of vehicle speed for the retarder-equipped vehicle.

In summary, the ΔV interpretation appears to be more straightforward than the ΔW interpretation because the weight of the vehicle required for determining ΔV is known while the velocity required for determining ΔW is not known a priori.

For either the ΔV or ΔW interpretation, grade information or its equivalent is needed if minimum time operations are to be estimated for mountain descents. In the prototype grade severity rating system, the upper bound on brake temperature was selected to be 500°F. At this temperature, typical brake linings may be at the verge of starting to fade. However, the wear of brake linings is much greater at 500°F than it is in the range from 150 to 250°F. If a retarder were purchased on the basis of saving brake wear, then operating at minimum time conditions may not achieve the desired brake savings unless the retarder can absorb enough power to keep the work done by the foundation brakes to a level such that brake temperatures will remain much lower than 500°F. Clearly, brake savings are maximized by using the retarder alone. If the control speed of the retarder/vehicle combination is satisfactory, then the foundation brakes need not be utilized in descents of steep grades.

3. DETERMINATION OF BRAKE WEAR AS A FUNCTION OF RETARDER USE

3.1 Rationale and Approach Employed in Studying Brake Wear

The use of retarders can greatly reduce brake wear thereby saving on the costs associated with relining brake shoes or pads and maintaining or replacing brake drums or discs. In the Phase I work [1], a brake life extension factor (BLEF) is introduced into return on investment analyses to illustrate the economic benefits of employing retarders in various situations. Since the Phase I results are presented for a range of BLEF's, anticipated values of BLEF's are needed for estimating or predicting return on investment in proposed retarder applications.

Retarder manufacturers have testimonials from customers indicating large brake life extension factors for particular cases. Although this information shows that major brake savings can be obtained through retarder use, almost invariably the severity of the duty cycle involved is not quantified in a manner that can be extrapolated to situations differing from those surveyed. To compensate for the limitations of specific testimonials, a general approach, based on wear savings being proportional to work savings, has been described in [7]. In this approach, the amount of work done by the foundation brakes in controlling and maintaining speed on the level and on grades is computed for situations in which (1) a retarder is not used and the foundation brakes do all the work and (2) a designated part of the work is done by a retarder, thereby reducing the work done by the foundation brakes. The amount of work done without a retarder (item (1) above) divided by the amount of work done by the foundation brakes when a retarder is in use (item (2)) is a first-order estimate of the brake life extension factor for the retarder, vehicle, and duty cycle employed in the calculations.

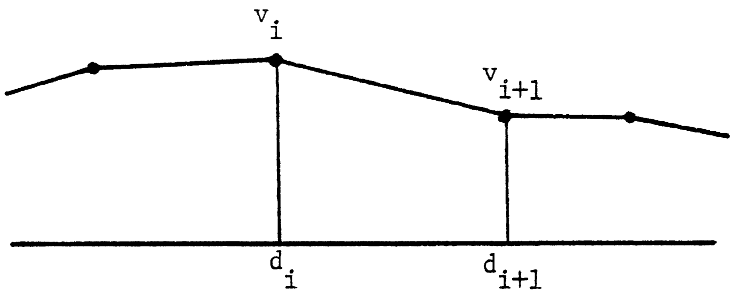
The quality of the estimates made using this wear-proportional-to-work approach depends upon (a) whether drivers actually use retarders as assumed in the calculations and (b) whether high brake temperatures would be encountered in the defined duty cycle. With regard to item (a), the estimation of random variations in driver characteristics is deemed to be unreasonable for the deterministic approach taken herein.

On the other hand, brake wear is known to be highly dependent upon brake temperature. Furthermore, retarders can provide an important safety margin when used in operations where high brake temperatures are encountered. For high temperature applications, brake wear is likely to be significantly underestimated unless temperature influences are considered. Consequently, the approach taken in this study has been to attempt to extend the wear-proportional-to-work approach to a more realistic one in which brake temperatures are predicted, and then measured brake characteristics are employed to estimate wear. To apply the wear prediction procedure developed in this study, the effectiveness of a retarder with respect to brake savings would be estimated by calculating brake wear with and without the retarder in use for a pertinent duty cycle (vehicle route).

3.2 Summary of the Method Developed for Predicting Brake Temperature

The method developed for estimating brake wear is based on using predicted brake temperatures, horsepowers, and application periods for a series of brake applications constituting any specified duty cycle for a selected vehicle. The duty cycle is specified by describing the route to be traveled in terms of (1) an elevation profile (altitude versus distance) and (2) a velocity profile (velocity versus distance). These profiles consist of altitude and velocity levels at sequential points (distances) along a proposed route. The calculation procedure uses information from the "current" point and the next point along the route to determine the status of the brakes while traveling from the current point to the next point. If the brakes are not needed between the current and the next points, the vehicle is assumed to arrive at the next point at the prescribed velocity with the brakes cooled appropriately. If the brakes are needed, the power absorbed by each brake is calculated taking into account (1) natural retardation, (2) retarder power (if a retarder is used), (3) elevation changes, and (4) brake proportioning.

In the calculation procedure described herein, it is assumed that sufficient velocity-distance points are given to allow accurate predictions based on constant acceleration levels between points. Based on this assumption, the velocity profile is as sketched below. For



the linear velocity characteristic illustrated in the sketch, the acceleration, A, between the current point, d_i, and the next point, d_{i+1}, is given by the following equation:

$$A = \frac{v_{i+1}^2 - v_i^2}{2(d_{i+1} - d_i)}$$

and the time period, T, for traveling from point d_i to d_{i+1} is given by

$$T = \frac{2(d_{i+1} - d_i)}{(v_{i+1} + v_i)}$$

(For computational simplicity, $A = (v_{i+1} - v_i)/T$.)

The slope of the hill is calculated from elevation versus distance data for the proposed route; viz.:

$$S = (e_{i+1} - e_i)/(d_{i+1} - d_i)$$

where e is the elevation

Under these conditions, the power (HP_B) to be absorbed by the brakes is given by:

$$HP_B = -m\ A\ V - HP_N - HP_{ENG} - HP_{RET} - S\ mg\ V \qquad (20)$$

where

m is the mass of the vehicle

A is the acceleration

V is the velocity

S is the slope of the hill

HP_N is natural retardation

HP_{ENG} is engine drag

HP_{RET} is retarder power

The proportioning of the brake system is used to divide the total braking power into separate power requirements for the tractor's front brakes, the tractor's rear brakes, and the trailer's brakes. In these calculations brake imbalance is ignored so that at each location (tractor front, tractor rear, or trailer) the brake power is equally divided among the number of brakes at that location.

Once the power into the brake is determined, bulk temperature calculations are used to predict brake temperature, θ, viz.,

$$\theta(t) = \theta_o + \int_{t_o}^{t} \frac{HP_B - h(V)(\theta-\theta_a)dt}{m_B C_p} \qquad (21)$$

$$\left(\text{i.e., } m_B C_p \frac{d\theta}{dt} = HP_B - h(V)(\theta-\theta_a)\right)$$

where

$m_B C_p$ is the thermal capacitance

$h(V)$ is the cooling coefficient

θ_o is the initial temperature

θ_a is the ambient temperature

The above equation is solved for θ by numerical integration methods.

The intermediate results of the calculations are a temperature and a horsepower profile for each brake. These temperature and horsepower profiles, along with brake application times, are intended for use in predicting brake wear. Empirical relationships for estimating brake wear are presented in the following sections. The details of the manner in which numerical calculations of brake temperature and horsepower profiles are accomplished are illustrated in the computer code presented in Appendix B.

3.3 Measurement of Factors Influencing Brake Wear

In this study, a semi-empirical approach has been employed to develop a mathematical representation of the wear process. In order to develop a semi-empirical representation, experimental data need to be gathered in sufficient quantity to characterize the basic features of the phenomenon to be "modeled." (In other words, a semi-empirical representation is essentially a phenomenological description expressed in mathematical terms.) In this case, results from inertia dynamometer tests have been examined to develop preliminary sets of relationships that appear to be useful for predicting brake wear. These relationships will be presented in Section 3.4 after reviewing test procedures, experimental results, and preliminary findings in Sections 3.3.1, 3.3.2, and 3.3.3.

3.3.1 Test Procedures Employed in Studying Brake Wear. A sequence of dynamometer tests (see Table 11) has been utilized to investigate brake wear. This sequence consists of four parts: (1) a series of tests whose purpose is to provide information for use in characterizing brake wear for operating temperatures ranging from 150°F to 700°F (Steps 1 through 17 in Table 11); (2) a simulation of the work performed by the brake during 20 mountain descents in which the driver controls velocity by "snubbing" the brake 25 times during each descent (Step 18 in Table 11); (3) a simulation of descending the same mountain as in (2) except in these 20 runs the driver is assumed to employ a constant drag rather than using a snubbing technique (Step 19 in Table 11); and (4) a special subsequence of tests whose purpose is to investigate the wear rate experienced during operation at normal temperature levels following conditioning at elevated temperatures (Steps 20 through 22 in Table 11).

Note that in all steps except 18 and 19 a warm-up procedure, which gets the brake to 700°F, is used before starting the snubs. This

Table 11

Dynamometer Test Procedure, Brake Wear Versus Temperature [8]

FMVSS 121 Burnish (Brake Conditioning)

200 Stops	40 mph	10 fps.	350° IBT
200 Stops	40 mph	10 fps.	500° IBT

<u>Brake Test Preparation</u>

Disassemble brake assemblies.

Clean brake shoes and linings thoroughly and completely (vacuum, wipe, etc.).

Measure each shoe and lining assembly at eight (8) locations (four (4) locations per lining segment).

Scribe marks on shoes on both sides so the measurements can be made at the same locations each time.

Mark shoes 1 & 2 so the same shoe can be reinstalled in the same location and identified for measurement and weighing.

Weigh each shoe and lining assembly.

Record all weights and measurements.

Step 1. Warm Up (The following warm-up procedure was also incorporated in the subsequent steps:

25 Stops (Preparation)	40 mph	50,186 in-lbs	10 fps^2

Step 2. Warm Up. (Same as Step 1). Then

500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	150° IBT

Step 3. Warm Up. Then

500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	200° IBT

Step 4. Warm Up. Then

500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	300° IBT

Step 5. Warm Up. Then

500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	400° IBT

Step 6. Warm Up. Then

500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	500° IBT

Step 7. Warm Up. Then

500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	600° IBT

Table 11 (Cont.)

Step 8.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	700° IBT
Step 9.	Warm Up. (Preparation)			
Step 10.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	700° IBT
Step 11.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	600° IBT
Step 12.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	500° IBT
Step 13.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	400° IBT
Step 14.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	300° IBT
Step 15.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	200° IBT
Step 16.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	150° IBT
Step 17.	Warm Up. Then (Preparation)			
Step 18.	<u>20</u> Sets of <u>25</u> Snubs (Preparation)	45-39 mph 5.6 Sec. Off ----------------	16,800 in-lbs	150° IBT 2.9 Sec. On.
Step 19.	<u>20</u> Drags <u>42</u> mph 223 Sec. On (3 Min. 43 Sec.) --------------- (Preparation		5,500 in-lbs torque	150° IBT 18 Min. Off
Step 20.	Warm Up. Then 500 Snubs (Preparation)	45-39 mph	16,800 in-lbs	600° IBT

Table 11 (Cont.)

Step 21.	Warm Up. Then			
	500 Snubs	45-39 mph	16,800 in-lbs	700° IBT
	(Preparation)			
Step 22.	Warm Up. Then			
	500 Snubs	45-39 mph	16,800 in-lbs	200° IBT
	(Preparation)			

******NOTE: Check cold stroke before and after test.

warm-up procedure is described by Step 1. After the warm-up, the brake is allowed to cool from 700°F to the desired initial brake temperature (IBT) for a series of 500 snubs from 45 to 39 mph. Each snub is performed at the desired IBT.

The amount of wear during the snubs (not including the wear during warm-up) is determined for a sequence of increasing and, then, decreasing IBT's as specified in Table 11. In order to measure wear, it is necessary to disassemble the brake and proceed according to the instructions given in Table 11 under the heading "Brake Test Preparation."

The total dynamometer procedure is very time consuming, requiring at least two weeks to complete a single brake. Nevertheless, we do not recommend leaving out any of the steps because brake wear is a function of both temperature and past work history, thereby necessitating increasing and decreasing temperature sequences (and also Steps 20 through 22) to define the influence of work history (see Section 3.4). Possibly, if results from tests of several brakes confirmed the generality of the semi-empirical model described in Section 3.4, a simplified (shortened) procedure could provide a valid approach for characterizing brakes.

3.3.2 Experimental Results Characterizing Brake Wear. Inertia dynamometer tests have been performed on the two brakes described in Table 12. These brakes are samples of popular types of brake hardware as currently installed on typical heavy trucks.

Table 12

Brakes Used in Wear Tests

Brake #1	Brake #2
16.5 in x 7 in S-cam	16.5 in x 7 in S-cam
24 in^2 chamber	24 in^2 chamber
6 in slack adjuster	6.5 in slack adjuster
551 C lining	MM-8C5 lining

The data obtained from the basic procedure (Steps 1 through 17) indicate a large amount of "hysteresis" in the results, with greater wear occurring after high temperature operation than that which occurred before high temperature operation (see Figs. 6 and 7).

Brake #2 was tested through Steps 20, 21, and 22 to provide new information on the wear that accrues during low temperature brake applications performed immediately after a set of high temperature snubs; that is, after completing the hysteresis loop, additional tests were performed at IBT's of 600°F, 700°F, and then 200°F. These additional tests were added to test the hypothesis that high temperature snubs leave a "charred" layer that wears much more rapidly than normal "uncharred" lining material. This hypothesis is supported by the results obtained at 200°F as presented in Figure 7. The measured wear at 200°F is 0.0022 inches per 500 snubs when these snubs are <u>not</u> preceded by high temperature snubs. This compares to 0.0090 inches per 500 snubs (approximately a 300% increase) when the immediately preceding snubs had been at 700°F. Clearly, wear processes depend upon the past work history of the brake, not just the current temperature of the brake.

This finding concerning the importance of past work history certainly complicates the situation with regard to predicting brake wear for various duty cycles that may apply to vehicles in service.

3.3.3 <u>Braking Technique and Its Effect on Brake Wear</u>. Before attempting to explore possible means for treating the work history matter, however, the discussion of results from the dynamometer test procedure will be extended to cover two steps that have not been addressed so far. These steps (numbers 18 and 19 in Table 11) are approximate simulations of duty cycles applicable to the brakes installed on an 80,000-lb tractor-semitrailer that is descending Martin's Mountain on westbound highway US 48 approaching Cumberland, Maryland from the east.

Martin's Mountain was included in the Phase II field study [2]. The section of road under discussion is a fairly uniform 6.4% grade that is approximately 2.5 miles long. One strategy used in descending this grade is to pulse the brakes every 0.1 mile, causing the vehicle speed

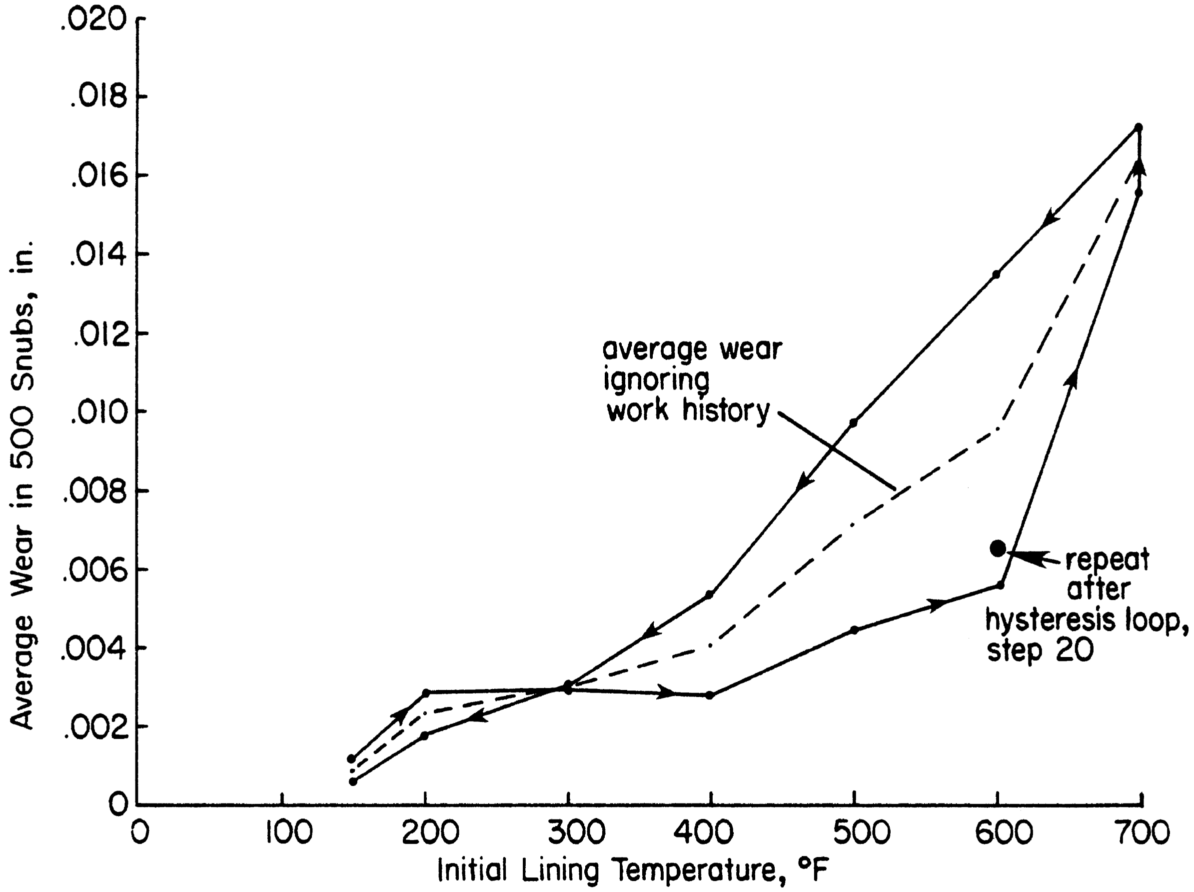


Figure 6. Wear history, Brake #1.

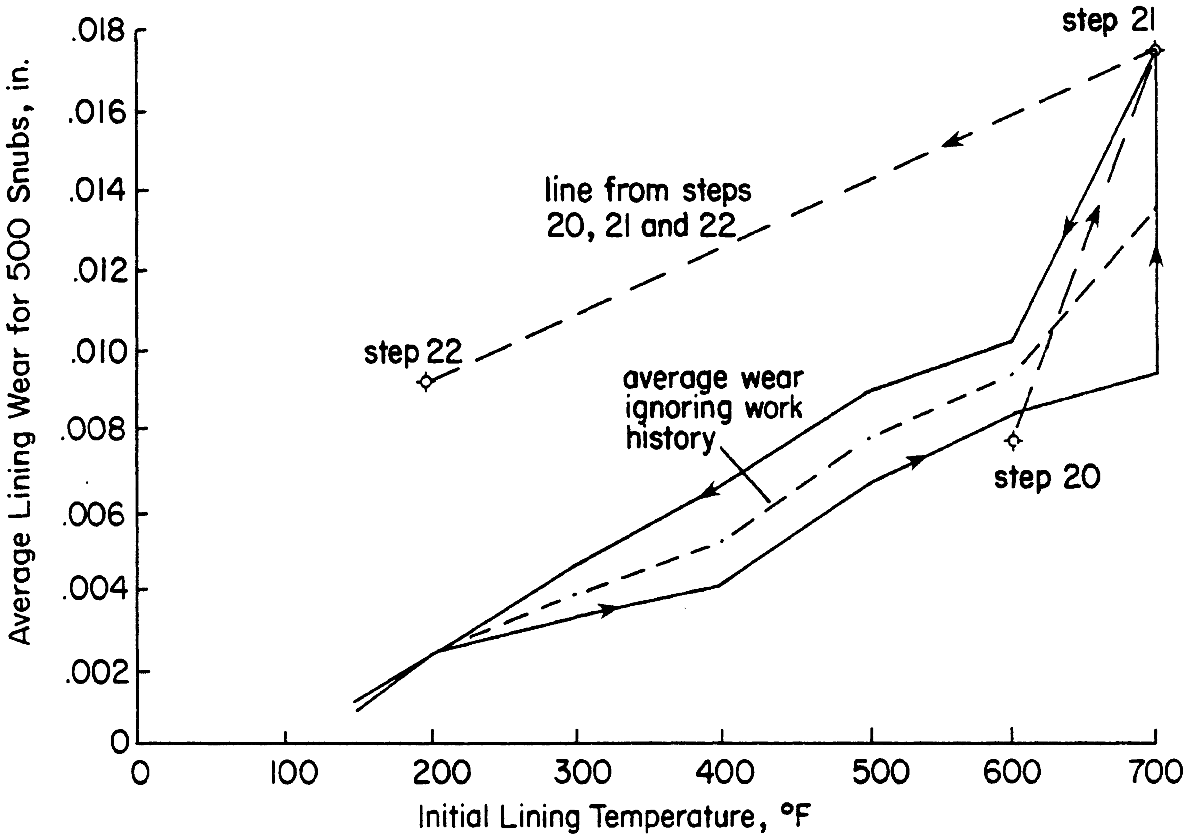


Figure 7. Wear history, Brake #2 [8].

to cycle between 40 and 44 mph. (In the dynamometer procedure, the brake is cycled between 39 and 45 mph to attain an equivalent duty cycle using the control system built into the dynamometer.) In Step 18, twenty descents of Martin's Mountain are simulated in order to work the brake enough to achieve a level of wear that is large enough to measure with reasonable accuracy.

Another approach to descending Martin's Mountain would be to apply continuously a low level of brake pressure, producing a uniform drag. This approach is simulated by Step 19 of the dynamometer procedure.

Interestingly, even though the total energy involved is equivalent in Steps 18 and 19, the pulsing technique appears to result in slightly lower temperatures and total wear than those obtained by the constant drag technique (see Table 13, Step Numbers 18 and 19). These differences might be due to (a) better cooling occurring during the periods when the brake is not applied in the pulsing mode of operation or (b) matters related to the pressure levels involved—approximately 20 psi during pulses and less than 10 psi during the constant drag tests or (c) the order of testing. In any event, this study appears to have inadvertently uncovered the need for examining whether pulsing or constant drag is the preferable means for performing a mountain descent. The small amount of data gathered here favors the pulsing method.

3.4 A Semi-Empirical Method for Including Work History When Estimating Brake Wear

The influence of work history on brake wear might be neglected if the average wear at each temperature level could be used to estimate the influence of temperature on wear. An example of an "average" wear function is illustrated by the dashed lines passing through the middle of the hysteresis loop presented in Figures 6 and 7. However, the data, corresponding to the line labeled "Steps 20, 21, 22" in Figure 7, show the deficiency of the averaging approach when it is applied to duty cycles in which the brakes are allowed to cool after a series of operations that cause a high temperature to be reached. If the average of the hysteresis loop in Figure 7 were to be used to estimate wear occurring at 200°F

Table 13

Example Results: Brake #2

Air Brake Wear vs. Temperature

Step Number	Test	Initial Temperature, °F Lining	Drum	Average Wear, in.
2	500 snubs	150	200	.0009
3	500 snubs	200	250	.0022
4	500 snubs	300	415	.0032
5	500 snubs	400	460	.0039
6	500 snubs	500	540	.0064
7	500 snubs	600	650	.0081
8	500 snubs	700	760	.0092
10	500 snubs	700	760	.0171
11	500 snubs	600	620	.0100
12	500 snubs	500	540	.0087
13	500 snubs	400	460	.0064
14	500 snubs	300	350	.0044
15	500 snubs	200	250	.0022
16	500 snubs	150	175	.0011
18	20 sets of 25 snubs	varied*		.0045
19	20 drags	varied**		.0066
20	500 snubs	600		.0075
21	500 snubs	700		.0174
22	265 snubs***	200		.0049

*At the start of each of the 25 snub series, IBT was 150°F on drum and lining. At the end of the series (25th stop), lining temperature was 320-470°F and drum temperature was 465-600°F (reason for large variation between sets is unknown).

**At the start of the drags, IBT was 150°F on drum and lining. At the end of the drags, lining temperatures were 340-490°F and drum temperatures were 460-685°F (reason for large variation between drags is unknown).

***Only 265 snubs due to dynamometer breakdown (extrapolation to 500 snubs yields .0090 in. of wear).

after operation at 700°F, the estimated level of wear would only be approximately 25% of the measured level of wear for the 700°F-then-200°F sequence of brake operation. Clearly, the wear phenomenon under study responds to the past history of brake usage, and in this case, failure to take this into account would result in an unacceptably inaccurate estimation of brake wear.

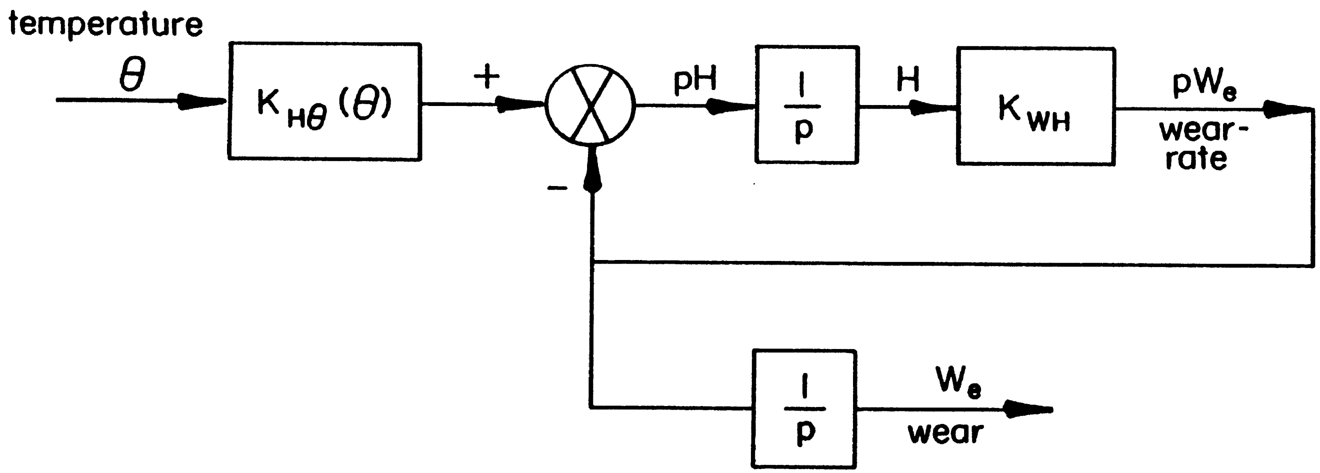
To describe this wear phenomenon in a semi-empirical model, we define a variable, H, that represents the past work history of the brake. Intuitively, H is viewed as a measure of the depth and extent to which the rubbing materials have been degraded (or "charred") by use at elevated temperatures. (For our purposes, H can be expressed in inches.) As the brake wears during operation at low temperatures, H is reduced to a nominal level that corresponds to a normal brake condition. During brake usage of sufficient severity to cause the temperature to build up, H is hypothesized to increase, thereby forming a basis for predicting a subsequent increase in the rate at which the brake will wear with temperature.

Assuming that the variable H represents the general characteristics of the wear phenomenon as measured, we have developed semi-empirical relationships suitable for "modeling" the wear process. This model has been conceived as a feedback system in which the rate of change of wear with respect to work (i.e., wear rate) is compared to the influences of temperature in determining the rate of change of the work history variable, H (see Figure 8). The detailed reasoning leading to the development of the model illustrated in Figure 8 will be discussed next.

The following equations and accompanying definitions express in mathematical terms the wear phenomenon as described in the previous paragraphs:

$$\frac{\Delta W_e}{\Delta W} \doteq K_{WH}\, \overline{H} \qquad (22)$$

$$\Delta H = K_{H\theta}(\theta)\Delta W - \Delta W_e \qquad (23)$$



p is an operator representing the derivative with respect to work.
1/p represents the integral with respect to work.

Figure 8. Conceptualization of the wear process.

where

ΔW_e	is an incremental change in wear (in)
ΔW	is an incremental amount of work (in-lb)
ΔH	is an incremental change in H (in)
$\Delta W_e/\Delta W$	is referred to herein as the "wear rate" (in/in-lb)
$\bar{H}$	represents the mean value of work, H, during an increment of work ΔW at a nominal temperature, θ
K_{WH}	represents a first-order estimate of the influence of $\bar{H}$ on wear rate ((in-lb)$^{-1}$)
$K_{H\theta}(\theta)$	is a function of temperature that determines the influence of work on the work-history variable, H (in/in-lb)

For a given temperature, Equation (23) indicates that H will quit changing when

$$K_{H\theta}(\theta)\Delta W - \Delta W_e = 0 \quad ,$$

that is, when the wear rate is given by:

$$\frac{\Delta W_e}{\Delta W} = K_{H\theta}(\theta) \qquad (24)$$

Equation (24) states that the function $K_{H\theta}(\theta)$ represents the steady-state wear rate at various temperatures. If the brake were to be repeatedly worked at a specified temperature, the wear rate would eventually reach the value given by $K_{H\theta}(\theta)$.

The quantity $(1/K_{WH})$ represents a "work constant" (analogous to a time constant in dynamics) determining the rate at which steady state is approached for the system defined by Equations (22) and (23). To aid in understanding the meaning of the work constant, the following operator is introduced:

$$p = d(\cdot)/dW = \text{rate of change with respect to work}$$

and

$$1/p = \text{the integral with respect to work}$$

Using the operator p, Equations (22) and (23) may be interpreted as follows for infinitesimal increments of work:

$$p\,W_e = K_{WH}H \tag{25}$$

$$p\,H = K_{H\theta}(\theta) - p\,W_e \tag{26}$$

where $p\,W_e$ is the wear rate.

By combining (25) and (26), the following differential equation is obtained for H:

$$p\,H = K_{H\theta}(\theta) - (K_{WH}H)$$

or (27)

$$(p + K_{WH})H = K_{H\theta}(\theta)$$

The general solution of (27) for a fixed temperature, θ, is as follows:

$$H = H_o e^{-K_{WH}W} + \left(1 - e^{-K_{WH}W}\right)\left(\frac{K_{H\theta}(\theta)}{K_{WH}}\right) \tag{28}$$

where H_o is the initial value of H at the start of working the brake.
Based on (28), the wear rate may be expressed as follows:

$$p\,W_e = K_{WH}H_o\, e^{-K_{WH}W} + \left(1 - e^{-K_{WH}W}\right)K_{H\theta}(\theta)$$

or (29)

$$p\,W_e = (K_{WH}H_o - K_{H\theta}(\theta))e^{-K_{WH}W} + K_H(\theta)$$

The system of Equations (25) and (26) are represented by the block diagram previously presented in Figure 8. As shown in Figure 8, the total wear is simply the accumulated (integrated) wear rate. At a fixed temperature, the accumulated wear, W_e, is equal to the integral of $p\,W_e$, where $p\,W_e$ is given by Equation (29), viz.,

$$W_e = K_{H\theta}(\theta)W + \left(H_o - \frac{K_{H\theta}(\theta)}{K_{WH}}\right)\left(1 - e^{-K_{WH}W}\right) \qquad (30)$$

where

W is the amount of work done

H_o is the initial value of work history when the work was started

W_e is the amount of wear due to the work done since H_o was established

Now, consider using the semi-empirical model to represent the data presented in Figure 7. As indicated in our wear conceptualization, $K_{H\theta}(\theta)$ is the steady-state wear rate at each temperature. To first approximation, the steady-state wear rate ($K_{H\theta}(\theta)$) may be estimated to lie near the average of the data at temperatures less than 700°F with the highest value of the data at 700°F being on the order of the assumed steady-state value. The "width" of the modeled hysteresis loop at each temperature depends upon the value selected for K_{WH}. As an initial estimate, let $K_{WH}W_{500} = 2.0$ where W_{500} equals the amount of work done in 500 snubs ($W_{500} = 74.3 \times 10^6$ in-lb in this case). The value of 2.0 for $K_{WH}W_{500}$ means that $(1 - e^{-K_{WH}W_{500}}) = 0.8647$, which seems to be reasonable for a hysteresis loop of the size shown in Figure 7. (If desired, the value of K_{WH} could be changed iteratively in a process of improving the fit to the measured data.) Based on the considerations presented in this paragraph, an initial set of parametric values for modeling the wear results presented in Figure 7 are summarized in Table 14.

Table 14

Wear Parameters for a Semi-Empirical Model

$W_{500} = 74.3 \times 10^6$ in-lb

θ	$K_{H\theta}(\theta)W_{500}$	$K_{H\theta}(\theta)/K_{WH}$
150	.0010	.0005
200	.0022	.0011
300	.0038	.0019
400	.0051	.0025
500	.0076	.0038
600	.0092	.0046
700	.0172	.0086

Using the parameters given in Table 14, the following results (Table 15) are obtained from an example calculation approximating the duty cycle pertaining to the data presented in Figure 7. The calculated results are in good agreement with test results for temperatures from 300°F to 600°F. Although more work could be done to provide a better fit to the data, the results are close enough to support the conceptual ideas underlying the semi-empirical model and to justify further investigation into the merits of estimating brake wear using this model.

In hindsight, the concepts underlying the model have interesting implications with respect to measuring brake wear. For example, the practice of heating the brake to 700°F by repeated applications and then letting it cool to the desired temperature has a bearing on the initial value of H at the start of a series of snubs. Possibly, the warm-up procedure might be modified or the data processed to compensate for the degradation caused by the warm-up. In addition, testing could be performed until nearly steady-state wear rates were obtained, thereby aiding in developing a better understanding of the validity of the model. Furthermore, more testing similar to a 200°F, 600°F, 200°F sequence would lend information that could be used in evaluating the validity of the model and the repeatability of the test results.

Table 15

Example Calculations of Wear

For these calculations:

1. $H_o = 0$ initially (at 200°F)

2. $H_f = H_o(0.1353) + (0.4323)K_{H\theta}W_{500}$
   where H_f is the value of H at the end of a series of snubs

3. $W_e = K_{H\theta}W_{500} + 0.8647H_o - 0.4323K_{H\theta}W_{500}$

θ °F	$K_{H\theta}W_{500}$	H_o	H_f	Calc. W_e	Fig. 7 Meas. W_e
200	.0022	0	.0010	.0012	.0022
300	.0038	.0010	.0017	.0031	.0032
400	.0051	.0017	.0024	.0044	.0039
500	.0076	.0024	.0036	.0064	.0064
600	.0092	.0036	.0045	.0083	.0081
700	.0172	.0045	.0080	.0137	.0092
700	.0172	.0080	.0085	.0167	.0171
600	.0092	.0085	.0051	.0125	.0100
500	.0076	.0051	.0040	.0087	.0087
400	.0051	.0040	.0027	.0064	.0064
300	.0038	.0027	.0020	.0045	.0044
200	.0022	.0020	.0013	.0029	.0022
600	.0092	.0013	.0042	.0063	.0075
700	.0172	.0042	.0080	.0134	.0174
200	.0022	.0080		.0081	.0090

3.5 Prediction of the Influence of Retarder Use on Brake Wear

The purpose of this sub-section is to tie the experimental and modeling results concerning brake wear to those operational considerations that are pertinent to the brake savings obtainable through the use of retarders. Although this work represents a very modest effort compared to that which could be applied to the study of brake wear, the findings have clear implications with regard to those heavy vehicle applications in which extraordinary brake savings can be realized. Obviously, if the foundation brakes are not used, they will not wear, and hence, if a retarder is used to perform some portion of the braking of a vehicle, a brake savings will occur. However, if brakes on a vehicle rise to high temperatures due to the severity of the mountains the vehicle descends, or the number of stops that the vehicle makes in a short time, the wear rate of the brakes will be much higher than that attained during comparable low temperature applications. But this temperature effect is not the whole story; past work history also influences wear rate in that high wear rates occur after high temperature operation even though the brake has cooled before it is applied again. The following example employs the temperature and wear models developed in this study to illustrate the combined importance of both temperature and work history in a duty cycle in which a vehicle makes a series of mountain descents along a hypothetical route. Since using a retarder lowers both (a) the temperature level of brake operation and (b) the amount of work done by the foundation brakes, retarder usage lengthens brake life by influencing both of the main phenomena contributing to brake wear.

3.5.1 An Illustrative Prediction of Brake Wear During Repeated Mountain Descents. For example, assume that a heavy truck has a route consisting of several mountains. The primary braking on this route is that needed to control speed while descending each of these mountains. For ease in constructing a simple example (although there is no reason why the computational tools developed in this study could not be applied to a complex situation), assume that each of these mountains is similar to Martin's Mountain (as previously discussed) and that the driver controls speed by applying 25 pulses of braking similar to those used in the dynamometer tests performed in this study.

A temperature profile representative of a descent of Martin's Mountain has been computed using the techniques described in Section 3.2. The temperature profile consists of a series of increases in temperature when the brake is applied followed by a cooling period until the brake is applied again. The second column of Table 16 presents an estimate of the average temperature occurring during each of the 25 snubs needed to control vehicle speed in the neighborhood of 40 mph using typical foundation brakes.

The work done during a single snub is the product of the average power absorbed by the brake multiplied by the length of time the brake is applied. (Note that the power absorbed by the brake also determines the temperature rise occurring during a snub. See Equation (21).) For this example calculation, the work, W_1, done during a single snub is taken to be 1.486×10^5 in-lbs, corresponding to one of the snubs employed in the sets of 500 snubs used in the dynamometer tests.

In this case, we choose to apply Equations (28) and (30) to each snub, viz.,

$$H_{i+1} = H_i e^{-K_{WH}W_1} + \left(1 - e^{-K_{WH}W_1}\right) \frac{K_{H\theta}}{K_{WH}}$$

and

$$W_{ei} = K_{H\theta}W_1 + \left(H_i - K_{H\theta}/K_{WH}\right) \left(1 - e^{-K_{WH}W_1}\right)$$

where

i	ranges from 1 to 25 to designate the sequence of snubs during each mountain descent
H_i	is the work history variable
W_1	is the work done in a single snub (1.486×10^5 in-lbs)

Table 16

Predicted Wear During Mountain Descents

Snub Number	Average Temperature, °F	$10^5 K_{H\theta} W_1$	First Descent $10^3 H_i$	First Descent $10^5 W_{ei}$	Second Descent $10^3 H_i$	Second Descent $10^5 W_{ei}$
i=1	154	.22	.55	.22	.6336	.2534
2	164	.26	.5500	.22	.6333	.2533
3	172	.30	.5504	.2202	.6333	.2533
4	180	.34	.5512	.2205	.6338	.2535
5	189	.38	.5524	.2210	.6347	.2539
6	197	.42	.5540	.2216	.6359	.2544
7	205	.46	.5560	.2224	.6376	.2550
8	213	.48	.5583	.2233	.6396	.2558
9	221	.50	.5609	.2244	.6419	.2568
10	229	.54	.5637	.2255	.6443	.2577
11	237	.56	.5668	.2267	.6471	.2588
12	245	.58	.5701	.2280	.6501	.2600
13	253	.60	.5737	.2295	.6533	.2613
14	260	.64	.5774	.2310	.6567	.2627
15	268	.66	.5815	.2326	.6605	.2642
16	276	.68	.5858	.2343	.6645	.2658
17	283	.70	.5902	.2361	.6686	.2674
18	291	.74	.5949	.2380	.6729	.2692
19	298	.76	.5999	.2400	.6776	.2710
20	305	.78	.6051	.2420	.6825	.2730
21	312	.80	.6105	.2442	.6876	.2750
22	320	.82	.6160	.2464	.6928	.2771
23	327	.84	.6218	.2487	.6983	.2793
24	334	.84	.6277	.2511	.7035	.2816
25	341	.86	.6336	.2534	.7095	.2838
		Total Inches of Wear		$(5.8)10^{-5}$		$(6.6)10^{-5}$

K_{WH} is $(2/74.3 \times 10^6)\ (\text{in-lb})^{-1}$

$K_{WH}W_1 = 0.004$, $e^{-K_{WH}W_1} \approx 0.004$, and $1 - e^{-K_{WH}W_1} \approx 0.996$

$K_{H\theta}$ is a function of temperature as indicated in Table 14

(Pertinent values of $K_{H\theta}W_1$ are given in the third column of Table 16.)

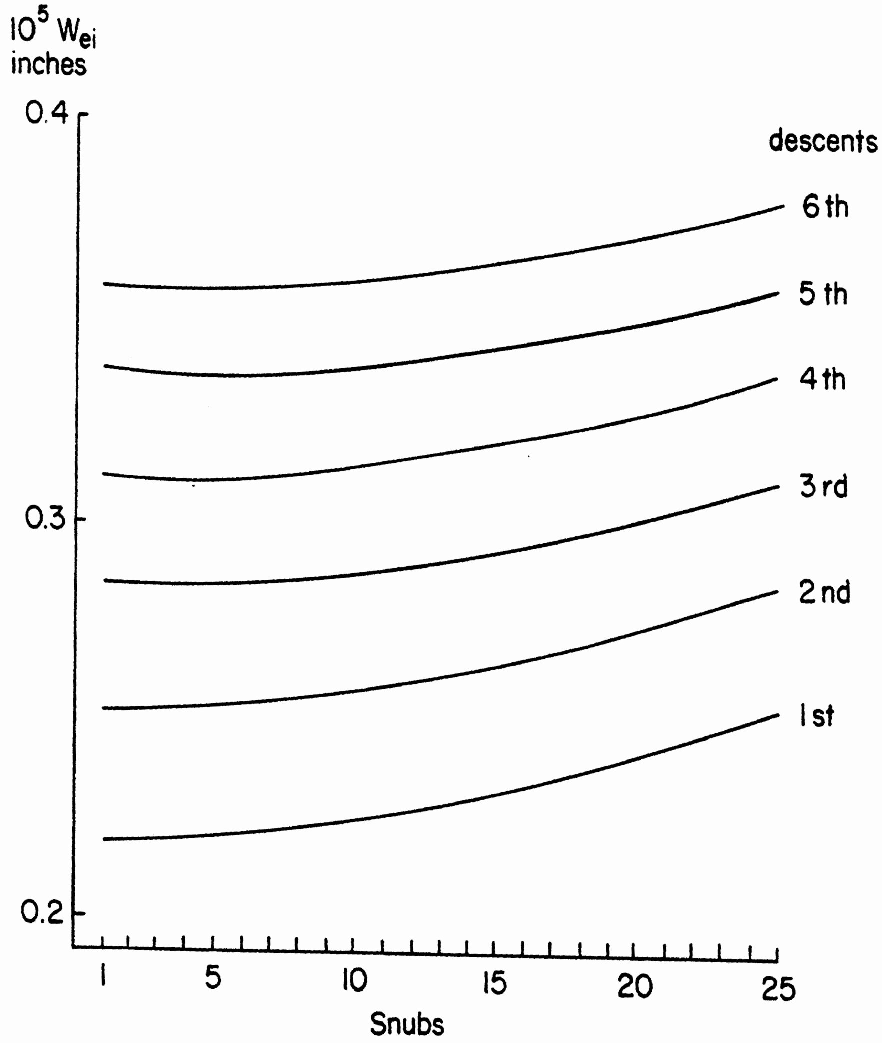
W_{ei} is the brake wear resulting from the i^{th} snub

Initially, the brake is presumed to have been conditioned by repeated operation around 150°F such that $H_1 = 0.55 \times 10^{-3}$, which is the normal value of work history for this temperature. The changes in work history and wear per snub (W_{ei}) increase during the "First Descent" as shown in the fourth and fifth columns of Table 16. Work history increases from $H_1 = .55\ (10^{-3})$ inches to $H_{25} = .6336\ (10^{-3})$ inches and the total brake wear accumulates to $5.8\ (10^{-5})$ inches during the descent of the first mountain.

By the time the vehicle reaches the summit of the second mountain its brakes are presumed to have cooled to 150°F again. However, the work history starts at $H_1 = .6336\ (10^{-3})$ inches, that is, the value retained from the end of the previous descent. Although the work history decreases slightly during the first few snubs, the brake temperature soon builds up to a level such that the work history increases throughout most of the second descent (see the last two columns of Table 16). The amount of wear accumulated during the second descent is larger than that accumulated during the first descent because of the influence of work history.

On the average, work history will continue to increase during each succeeding mountain descent and, consequently, the accumulated wear will increase during succeeding descents. The progression of the wear per snub during six mountain descents is illustrated in Figure 9. Clearly, the total wear for the sixth descent (9.2×10^{-5} inches) is much greater than that achieved on the first descent (5.8×10^{-5} inches).

Now consider the same situation except that the vehicle is equipped with a retarder. Assume that the retarder does not have enough power



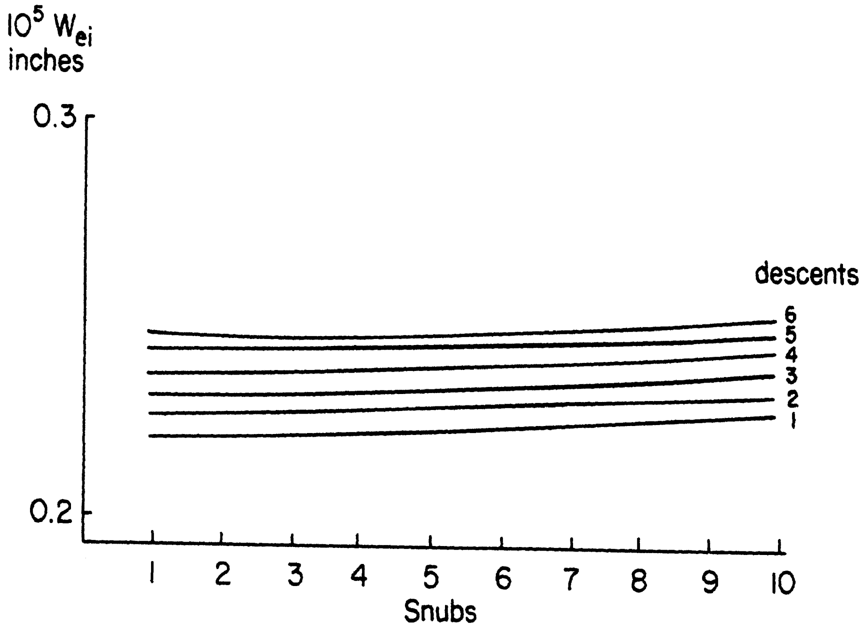
Descent	Total Wear x 10^5 inches
1	5.8
2	6.6
3	7.3
4	8.0
5	8.6
6	9.2
Total	45.5

Figure 9. Wear progression during mountain descents.

to maintain 40 mph so the driver periodically snubs the brakes to control speed. Let us presume that, instead of 25 snubs, 10 snubs are enough to control speed. (A moderately powerful retarder could achieve this.) Based on the amounts of work done without and with the retarder, a brake savings of 25 to 10 (i.e., BLEF = 2.5) would be anticipated. However, the effect of work history will be much less for the retarder-equipped vehicle as can be seen by comparing the wear results presented in Figures 9 and 10. By including the influence of work history in addition to the reduction in work itself, a brake life extension factor of 3.2 (due to retarder use) is predicted for a hypothetical duty cycle consisting of six mountain descents.

The results of this example indicate that retarders should be especially effective in reducing brake wear in duty cycles consisting of repeated periods of intensive brake usage (characterized by significant temperature increases) even if the brakes cool between these periods of heavy use.

3.5.2 Status of the Ability to Predict Brake Wear. The ability to predict brake life extension factors (BLEF's due to retarder use) depends upon the ability to predict brake wear as a function of the sequence of work done by the foundation brakes. During this project, computational methods (tools) have been developed to a level where they show promise as means for evaluating the role of work history in assessing brake wear. The temperature and wear models are ready to be combined into simulation programs (computer codes) that can be used to study the influences of typical duty cycles on brake wear. Results from both vehicle experiments and further dynamometer testing are needed to refine and improve both (a) the details of the basic models and (b) the means for determining parametric values for use in the models, thereby providing a convenient methodology for predicting brake wear and BLEF's.



Descent		Total Wear x 10^5 inches
1		2.2
2		2.3
3		2.3
4		2.4
5		2.4
6		2.6
	Total	14.1

Figure 10. Wear progression during mountain descents with a retarder in use.

4. THE INFLUENCE OF RETARDER TORQUE ON DIRECTIONAL STABILITY*

In general, directional response problems do not become unmanageable for a driver until the tires on an axle set are incapable of supplying adequate lateral force for directional control and stability. Under braking conditions, the lateral force capabilities of tires are reduced as the tires are required to produce increasing amounts of longitudinal force. Severe stability and control problems occur when the lateral force capability at a particular axle set is much less than that available at other axle locations. Specifically, if the rear tires of the tractor of a tractor-semitrailer vehicle lose a significant portion of their lateral force capability, the vehicle tends to go into a tractor jackknife and if the trailer wheels lose lateral force capability, a trailer-swing-type of jackknifing may occur. Hence, there is a possibility that tractor-installed retarders may contribute to the initiation of a tractor jackknife and trailer-installed retarders may contribute to an instability characterized by a trailer swing.

The technical literature contains limited information on retarder-induced directional control problems. Highway signs instructing truck drivers to turn off retarders on snow-covered or icy roads are reported to exist in certain regions of the United States [1]. Specific truck accidents on slippery roads have been attributed to retarder usage. However, a detailed understanding of the control problems encountered by drivers of retarder-equipped tractor-semitrailers as operated in the U.S. has not been established.

The purposes of the following discussion are to: (1) assess the conditions under which retarder torque may lead to directional control problems, (2) quantify the nature of the control difficulties encountered in these adverse conditions, and (3) describe the characteristics of unsafe situations that might result from improper use of retarders.

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*A revised and enhanced version of the material in this chapter is presented in SAE Paper No. 831788 entitled "Directional Control of Retarder-Equipped Heavy Trucks Operating on Slippery Surfaces," co-authored by P.S. Fancher and R.W. Radlinski [9].

4.1 Dynamics of Vehicle Operation During Retardation

To aid in developing a fundamental understanding of the dynamics of retarder braking, a special version of a comprehensive vehicle simulation was designed to facilitate a detailed analysis of the influence of retarder torque on wheel speeds during decelerations in turning maneuvers. The so-called "PHASE 4" braking and handling simulation [10] has been supplemented by a subroutine that adds the influences of retarder braking to the computerized vehicle model. In this special version of the PHASE 4 model, retarder characteristics are represented as a function of engine speed. Engine speed, which is calculated from the average of the speeds of the drive wheels (taking into account the transmission and rear-axle gear ratios), is used in a table look-up function to determine retarder torque. Retarder torque is (1) multiplied by the appropriate gear ratio for the operating conditions to be simulated, (2) divided by the driveline efficiency, and (3) divided into equal amounts of torque applied to each of the drive wheels of the vehicle. The exact details of the calculations performed in implementing this addition to the vehicle model are contained in the listing of a subroutine entitled "RETARD" which is included in Appendix C.

This vehicle model was applied to the simulation of a vehicle similar to one that was subsequently tested by NHTSA at VRTC. A detailed listing of the vehicle parameters used in the simulation study are presented in Appendix C. The simulated vehicle is representative of a typical five-axle tractor-semitrailer. The vehicle is simulated in an unloaded condition because jackknifing is likely to be a greater problem for unloaded vehicles than it is for loaded vehicles. In an unloaded state, the static load on each drive axle is equal to 5,081 lbs and the simulated vehicle weighs 28,210 lbs.

The retarder characteristics employed in the analysis correspond to measured results obtained in Phase II. The influences of both engine drag and the retarder are combined into a single function expressing the torque generated by the retarder and engine at various engine speeds (see Table 17). The model also includes rolling resistance and aerodynamic

Table 17

Retardation, Engine Plus Retarder Torque

Total Torque (ft.lb)	vs.	Engine Speed (rad/sec)	(rpm)
0		0	0
509		136	(1300)
630		164	(1560)
759		192	(1830)
930		220	(2100)

drag so that the total retardation characteristics of the simulated vehicle are equivalent to those measured for a particular vehicle (that is, for the vehicle designated as #2 in the Phase II tests [2]).

Conditions for which jackknifing of the simulated vehicle are predicted were found by trial and error and by adjusting forward velocity and tire/road friction level. The computer predictions indicate that the simulated vehicle will jackknife if its retarder is switched fully on while the vehicle is making a turn of approximately 0.15 g at a forward velocity of 32 ft/sec (21.8 mph) with the peak friction between the truck's tires and the road being 0.20. (Appendix C contains a detailed listing of time histories of all pertinent vehicle dynamics variables calculated in this case.)

Examination of the detailed time histories provides interesting insights into the dynamic behavior of the system. The consequences of the constraints on speeds and torques due to the differentials (one for each axle and one interaxle differential) are somewhat surprising at first observation. In particular, when the retarder is applied in a turning maneuver, the lightly loaded drive wheels may turn backwards if the tire/road friction is of an appropriate value. This phenomenon (which was subsequently observed in vehicle tests) is possible because, due to differential action, the speed of the driveline is the average of the output speeds at each drive wheel (with gear ratios being properly accounted for) and the output torques are equal fractions (1/4 for four driven wheels) of the input torque. The dynamics of the driven wheels are such that even if some of them are turning backwards, the algebraic sum of all of the wheel speeds adds up to the driveline speed.

Another interesting feature of the simulated performance has to do with the decrease in retarder torque as the average wheel speed decreases. This feature of retarder performance means that in straight-line braking, the retarder will not lock the drive wheels, although large amounts of slip corresponding to tire operation at points beyond the peak of the μ-slip curve are possible on slippery surfaces.

If both the foundation brakes and the retarder are used in straight-line braking, the retarder torque may provide enough additional torque to cause tires on the drive axles to operate beyond the peak of the μ-slip curve. However, as in the previous situation, the retarder torque becomes small at low rotational speeds with the result that the drive wheels may or may not lock up, depending upon the torque applied by the foundation brakes.

(In reality, the engine may stall if the wheel speeds are low and the transmission is still in gear. Also, retarders usually "cut out" at some low engine speed.)

The simulation study shows that the tradeoffs between vehicle speed, applied torque due to the retarder, and tire/road friction are very important. Peak tire/road friction decreases as forward velocity increases. However, the amount of torque applied to the drive wheels by the retarder is reduced if a higher gear is needed to operate at increased velocity. Hence, the possibility for directional instability depends upon selecting the appropriate velocity for the surface conditions, gear ratios, and retarder involved in vehicle experiments (and/or simulated tests).

4.2 Experimental Results from Driver-Controlled Tests

Based on the theoretical results from the simulation, driver-controlled vehicle tests were planned and executed at VRTC. The tests were conducted with two vehicles—the first being similar to the one simulated and the second consisting of a 4x2 tractor and single-axle semitrailer. The second vehicle was included in the study because this vehicle was known to have noticeable adverse directional response characteristics on slippery surfaces when the driver suddenly closed the throttle.

Each of the vehicles had a retarder. The torque versus speed characteristics of these retarders (as they were operating during the tests) were measured by drawbar pull tests (see Table 18). Neither of these retarders are especially powerful by present day standards, thus they do not constitute a "worst case situation" in terms of the maximum torque capability available on the market.

The test driver was very experienced in conducting heavy truck braking experiments on slippery surfaces. His performance is representative of the best that can be expected from an experienced driver that has developed driving skills by practicing the test maneuvers. The fastest speed that the driver can negotiate the test course is a measure of the upper bound on driver/vehicle system performance.

The tests were conducted on the Vehicle Dynamics Area (VDA) at the Transportation Research Center (TRC) of Ohio. Two constant radii turns were used—one with a 500-foot radius and the other with a 200-foot radius. The turns were marked by traffic cones arranged to delineate 12-foot lanes.

For wet tests the lanes were placed on a jennite-coated section of the VDA. The skid number of this wetted surface was 20 (μ=0.2). However, previously conducted tests of truck tires indicate that the peak tire/road friction would be approximately 0.3 on this surface.

Additional tests were performed on a 500-foot radius turn during the winter when icy conditions could be maintained on the VDA. The maximum tire/road friction level of icy surfaces tends to lie between

Table 18

Retarder Characteristics of Test Vehicles
(measured with load cell drawbar)

1972 Peterbilt 4x2 with DDA 8V72, Jacobs Retarder

	Retarding h.p. in 6th Direct*	
Engine RPM	Engine and Retarder	Engine Only
1650	134	66
2200	193	113

1978 Ford 6x4 with Cummins 350, Jacobs Retarder

	Retarding h.p. in 6th Direct*	
Engine RPM	Engine and Retarder	Engine Only
1625	162	28
2200	251	76

*Parasitic drag in neutral has been subtracted from these values.

0.1 and 0.14, with 0.1 being typical of "wet" ice as may be encountered when hard ice has a thin coat of water lying on it. Although the exact friction level is difficult to control on icy surfaces, results from tests performed one after the other with and without the retarder in operation can be used to obtain a quantitative comparison providing an assessment of the influence of retarder braking on icy roads.

The test procedure consisted of several passes through the test course at gradually increasing speeds until the maximum controllable speed was reached. The resolution of this process was found to be surprisingly consistent with the influences of one mile/hour differences in forward velocity being readily discernible.

Several types of control modes were investigated. First, the course was driven at constant velocity. This established the maximum speed at which the driver could negotiate the course while staying in the lane. (This type of maneuver is later referred to as a "drive-through" test.) Second, the course was followed at constant speed until the throttle was closed causing engine drag to retard the vehicle. The driver applied steering corrections to keep the vehicle within the lane. Third, the speed in the curve was kept constant up to a fixed point, at which the retarder was applied. In this case, the retarder plus the engine drag caused the vehicle to slow more rapidly with a greater directional disturbance than that caused by engine drag alone. In general, the maximum controllable initial speed was lower in the situation in which the retarder was activated (see Table 19).

The test results (Table 19) also contain information on the best wheels-unlocked stopping distances that the driver was able to attain using the foundation brakes with and without the retarder in operation. These results show that the use of retarders will upset the braking distributions of the test vehicles in a manner that will result in longer minimum distance stable stops while braking and turning on low coefficient surfaces. Apparently, the driver can modulate the treadle valve to achieve shorter stopping distances when the retarder is not in use than when it is in use.

Table 19

Retarder Stability Tests -- VRTC/NHTSA

A -- Test Results for Wet Jennite Surface
-- Corrective Steering and No Service Braking

Vehicle	Loading	Curve Radius	Maximum Steady Drive Through Speed (mph)	Decelerate in Turn--Maximum Controllable Initial Speed (mph)		Retarder Effect % Speed Loss
				W/O Retarder (Engine Drag)	With Retarder	
6x4 - S2	Empty	200'	24 (Plow Out)	26 (Plow Out)	25 (Jackknife)	3.8
	Empty	500'	41 (Plow Out)	42 (Plow Out)	40 (Jackknife)	4.8
	Bobtail	200'	27 (Plow Out)	29 (Plow Out)	27 (Spin Out)	7.4
4x2 - S1	Empty	200'	29 (Plow Out)	28 (Jackknife)	25 (Jackknife)	10.7
	Empty	500'	41 (Plow Out)	42 (Jackknife)	39 (Jackknife)	7.1
	Loaded	200'	28 (Plow Out)	28 (Jackknife)	27 (Jackknife)	3.6

Table 19 (Cont.)

B -- Test Results for 500 Ft. Radius Curve on Ice Surface--Corrective Steering and No Service Braking

Vehicle	Loading	Maximum Steady Drive Through Speed (mph)	Decelerate in Turn -- Maximum Controllable Initial Speed (mph)			Retarder Effect % Speed Loss
			Without Retarder	With Partial* Retarder	With Full Retarder	
6x4-S2	Empty	25 (Plow Out)	25 (Jackknife)	20 (Jackknife)	0 (Jackknife)	100
	Loaded	23 (Plow Out)	24 (Plow Out)	27 (Plow Out)	24 (Jackknife)	0
4x2-S1	Empty	23 (Plow Out)	15 (Jackknife)	NA	0 (Jackknife)	100

*Partial retarder indicates operation where retarder output is reduced to 1/3 (retarder operational on only 2 of 6 engine cylinders).

Table 19 (Cont.)

C -- Test Results for Wet Jennite Surface--Corrective Steering and Service Brakes Utilized

Vehicle	Loading	Curve Radius	Initial Speed (mph)	Best In-Lane Stopping Distance (ft)		Retarder Effect % Increase in Stopping Distance
				Without Retarder	With Retarder	
6x4-S2	Empty	200'	25	88	96	9.1
	Empty	500'	40	311	323	3.9
	Bobtail	200'	25	98	123	25.5
4x2-S1	Empty	200'	25	88	98	11.4
	Empty	500'	35	183	224	22.4
	Loaded	200'	25	98	103	5.1

The test results obtained without employing the foundation brakes require explanation. The form of the instability (plow out or jackknife, as indicated in Table 19) depends upon whether the lateral force demands are first exceeded at the front wheels or at the drive wheels. The test vehicles experience a plow out at the limit of the "drive through" maneuver. This plow-out response indicates that the front tires cannot generate the side forces that would be required to negotiate the turn above the limit velocity. However, when deceleration is present due to either engine drag or retarder plus engine drag, the limit response changes to a jackknife, indicating that the longitudinal slip generated by the engine and/or retarder drag is large enough to cause the side force capability at the drive wheels to be insufficient to prevent jackknife.

The jackknifes caused by engine drag alone occur at nearly the same speed as the speed at which the plow out occurred in the drive-through tests, although the location of lateral force insufficiency has shifted from the front to the drive wheels. In some cases, the jackknife instability occurred at a speed higher than the maximum drive-through speed. The addition of engine drag appears to have helped to balance the yaw moment acting on the tractor and to slow the vehicle enough to allow the driver to control the situation at initial speeds exceeding the drive-through speed.

However, when the retarder is used, the vehicle's rear tires are not able to maintain a yaw moment balance at speeds equal to the drive-through speed. The amount of speed reduction below the drive-through speed depends upon the gear ratio involved and the load on the vehicle. The influence of the retarder is greater when the vehicle is operating in low gears and at light loads. On icy surfaces, the use of the retarder in the "full on" position results in an immediate jackknife if the vehicle is negotiating a turn when empty. The severity and rapidity of the jackknife is such that there is little the driver can do to control the situation.

If the three-axle tractor/two-axle semitrailer is loaded, retarder operation at 1/3 maximum provides some stability margin over the operation without the retarder for this vehicle operating on an icy surface. At full retardation, the loss-of-control mode shifts from plow out to jackknife on the icy surface. Clearly, as is expected to occur in general, jackknifing problems are much more critical for the unloaded (empty) vehicle than they are for a fully loaded vehicle.

4.3 Predictions for Situations Not Simulated or Tested

The purpose of this section is to provide a simple analytical method for estimating the bounds of safe vehicle operation when using retarders on slippery surfaces. This simplified model aids in describing unsafe situations through the use of a small (approaching minimum) number of operating variables and parameters. The experience gained in performing vehicle simulations and evaluating test results has been applied in developing this simplified method for identifying situations that challenge the ability of drivers to maintain directional control when a retarder is in use.

The important factors to be considered with respect to the influence of a retarder on directional controllability are listed in Table 20. Situations that may be unsafe can be identified by comparing the frictional demands made by the retarder in developing road-wheel brake forces (item 1 in Table 20) with the frictional requirements needed to maintain yaw moment balance in a turning maneuver (items 2 and 3 in Table 20 contribute to this requirement). Both the longitudinal frictional demand and the lateral frictional requirement are functions of forward velocity. At a given level of tire/road friction capability, the following equations may be used to make a first-order estimate of the speed above which directional control problems will arise because the longitudinal force demand caused by the retarder exceeds the longitudinal force capability determined by the lateral force requirements, viz.,

Table 20

Factors Influencing Directional Control
During Retarder Operation.

1. Road wheel brake force as a function of forward velocity

   Important characteristics:

   a. retarder and engine torque as a function of rotational speed

   b. gearing, differentials, and tire radii determining retarder speed as a function of forward velocity

2. Load on the retarded wheels and the percentage of that load available for lateral force generation

   Important characteristics:

   a. loading state of the vehicle

   b. tire/road friction level

   c. interaction of longitudinal and lateral force in determining directional control limits

3. Lateral force requirements needed for following a desired path

   Important characteristics:

   a. lateral acceleration required (path radius or curvature and velocity)

   b. lateral force required of the wheels on the retarded axle(s) in order to maintain directional control and yaw stability

1. Longitudinal force demand, F_{XD}, at velocity, V.

$$F_{XD}(V) = \frac{T_R}{R_T} G_i \tag{31}$$

where T_R is retarder torque, R_T is tire radius, and G_i is the gear ratio

For an engine speed retarder, the retarder torque is a function of engine speed, N_E, i.e.,

$$T_R = T_R(N_E) \tag{32}$$

and

$$N_E = G_i \; V \; G_T \tag{33}$$

where G_i is a gear ratio appropriate to the velocity, V (mph), and G_T is the number of tire rev./min. per mph.

2. Lateral force requirement, F_{YR}, at velocity, V.

$$\frac{F_{YR}}{F_Z} = A_y = \frac{V^2}{Rg} \tag{34}$$

where

- F_Z is the load on the wheel sets being retarded
- A_y is the lateral acceleration level of the turn (in g units)
- R is the radius of the turn
- g is the gravitational constant

3. Longitudinal force capability, F_{XL}, for directional stability

$$F_{XL} = F_Z\sqrt{\mu^2 - A_y^2} \tag{35}$$

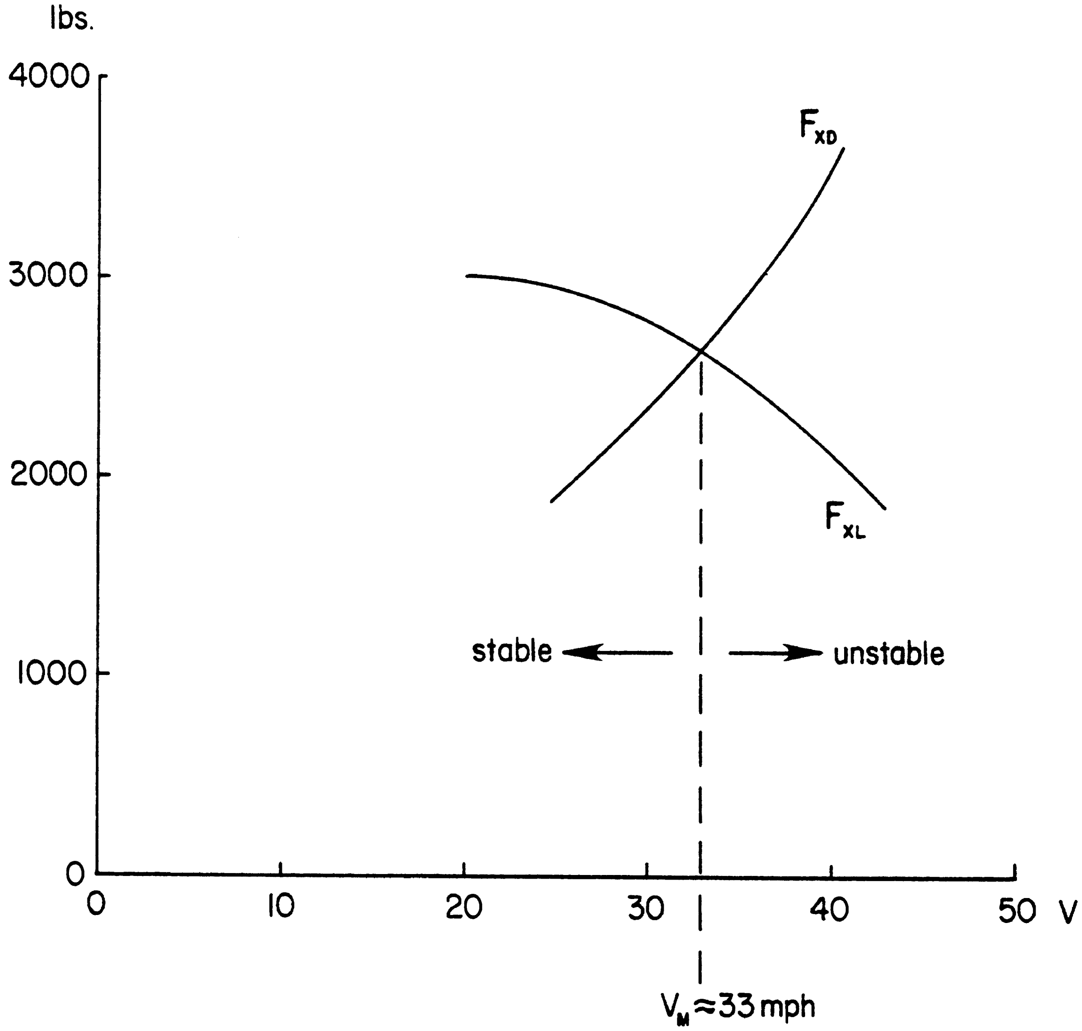
where μ is a measure of the available tire/road friction

Equation (34) is based on the assumption that at low levels of longitudinal and lateral acceleration on a slippery surface an equilibrium condition is achieved when each axle set is producing a lateral force that is proportional to the vertical load carried on that axle. Under these conditions, a yaw moment balance is assumed to be satisfied.

Equation (35) results from the vector sum of the longitudinal and lateral forces being set equal to the total frictional force available at the limit of vehicle performance.

The maximum controllable speed, V_m, is estimated by the simultaneous solution of Equations (33), (34), and (35), as illustrated in Figure 11. As shown in the figure, stable operation in a particular gear occurs at speeds for which the retarder demand, F_{XD}, for that gear is less than F_{XL}, the force limit for the maneuver and available friction level. Diagrams similar to Figure 11 can be readily constructed for any combination of retarder, vehicle, maneuver, and friction level given engine and retarder torque/speed characteristics, gear ratios, tire radii, wheel loads, turn radii, and friction levels (see Reference [9] for several examples).

This simplified procedure can be applied to driveline and trailer axle retarders (when retarder speed is properly accounted for in the analysis). In the case of a trailer axle retarder, the instability mode is trailer swing rather than jackknifing. Since trailer swing is a slower developing instability than a jackknife, the driver may be better able to cope with it. Nevertheless, trailer swing is a dangerous situation to be avoided.



Example parametric values:

Tires: rpm/mph - 8.6
loaded radius - 1.625' (10x20 tire)

Overall gear ratio: 6.0 (rear axle - 4.44; transmission - 1.35)

Turn radius: 600'

Friction: 0.3

Retarder plus engine torque:

rpm	ft-lbs
1300	509
1560	630
2100	930

Load on drive wheels: 10,162 lbs
(empty vehicle, load on all 4 duals)

Figure 11. Estimation of maximum controllable speed, V_m

5. SUMMARY AND CONCLUSIONS

The primary products of this phase of research on retarders have been development of methodologies for estimating the influences of retarder power (torque) on (1) downhill speed control, (2) brake wear, and (3) directional control on slippery surfaces.

With regard to downhill speed control, a retardation prediction procedure has been developed and refined to the point where it could serve as a proposed recommended practice for estimating the control speeds on downgrades that can be maintained by retarders installed on heavy vehicles. This procedure is of sufficient generality that it can be applied to engine, driveline, or trailer-axle retarders operating on pneumatic (exhaust or engine brakes), hydraulic, or electrical principles. The basic information needed to describe the retarder is its power output as a function of its rotational speed. By employing this description of the retarder and parameters describing the weight and natural retardation of the vehicle, the retardation performance of specified vehicles may be predicted using the computer code presented in Appendix A.

The prediction of brake wear is a difficult undertaking because of the number of uncontrolled and almost unpredictable situations that can arise in service. Nevertheless, the use of retarders clearly reduces the amount of work done by the foundation brakes, thereby producing a brake savings. In earlier investigations of the economics of retarder use [1], a brake-life extension factor was utilized to quantify the influence of brake savings on the benefits to be obtained from retarder use.

In this third phase of the study of retarders, a semi-empirical approach for estimating brake wear has been developed. This approach makes use of (a) a procedure for predicting brake temperatures for duty cycles defined by velocity and elevation profiles describing a specific vehicle trip or route (see Appendix B) and (b) a model of brake wear based on work-at-temperature relationships derived from experimental data obtained from measurements made on a brake dynamometer (see Section 3.4).

The methodology involved in applying this approach to a particular situation would be as follows: (1) define elevation and velocity profiles representative of the vehicle route involved, (2) calculate the brake temperatures pertaining to this route and augment these temperature calculations with wear calculations based on the work-at-temperature model developed in this study, (3) perform these wear (and temperature) calculations with and without the retarder in use, and (4) compute the brake-life extension factor as the ratio formed by dividing the wear when the retarder was not in use by the wear when the retarder was in use.

Even though (1) the temperature prediction procedure employed herein produces results that are compatible with temperatures measured in the field (e.g., descents of Martin's Mountain or in studies associated with the proposed grade severity rating system) and (2) the brake wear calculation procedure employs parameters based on test data, the described methodology for predicting brake wear represents a preliminary step towards developing a relatively simple approach for treating a very complex subject. The introduction of the variable, H, representing brake work history, has an important conceptual advantage that we believe to be useful for explaining why different sequences of essentially the same total amount of work produce different amounts of wear. This approach to modeling brake wear merits further investigation. Furthermore, field measurements of brake wear (and also temperature) occurring over well-defined service routes need to be compared to predictions of brake wear before the overall methodology can be accepted as a reasonably accurate and practical approach for estimating brake wear as a function of the duty cycle involved.

Downhill speed control and brake savings are benefits to be expected from retarders. However, the improper use of a retarder on slippery surfaces can be a disbenefit with respect to directional control. Vehicle experiments have been conducted to find the performance bounds within which the driver can maintain directional control when a retarder is activated during turning maneuvers on a slippery surface. The vehicle experiments and computer simulations performed in this study indicate how experimentation or analysis can be used to examine the limits of safe performance for specific combinations of vehicle, surface friction, initial forward velocity, and turn radius.

A simplified analytical method has been developed for estimating the bounds of safe vehicle operation on slippery surfaces (see Section 4.3). This simplified method compares the longitudinal force demand generated by retarder operation with the longitudinal force limit determined by the lateral force requirements of the turning maneuver and the available level of tire/road friction. The bound of controllable vehicle operation is approximated through determining the speed at which the longitudinal force demand exceeds the longitudinal force limit at the wheels to which the retarder applies torque. The assumption implicit in this approximation is that the driver will be able to steer to control the vehicle up to the point where the tires can no longer furnish the lateral forces needed to follow the desired path and control the yaw moments acting on the vehicle. The test results appear to indicate that even though the vehicle slows down when the retarder is applied, the speed reduction does not occur in a manner that allows the driver to regain directional control.

Clearly, the procedure for predicting the maximum controllable speed is not based on irrefutable logic, but rather it represents a description of the circumstances that will challenge the driver's ability to control the vehicle. By evaluating Equations (31) through (35), the bounds of controllable vehicle operation can be estimated for various combinations of retarder torque capability, vehicle loading, gear ratios, tire sizes, turn radii, and tire/road friction. The simplified procedure serves to summarize the influences of the primary quantities that determine the circumstances in which retarder operation may be a hazard rather than a benefit.

In summary, the research investigations conducted in Phase III have led to the development of analytical and computational tools for quantifying the influences of retarder characteristics on downhill speed control, reduced brake wear, and directional stability.

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APPENDIX A

A Retardation Prediction Procedure

This appendix contains a computer code and example results for a current version of the "Retardation Prediction Procedure."

```
C
C*********************************************************************
C*
C*               TRUCK RETARDATION PREDICTION PROCEDURE
C*
C*********************************************************************
C
C      THIS RECOMMENDED PRACTICE PROVIDES A UNIFORM METHOD FOR
C      CALCULATING THE CONTROL SPEEDS MAINAINABLE BY EITHER ENGINE,
C      DRIVELINE, OR TRAILER-AXLE RETARDERS EMPLOYED ON HEAVY
C      VEHICLES OPERATING ON DOWNGRADE SECTIONS OF HIGHWAYS.
C
C    LIST OF INDICES
C
C      IG : GEAR NUMBERS (RANGE 1 TO 20)
C      IV : VELOCITY INDEX (RANGE 1 TO 4)
C      IT : TIRE OPTIONS (RANGE 1 TO 3)
C      IA : AERODYNAMIC FACTORS (RANGE 1 TO 3)
C      ID : DRIVE AXLE TYPES (RANGE 1 TO 3)
C      IRS : ROAD SURFACE FACTORS (RANGE 1 TO 2)
C      IED : ENGINE DRAG OPTION (RANGE 1 TO 2)
C      IAE : DRIVE AXLE EFFICIENCY OPTION (RANGE 1 TO 2)
C      ITT : TRANSMISSION EFFICIENCY OPTION (RANGE 1 TO 2)
C      IER, IDL, ITR : DO-LOOP INDICES FOR ENGINE SPEED, DRIVELINE AND
C                      TRAILER-AXLE RETARDERS
C
C    TABLE AND ARRAY INDICES
C
C      NDA : NO. OF DRIVE AXLES (1 OR 2)
C      NE  : NUMBER OF POINTS IN ENGINE DRAG TABLE (10 MAX)
C      NG  : NUMBER OF GEARS (20 MAX)
C      NESR : NUMBER OF POINTS IN ENGINE SPEED RETARDER TABLE (20 MAX)
C      NDLR : NUMBER OF POINTS IN DRIVELINE RETARDER TABLE (20 MAX)
C      NTR : NUMBER OF POINTS IN TRAILER AXLE RETARDER TABLE (20 MAX)
C
C    TABLE CORRECTION VARIABLES
C
C      INDEX, INO, IFLAG : USED ONLY IF USER DOES NOT INCLUDE VEMAX
C         AND/OR VEMIN IN ENGINE DRAG TABLE.  INDEX IS ARRAY POINTER
C         INDEX, INO IS THE INCREMENT (1 OR 2) AND IFLAG IS THE KEY.
C
C    DEFINITION OF VARIABLES
C
C      VV(IG,IV) : VEHICLE VELOCITY INDEXED FOR GEAR IG
C        VV(IG,1) = VEHICLE VELOCITY AT MAXIMUM ENGINE SPEED (MPH)
C        VV(IG,4) = VEHICLE VELOCITY AT MINIMUM ENGINE SPEED (MPH)
C        VV(IG,2) = VV(IG,4) + 2/3( VV(IG,1) - VV(IG,4) ), (MPH)
C        VV(IG,3) = VV(IG,4) + 1/3( VV(IG,1) - VV(IG,4) ), (MPH)
C      PN(IG,IV) : ROLLING RESISTANCE AND AERODYNAMIC DRAG POWER, (HP)
C      PE(IG,IV) : RETARDATION POWER DUE TO ENGINE DRAG, (HP)
C      PV(IG,IV) : POWER DUE TO ENGINE DRAG, ROLLING RESISTANCE AND
C                  AERODYNAMIC DRAG
C      PRE(IG,IV) : POWER DUE TO AN ENGINE SPEED RETARDER, (HP)
C      PRD(IG,IV) : POWER DUE TO A DRIVELINE RETARDER, (HP)
C      PRT(IG,IV) : POWER DUE TO A TRAILER-AXLE RETARDER, (HP)
C      PS(IG,IV) : TOTAL RETARDING POWER, (HP)
C      RPME(IG,IV) : ENGINE SPEED AT GEAR IG, VELOCITY INDEX IV
C      RPMV(IG,IV) = RPME(IG,IV) IN REVERSE ORDER
```

```
C       HPE(IG,IV) : DRAG HORSE POWER AT GEAR IG, VELOCITY INDEX IV
C       RPMES : CALCULATED ENGINE SPEED AT GEAR IG, VELOCITY IV
C       RPMD : CALCULATED DRIVELINE SPEED AT GEAR IG, VELOCITY IV
C       RPMT : CALCULATED TRAILER AXLE SPEED AT GEAR IG, VELOCITY IV
C       GRM(IG,IV) : GRADE AT WHICH VV(IG,IV) IS AN EQUILIBRIUM
C                    CONTROL SPEED
C
C     DESCRIPTOR VARIABLES
C
C       VEH : VEHICLE DESCRIPTOR
C       TIRE : TIRE DESCRIPTOR
C       ENG : ENGINE DESCRIPTOR
C       DT : DRIVE TRAIN DESCRIPTOR
C       T : TRANSMISSION DESCRIPTOR
C
C     DEFINITIONS OF PARAMETERS
C       VEMAX : MAXIMUM ENGINE SPEED
C       VEMIN : MINIMUM ENGINE SPEED
C       W : VEHICLE WEIGHT AS LOADED
C       A : FRONTAL CROSSECTIONAL AREA
C       RM : NUMBER OF TIRE REVOLUTIONS PER MILE OF TRAVEL
C       CA : AIR RESISTANCE COEFFICIENT
C       CAW : TYPICAL AIR RESISTANCE COEFFICIENT WITH AERODYNAMIC AIDS
C       CAN : TYPICAL AIR RESISTANCE COEFFICIENT WITH NO AERODYNAMIC AIDS
C       CR1,CR2 : ROLLING RESISTANCE COEFFICIENTS
C       CRR1, CRR2 : TYPICAL ROLLING RESISTANCE COEFFICIENTS WITH
C                    RADIAL TIRES
C       CRB1, CRB2 : TYPICAL ROLLING RESISTANCE COEFFICIENTS WITH
C                    BIAS PLY TIRES
C       CH :  HIGHWAY SURFACE COEFFICIENT
C       CHG : HIGHWAY SURFACE COEFFICIENT, GOOD ROAD
C       CHF : HIGHWAY SURFACE COEFFICIENT, FAIR ROAD
C       CHP : HIGHWAY SURFACE COEFFICIENT, POOR ROAD
C       ED :  DRIVE AXLE EFFICIENCY
C       EDS : TYPICAL DRIVE AXLE EFFICIENCY, SINGLE DRIVE
C       EDT :  TYPICAL DRIVE AXLE EFFICIENCY, TANDEM DRIVE
C       ARD :  DRIVE AXLE RATIO
C       ART :  TRAILER AXLE RATIO
C       EO :  OVERALL DRIVELINE EFFICIENCY
C       ET : TRANSMISSION EFFICIENCY
C       ETMT : TYPICAL MANUAL TRANSMISSION EFFICIENCY
C       ETAT : TYPICAL AUTOMATIC TRANSMISSION EFFICIENCY
C       ETR :  TRAILER AXLE EFFICIENCY
C       PRS :  RATED ENGINE POWER (HP) AT RATED ENGINE SPEED
C       G(IG) : GEAR RATIO FOR GEAR IG
C       CPE1T : LINEAR ENGINE DRAG COEFFICIENT
C       CPE3T :  CUBIC ENGINE DRAG COEFFICIENT
C       SER, HPER : TABLE ENTRIES FOR ENGINE SPEED RETARDER
C       DRPM,HPDR : TABLE ENTRIES FOR DRIVELINE RETARDER
C       TRPM,HPTR : TABLE ENTRIES FOR TRAILER RETARDER
C
C
C     LIST OF TYPICAL VALUES
C
        CAW = 0.7
        CAN = 0.9
        CRR1 = .0041
        CRR2 = 0.000041
```

```
      CRB1 = .0066
      CRB2 = 0.000046
      CHG = 1.0
      CHF = 1.2
      CHP = 1.5
      EDS = 0.95
      EDT = 0.92
      ETMT = 0.95
      ETAT = 0.99
      ETRT = 0.95
      CPE1T = 0.006
      CPE3T = 8.4E-09
C
C   BEGIN I/O OPERATIONS - UNITS USED :
C     IR = 5 : FILE/DEVICE FOR READ
C     IW = 6 : FILE/DEVICE FOR WRITE
C
      IR = 5
      IW = 6
C
C   INPUT VEHICLE PARAMETERS
C
  251 CONTINUE
      WRITE(IW,100)
  100 FORMAT('&VEHICLE DESCRIPTION : ')
      READ(IR,101) VEH
  101 FORMAT(A4)
      WRITE(IW,102)
  102 FORMAT('&GVW/GCW (LB) : ')
      READ(IR,99) W
   99 FORMAT(F12.8)
      WRITE(IW,103)
  103 FORMAT('&FRONTAL AREA (FT**2) : ')
      READ(IR,99) A
  670 WRITE(IW,104)
  104 FORMAT('&AEROAIDS (1=NONE, 2=TYPICAL, 3=USERS CHOICE) :')
      READ(IR,98) IA
   98 FORMAT(I1)
      IF (IA .LT. 1 .OR. IA .GT. 3) GO TO 670
      IF (IA .EQ. 1) CA = CAN
      IF (IA .EQ. 2) CA = CAW
      IF (IA .NE. 3) WRITE(IW,105) CA
  105 FORMAT(' ',T5,'CA = ',F7.2)
      IF (IA .EQ. 3) WRITE(IW,106)
  106 FORMAT('&',T5,'CA = ')
      IF (IA .EQ. 3) READ(IR,99) CA
C
C   INPUT TIRE PARAMETERS
C
      WRITE(IW,107)
  107 FORMAT(////'&TIRE DESCRIPTION : ')
      READ(IR,101) TIRE
      WRITE(IW,108)
  108 FORMAT('&NO. OF REV PER MILE (498.0 FOR 10X20 TIRES) :')
      READ(IR,99) RM
  671 WRITE(IW,109)
  109 FORMAT('&ROLLING RESISTANCE FACTORS (1=RADIAL, 2=BIAS, ',
     1     '3=USERS CHOICE) :')
```

```
      READ(IR,98) IT
      IF (IT .LT. 1 .OR. IT .GT. 3) GO TO 671
      IF (IT .NE. 1) GO TO 10
      CR1 = CRR1
      CR2 = CRR2
   10 IF (IT .NE. 2) GO TO 11
      CR1 = CRB1
      CR2 = CRB2
   11 IF (IT .EQ. 3) GO TO 12
      WRITE(IW,110) CR1, CR2
  110 FORMAT(' ',T5,'CR1 =',F7.4/T5,'CR2 =',F8.6)
      GO TO 13
   12 WRITE(IW,111)
  111 FORMAT('&',T5,'CR1 =')
      READ(IR,99) CR1
      WRITE(IW,112)
  112 FORMAT('&',T5,'CR2 =')
      READ(IR,99) CR2
   13 CONTINUE
  672 WRITE(IW,113)
  113 FORMAT('&ROAD SURFACE FACTORS (1=GOOD, 2=FAIR, 3=POOR, '
     1      ,'4=USERS CHOICE) :')
      READ(IR,98) IRS
      IF (IRS .LT. 1 .OR. IRS .GT. 4) GO TO 672
      IF (IRS .EQ. 1) CH = CHG
      IF (IRS .EQ. 2) CH = CHF
      IF (IRS .EQ. 3) CH = CHP
      IF (IRS .NE. 4) WRITE(IW,114) CH
  114 FORMAT(' ',T5,'CH = ',F7.4)
      IF (IRS .EQ. 4) WRITE(IW,115)
  115 FORMAT('&',T5,'CH = ')
      IF (IRS .EQ. 4) READ(IR,99) CH
C
C   INPUT ENGINE PARAMETERS
C
C   ARRAY DECLARATIONS
C
      DIMENSION RPME(10), HPE(10), G(20)
C
      WRITE(IW,116)
  116 FORMAT(///'&ENGINE DESCRIPTION : ')
      READ(IR,101) ENG
      WRITE(IW,117)
  117 FORMAT('&VEMAX (MAXIMUM ENGINE SPEED, RPM) : ')
      READ(IR,99) VEMAX
      WRITE(IW,118)
  118 FORMAT('&VEMIN (MINIMUM ENGINE SPEED, RPM) : ')
      READ(IR,99) VEMIN
      WRITE(IW,119)
  119 FORMAT('&PRS (RATED HORSEPOWER) :')
      READ(IR,99) PRS
  673 WRITE(IW,120)
  120 FORMAT('&ENGINE DRAG (1=TYPICAL, 2=USERS CHOICE) (HP VS. RPM) :')
      READ(IR,98) IED
      IF (IED .LT. 1 .OR. IED .GT. 2) GO TO 673
      IF (IED .EQ. 2) GO TO 14
      NE = 4
      RPME(1) = VEMIN
```

```
      RPME(2) = VEMIN + (VEMAX-VEMIN)/3.
      RPME(3) = VEMIN + (VEMAX-VEMIN)*2./3.
      RPME(4) = VEMAX
      DO 15 IED = 1,NE
      HPE(IED) = (PRS/350.)*(CPE1T*RPME(IED) +CPE3T*RPME(IED)**3)
   15 CONTINUE
      WRITE(IW,121) NE
  121 FORMAT(' ',T5,'NO. OF DATA POINTS :',I2)
      WRITE(IW,122)
      DO 16 IED = 1,NE
      WRITE(IW,123) RPME(IED), HPE(IED)
  122 FORMAT(' ',T5,'RPM VALUE', T20,'HORSEPOWER')
  123 FORMAT(' ',T5,F10.2,T20,F10.2)
   16 CONTINUE
      GO TO 17
   14 CONTINUE
C
C   USER SUPPLIED TABLE
C     NOTE * MUST AT LEAST HAVE BOUNDARIES OF VEMIN AND VEMAX
C     IF NOT, PROGRAM WILL RECALCULATE TABLE TO INCLUDE VEMIN AND VEMAX
C
      WRITE(IW,124)
  124 FORMAT('&',T5,'NO. OF DATA POINTS (I1) :')
      READ(IR,98) NE
      WRITE(IW,170)
  170 FORMAT(' ENTER ENGINE RPM AND HORSEPOWER, ONE PAIR/LINE'/
     1      'SEPARATE BY A COMMA :')
      IFLAG = 0
      INO = 0
      DO 18 IED = 1,NE
      INDEX = IED + INO
      READ(IR,666) RPME(INDEX), HPE(INDEX)
      IF (IED .GT. 1) GO TO 19
      IF (RPME(1) .LE. VEMIN) GO TO 19
      RPME(INDEX+1) = RPME(INDEX)
      HPE(INDEX+1) = HPE(INDEX)
      RPME(INDEX) = VEMIN
      HPE(INDEX) = (PRS/350.)*(CPE1T*VEMIN + CPE3T*VEMIN**3)
      INO = 1
      IFLAG = 1
   19 IF (IED .NE. NE) GO TO 18
      IF (RPME(INDEX) .GE. VEMAX) GO TO 18
      IFLAG = 2
      RPME(INDEX+1) = VEMAX
      HPE(INDEX+1) = (PRS/350.)*(CPE1T*VEMAX + CPE3T*VEMAX**3)
   18 CONTINUE
      IF (IFLAG .EQ. 0) GO TO 17
      NE = NE + IFLAG
      WRITE(IW,126)
  126 FORMAT(' ',T5,' RECALCULATED TABLE TO INCLUDE VEMIN AND VEMAX :')
      WRITE(IW,121) NE
      WRITE(IW,122)
      DO 20 IED = 1,NE
      WRITE(IW,123) RPME(IED), HPE(IED)
   20 CONTINUE
   17 CONTINUE
C
C   DRIVE AXLE DESCRIPTION
```

```
C
      WRITE(IW,644)
  644 FORMAT(///'&DRIVE AXLE DESCRIPTION :')
      READ(IR,101)DT
      WRITE(IW,645)
  645 FORMAT('&DRIVE AXLE RATIO :')
      READ(IR,99) ARD
      WRITE(IW,146)
  146 FORMAT('&NUMBER OF DRIVE AXLES (1 OR 2) : ')
      READ(IR,98) NDA
  674 WRITE(IW,127)
  127 FORMAT('&DRIVE AXLE EFFICIENCY (1=TYPICAL, 2=USERS CHOICE) : ')
      READ(IR,98) IAE
      IF (IAE .LT. 1. OR. IAE .GT. 2) GO TO 674
      IF (IAE .NE. 1) GO TO 21
      IF (NDA .EQ. 1) ED = EDS
      IF (NDA .EQ. 2) ED = EDT
      WRITE(IW,128) ED
  128 FORMAT(' ',T5,'ED = ',F7.4)
      GO TO 22
   21 WRITE(IW,129)
  129 FORMAT('&',T5,'ED = ')
      READ(IR,99) ED
C
C   TRANSMISSION
C
   22 WRITE(IW,130)
  130 FORMAT(///'&TRANSMISSION DESCRIPTION :')
      READ(IR,101) T
      WRITE(IW,131)
  131 FORMAT('&TYPE (1=MANUAL, 2=AUTOMATIC) :')
      READ(IR,98) ITT
      WRITE(IW,132)
  132 FORMAT('&NUMBER OF GEARS :')
      READ(IR,980) NG
  980 FORMAT(I2)
      WRITE(IW,133)
  133 FORMAT('GEAR RATIOS :')
      DO 23 I=1,NG
      IF (I .LT. 10) WRITE(IW,134) I
      IF (I .GE. 10) WRITE(IW,135) I
  134 FORMAT('&',T5,'G(',I1,') : ')
  135 FORMAT('&',T5,'G(',I2,') : ')
      READ(IR,99) G(I)
   23 CONTINUE
  675 WRITE(IW,136)
  136 FORMAT('&TRANSMISSION EFFICIENCY (1=TYPICAL, 2=USERS CHOICE) : ')
      READ(IR,98) ITE
      IF (ITE .LT. 1 .OR. ITE .GT. 2) GOTO 675
      IF (ITE .NE. 1) GO TO 24
      IF (ITT .EQ. 1) ET = ETMT
      IF (ITT .EQ. 2) ET = ETAT
      WRITE(IW,137) ET
  137 FORMAT(' ',T5,'ET =',F7.4)
      GO TO 25
   24 WRITE(IW,138)
  138 FORMAT('&',T5,'ET = ')
      READ(IR,99) ET
```

```
C
C   PRINT OUT SUMMARY
C
  25 WRITE(IW,139)
 139 FORMAT(/'O****************************************************')
C
C   ARRAYS FOR SUMMARY
C
      DIMENSION RPMV(4), VV(20,4), PN(20,4), PE(20,4), PV(20,4)
C
      RPMV(1) = VEMAX
      RPMV(2) = VEMAX - (VEMAX-VEMIN)/3.
      RPMV(3) = VEMIN + (VEMAX-VEMIN)/3.
      RPMV(4) = VEMIN
C
      DO 5 IG = 1,NG
      DO 5 IV = 1,4
      VV(IG,IV) = (RPMV(IV)*60.)/(RM*ARD*G(IG))
    5 CONTINUE
C
      EO = ET*ED
      DO 6 IG = 1,NG
      DO 6 IV = 1,4
      PN(IG,IV) = ((A*CA*(.0024)*(VV(IG,IV)**3)) +
     1      (CH*W*(CR1+CR2*VV(IG,IV))*VV(IG,IV)))/375.
      CALL TABLE(1,NE,RPME,HPE,RPMV(IV),PE(IG,IV) )
      PV(IG,IV) = PN(IG,IV) + PE(IG,IV)/ EO
C
    6 CONTINUE
C
      WRITE(IW,140)
 140 FORMAT('OSUMMARY OF VEHICLE CHARACTERISTICS :'/
     1          ' -----------------------------------'/'O',T5,'GEAR',T15,
     2'VEH. VEL.',T30,'RETARDATION',T50,'VEH. VEL.',T65,'RETARDATION'/
     3T13,'AT VEMAX (MPH)',T28,'AT VEMAX (HP)',T48,'AT VEMIN (MPH)',
     4T63,'AT VEMIN (HP)')
C
      DO 7 IG = 1,NG
      WRITE(IW,141) IG,VV(IG,1),PV(IG,1),VV(IG,4),PV(IG,4)
 141 FORMAT(T7,I2,T15,F8.2,T30,F8.2,T50,F8.2,T65,F8.2)
    7 CONTINUE
      WRITE(IW,142) EO
 142  FORMAT('O',T5,'OVERALL EFFICIENCY, EO = ',F7.2)
      WRITE(IW,139)
C
C   RETARDER INFORMATION
C
C   INITIALIZE ALL RETARDERS TO ZERO
C
      DIMENSION PRE(20,4), PRD(20,4), PRT(20,4)
 250 CONTINUE
      DO 9 IG = 1,NG
      DO 9 IV = 1,4
      PRE(IG,IV)= O.
      PRD(IG,IV) =O.
      PRT(IG,IV) = O.
    9 CONTINUE
      WRITE(IW,143)
```

```
  143 FORMAT('&RETARDER DESCRIPTIONS : ')
      READ(IR,101) RD
      WRITE(IW,144)
C
C   ENGINE SPEED RETARDER
C
  144 FORMAT('OENGINE SPEED RETARDER :'/'&ENTER NO. OF DATA POINTS ',
     1      ' (I2 - ENTER O FOR NO RETARDER) ')
      DIMENSION SER(20),HPER(20)
      READ(IR,980) NESR
      IF (NESR .EQ. O) GO TO 26
      WRITE(IW,145)
  145 FORMAT('NOTE: FIRST ENGINE SPEED SHOULD BE LESS THAN OR EQUAL'/
     1       '       TO VEMIN, AND LAST ENGINE SPEED SHOULD BE GREATER'/
     2       '       THAN OR EQUAL TO VEMAX'/
     3    'O      ENTER ENGINE SPEED AND RETARDER HP, ONE PAIR/LINE, '
     4       ,'SEPARATE BY A COMMA')
      DO 8 IER = 1,NESR
      READ(IR,666) SER(IER),HPER(IER)
  666 FORMAT(2F10.4)
    8 CONTINUE
C
C   INTERPOLATE USING TABLE SUBROUTINE FOR PRE VALUES
C
      DO 30 IG = 1,NG
      DO 30 IV = 1,4
      RPMES = VV(IG,IV)/60.*RM*G(IG)*ARD
      CALL TABLE(1,NESR,SER,HPER,RPMES,PRE(IG,IV) )
   30 CONTINUE
C
C
C   DRIVELINE RETARDER
C
      DIMENSION DRPM(20), HPDR(20)
   26 CONTINUE
      WRITE(IW,150)
  150 FORMAT(///'ODRIVELINE RETARDER :'/'&ENTER NO. OF DATA POINTS',
     1      ' (ENTER A O FOR NO RETARDER) ')
      READ(IR,980) NDLR
      IF (NDLR .EQ. O) GO TO  27
      WRITE(IW,151)
  151 FORMAT('ENTER DRIVELINE RPM AND RETARDER HP ONE PAIR/LINE'/
     1       'SEPARATE BY A COMMA' )
      DO 41 IDL = 1,NDLR
      READ(IR,666) DRPM(IDL), HPDR(IDL)
   41 CONTINUE
C
C   INTERPOLATE FOR PRD VALUES USING SUBROUTINE TABLE
C
      DO 31 IG = 1,NG
      DO 31 IV = 1,4
      RPMD = VV(IG,IV)/60. * RM * ARD
      CALL TABLE(1,NDLR,DRPM,HPDR,RPMD,PRD(IG,IV))
   31 CONTINUE
C
C   TRAILER AXLE RETARDER
C
      DIMENSION TRPM(20), HPTR(20)
```

```
   27 CONTINUE
      WRITE(IW,155)
  155 FORMAT(///'OTRAILER RETARDER :'/'&ENTER NO. OF DATA POINTS ',
     1      '(ENTER A O FOR NO RETARDER)' )
      READ(IR,980) NTR
      IF (NTR .EQ. O) GO TO  28
      WRITE(IW,156)
  156 FORMAT('&ENTER TRAILER AXLE RATIO : ')
      READ(IR,99) ART
      WRITE(IW,157)
  157 FORMAT('&ENTER TRAILER AXLE EFFICIENCY : ')
      READ(IR,99) ETR
      WRITE(IW,158)
  158 FORMAT(' ENTER TRAILER RPM AND RETARDER HP, ONE PAIR/LINE'/
     1       ' SEPARATE BY A COMMA ')
      DO 42 ITR = 1,NTR
      READ(IR,666) TRPM(ITR), HPTR(ITR)
   42 CONTINUE
C
C   INTERPOLATE FOR PRT USING SUBROUTINE TABLE
C
      DO 32 IG = 1,NG
      DO 32 IV=1,4
      RPMT = VV(IG,IV)/60. * RM * ART
      CALL TABLE(1,NTR,TRPM,HPTR,RPMT,PRT(IG,IV))
   32 CONTINUE
   28 CONTINUE
      WRITE(IW,139)
C
C   CALCULATION OF PS(IG,IV)
C
      DIMENSION PS(20,4)
      DO 33 IG = 1,NG
      DO 33 IV = 1,4
      PS(IG,IV) = PV(IG,IV) + PRE(IG,IV)/EO + PRD(IG,IV)/ED +
     1      PRT(IG,IV)/ETR
   33 CONTINUE
C
      WRITE(IW,160)
  160 FORMAT('OSUMMARY OF TOTAL RETARDATION'/
     1       ' ----------------------------')
  161 FORMAT('O',T5,'GEAR',T15,'VEH. VEL. ',T30,'HP (TOTAL)')
      DO 34 IV=1,4
      DO 34 IG = 1,NG
      IF (IG .EQ. 1) WRITE(IW,161)
      WRITE(IW,162) IG,VV(IG,IV),PS(IG,IV)
  162 FORMAT(T6,I2,T14,F10.2,T30,F10.2)
   34 CONTINUE
C
C    CALCULATE MAXIMUM GRADE
C
      DIMENSION GRM(20,4)
      DO 36 IG = 1,NG
      DO 36 IV = 1,4
      GRM(IG,IV) = ((PS(IG,IV)*375.)/(W*VV(IG,IV)))*100.
   36 CONTINUE
C
      WRITE(IW,139)
```

```
      WRITE(IW,165)
  165 FORMAT('OMAXIMUM GRADES AT VARIOUS CONTROL SPEEDS'/
     1       ' ----------------------------------------')
  166 FORMAT('O',T5,'GEAR',T15,'VEH. VEL.',T30,'GRADE (%)')
      DO 37 IV = 1,4
      DO 37 IG = 1,NG
      IF (IG .EQ. 1) WRITE(IW,166)
      WRITE(IW,162) IG,VV(IG,IV),GRM(IG,IV)
   37 CONTINUE
C
      WRITE(IW,260)
  260 FORMAT(///' ')
C*********************************************************************
C*
C*    PLOT ROUTINE REQUIRES 132 CHARACTER LINE CAPABILITY
C      IF USER HAS SUCH APABILITY AVAILABLE AND WISHES TO PLOT
C      RESULTS, REMOVE COMMENT 'C' FROM THE NEXT CALL STATEMENT
C      BEFORE COMPILING THE SOURCE FOR THE PROGRAM
C*
C*********************************************************************
C      CALL PLOT(GRM,VV,NG,IW)
C
C    CHECK FOR RERUN CONDITIONS
C
      DATA END / 'E   '/
      DATA REP /'N   '/
      DATA RET /'R   '/
      WRITE(IW,139)
      WRITE(IW,255)
  255 FORMAT('&E - EXIT, N - NEW RUN, R - CHANGE RETARDER : ')
      READ(IR,101) WHAT
      IF (WHAT .EQ. END) CALL EXIT
      IF (WHAT .EQ. REP) GO TO 251
      IF (WHAT .EQ. RET) GO TO 250
      END
C
C    *** SUBROUTINE TABLE ***
C
C    ARGUMENTS USED :
C           M : LOWER ARRAY INDEX
C           N : UPPER ARRAY INDEX
C           X : ARRAY CONTAINING INDEPENDENT VARIABLES
C           Y : ARRAY CONTAINING DEPENDENT VARIABLES
C           Z : VALUE FOR WHICH Y VALUE IS TO BE CALCULATED
C           Q : RETURNED VALUE OF Y
C
      SUBROUTINE TABLE(M, N, X, Y, Z, Q)
      DIMENSION X(1), Y(1)
      DO 20 I = M, N
        IF (Z .LE. X(I)) GO TO 30
   20 CONTINUE
      Q = Y(N)
      RETURN
   30 IF (I .NE. M .AND. Z .NE. X(I)) GO TO 40
      Q = Y(I)
      IF (I .EQ. M .AND. Z .LT. X(I)) Q = Y(M)
      RETURN
   40 Q = (Y(I)*(Z - X(I - 1)) - Y(I - 1)*(Z - X(I))) / (X(I) - X(I
```

```
     1- 1))
      RETURN
      END
      SUBROUTINE PLOT(GRM,VV,NG,IW)
      DIMENSION GRM(20,4),VV(20,4)
      LOGICAL * 1 GRID(40,120), SYM(20), BLANK
      DATA SYM/'1','2','3','4','5','6','7','8','9','A','B','C','D',
     1      'E','F','*','+','&','X','0'/
      DATA BLANK /' '/
      DO 10 I=1,40
      DO 10 J=1,120
      GRID(I,J) = BLANK
   10 CONTINUE
C
      DO 11 IG = 1,NG
      MG = 0
      MVC = 0
      DO 11 IV=1,4
      IF (GRM(IG,IV) .GT. 10.) GO TO 11
      IF (VV(IG,IV) .GT. 60.) GO TO 11
      MG = 4.*(GRM(IG,IV) + .05)
      MG = 41 - MG
      MVC = 2.*(VV(IG,IV) + .05)
      GRID(MG,MVC) = SYM(IG)
   11 CONTINUE
C
      INC = 10
      DO 12 I=1,40
      IF ( (I-1)/4*4 .NE. (I-1) ) GO TO 21
      WRITE(IW,100) INC, (GRID(I,J),J=1,120)
  100 FORMAT(T6,I2,' +',120A1)
      INC = INC - 1
      GO TO 12
   21 IF (I .LT. 26 .OR. I .GT. 28) GO TO 22
      IF (I .EQ. 26) WRITE(IW,104) (GRID(I,J),J=1,120)
      IF (I .EQ. 27) WRITE(IW,105) (GRID(I,J),J=1,120)
      IF (I .EQ. 28) WRITE(IW,106) (GRID(I,J),J=1,120)
  104 FORMAT(T2,'MAX',T9,'I',120A1)
  105 FORMAT(T2,'GRADE',T9,'I',120A1)
  106 FORMAT(T2,'(%)',T9,'I',120A1)
      GO TO 12
   22 CONTINUE
      WRITE(IW,110) (GRID(I,J),J=1,120)
  110 FORMAT(T9,'I',120A1)
   12 CONTINUE
C
      WRITE(IW,111)
  111 FORMAT(T7,'0',T9,'+---------+---------+---------+---------+',
     1 '---------+---------+---------+---------+---------+---------+',
     1   '---------+---------+'//T9,'0',T29,'10',T49,'20',T69,'30',
     1   T89,'40',T109,'50',T129,'60'//
     2   T52,'CONTROL VELOCITY (MPH)'//)
      RETURN
      END
```

```
#Execution begins
 VEHICLE DESCRIPTION :
 GVW/GCW (LB) :  75880.
 FRONTAL AREA (FT**2) :  84.
 AEROAIDS (1=NONE, 2=TYPICAL, 3=USERS CHOICE) : 1
    CA =    0.90



 TIRE DESCRIPTION :
 NO. OF REV PER MILE (498.0 FOR 10X20 TIRES) : 498.
 ROLLING RESISTANCE FACTORS (1=RADIAL, 2=BIAS, 3=USERS CHOICE) : 1
    CR1 = 0.0041
    CR2 =0.000041
 ROAD SURFACE FACTORS (1=GOOD, 2=FAIR, 3=POOR, 4=USERS CHOICE) : 2
    CH =  1.2000



 ENGINE DESCRIPTION :
 VEMAX (MAXIMUM ENGINE SPEED, RPM) :  2100.
 VEMIN (MINIMUM ENGINE SPEED, RPM) :  800.
 PRS (RATED HORSEPOWER) : 350.
 ENGINE DRAG (1=TYPICAL, 2=USERS CHOICE) (HP VS. RPM) : 1
    NO. OF DATA POINTS : 4
    RPM VALUE      HORSEPOWER
       800.00          9.10
      1233.33         23.16
      1666.67         48.89
      2100.00         90.39



 DRIVE AXLE DESCRIPTION :
 DRIVE AXLE RATIO : 3.7
 NUMBER OF DRIVE AXLES (1 OR 2) :  2
 DRIVE AXLE EFFICIENCY (1=TYPICAL, 2=USERS CHOICE) :  1
    ED =  0.9200



 TRANSMISSION DESCRIPTION :
 TYPE (1=MANUAL, 2=AUTOMATIC) : 1
 NUMBER OF GEARS : 13
 GEAR RATIOS :
    G(1) :  12.51
    G(2) :  8.35
    G(3) :  6.12
    G(4) :  4.56
    G(5) :  3.38
    G(6) :  2.47
    G(7) :  2.14
    G(8) :  1.81
    G(9) :  1.57
    G(10) :  1.35
    G(11) :  1.17
    G(12) :  1.00
    G(13) :  0.87
 TRANSMISSION EFFICIENCY (1=TYPICAL, 2=USERS CHOICE) :  1
    ET = 0.9500
```



```
****************************************************
```

SUMMARY OF VEHICLE CHARACTERISTICS :

GEAR	VEH. VEL. AT VEMAX (MPH)	RETARDATION AT VEMAX (HP)	VEH. VEL. AT VEMIN (MPH)	RETARDATION AT VEMIN (HP)
1	5.47	109.24	2.08	12.53
2	8.19	112.51	3.12	13.63
3	11.17	116.47	4.26	14.87
4	15.00	122.22	5.71	16.52
5	20.23	131.65	7.71	18.90
6	27.68	148.88	10.55	22.59
7	31.95	161.19	12.17	24.88
8	37.78	181.34	14.39	28.25
9	43.56	205.65	16.59	31.88
10	50.65	242.27	19.30	36.81
11	58.45	292.21	22.27	42.85
12	68.38	372.76	26.05	51.66
13	78.60	478.12	29.94	62.14

OVERALL EFFICIENCY, EO = 0.87

****

RETARDER DESCRIPTIONS :

ENGINE SPEED RETARDER :
ENTER NO. OF DATA POINTS (I2 - ENTER 0 FOR NO RETARDER) 04
NOTE: FIRST ENGINE SPEED SHOULD BE LESS THAN OR EQUAL
TO VEMIN, AND LAST ENGINE SPEED SHOULD BE GREATER
THAN OR EQUAL TO VEMAX

ENTER ENGINE SPEED AND RETARDER HP, ONE PAIR/LINE, SEPARATE BY A COMMA

```
800.,60.
1300.,125.
1900.,210.
2200.,325.
```

DRIVELINE RETARDER :
ENTER NO. OF DATA POINTS (ENTER A 0 FOR NO RETARDER) 00

TRAILER RETARDER :
ENTER NO. OF DATA POINTS (ENTER A 0 FOR NO RETARDER) 00

****

SUMMARY OF TOTAL RETARDATION

GEAR	VEH. VEL.	HP (TOTAL)
1	5.47	448.20
2	8.19	451.47
3	11.17	455.42
4	15.00	461.18
5	20.23	470.60
6	27.68	487.84
7	31.95	500.14
8	37.78	520.29
9	43.56	544.61

11	58.45	631.17
12	68.38	711.72
13	78.60	817.08

GEAR	VEH. VEL.	HP (TOTAL)
1	4.34	274.82
2	6.50	277.30
3	8.87	280.23
4	11.90	284.35
5	16.06	290.83
6	21.97	302.09
7	25.36	309.82
8	29.98	322.12
9	34.57	336.57
10	40.20	357.82
11	46.39	386.17
12	54.27	430.97
13	62.38	488.57

GEAR	VEH. VEL.	HP (TOTAL)
1	3.21	162.92
2	4.81	164.67
3	6.56	166.70
4	8.81	169.47
5	11.88	173.65
6	16.26	180.50
7	18.77	184.99
8	22.19	191.88
9	25.58	199.68
10	29.75	210.77
11	34.33	225.07
12	40.16	246.98
13	46.16	274.36

GEAR	VEH. VEL.	HP (TOTAL)
1	2.08	81.18
2	3.12	82.28
3	4.26	83.52
4	5.71	85.17
5	7.71	87.55
6	10.55	91.24
7	12.17	93.53
8	14.39	96.90
9	16.59	100.53
10	19.30	105.46
11	22.27	111.50
12	26.05	120.31
13	29.94	130.79

****

MAXIMUM GRADES AT VARIOUS CONTROL SPEEDS

GEAR	VEH. VEL.	GRADE (%)
1	5.47	40.52
2	8.19	27.24
3	11.17	20.14
4	15.00	15.20
5	20.23	11.50
6	27.68	8.71
7	31.95	7.74
8	37.78	6.81
9	43.56	6.18

11	58.45	5.34
12	68.38	5.14
13	78.60	5.14

GEAR	VEH. VEL.	GRADE (%)
1	4.34	31.31
2	6.50	21.08
3	8.87	15.62
4	11.90	11.81
5	16.06	8.95
6	21.97	6.79
7	25.36	6.04
8	29.98	5.31
9	34.57	4.81
10	40.20	4.40
11	46.39	4.11
12	54.27	3.92
13	62.38	3.87

GEAR	VEH. VEL.	GRADE (%)
1	3.21	25.08
2	4.81	16.92
3	6.56	12.55
4	8.81	9.51
5	11.88	7.22
6	16.26	5.49
7	18.77	4.87
8	22.19	4.27
9	25.58	3.86
10	29.75	3.50
11	34.33	3.24
12	40.16	3.04
13	46.16	2.94

GEAR	VEH. VEL.	GRADE (%)
1	2.08	19.27
2	3.12	13.03
3	4.26	9.70
4	5.71	7.37
5	7.71	5.61
6	10.55	4.28
7	12.17	3.80
8	14.39	3.33
9	16.59	2.99
10	19.30	2.70
11	22.27	2.47
12	26.05	2.28
13	29.94	2.16

```
****************************************************
E - EXIT, N - NEW RUN, R - CHANGE RETARDER :  R
RETARDER DESCRIPTIONS :

ENGINE SPEED RETARDER :
ENTER NO. OF DATA POINTS  (I2 - ENTER 0 FOR NO RETARDER)  00
```



```
DRIVELINE RETARDER :
```

ENTER DRIVELINE RPM AND RETARDER HP ONE PAIR/LINE
SEPARATE BY A COMMA
0.,0.
3000.,440.

TRAILER RETARDER :
ENTER NO. OF DATA POINTS (ENTER A 0 FOR NO RETARDER) 00

****

SUMMARY OF TOTAL RETARDATION

GEAR	VEH. VEL.	HP (TOTAL)
1	5.47	136.00
2	8.19	152.60
3	11.17	171.17
4	15.00	195.64
5	20.23	230.69
6	27.68	284.42
7	31.95	317.63
8	37.78	366.30
9	43.56	418.89
10	50.65	490.26
11	58.45	578.35
12	68.38	707.54
13	78.60	862.93

GEAR	VEH. VEL.	HP (TOTAL)
1	4.34	81.72
2	6.50	94.78
3	8.87	109.30
4	11.90	128.28
5	16.06	155.10
6	21.97	195.32
7	25.36	219.64
8	29.98	254.58
9	34.57	291.47
10	40.20	340.30
11	46.39	398.92
12	54.27	482.33
13	62.38	579.63

GEAR	VEH. VEL.	HP (TOTAL)
1	3.21	45.53
2	4.81	55.12
3	6.56	65.72
4	8.81	79.49
5	11.88	98.71
6	16.26	127.00
7	18.77	143.76
8	22.19	167.40
9	25.58	191.81
10	29.75	223.30
11	34.33	260.02
12	40.16	310.49
13	46.16	367.26

GEAR	VEH. VEL.	HP (TOTAL)
1	2.08	22.73
2	3.12	28.90

4	5.71	44.48
5	7.71	56.63
6	10.55	74.22
7	12.17	84.48
8	14.39	98.71
9	16.59	113.12
10	19.30	131.28
11	22.27	151.86
12	26.05	179.19
13	29.94	208.73

****

MAXIMUM GRADES AT VARIOUS CONTROL SPEEDS

GEAR	VEH. VEL.	GRADE (%)
1	5.47	12.30
2	8.19	9.21
3	11.17	7.57
4	15.00	6.45
5	20.23	5.64
6	27.68	5.08
7	31.95	4.91
8	37.78	4.79
9	43.56	4.75
10	50.65	4.78
11	58.45	4.89
12	68.38	5.11
13	78.60	5.43

GEAR	VEH. VEL.	GRADE (%)
1	4.34	9.31
2	6.50	7.21
3	8.87	6.09
4	11.90	5.33
5	16.06	4.77
6	21.97	4.39
7	25.36	4.28
8	29.98	4.20
9	34.57	4.17
10	40.20	4.18
11	46.39	4.25
12	54.27	4.39
13	62.38	4.59

GEAR	VEH. VEL.	GRADE (%)
1	3.21	7.01
2	4.81	5.66
3	6.56	4.95
4	8.81	4.46
5	11.88	4.11
6	16.26	3.86
7	18.77	3.79
8	22.19	3.73
9	25.58	3.71
10	29.75	3.71
11	34.33	3.74
12	40.16	3.82
13	46.16	3.93

GEAR	VEH. VEL.	GRADE (%)
1	2.08	5.39
2	3.12	4.58

4	5.71	3.85
5	7.71	3.63
6	10.55	3.48
7	12.17	3.43
8	14.39	3.39
9	16.59	3.37
10	19.30	3.36
11	22.27	3.37
12	26.05	3.40
13	29.94	3.45

```
*****************************************************
E - EXIT, N - NEW RUN, R - CHANGE RETARDER :  R
RETARDER DESCRIPTIONS :  00

ENGINE SPEED RETARDER :
ENTER NO. OF DATA POINTS  (I2 - ENTER 0 FOR NO RETARDER)  00


DRIVELINE RETARDER :
ENTER NO. OF DATA POINTS (ENTER A 0 FOR NO RETARDER)  00


TRAILER RETARDER :
ENTER NO. OF DATA POINTS (ENTER A 0 FOR NO RETARDER) 02
ENTER TRAILER AXLE RATIO :  3.7
ENTER TRAILER AXLE EFFICIENCY :  .95
ENTER TRAILER RPM AND RETARDER HP, ONE PAIR/LINE
SEPARATE BY A COMMA
0.,0.
3000.,440.

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```

SUMMARY OF TOTAL RETARDATION

GEAR	VEH. VEL.	HP (TOTAL)
1	5.47	135.16
2	8.19	151.34
3	11.17	169.44
4	15.00	193.32
5	20.23	227.57
6	27.68	280.14
7	31.95	312.69
8	37.78	360.46
9	43.56	412.15
10	50.65	482.43
11	58.45	569.32
12	68.38	696.97
13	78.60	850.77

GEAR	VEH. VEL.	HP (TOTAL)
1	4.34	81.05
2	6.50	93.78

4	11.90	126.44
5	16.06	152.62
6	21.97	191.92
7	25.36	215.72
8	29.98	249.94
9	34.57	286.12
10	40.20	334.08
11	46.39	391.75
12	54.27	473.94
13	62.38	569.99

GEAR	VEH. VEL.	HP (TOTAL)
1	3.21	45.03
2	4.81	54.37
3	6.56	64.71
4	8.81	78.12
5	11.88	96.88
6	16.26	124.48
7	18.77	140.86
8	22.19	163.97
9	25.58	187.86
10	29.75	218.71
11	34.33	254.71
12	40.16	304.28
13	46.16	360.12

GEAR	VEH. VEL.	HP (TOTAL)
1	2.08	22.41
2	3.12	28.42
3	4.26	35.05
4	5.71	43.60
5	7.71	55.44
6	10.55	72.59
7	12.17	82.59
8	14.39	96.48
9	16.59	110.55
10	19.30	128.29
11	22.27	148.42
12	26.05	175.16
13	29.94	204.10

****

MAXIMUM GRADES AT VARIOUS CONTROL SPEEDS

GEAR	VEH. VEL.	GRADE (%)
1	5.47	12.22
2	8.19	9.13
3	11.17	7.49
4	15.00	6.37
5	20.23	5.56
6	27.68	5.00
7	31.95	4.84
8	37.78	4.72
9	43.56	4.68
10	50.65	4.71
11	58.45	4.81
12	68.38	5.04
13	78.60	5.35

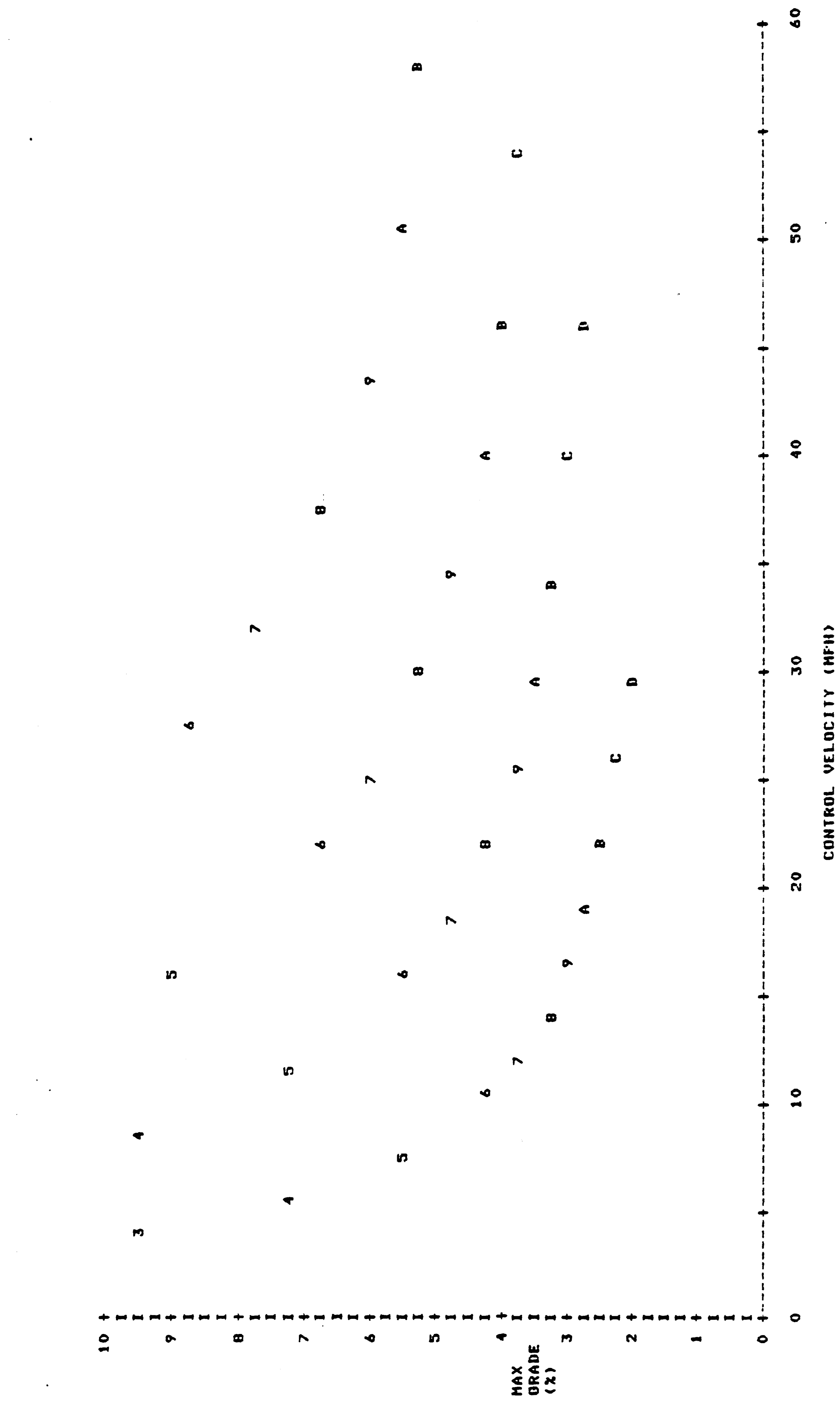
GEAR	VEH. VEL.	GRADE (%)
1	4.34	9.23
2	6.50	7.13

4	11.90	5.25
5	16.06	4.70
6	21.97	4.32
7	25.36	4.20
8	29.98	4.12
9	34.57	4.09
10	40.20	4.11
11	46.39	4.17
12	54.27	4.32
13	62.38	4.52

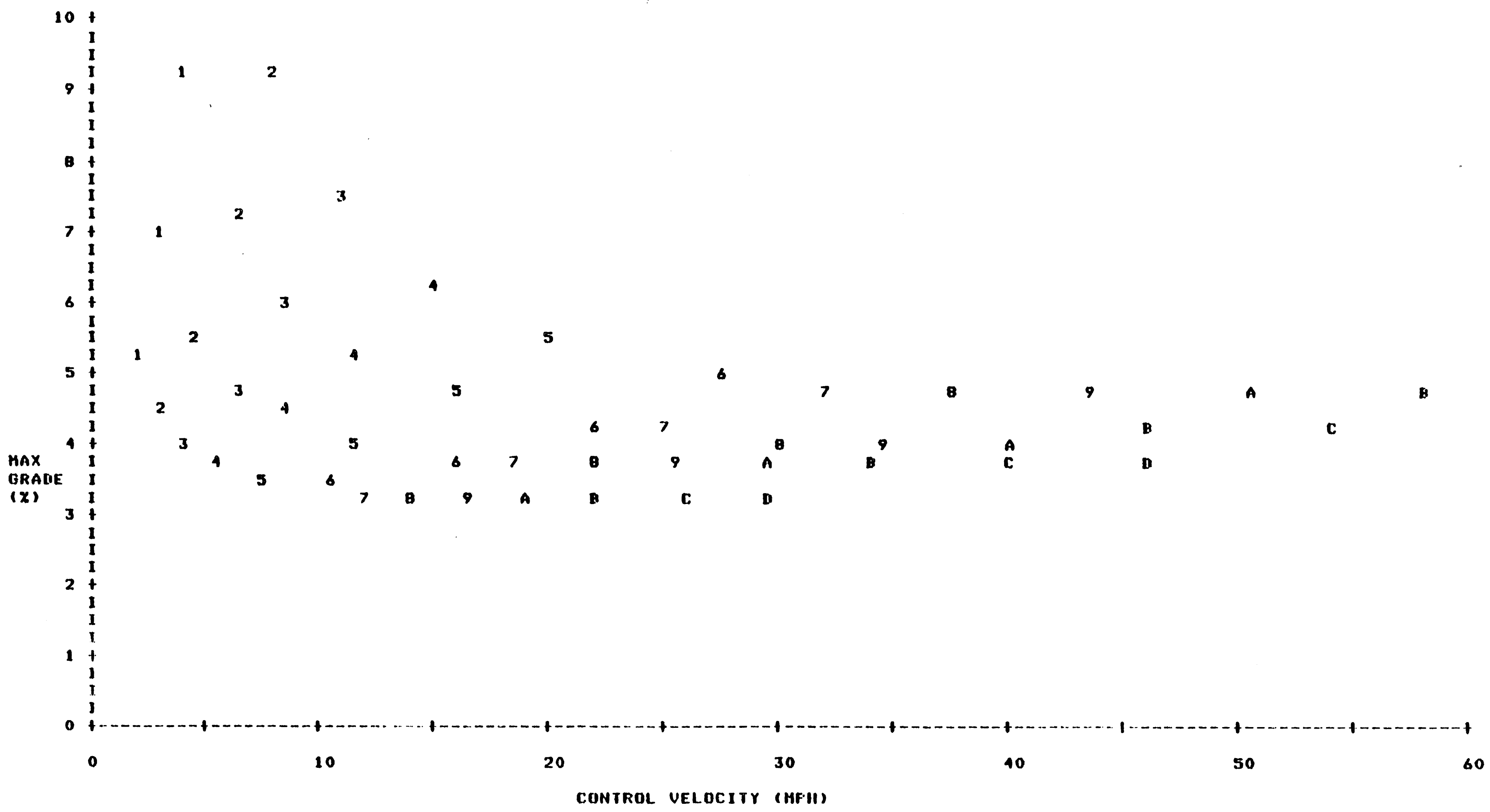
GEAR	VEH. VEL.	GRADE (%)
1	3.21	6.93
2	4.81	5.59
3	6.56	4.87
4	8.81	4.38
5	11.88	4.03
6	16.26	3.78
7	18.77	3.71
8	22.19	3.65
9	25.58	3.63
10	29.75	3.63
11	34.33	3.67
12	40.16	3.74
13	46.16	3.86

GEAR	VEH. VEL.	GRADE (%)
1	2.08	5.32
2	3.12	4.50
3	4.26	4.07
4	5.71	3.77
5	7.71	3.55
6	10.55	3.40
7	12.17	3.35
8	14.39	3.31
9	16.59	3.29
10	19.30	3.29
11	22.27	3.29
12	26.05	3.32
13	29.94	3.37

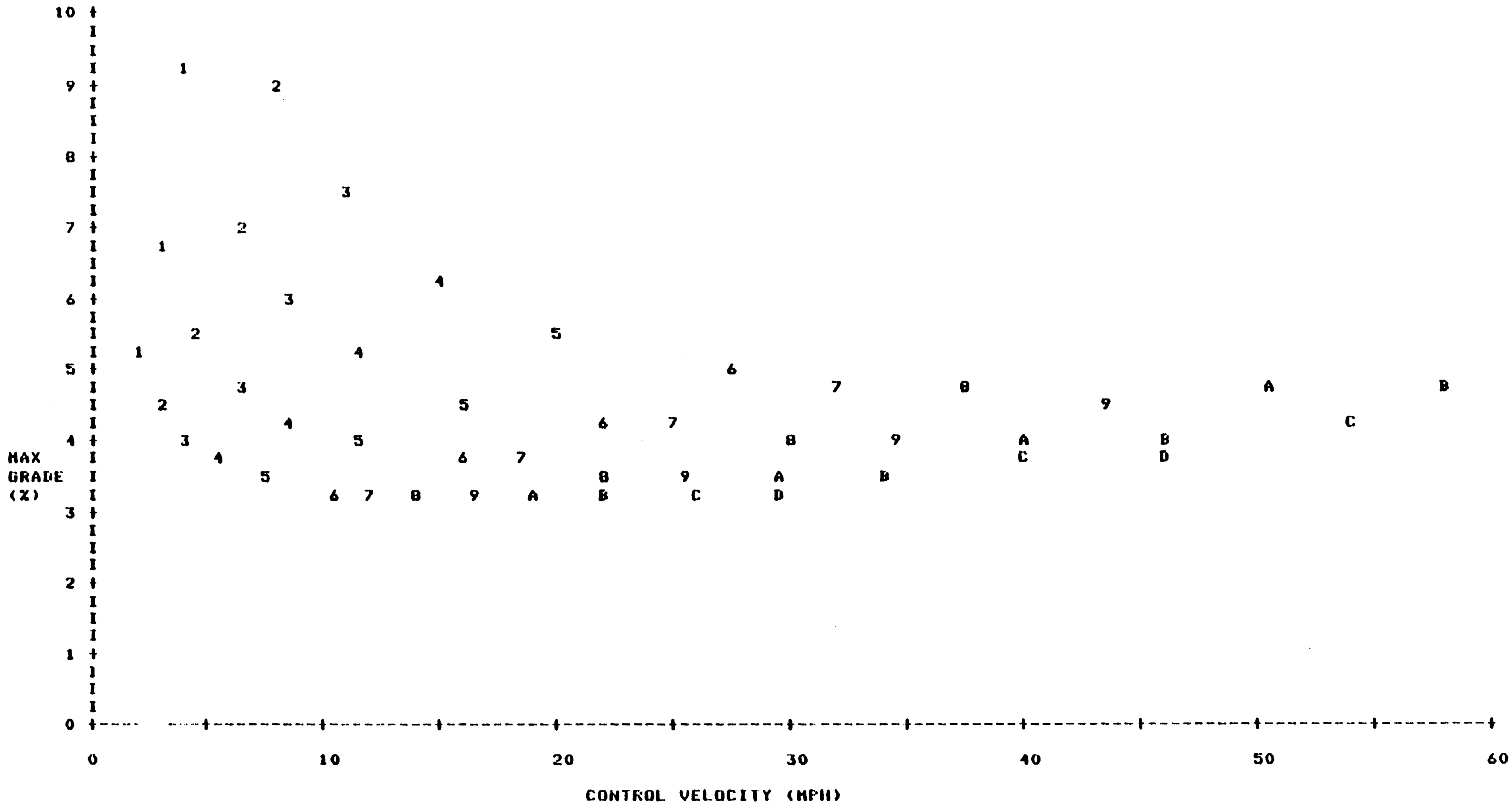
```
 *************************************************
 E - EXIT, N - NEW RUN, R - CHANGE RETARDER :  E
#Execution terminated
#
```



ENGINE SPEED



DRIVELINE




```
*******************************************************
 E - EXIT, N - NEW RUN, R - CHANGE RETARDER :  E
$Execution terminated
$
```

TRAILER

APPENDIX B

A Brake Temperature Algoritym

This appendix provides a simple algorithm for computing brake temperatures based on the power absorbed and dissipated by the brake.

```
C*************************************************
C
C   BRAKE TEMPERATURE          PREDICTION PROCEDURE
C
C*************************************************
C
C   THE PURPOSE OF THIS PROGRAM IS TO PREDICT BRAKE TEMPERATURE
C          AS A FUNCTION OF VELOCITY AND ELEVATION PROFILES FOR A
C     USER-SPECIFIED 5-AXLE TRACTOR SEMITRAILER.
C
C   THE INPUT INFORMATION REQUIRED TO RUN THIS PROGRAM CONSISTS OF SETS
C     OF DATA DESCRIBING (1) THE ROUTE (ELEVATION AND VELOCITY) AND
C     (2) THE BRAKING / RETARDING CAPABILITY OF THE SPECIFIED VEHICLE
C     AND ITS WEIGHT.
C
C   THE PROGRAM CALCULATES THE TEMPERATURE AND WEAR FOR EACH BRAKE ON
C   . THE TRACTOR AND SEMITRAILER.  THE OUTPUTS FROM THIS CALCULATION
C     ARE TIME (OR DISTANCE) HISTORIES OF TEMPERATURE           FOR
C     EACH BRAKE.  THE NUMERICS USED TO SUMMARIZE THESE TIME HISTORIES
C     ARE THE MAXIMUM TEMPERATURES ATTAINED
C
C
C*******************************************************************
C
      DIMENSION D(200), E(200), V(200), TEMP1(10), TEMPA(10), HPB(10),
     1     PROP(10), CH1(10), CH2(10), H(10), TIME(200), SLOPE(200),
     2     ACC(200), TP(200), TEMP(10,200)
      REAL MCP(10)
C
C   READ IN PROFILE DATA
C
      READ(5,100) NPTS
  100 FORMAT(I3)
      DO 10 I=1,NPTS
      READ(5,101) D(I), V(I), E(I)
  101 FORMAT(3F10.4)
   10 CONTINUE
C
C   READ IN TEMPERATURES
C
      READ(5,102) TEMP1
      READ(5,102) TEMPA
  102 FORMAT(10F12.6)
      READ(5,101) DT
C
C   VEHICLE PARAMETERS
C
      READ(5,101) W
      READ(5,102) PROP
C
C   READ IN RETARDER PARAMETERS
C
      READ(5,105) CRR
      READ(5,105) CA
      READ(5,105) CE
      READ(5,105) AF
      READ(5,105) HPRE
      READ(5,105) HPR
```

```
  105 FORMAT(F10.4)
      HPE = HPRE * CE
C
C   READ IN BRAKE PARAMETERS
C
      READ(5,102) MCP
      READ(5,102) CH1
      READ(5,102) CH2
C
C   CALCULATIONS FOR TIME, SLOPES AND ACCELERATIONS
C
      NPTS1 = NPTS - 1
      TIME(1) = 0.
      DO 11 I=1,NPTS1
      TP(I) = 2. * ( D(I+1) - D(I) ) / (V(I+1)+V(I))
      TIME(I+1) = TIME(I) + TP(I)
C
      ACC(I) = (( V(I+1) - V(I) ) / TP(I) ) *5280./3600./3600.
C
      SLOPE(I) = (( E(I+1) - E(I) ) / (D(I+1) - D(I) ))/5280.
      TP(I) = TP(I)*3600.
   11 CONTINUE
C
C   UNITS AFTER THESE CALCS :  TIME IN HOURS, SLOPE IN RADIANS,
C     ACCELERATIONS IN FT/SEC**2 AND TP IN SEC
C
C
C   TEMPERATURE CALCULATIONS
C
      DO 20 I=1,NPTS1
      IF (I .NE. 1) GO TO 50
      DO 51 J=1,10
      TEMP(J,1) = TEMP1(J)
   51 CONTINUE
      GO TO 52
   50 CONTINUE
      DO 53 J=1,10
      TEMP(J,I) = TEMP(J,I-1)
   53 CONTINUE
   52 CONTINUE
C
      ISTEP = TP(I) / DT
      TO = 0.0
C
C   INTEGRATE OVER TIME INTERVAL TP
C
      DO 21 J=1,ISTEP
      VBAR = V(I)*5280./3600. + (TO + DT/2.) * ACC(I)
      TO = TO + DT
      HPN = (CRR*W*VBAR)/550. + CA*(AF*VBAR**3)/550.
      HPBT = ( -SLOPE(I)*W*VBAR)/550. - (W*(ACC(I)/32.2)*VBAR)/550.
     1     - HPN - HPE - HPR
      IF (HPBT .LT. 0.) HPBT = 0.
C
C
      DO 25 KJ = 1,10
      HPB(KJ) = PROP(KJ)*HPBT
      H(KJ) = CH1(KJ) + CH2(KJ)*VBAR*3600./5280.
```

```
          TEMP(KJ,I) = TEMP(KJ,I) +DT*(HPB(KJ) - H(KJ)*
     1         (TEMP(KJ,I)-TEMPA(KJ)))/ MCP(KJ)/3600.
   25 CONTINUE
   21 CONTINUE
      ACC(I) = ACC(I) / 32.2
   20 CONTINUE
C
C   WRITE OUT CALCULATIONS AND INPUT
C
      WRITE(6,200)
  200 FORMAT('1PREDICTION RESULTS :'/' --------------------'///
     1   T2,'TIME',T10,'DIST.',T18,'ELEV.',T26,'VEL.',T34,'SLOPE',
     2   T42,'ACCEL.',T52,'TEMP1',T60,'TEMP2',T68,'TEMP3',T76,
     3   'TEMP4',T84,'TEMP5',T92,'TEMP6',T100,'TEMP7',T108,'TEMP8',
     4   T116,'TEMP9',T124,'TEMP10' / T2,'(HRS)',T10,'(MILES)',
     5   T18,'(FT)',T26,'(MPH)',T34,'(RAD)',T43,'(G)',T53,'(F)',
     6   T61,'(F)',T69,'(F)',T77,'(F)',T85,'(F)',T93,'(F)',T101,
     7   '(F)', T109, '(F)', T117, '(F)', T125, '(F)'/)
C
      DO 60 I=1,NPTS1
      IF (I .EQ. 1)
     1WRITE(6,201) TIME(I), D(I), E(I), V(I), SLOPE(I), ACC(I),
     1      (TEMP1(J),J=1,10)
      IF (I .NE. 1)
     1WRITE(6,201) TIME(I), D(I), E(I), V(I), SLOPE(I), ACC(I),
     1      (TEMP(J,I-1),J=1,10)
  201 FORMAT(T2,F6.4,T10,F7.2,T18,F7.2,T26,F7.2,T34,F7.3,T42,F7.3,T52,
     1    F7.2,T60,F7.2,T68,F7.2,T76,F7.2,T84,F7.2,T92,F7.2,T100,F7.2,
     2    T108,F7.2,T116,F7.2,T124,F7.2)
   60 CONTINUE
      WRITE(6,202) TIME(NPTS), D(NPTS), E(NPTS), V(NPTS)
     1   ,(TEMP(J,NPTS1),J=1,10)
  202 FORMAT(T2,F6.4,T10,F7.2,T18,F7.2,T26,F7.2,T52,
     1    F7.2,T60,F7.2,T68,F7.2,T76,F7.2,T84,F7.2,T92,F7.2,T100,F7.2,
     2    T108,F7.2,T116,F7.2,T124,F7.2)
      END
```

EXAMPLE

PREDICTION RESULTS :

TIME (HRS)	DIST. (MILES)	ELEV. (FT)	VEL. (MPH)	SLOPE (RAD)	ACCEL. (G)	TEMP1 (F)	TEMP2 (F)
0.0	0.0	1700.00	44.00	-0.064	-0.063	100.00	100.00
0.0008	0.03	1688.44	40.00	-0.064	0.032	105.97	105.97
0.0024	0.10	1666.00	44.00	-0.064	-0.063	105.76	105.76
0.0032	0.13	1654.44	40.00	-0.064	0.032	111.72	111.72
0.0048	0.20	1632.00	44.00	-0.064	-0.063	111.49	111.49
0.0056	0.23	1620.44	40.00	-0.064	0.032	117.43	117.43
0.0071	0.30	1598.00	44.00	-0.064	-0.063	117.18	117.18
0.0080	0.33	1586.44	40.00	-0.064	0.032	123.12	123.12
0.0095	0.40	1564.00	44.00	-0.064	-0.063	122.84	122.84
0.0103	0.43	1552.44	40.00	-0.064	0.032	128.77	128.77
0.0119	0.50	1530.00	44.00	-0.064	-0.063	128.47	128.47
0.0127	0.53	1518.44	40.00	-0.064	0.032	134.39	134.39
0.0143	0.60	1496.00	44.00	-0.064	-0.063	134.08	134.08
0.0151	0.63	1484.44	40.00	-0.064	0.032	139.98	139.98
0.0167	0.70	1462.00	44.00	-0.064	-0.063	139.65	139.65
0.0175	0.73	1450.44	40.00	-0.064	0.032	145.54	145.54
0.0190	0.80	1428.00	44.00	-0.064	-0.063	145.19	145.19
0.0199	0.83	1416.44	40.00	-0.064	0.032	151.07	151.07
0.0214	0.90	1394.00	44.00	-0.064	-0.063	150.70	150.70
0.0222	0.93	1382.44	40.00	-0.064	0.032	156.57	156.57
0.0238	1.00	1360.00	44.00	-0.064	-0.063	156.18	156.18
0.0246	1.03	1348.44	40.00	-0.064	0.032	162.04	162.04
0.0262	1.10	1326.00	44.00	-0.064	-0.063	161.63	161.63
0.0270	1.13	1314.44	40.00	-0.064	0.032	167.48	167.48
0.0286	1.20	1292.00	44.00	-0.064	-0.063	167.05	167.05
0.0294	1.23	1280.44	40.00	-0.064	0.032	172.89	172.89
0.0310	1.30	1258.00	44.00	-0.064	-0.063	172.44	172.44
0.0318	1.33	1246.44	40.00	-0.064	0.032	178.27	178.27
0.0333	1.40	1224.00	44.00	-0.064	-0.063	177.80	177.80
0.0341	1.43	1212.44	40.00	-0.064	0.032	183.63	183.63
0.0357	1.50	1190.00	44.00	-0.064	-0.063	183.14	183.14
0.0365	1.53	1178.44	40.00	-0.064	0.032	188.95	188.95
0.0381	1.60	1156.00	44.00	-0.064	-0.063	188.44	188.44
0.0389	1.63	1144.44	40.00	-0.064	0.032	194.24	194.24
0.0405	1.70	1122.00	44.00	-0.064	-0.063	193.71	193.71
0.0413	1.73	1110.44	40.00	-0.064	0.032	199.51	199.51
0.0429	1.80	1088.00	44.00	-0.064	-0.063	198.96	198.96
0.0437	1.83	1076.44	40.00	-0.064	0.032	204.74	204.74
0.0452	1.90	1054.00	44.00	-0.064	-0.063	204.18	204.18
0.0460	1.93	1042.44	40.00	-0.064	0.032	209.95	209.95
0.0476	2.00	1020.00	44.00	-0.064	-0.063	209.37	209.37
0.0484	2.03	1008.44	40.00	-0.064	0.032	215.13	215.13
0.0500	2.10	986.00	44.00	-0.064	-0.063	214.53	214.53
0.0508	2.13	974.44	40.00	-0.064	0.032	220.28	220.28
0.0524	2.20	952.00	44.00	-0.064	-0.063	219.66	219.66
0.0532	2.23	940.44	40.00	-0.064	0.032	225.40	225.40
0.0548	2.30	918.00	44.00	-0.064	-0.063	224.76	224.76
0.0556	2.33	906.44	40.00	-0.064	0.032	230.50	230.50
0.0571	2.40	884.00	44.00	-0.064	-0.063	229.84	229.84
0.0580	2.43	872.44	40.00	-0.064	0.032	235.56	235.56
0.0595	2.50	850.00	44.00			234.89	234.89

TEMP3 (F)	TEMP4 (F)	TEMP5 (F)	TEMP6 (F)	TEMP7 (F)	TEMP8 (F)	TEMP9 (F)	TEMP10 (F)
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
107.64	107.64	107.64	107.64	108.85	108.85	108.85	108.85
107.42	107.42	107.42	107.42	108.62	108.62	108.62	108.62
115.04	115.04	115.04	115.04	117.46	117.46	117.46	117.46
114.80	114.80	114.80	114.80	117.21	117.21	117.21	117.21
122.41	122.41	122.41	122.41	126.02	126.02	126.02	126.02
122.14	122.14	122.14	122.14	125.74	125.74	125.74	125.74
129.73	129.73	129.73	129.73	134.54	134.54	134.54	134.54
129.44	129.44	129.44	129.44	134.23	134.23	134.23	134.23
137.02	137.02	137.02	137.02	143.02	143.02	143.02	143.02
136.70	136.70	136.70	136.70	142.67	142.67	142.67	142.67
144.27	144.27	144.27	144.27	151.44	151.44	151.44	151.44
143.92	143.92	143.92	143.92	151.07	151.07	151.07	151.07
151.48	151.48	151.48	151.48	159.82	159.82	159.82	159.82
151.10	151.10	151.10	151.10	159.42	159.42	159.42	159.42
158.64	158.64	158.64	158.64	168.16	168.16	168.16	168.16
158.24	158.24	158.24	158.24	167.72	167.72	167.72	167.72
165.77	165.77	165.77	165.77	176.45	176.45	176.45	176.45
165.34	165.34	165.34	165.34	175.98	175.98	175.98	175.98
172.86	172.86	172.86	172.86	184.69	184.69	184.69	184.69
172.41	172.41	172.41	172.41	184.20	184.20	184.20	184.20
179.91	179.91	179.91	179.91	192.89	192.89	192.89	192.89
179.43	179.43	179.43	179.43	192.37	192.37	192.37	192.37
186.92	186.92	186.92	186.92	201.04	201.04	201.04	201.04
186.42	186.42	186.42	186.42	200.49	200.49	200.49	200.49
193.89	193.89	193.89	193.89	209.15	209.15	209.15	209.15
193.37	193.37	193.37	193.37	208.57	208.57	208.57	208.57
200.83	200.83	200.83	200.83	217.22	217.22	217.22	217.22
200.28	200.28	200.28	200.28	216.61	216.61	216.61	216.61
207.73	207.73	207.73	207.73	225.24	225.24	225.24	225.24
207.15	207.15	207.15	207.15	224.60	224.60	224.60	224.60
214.59	214.59	214.59	214.59	233.22	233.22	233.22	233.22
213.99	213.99	213.99	213.99	232.55	232.55	232.55	232.55
221.41	221.41	221.41	221.41	241.15	241.15	241.15	241.15
220.78	220.78	220.78	220.78	240.45	240.45	240.45	240.45
228.19	228.19	228.19	228.19	249.04	249.04	249.04	249.04
227.54	227.54	227.54	227.54	248.31	248.31	248.31	248.31
234.94	234.94	234.94	234.94	256.88	256.88	256.88	256.88
234.27	234.27	234.27	234.27	256.05	256.05	256.05	256.05
241.65	241.65	241.65	241.65	264.54	264.54	264.54	264.54
240.96	240.96	240.96	240.96	263.71	263.71	263.71	263.71
248.33	248.33	248.33	248.33	272.19	272.19	272.19	272.19
247.61	247.61	247.61	247.61	271.36	271.36	271.36	271.36
254.97	254.97	254.97	254.97	279.82	279.82	279.82	279.82
254.22	254.22	254.22	254.22	278.99	278.99	278.99	278.99
261.51	261.51	261.51	261.51	287.44	287.44	287.44	287.44
260.69	260.69	260.69	260.69	286.38	286.38	286.38	286.38
267.95	267.95	267.95	267.95	294.82	294.82	294.82	294.82
267.13	267.13	267.13	267.13	293.72	293.72	293.72	293.72
274.38	274.38	274.38	274.38	302.14	302.14	302.14	302.14
273.55	273.55	273.55	273.55	301.04	301.04	301.04	301.04

APPENDIX C

Simulation of a Retarder-Equipped Tractor-semitrailer

This appendix contains (1) a listing of a subroutine entitled "RETARDER," (2) a set of parametric data describing a retarder-equipped tractor-semitrailer, and (3) tabulated values of time histories calculated for an example turning maneuver in which jackknifing occurs after the retarder is applied with the vehicle operating on a slippery surface.

```
      SUBROUTINE RETARD
      COMMON /WSPD/ UW(4,2,2,2)
      COMMON /TIRES/ SRAD(4,2,2,2), CALF(4,2,2,2), DTS(4,2,2,2),
     1       KT(4,2,2,2), CS(4,2,2,2), N(4,2,2,2), CAT(4,2,2,2),
     2       YT(4,2,2,2), YTD(4,2,2,2), TSUM(4,3), XAXFOR(4,2,2),
     3       YAXFOR(4,2,2), FYI(4,2,2,2), FXI(4,2,2,2), FXW(4,2,2,2),
     4       FYW(4,2,2,2), ALFPRM(4,2,2,2), SLIP(4,2,2,2)
      COMMON/AEROL/CRR,AAERO,CDAERO
      DIMENSION RPM(20),HP(20),TR(20),WR(20)
       READ(7,100)GI,AR,EFF,DRIVE,CRR,AAERO,CDAERO
  100 FORMAT(10F10.2)
      READ(7,150) NT
       READ(7,200)((RPM(I),HP(I)),I=1,NT)
  150 FORMAT(I2)
  200 FORMAT(2F10.2)
      DO 50 I=1,NT
       WR(I)=RPM(I)*2.*3.1416/60.
       TR(I)=HP(I)*550./(WR(I)+0.001)
   50 CONTINUE
      RETURN
      ENTRY RETCAL(T3456,RPAR)
      W3=UW(1,2,1,1)*(1.-SLIP(1,2,1,1))/SRAD(1,2,1,1)
      W4=UW(1,2,1,2)*(1.-SLIP(1,2,1,2))/SRAD(1,2,1,2)
      W5=UW(1,2,2,1)*(1.-SLIP(1,2,2,1))/SRAD(1,2,2,1)
      W6=UW(1,2,2,2)*(1.-SLIP(1,2,2,2))/SRAD(1,2,2,2)
      WE=AR*GI*(W3+W4+W5+W6)/4.
      IF(DRIVE.LE.1.5) WE=AR*GI*(W3+W4)/2.
      CALL TABLE(1,NT,WR,TR,WE,TRET)
       T3456=TRET*AR*GI/4./EFF
      IF(DRIVE.LE.1.5) T3456=TRET*AR*GI/2./EFF
      RPAR=DRIVE
      RETURN
      ENTRY RETECH
      WRITE(6,1000)
 1000 FORMAT('1',T20,'***  RETARDER PARAMETERS / TABLES  ***')
      WRITE(6,1100)GI,AR,EFF,DRIVE
 1100 FORMAT('0',T20,'GEAR RATIO :',F6.2,/,T20,'AXLE RATIO :',F6.2,/,T20,
     1 'EFFICIENCY :',F6.2,/,T20,'NO. OF RETARD AXLES :',F3.1)
      WRITE(6,1200)((RPM(I),HP(I)),I=1,NT)
 1200 FORMAT('0',T20,'ENGINE RPM VS. HORSEPOWER TABLE :',
     1/,(T20,2F10.2))
      WRITE(6,1300)((TR(I),WR(I)),I=1,NT)
 1300 FORMAT('0',T20,'TORQUE (FT-LB)  VS.  ENGINE SPEED (RAD/S) :',
     1/,(T20,2F10.2))
      WRITE(6,2000)
 2000 FORMAT('0','0',T20,'***  ROLLING RESISTANCE AND AERO DRAG PARAMETERS   ***')
      WRITE(6,2100) CRR,AAERO,CDAERO
 2100 FORMAT('0',T20,'ROLLING RESISTANCE COEFF :',F6.3,/,T20,
     1'AERODYNAMIC EFFECTIVE AREA (FT**2) :',F6.2,/,
     2T20,'AERODYNAMIC DRAG COEFFICIENT :',F6.2)
      RETURN
      END
```

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

SIMULATION OPERATION PARAMETERS:

VEHICLE CONFIGURATION (NUMBER OF TRAILERS - ENTER 0 FOR A STRAIGHT TRUCK) 1
INITIAL VELOCITY (FT/SEC) 33.00
STEER TABLE (NUMBER OF LINES): POSITIVE -STEER ANGLE TABLE, NEGATIVE - PATH FOLLOWER TABLE 3
TABLE ENTRIES:

TIME (SEC)	LEFT WHEEL (DEG)	RIGHT WHEEL (DEG)
0.0	0.0	0.0
0.50	100.00	100.00
10.00	100.00	100.00

TREADLE PRESSURE TABLE (NUMBER OF LINES) 4
TABLE ENTRIES:

TIME (SEC)	PRESSURE (PSI)
0.0	0.0
2.00	0.0
2.10	2.00
10.00	2.00

MAXIMUM SIMULATION TIME (SEC) 4.00
TIME INCREMENT OF OUTPUT (SEC) 0.10

ROAD KEY = 0 : FLAT ROAD.

OUTPUT PAGE OPTION KEYS: 0 DELETES PAGES

SPRUNG MASS POSITION	SPRUNG MASS VELOCITY	SPRUNG MASS ACCELERATION	TIRE FORCES PAGES	BRAKE SUMMARY PAGES	LATERAL PAGES	UNSPRUNG MASS PAGES	TEMP PAGES
1	1	1	1	1	1	1	0

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR PARAMETERS

WHEELBASE - DISTANCE FROM FRONT AXLE TO CENTER OF REAR SUSPENSION (IN)	152.00
BASE VEHICLE CURB WEIGHT ON FRONT SUSPENSION (LB)	8960.00
BASE VEHICLE CURB WEIGHT ON REAR SUSPENSION (LB)	6540.00
SPRUNG MASS CG HEIGHT (IN. ABOVE GROUND)	44.00
SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	15000.00
SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	75000.00
SPRUNG MASS YAW MOMENT OF INERTIA (IN-LB-SEC**2)	75000.00
PAYLOAD WEIGHT (LB)	0.0
*** ZERO ENTRY INDICATES NO PAYLOAD ***	
*** FIVE PAYLOAD DESCRIPTION PARAMETERS ARE NOT ENTERED ***	
FIFTH WHEEL LOCATION (IN. AHEAD OF REAR SUSP. CENTER)	14.35
FIFTH WHEEL HEIGHT ABOVE GROUND (IN)	48.00
TRACTOR FRAME STIFFNESS (IN-LB/DEG)	50000.00
TRACTOR FRAME TORSIONAL AXIS HEIGHT ABOVE GROUND (IN)	36.00

TRACTOR FRONT SUSPENSION AND AXLE PARAMETERS

	LEFT SIDE	RIGHT SIDE
SUSPENSION SPRING RATE (LB/IN/SIDE/AXLE)	-119.00	-119.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***		
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***		
SUSPENSION VISCOUS DAMPING (LB-SEC/IN/SIDE/AXLE)	0.0	0.0
COULOMB FRICTION (LB/SIDE/AXLE)	0.0	0.0

AXLE ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	3719.00
ROLL CENTER HEIGHT (IN. ABOVE GROUND)	23.00
ROLL STEER COEFFICIENT (DEG. STEER/DEG. ROLL)	0.0
AUXILIARY ROLL STIFFNESS (IN-LB/DEG/AXLE)	1500.00
LATERAL DISTANCE BETWEEN SUSPENSION SPRINGS (IN)	32.00
TRACK WIDTH (IN)	80.00
UNSPRUNG WEIGHT (LB)	1200.00
STEERING GEAR RATIO (DEG STEERING WHEEL/DEG ROAD WHEEL)	28.00
STEERING STIFFNESS (IN-LB/DEG)	11000.00
TIE ROD STIFFNESS (IN-LB/DEG)	11000.00
MECHANICAL TRAIL (IN)	1.00
TORSIONAL WRAP-UP STIFFNESS (IN-LB/IN)	150000.00
LATERAL OFFSET OF STEERING AXIS (IN)	3.00

TRACTOR FRONT TIRES AND WHEELS

	LEFT SIDE	RIGHT SIDE
CORNERING STIFFNESS (LB/DEG/TIRE)	-1.00	-1.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***		
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***		
LONGITUDINAL STIFFNESS (LB/SLIP/TIRE)	-2.00	-2.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***		
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***		
CAMBER STIFFNESS (LB/DEG/TIRE)	0.0	0.0
ALIGNING MOMENT (IN-LB/DEG/TIRE)	700.00	700.00
TIRE SPRING RATE (LB/IN/TIRE)	4500.00	4500.00
TIRE LOADED RADIUS (IN)	19.50	19.50
POLAR MOMENT OF INERTIA (IN-LB-SEC**2/WHEEL)	103.00	103.00

HSRI/MVMA BRAKING AND HANDLING SIMULATION OF TRUCKS, TRACTOR-SEMITRAILERS, DOUBLES, AND TRIPLES - PHASE 4.   INPUT PAGE NO. 3
RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR REAR SUSPENSION AND AXLE PARAMETERS

SUSPENSION KEY - 0 INDICATES SINGLE AXLE, 1 INDICATES FOUR SPRING, 2 WALKING BEAM	1
TANDEM AXLE SEPARATION (IN BETWEEN LEADING AND TRAILING AXLES)	48.00
STATIC LOAD TRANSFER (PERCENT LOAD ON LEAD AXLE)	50.00
DYNAMIC LOAD TRANSFER (% BRAKE TORQUE REACTED AS TANDEM AXLE LOAD TRANSFER)	-35.00

	LEADING TANDEM AXLE		TRAILING TANDEM AXLE	
	LEFT SIDE	RIGHT SIDE	LEFT SIDE	RIGHT SIDE
SUSPENSION SPRING RATE (LB/IN/SIDE/AXLE)	-121.00	-121.00	-121.00	-121.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***				
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***				
SUSPENSION VISCOUS DAMPING (LB-SEC/IN/SIDE/AXLE)	0.0	0.0	0.0	0.0
COULOMB FRICTION (LB/SIDE/AXLE)	0.0	0.0	0.0	0.0

	LEADING TANDEM AXLE	TRAILING TANDEM AXLE
AXLE ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	4458.00	4458.00
ROLL CENTER HEIGHT (IN. ABOVE GROUND)	29.00	29.00
ROLL STEER COEFFICIENT (DEG. STEER/DEG. ROLL)	0.0	0.0
AUXILIARY ROLL STIFFNESS (IN-LB/DEG/AXLE)	6000.00	6000.00
LATERAL DISTANCE BETWEEN SUSPENSION SPRINGS (IN)	38.00	38.00
TRACK WIDTH (IN)	72.00	72.00
UNSPRUNG WEIGHT (LB)	2300.00	2300.00

TRACTOR REAR TIRES AND WHEELS

	LEADING TANDEM AXLE		TRAILING TANDEM AXLE	
	LEFT SIDE	RIGHT SIDE	LEFT SIDE	RIGHT SIDE
DUAL TIRE SEPARATION (IN)	13.00	13.00	13.00	13.00
CORNERING STIFFNESS (LB/DEG/TIRE)	-1.00	-1.00	-1.00	-1.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***				
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***				
LONGITUDINAL STIFFNESS (LB/SLIP/TIRE)	-2.00	-2.00	-2.00	-2.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***				
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***				
CAMBER STIFFNESS (LB/DEG/TIRE)	0.0	0.0	0.0	0.0
ALIGNING MOMENT (IN-LB/DEG/TIRE)	300.00	300.00	300.00	300.00
TIRE SPRING RATE (LB/IN/TIRE)	4500.00	4500.00	4500.00	4500.00
TIRE LOADED RADIUS (IN)	19.50	19.50	19.50	19.50
POLAR MOMENT OF INERTIA (IN-LB-SEC**2/WHEEL)	115.00	115.00	115.00	115.00

```
TRACTOR FRONT BRAKES                                                                       LEFT SIDE          RIGHT SIDE
--------------------                                                                       ---------          ----------

    TIME LAG (SEC)                                                                            0.0500              0.0500
    RISE TIME (SEC)                                                                           0.2500              0.2500
    BRAKE TORQUE (IN-LB/PSI/BRAKE)                                                           -5.0000             -5.0000
         ***  NEGATIVE ENTRY INDICATES TABLE ENTERED ***
         ***  ECHO WILL APPEAR ON TABLE INDEX PAGE ***
    BRAKE HYSTERESIS KEY: O ENTRY INDICATES BRAKE HYSTERESIS OPTION NOT IN USE ON VEHICLE TRAIN                        O
    BRAKE PROPORTIONING KEY: O ENTRY INDICATES BRAKE PROPORTIONING OPTION NOT IN USE ON VEHICLE TRAIN                  O

TRACTOR REAR BRAKES                                                        LEADING TANDEM AXLE            TRAILING TANDEM AXLE
--------------------                                                       -------------------            --------------------
                                                                          LEFT SIDE   RIGHT SIDE         LEFT SIDE   RIGHT SIDE
                                                                          ---------   ----------         ---------   ----------

    TIME LAG (SEC)                                                           0.0750       0.0750            0.0750       0.0750
    RISE TIME (SEC)                                                          0.2500       0.2500            0.2500       0.2500
    BRAKE TORQUE (IN-LB/PSI/BRAKE)                                          -7.0000      -7.0000           -7.0000      -7.0000
         ***  NEGATIVE ENTRY INDICATES TABLE ENTERED ***
         ***  ECHO WILL APPEAR ON TABLE INDEX PAGE ***
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RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRAILER NO. 1 PARAMETERS

WHEELBASE - DISTANCE FROM KINGPIN TO CENTER OF REAR SUSPENSION (IN)	390.00
BASE VEHICLE KINGPIN STATIC LOAD (LB)	4000.00
BASE VEHICLE CURB WEIGHT ON REAR SUSPENSION (LB)	8710.00
SPRUNG MASS CG HEIGHT (IN. ABOVE GROUND)	40.00
SPRUNG MASS ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	65362.00
SPRUNG MASS PITCH MOMENT OF INERTIA (IN-LB-SEC**2)	508233.00
SPRUNG MASS YAW MOMENT OF INERTIA (IN-LB-SEC**2)	762349.00
PAYLOAD WEIGHT (LB)	

*** ZERO ENTRY INDICATES NO PAYLOAD ***
*** FIVE PAYLOAD DESCRIPTION PARAMETERS ARE NOT ENTERED ***

TRAILER NO. 1 REAR SUSPENSION AND AXLE PARAMETERS

	LEADING TANDEM AXLE			TRAILING TANDEM AXLE	
	LEFT SIDE	RIGHT SIDE		LEFT SIDE	RIGHT SIDE
SUSPENSION KEY - 0 INDICATES SINGLE AXLE, 1 INDICATES FOUR SPRING, 2 WALKING BEAM			1		
TANDEM AXLE SEPARATION (IN BETWEEN LEADING AND TRAILING AXLES)			48.00		
STATIC LOAD TRANSFER (PERCENT LOAD ON LEAD AXLE)			50.00		
DYNAMIC LOAD TRANSFER (% BRAKE TORQUE REACTED AS TANDEM AXLE LOAD TRANSFER)			-35.00		
SUSPENSION SPRING RATE (LB/IN/SIDE/AXLE)	-122.00	-122.00		-122.00	-122.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***					
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***					
SUSPENSION VISCOUS DAMPING (LB-SEC/IN/SIDE/AXLE)	0.0	0.0		0.0	0.0
COULOMB FRICTION (LB/SIDE/AXLE)	0.0	0.0		0.0	0.0
AXLE ROLL MOMENT OF INERTIA (IN-LB-SEC**2)	4746.00				4746.00
ROLL CENTER HEIGHT (IN. ABOVE GROUND)	29.00				29.00
ROLL STEER COEFFICIENT (DEG. STEER/DEG. ROLL)	0.0				0.0
AUXILIARY ROLL STIFFNESS (IN-LB/DEG/AXLE)	34000.00				34000.00
LATERAL DISTANCE BETWEEN SUSPENSION SPRINGS (IN)	36.50				36.50
TRACK WIDTH (IN)	71.50				71.50
UNSPRUNG WEIGHT (LB)	1520.00				1520.00

TRAILER NO. 1 REAR TIRES AND WHEELS

	LEADING TANDEM AXLE		TRAILING TANDEM AXLE	
	LEFT SIDE	RIGHT SIDE	LEFT SIDE	RIGHT SIDE
DUAL TIRE SEPARATION (IN)	13.50	13.50	13.50	13.50
CORNERING STIFFNESS (LB/DEG/TIRE)	-1.00	-1.00	-1.00	-1.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***				
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***				
LONGITUDINAL STIFFNESS (LB/SLIP/TIRE)	-2.00	-2.00	-2.00	-2.00
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***				
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***				
CAMBER STIFFNESS (LB/DEG/TIRE)	0.0	0.0	0.0	0.0
ALIGNING MOMENT (IN-LB/DEG/TIRE)	300.00	300.00	300.00	300.00
TIRE SPRING RATE (LB/IN/TIRE)	4100.00	4100.00	4100.00	4100.00
TIRE LOADED RADIUS (IN)	19.50	19.50	19.30	19.30
POLAR MOMENT OF INERTIA (IN-LB-SEC**2/WHEEL)	115.00	115.00	115.00	115.00

TRAILER NO. 1 REAR BRAKES

	LEADING TANDEM AXLE		TRAILING TANDEM AXLE	
	LEFT SIDE	RIGHT SIDE	LEFT SIDE	RIGHT SIDE
TIME LAG (SEC)	0.0700	0.0700	0.0700	0.0700
RISE TIME (SEC)	0.1790	0.1790	0.1790	0.1790
BRAKE TORQUE (IN-LB/PSI/BRAKE)	-8.0000	-8.0000	-8.0000	-8.0000
*** NEGATIVE ENTRY INDICATES TABLE ENTERED ***				
*** ECHO WILL APPEAR ON TABLE INDEX PAGE ***				
ANTILOCK KEY: 1 INDICATES ANTILOCK WILL BE USED			-1	

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRAILER NO. 1 PAYLOAD = 0.0 LBS.	EMPTY	LOADED
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO REAR SUSPENSION (IN)	161.324	161.324
DISTANCE FROM TRAILER SPRUNG MASS CENTER TO GROUND (IN)	40.000	40.000
ROLL MOMENT OF INERTIA OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	65361.984	65361.984
PITCH MOMENT OF INERTIA OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	508233.000	508233.000
YAW MOMENT OF INERTIA OF TRAILER SPRUNG MASS (IN-LB-SEC**2)	762348.938	762348.938

TRACTOR PAYLOAD = 0.0 LBS	EMPTY	LOADED
DISTANCE FROM TRACTOR SPRUNG MASS CENTER TO REAR SUSPENSION (IN)	121.600	121.600
DISTANCE FROM TRACTOR SPRUNG MASS CENTER TO GROUND (IN)	44.000	44.000
ROLL MOMENT OF INERTIA OF TRACTOR SPRUNG MASS (IN-LB-SEC**2)	15000.000	15000.000
PITCH MOMENT OF INERTIA OF TRACTOR SPRUNG MASS (IN-LB-SEC**2)	75000.000	75000.000
YAW MOMENT OF INERTIA OF TRACTOR SPRUNG MASS (IN-LB-SEC**2)	75000.000	75000.000

THE STATIC LOADS ON THE AXLES ARE:

AXLE NUMBER	LOAD
NS(1,1,1)	9337.625
NS(1,2,1)	5081.184
NS(1,2,2)	5081.184
NS(2,2,1)	4354.996
NS(2,2,2)	4354.996
TOTAL	28209.984

THE TRACTOR TOTAL MASS CENTER IS 64.134 INCHES BEHIND THE FRONT AXLE
THE TOTAL YAW MOMENT OF INERTIA IS 227888.250 IN-LB-SEC**2

THE FIRST TRAILER TOTAL MASS CENTER IS 267.261 INCHES BEHIND THE KINGPIN
THE TOTAL YAW MOMENT OF INERTIA IS 932319.000 IN-LB-SEC**2

SPRING TABLES

NO. OF LINES	FORCE (LB)	DEFLECTION (IN)	TABLE NO.
4			-119.00
	-20000.00	-20.00	
	0.0	0.0	
	9250.00	7.20	
	25000.00	7.50	
	(SPRING COMPRESSION ENVELOPE)		
	-20000.00	-20.00	
	0.0	0.0	
	8040.00	7.20	
	25000.00	7.50	
	(SPRING EXTENSION ENVELOPE)		

SUSPENSION DEFLECTION CONSTANTS = 0.08000 INCHES COMPRESSION, 0.08000 INCHES EXTENSION.

SPRING STATIC EQUILIBRIUM CONDITION: 4068.81 LB, 3.39 INCHES. UNIT 1 SUSP 1 AXLE 1

NO. OF LINES	FORCE (LB)	DEFLECTION (IN)	TABLE NO.
9			-121.00
	-20000.00	-11.00	
	0.0	-1.00	
	0.0	0.0	
	4000.00	1.00	
	6500.00	1.50	
	9500.00	2.00	
	13000.00	2.50	
	17000.00	3.00	
	50000.00	4.00	
	(SPRING COMPRESSION ENVELOPE)		
	-25000.00	-11.00	
	0.0	-0.80	
	0.0	0.20	
	3000.00	1.00	
	5000.00	1.50	
	8000.00	2.00	
	11500.00	2.50	
	15500.00	3.00	
	40000.00	4.00	
	(SPRING EXTENSION ENVELOPE)		

SUSPENSION DEFLECTION CONSTANTS = 0.02000 INCHES COMPRESSION, 0.02000 INCHES EXTENSION.

SPRING STATIC EQUILIBRIUM CONDITION: 1390.59 LB, 0.46 INCHES. UNIT 1 SUSP 2 AXLE 1

SPRING STATIC EQUILIBRIUM CONDITION: 1390.59 LB, 0.46 INCHES. UNIT 1 SUSP 2 AXLE 2

9 -122.00

-30000.00	-11.00
0.0	-1.50
0.0	0.0
3375.00	0.50
7312.00	1.00
11812.00	1.50
16875.00	2.00
22500.00	2.50
56250.00	3.00

(SPRING COMPRESSION ENVELOPE)

-35000.00	-11.00
0.0	-1.30
0.0	0.20
1687.00	0.50
5625.00	1.00
10125.00	1.50
15187.00	2.00
20812.00	2.50
45000.00	3.00

(SPRING EXTENSION ENVELOPE)

SUSPENSION DEFLECTION CONSTANTS = 0.02000 INCHES COMPRESSION, 0.02000 INCHES EXTENSION.

SPRING STATIC EQUILIBRIUM CONDITION: 1417.50 LB, 0.32 INCHES. UNIT 2 SUSP 2 AXLE 1

SPRING STATIC EQUILIBRIUM CONDITION: 1417.50 LB, 0.32 INCHES. UNIT 2 SUSP 2 AXLE 2

MU-Y VS ALPHA TABLES

NO. OF LOADS	NO. OF VELOCITIES	TABLE NO.
1	1	-1

VELOCITY = 30.00 FT/SEC LOAD = 4500.00 LB

ALPHA (DEG)	MU - Y
0.0	0.0
1.00	0.15
2.00	0.20
12.00	0.20

ROLL-OFF TABLE

	SLIP				
ALPHA	0.0	0.04	0.10	0.50	1.00
0.0	1.00	1.00	0.90	0.30	0.10
4.00	1.00	1.00	0.90	0.30	0.10
8.00	1.00	1.00	0.90	0.35	0.13
12.00	1.00	1.00	0.90	0.42	0.17
16.00	1.00	1.00	0.90	0.48	0.22

PRESSURE VS TORQUE TABLES

NO. OF LINES	PRESSURE (PSI)	TORQUE (IN-LB)	TABLE NO
6			-5
	0.0	0.0	
	5.00	0.0	
	10.00	4327.00	
	20.00	8658.00	
	50.00	29470.00	
	100.00	65000.00	

PRESSURE VS TORQUE TABLES

NO. OF LINES	PRESSURE (PSI)	TORQUE (IN-LB)	TABLE NO
6			-7
	0.0	0.0	
	5.00	0.0	
	10.00	7796.00	
	20.00	24837.00	
	50.00	77578.00	
	100.00	160000.00	

PRESSURE VS TORQUE TABLES

NO. OF LINES	PRESSURE (PSI)	TORQUE (IN-LB)	TABLE NO
8			-8
	0.0	0.0	
	5.00	0.0	
	10.00	10000.00	
	20.00	25000.00	
	40.00	50000.00	
	60.00	85000.00	
	80.00	102000.00	
	100.00	119000.00	

MU-X VS. SLIP TABLES

NO. OF LOADS	NO. OF VELOCITIES	TABLE NO.
1	1	-2

VELOCITY = 30.00 FT/SEC LOAD = 4500.00 LB

SLIP	MU - X
0.0	0.0
0.20	0.20
1.00	0.20

ROLL-OFF TABLE

	SLIP				
ALPHA	0.0	0.04	0.10	0.50	1.00
0.0	1.00	1.00	1.00	1.00	1.00
4.00	1.00	1.00	1.00	1.00	1.00
8.00	0.75	0.75	0.75	0.95	1.00
12.00	0.50	0.50	0.60	0.90	0.95
16.00	0.40	0.40	0.45	0.85	0.95

*** RETARDER PARAMETERS / TABLES ***

GEAR RATIO : 2.47
AXLE RATIO : 4.44
EFFICIENCY : 0.86
NO. OF RETARD AXLES :2.0

ENGINE RPM VS. HORSEPOWER TABLE :

0.0	0.0
1300.00	126.00
1567.00	188.00
1833.00	265.00
2100.00	372.00

TORQUE (FT-LB) VS. ENGINE SPEED (RAD/S) :

0.0	0.0
509.05	136.14
630.11	164.10
759.30	191.95
930.37	219.91

*** ROLLING RESISTANCE AND AERO DRAG PARAMETERS ***

ROLLING RESISTANCE COEFF : 0.013
AERODYNAMIC EFFECTIVE AREA (FT**2) :100.00
AERODYNAMIC DRAG COEFFICIENT : 1.00

HSRI/MVMA BRAKING AND HANDLING SIMULATION OF TRUCKS, TRACTOR-SEMITRAILERS, DOUBLES, AND TRIPLES - PHASE 4. OUTPUT PAGE NO. 1.00.1

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR SPRUNG MASS POSITION

TIME (SEC)	FORWARD (FT)	LATERAL (FT)	VERTICAL (FT)	ROLL (DEG)	PITCH (DEG)	HEADING (DEG)	TURN RADIUS (FT)	SIDE SLIP (DEG)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	************	0.0
0.10	3.3805	0.0030	0.0005	-0.0714	-0.0064	0.0207	761.1677	0.1240
0.20	6.6740	0.0202	0.0014	-0.2849	-0.0192	0.1304	415.2983	0.3628
0.30	9.9620	0.0634	0.0018	-0.4027	-0.0120	0.3705	284.6689	0.6861
0.40	13.2439	0.1434	0.0011	-0.4390	-0.0120	0.7570	247.2441	1.0178
0.50	16.5186	0.2666	0.0006	-0.4827	-0.0084	1.2815	223.1194	1.2918
0.60	19.7853	0.4361	0.0010	-0.4798	-0.0077	1.9188	232.4624	1.4734
0.70	23.0437	0.6509	0.0015	-0.4845	-0.0160	2.6298	240.1675	1.5550
0.80	26.2931	0.9096	0.0015	-0.5788	-0.0101	3.3899	240.9746	1.5644
0.90	29.5329	1.2118	0.0008	-0.5200	-0.0077	4.1799	229.0735	1.5716
1.00	32.7617	1.5591	0.0009	-0.4306	-0.0164	4.9875	239.8582	1.5661
1.10	35.9794	1.9493	0.0020	-0.6663	-0.0038	5.8032	244.8014	1.5029
1.20	39.1859	2.3821	0.0021	-0.6943	-0.0126	6.6204	216.7993	1.5001
1.30	42.3801	2.8613	0.0014	-0.4343	-0.0264	7.4428	224.3266	1.5332
1.40	45.5616	3.3852	0.0010	-0.6730	-0.0247	8.2660	249.7861	1.4779
1.50	48.7304	3.9506	0.0015	-0.8043	-0.0119	9.0859	211.4635	1.4631
1.60	51.8847	4.5622	0.0024	-0.4538	-0.0072	9.9078	214.3321	1.5212
1.70	55.0243	5.2189	0.0024	-0.6558	-0.0273	10.7267	250.1408	1.4813
1.80	58.1492	5.9161	0.0019	-0.8636	-0.0173	11.5425	210.2235	1.4609
1.90	61.2578	6.6587	0.0011	-0.4400	-0.0196	12.3607	211.0812	1.5315
2.00	64.3499	7.4459	0.0015	-0.6039	-0.0264	13.1790	261.1396	1.4931
2.10	67.4257	8.2717	0.0023	-0.9177	-0.0122	13.9890	210.1612	1.4560
2.20	70.4771	9.1393	0.0079	-0.4571	-0.0963	14.8182	210.3346	1.5007
2.30	73.4922	10.0445	0.0253	-0.5033	-0.1831	15.7589	255.6765	1.3463
2.40	76.4719	10.9814	0.0296	-0.9194	-0.1880	16.8338	201.9176	1.0468
2.50	79.4090	11.9535	0.0185	-0.5572	-0.1334	18.1220	185.0009	0.6895
2.60	82.3023	12.9635	0.0092	-0.5313	-0.0752	19.6557	199.2268	0.0682
2.70	85.1504	14.0081	0.0110	-1.0729	-0.0981	21.3953	168.7628	-0.7381
2.80	87.9500	15.0905	0.0179	-0.7187	-0.1123	23.3910	157.5968	-1.6801
2.90	90.6962	16.2116	0.0199	-0.4388	-0.1217	25.6598	155.5372	-2.8646
3.00	93.3870	17.3690	0.0158	-1.1272	-0.1253	28.1626	160.1729	-4.3094
3.10	96.0217	18.5592	0.0114	-0.9312	-0.0677	30.9021	165.0772	-6.0359
3.20	98.5952	19.7775	0.0110	-0.3312	-0.0789	33.8814	162.8897	-8.0166
3.30	101.1055	21.0214	0.0139	-0.9308	-0.1008	37.0748	169.7431	-10.2408
3.40	103.5500	22.2863	0.0155	-1.0961	-0.1007	40.4892	161.4309	-12.5639
3.50	105.9243	23.5657	0.0152	-0.4055	-0.1036	44.1512	162.0988	-15.2735
3.60	108.2258	24.8546	0.0136	-0.7384	-0.0959	48.0384	174.0313	-18.2564
3.70	110.4545	26.1464	0.0123	-1.1513	-0.0872	52.1344	195.2890	-21.5437
3.80	112.6075	27.4324	0.0130	-0.4853	-0.0935	56.4657	210.7935	-25.1650
3.90	114.6825	28.7050	0.0141	-0.4747	-0.1110	61.0221	235.1506	-29.0897
4.00	116.6811	29.9573	0.0144	-1.1419	-0.0858	65.7842	357.2532	-33.3575

HSRI/MVMA BRAKING AND HANDLING SIMULATION OF TRUCKS, TRACTOR-SEMITRAILERS, DOUBLES, AND TRIPLES - PHASE 4. OUTPUT PAGE NO. 1.01.1

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR SPRUNG MASS VELOCITY (BODY AXES)

TIME (SEC)	FORWARD (FT/SEC)	LATERAL (FT/SEC)	VERTICAL (FT/SEC)	ROLL (DEG/SEC)	PITCH (DEG/SEC)	HEADING (DEG/SEC)	STEERING WHEEL ANGLE (DEG)
0.0	33.00	0.0	0.0	0.0	0.0	0.0	0.0
0.10	32.96	0.07	0.01	-1.73	-0.13	0.56	20.5
0.20	32.91	0.21	-0.00	-1.98	-0.01	1.70	40.5
0.30	32.86	0.39	-0.01	-0.47	0.01	3.13	60.5
0.40	32.80	0.58	-0.01	-0.44	-0.03	4.58	80.5
0.50	32.74	0.74	0.00	-0.31	0.02	5.88	100.0
0.60	32.68	0.84	0.01	0.31	-0.10	6.80	100.0
0.70	32.62	0.89	0.00	-0.65	-0.09	7.39	100.0
0.80	32.56	0.89	-0.00	-0.63	0.06	7.78	100.0
0.90	32.51	0.89	-0.00	1.64	-0.25	8.00	100.0
1.00	32.45	0.89	0.01	-0.82	0.01	8.15	100.0
1.10	32.39	0.85	0.02	-2.66	0.08	8.17	100.0
1.20	32.34	0.85	-0.01	2.47	-0.41	8.19	100.0
1.30	32.28	0.86	-0.01	0.69	0.06	8.27	100.0
1.40	32.23	0.83	-0.00	-3.94	-0.04	8.17	100.0
1.50	32.17	0.82	0.01	2.35	-0.05	8.21	100.0
1.60	32.11	0.85	0.01	1.99	-0.10	8.21	100.0
1.70	32.06	0.83	-0.01	-4.61	-0.28	8.15	100.0
1.80	32.00	0.82	-0.01	2.14	-0.02	8.19	100.0
1.90	31.94	0.85	-0.00	3.23	-0.00	8.23	100.0
2.00	31.89	0.83	-0.00	-5.34	-0.21	8.10	100.0
2.10	31.83	0.81	0.01	1.40	-0.06	8.12	100.0
2.20	31.60	0.83	0.11	4.52	-1.32	8.74	100.0
2.30	31.38	0.74	0.04	-4.95	-0.63	10.03	100.0
2.40	31.10	0.57	-0.15	-0.41	0.23	11.67	100.0
2.50	30.81	0.37	-0.19	4.85	0.80	14.19	100.0
2.60	30.51	0.04	-0.09	-4.91	-0.41	16.37	100.0
2.70	30.20	-0.39	0.01	-2.30	-0.51	18.58	100.0
2.80	29.85	-0.88	-0.02	7.09	-0.33	21.38	100.0
2.90	29.46	-1.47	-0.09	-3.80	-0.46	23.92	100.0
3.00	29.05	-2.18	-0.16	-5.25	-0.08	26.19	100.0
3.10	28.56	-3.01	-0.11	8.13	-0.18	28.63	100.0
3.20	27.99	-3.92	-0.04	0.01	-0.56	30.90	100.0
3.30	27.37	-4.89	-0.09	-7.81	-0.38	32.98	100.0
3.40	26.62	-5.93	-0.16	5.69	-0.80	35.33	100.0
3.50	25.76	-7.03	-0.11	3.67	-0.13	37.81	100.0
3.60	24.78	-8.17	-0.16	-7.80	-0.33	39.85	100.0
3.70	23.67	-9.35	-0.23	2.49	-0.91	42.08	100.0
3.80	22.39	-10.52	-0.12	6.71	-0.56	44.51	100.0
3.90	20.96	-11.66	-0.13	-6.41	-0.67	46.60	100.0
4.00	19.39	-12.77	-0.28	-2.77	-0.37	48.71	100.0

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TIME	TRACTOR SPRUNG MASS ACCELERATION (BODY AXES)						INERTIAL ACCEL. ALONG BODY AXES	
(SEC)	FORWARD (FT/SEC**2)	LATERAL (FT/SEC**2)	VERTICAL (FT/SEC**2)	ROLL (DEG/SEC**2)	PITCH (DEG/SEC**2)	HEADING (DEG/SEC**2)	LONGITUDINAL (FT/SEC**2)	LATERAL (FT/SEC**2)
0.0	-0.1344	0.0	0.0	0.0	0.3006	0.0	-0.1344	0.0
0.10	-0.4344	1.1076	-0.1324	-18.2955	-4.0611	9.2045	-0.4351	1.4289
0.20	-0.4953	1.6280	-0.3717	13.7037	-7.4506	13.2749	-0.5015	2.6062
0.30	-0.5623	1.9906	-0.0733	8.5997	-1.1291	14.8959	-0.5837	3.7833
0.40	-0.5889	1.7110	0.0337	-2.4793	0.0524	13.8061	-0.6355	4.3348
0.50	-0.5757	1.4178	-0.0202	4.3229	-5.8479	11.9333	-0.6515	4.7757
0.60	-0.5586	0.6964	0.0795	0.2638	-0.0094	7.5473	-0.6582	4.5718
0.70	-0.5716	0.2042	-0.1979	-14.0890	-2.1132	5.1168	-0.6858	4.4113
0.80	-0.5287	-0.0337	-0.2522	19.3672	-6.8912	3.1194	-0.6494	4.3881
0.90	-0.5626	0.0605	-0.0279	8.2086	-2.0184	1.5667	-0.6870	4.5970
1.00	-0.5199	-0.2458	0.3085	-44.9851	6.8593	0.8419	-0.6461	4.3717
1.10	-0.5395	-0.3394	0.0263	25.2646	-2.6271	0.3344	-0.6605	4.2785
1.20	-0.5432	0.1929	-0.2852	43.4895	-1.5050	1.0122	-0.6641	4.8132
1.30	-0.5277	-0.0311	-0.0515	-71.0575	-1.0736	1.0134	-0.6523	4.6268
1.40	-0.5498	-0.4468	1.0196	13.6700	24.4252	-0.0807	-0.6683	4.1459
1.50	-0.5654	0.2748	0.0460	70.1670	-1.5313	-0.5845	-0.6832	4.8848
1.60	-0.5418	0.1862	-0.1182	-78.7941	1.3007	-0.8186	-0.6640	4.7879
1.70	-0.5415	-0.4669	0.8382	-1.2565	29.2534	-1.2242	-0.6594	4.0924
1.80	-0.5460	0.2888	-0.3338	91.7253	-11.9344	-0.2643	-0.6626	4.8633
1.90	-0.5414	0.2306	-0.7566	-82.5462	-22.4980	0.8250	-0.6641	4.8202
2.00	-0.6053	-0.6259	0.5192	-19.8578	19.1645	-1.4694	-0.7227	3.8799
2.10	-0.5556	0.3029	-0.8218	111.0659	-25.5445	-0.2769	-0.6703	4.8135
2.20	-2.3177	-0.1484	1.4458	-73.2533	19.8112	13.0151	-2.4464	4.6631
2.30	-2.3992	-1.7151	-1.0978	-50.0800	28.9503	11.3631	-2.5288	3.7833
2.40	-3.0535	-1.6088	-0.8177	112.4822	28.0379	21.8899	-3.1698	4.7243
2.50	-2.6906	-2.5498	0.3342	-46.9152	-7.0064	26.1900	-2.7851	5.0976
2.60	-3.1704	-4.0715	1.5205	-80.9825	-6.1908	18.7512	-3.1802	4.6376
2.70	-3.2723	-4.3580	-0.2202	122.6096	-12.8600	26.1304	-3.1462	5.4381
2.80	-3.6577	-5.3938	-0.9085	-7.7145	-3.4070	28.4252	-3.3309	5.7502
2.90	-3.9671	-6.5276	-1.7974	-138.8472	-27.9385	23.0961	-3.3515	5.7644
3.00	-4.1646	-7.6873	-1.1155	120.1051	-15.7599	24.6056	-3.1658	5.5754
3.10	-5.2025	-8.7635	0.6238	55.5741	-14.9570	25.4116	-3.6987	5.5237
3.20	-5.8759	-9.4280	0.6230	-166.2894	11.7082	21.9841	-3.7634	5.6675
3.30	-6.5299	-10.1197	-1.6534	60.9742	-19.0008	22.9468	-3.7138	5.6204
3.40	-8.0360	-10.7430	0.3728	117.9508	9.4025	26.3043	-4.3754	5.6880
3.50	-9.1606	-11.2182	-0.0344	-140.6147	-5.4185	23.1866	-4.5193	5.7843
3.60	-10.2441	-11.6289	-1.0905	-8.7659	-3.9906	20.2095	-4.5575	5.5855
3.70	-12.0352	-11.7905	0.3585	150.1091	-2.5408	23.5049	-5.1682	5.6043
3.80	-13.6815	-11.6082	1.5828	-88.6481	14.3393	22.0175	-5.5086	5.7987
3.90	-14.9411	-11.2276	-1.6528	-90.0193	-5.1418	19.2891	-5.4541	5.8065
4.00	-16.8598	-10.7499	-0.8647	137.2373	-4.7922	20.9621	-6.0055	5.7217

HSRI/MVMA BRAKING AND HANDLING SIMULATION OF TRUCKS, TRACTOR-SEMITRAILERS, DOUBLES, AND TRIPLES - PHASE 4. OUTPUT PAGE NO. 1.03.1

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR FRONT AXLE TIRE FORCES

	LEFT SIDE					RIGHT SIDE					STEER ANGLE	
TIME (SEC)	VERTICAL (LB)	LONG. (LB)	LATERAL (LB)	MU-X	MU-Y	VERTICAL (LB)	LONG. (LB)	LATERAL (LB)	MU-X	MU-Y	LEFT (DEG)	RIGHT (DEG)
0.0	4668.81	-0.0	0.0	0.0	0.0	4668.81	-0.0	0.0	0.0	0.0	0.0	0.0
0.10	4828.34	-62.15	273.45	-0.0129	0.0566	4544.56	-55.61	237.42	-0.0122	0.0522	0.64	0.61
0.20	5030.17	-66.10	511.05	-0.0131	0.1016	4397.72	-53.35	404.89	-0.0121	0.0921	1.27	1.21
0.30	5162.48	-68.00	750.70	-0.0132	0.1454	4259.50	-50.91	556.31	-0.0120	0.1306	1.92	1.83
0.40	5201.70	-68.25	836.11	-0.0131	0.1607	4192.19	-49.85	647.13	-0.0119	0.1544	2.60	2.49
0.50	5239.74	-68.35	923.61	-0.0130	0.1763	4131.91	-49.32	697.17	-0.0119	0.1687	3.27	3.16
0.60	5224.14	-67.33	869.13	-0.0129	0.1664	4167.98	-50.53	661.09	-0.0121	0.1586	3.29	3.18
0.70	5221.07	-66.69	826.38	-0.0128	0.1583	4208.44	-51.46	632.74	-0.0122	0.1504	3.30	3.20
0.80	5227.86	-66.48	819.00	-0.0127	0.1567	4185.38	-51.65	611.59	-0.0123	0.1461	3.31	3.21
0.90	5181.94	-65.57	834.71	-0.0127	0.1611	4180.28	-51.83	639.27	-0.0124	0.1529	3.30	3.20
1.00	5130.14	-64.88	795.25	-0.0126	0.1550	4259.79	-52.97	600.42	-0.0124	0.1409	3.31	3.22
1.10	5210.60	-65.59	798.74	-0.0126	0.1533	4201.60	-52.47	572.40	-0.0125	0.1362	3.32	3.23
1.20	5260.50	-66.36	870.53	-0.0126	0.1655	4166.15	-51.92	655.11	-0.0125	0.1572	3.29	3.18
1.30	5125.76	-64.72	817.41	-0.0126	0.1595	4278.71	-53.25	646.56	-0.0124	0.1511	3.30	3.20
1.40	5173.65	-64.86	782.85	-0.0125	0.1513	4211.11	-52.96	550.47	-0.0126	0.1307	3.32	3.24
1.50	5269.98	-66.30	878.68	-0.0126	0.1667	4122.41	-51.49	653.48	-0.0125	0.1585	3.29	3.18
1.60	5127.44	-64.44	836.96	-0.0126	0.1632	4274.38	-53.47	661.87	-0.0125	0.1548	3.29	3.19
1.70	5181.23	-64.92	768.64	-0.0125	0.1484	4262.73	-53.51	534.47	-0.0126	0.1254	3.33	3.25
1.80	5289.95	-66.66	879.50	-0.0126	0.1663	4111.88	-51.26	649.90	-0.0125	0.1581	3.29	3.18
1.90	5110.23	-64.63	846.88	-0.0126	0.1657	4256.89	-52.93	669.71	-0.0124	0.1573	3.29	3.18
2.00	5127.63	-64.05	729.59	-0.0125	0.1423	4277.45	-53.81	512.07	-0.0126	0.1197	3.34	3.26
2.10	5311.86	-66.81	875.00	-0.0126	0.1647	4107.43	-51.19	642.97	-0.0125	0.1565	3.29	3.19
2.20	5337.27	-62.37	895.69	-0.0117	0.1678	4422.27	-46.22	703.00	-0.0105	0.1590	3.28	3.16
2.30	5646.18	-67.83	795.73	-0.0120	0.1409	4805.13	-52.33	551.68	-0.0109	0.1148	3.33	3.24
2.40	5834.18	-69.59	960.60	-0.0119	0.1647	4569.36	-46.14	706.43	-0.0101	0.1546	3.27	3.16
2.50	5385.62	-65.79	999.37	-0.0122	0.1856	4372.11	-42.64	765.39	-0.0098	0.1751	3.25	3.12
2.60	5166.60	-60.71	932.84	-0.0118	0.1806	4184.17	-40.67	708.61	-0.0097	0.1694	3.27	3.15
2.70	5579.39	-67.33	1115.88	-0.0121	0.2000	4080.28	-38.70	816.05	-0.0095	0.2000	3.22	3.08
2.80	5585.06	-67.64	1117.01	-0.0121	0.2000	4369.56	-40.61	873.91	-0.0093	0.2000	3.21	3.06
2.90	5522.79	-65.36	1104.56	-0.0118	0.2000	4445.32	-42.33	889.06	-0.0095	0.2000	3.21	3.06
3.00	5673.09	-66.60	1134.62	-0.0117	0.2000	4159.20	-38.43	831.84	-0.0092	0.2000	3.21	3.07
3.10	5385.18	-61.03	1077.03	-0.0113	0.2000	4139.96	-35.48	827.99	-0.0086	0.2000	3.22	3.08
3.20	5296.54	-59.54	1059.31	-0.0112	0.2000	4326.96	-38.51	865.39	-0.0089	0.2000	3.22	3.07
3.30	5632.00	-62.18	1126.40	-0.0110	0.2000	4170.04	-36.01	834.01	-0.0086	0.2000	3.21	3.07
3.40	5662.17	-58.80	1132.43	-0.0104	0.2000	4175.39	-32.84	835.08	-0.0079	0.2000	3.21	3.07
3.50	5413.23	-58.06	1082.65	-0.0107	0.2000	4370.47	-35.69	874.09	-0.0082	0.2000	3.21	3.07
3.60	5529.76	-57.98	1105.95	-0.0105	0.2000	4184.79	-36.33	836.96	-0.0087	0.2000	3.22	3.07
3.70	5616.46	-61.29	1123.29	-0.0109	0.2000	4088.27	-33.63	817.65	-0.0082	0.2000	3.21	3.07
3.80	5386.78	-57.82	1077.36	-0.0107	0.2000	4331.85	-34.64	866.37	-0.0080	0.2000	3.21	3.07
3.90	5464.79	-57.51	1092.96	-0.0105	0.2000	4334.80	-35.41	866.96	-0.0082	0.2000	3.21	3.07
4.00	5640.71	-59.30	1128.14	-0.0105	0.2000	4130.93	-32.00	826.19	-0.0077	0.2000	3.21	3.07

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR REAR SUSPENSION TIRE FORCES

LEADING TANDEM AXLE

TIME (SEC)	LEFT SIDE VERTICAL (LB)	LEFT SIDE LONG. (LB)	LEFT SIDE LATERAL (LB)	LEFT SIDE MU-X	LEFT SIDE MU-Y	RIGHT SIDE VERTICAL (LB)	RIGHT SIDE LONG. (LB)	RIGHT SIDE LATERAL (LB)	RIGHT SIDE MU-X	RIGHT SIDE MU-Y
0.0	2540.59	-0.0	0.0	0.0	0.0	2540.59	-0.0	0.0	0.0	0.0
0.10	2539.90	-21.47	-19.72	-0.0085	-0.0078	2496.28	-18.08	-19.42	-0.0072	-0.0078
0.20	2557.66	-29.98	-6.58	-0.0117	-0.0026	2358.60	-20.91	-6.10	-0.0089	-0.0026
0.30	2701.32	-34.91	28.16	-0.0129	0.0104	2409.75	-21.73	25.37	-0.0090	0.0105
0.40	2689.31	-35.57	40.95	-0.0132	0.0152	2332.69	-20.72	36.04	-0.0089	0.0155
0.50	2669.09	-35.02	62.11	-0.0131	0.0233	2350.90	-20.99	55.74	-0.0089	0.0237
0.60	2585.65	-32.86	88.11	-0.0127	0.0341	2443.35	-22.89	85.10	-0.0094	0.0348
0.70	2556.66	-31.19	99.54	-0.0122	0.0389	2410.16	-23.82	96.09	-0.0099	0.0399
0.80	2732.41	-32.46	143.63	-0.0119	0.0526	2304.05	-23.53	124.18	-0.0102	0.0539
0.90	2668.58	-31.10	194.59	-0.0117	0.0729	2402.05	-25.15	179.73	-0.0105	0.0748
1.00	2544.38	-29.20	167.98	-0.0115	0.0660	2400.11	-25.63	162.68	-0.0107	0.0678
1.10	2810.08	-31.82	185.10	-0.0113	0.0659	2185.03	-23.63	147.78	-0.0108	0.0676
1.20	2714.25	-30.83	262.96	-0.0114	0.0969	2324.77	-25.24	231.28	-0.0109	0.0995
1.30	2525.66	-28.57	215.56	-0.0113	0.0853	2342.26	-25.37	205.34	-0.0108	0.0877
1.40	2888.68	-32.41	184.06	-0.0112	0.0637	2224.72	-24.61	145.57	-0.0111	0.0654
1.50	2846.57	-32.12	296.67	-0.0113	0.1042	2309.27	-25.10	247.19	-0.0109	0.1070
1.60	2770.72	-31.07	260.84	-0.0112	0.0941	2434.16	-26.69	235.38	-0.0110	0.0967
1.70	2967.21	-33.14	178.89	-0.0112	0.0603	2183.73	-23.99	135.21	-0.0110	0.0619
1.80	2785.43	-31.47	290.42	-0.0113	0.1043	2306.44	-24.89	247.01	-0.0108	0.1071
1.90	2508.59	-28.37	256.58	-0.0113	0.1023	2278.60	-24.78	239.43	-0.0109	0.1051
2.00	2968.56	-33.08	159.39	-0.0111	0.0537	2183.06	-24.09	120.37	-0.0110	0.0551
2.10	2794.13	-31.31	278.90	-0.0112	0.0998	2328.01	-25.09	238.66	-0.0108	0.1025
2.20	1895.62	-379.12	133.37	-0.2000	0.0704	1725.53	-345.10	122.44	-0.2000	0.0710
2.30	2606.79	-521.36	111.70	-0.2000	0.0428	1687.96	-337.59	68.19	-0.2000	0.0404
2.40	2485.12	-497.02	122.90	-0.2000	0.0495	2111.58	-422.32	88.65	-0.2000	0.0420
2.50	2036.53	-407.31	92.32	-0.2000	0.0453	2223.59	-444.72	82.95	-0.2000	0.0373
2.60	2668.15	-533.63	116.15	-0.2000	0.0435	2000.62	-399.77	68.36	-0.1998	0.0342
2.70	2469.26	-488.49	115.74	-0.1978	0.0469	2054.08	-408.68	66.33	-0.1990	0.0323
2.80	2198.18	-428.73	109.94	-0.1950	0.0500	2363.39	-467.81	81.70	-0.1979	0.0346
2.90	2506.41	-481.62	134.09	-0.1922	0.0535	2071.75	-402.45	76.61	-0.1943	0.0370
3.00	2392.68	-447.50	145.06	-0.1870	0.0606	1890.67	-358.47	71.74	-0.1896	0.0379
3.10	2199.55	-399.39	151.03	-0.1816	0.0687	2316.05	-437.88	102.50	-0.1891	0.0443
3.20	2396.44	-427.25	179.36	-0.1783	0.0748	2116.28	-399.79	99.09	-0.1889	0.0468
3.30	2470.54	-437.71	191.10	-0.1772	0.0774	1795.49	-341.14	79.00	-0.1900	0.0440
3.40	2292.13	-404.45	181.59	-0.1765	0.0792	2266.40	-430.61	99.72	-0.1900	0.0440
3.50	2366.58	-417.75	187.06	-0.1765	0.0790	2191.97	-416.47	96.45	-0.1900	0.0440
3.60	2820.47	-495.08	230.20	-0.1755	0.0816	1861.29	-353.64	81.90	-0.1900	0.0440
3.70	2552.07	-445.14	215.66	-0.1744	0.0845	2209.82	-419.87	97.23	-0.1800	0.0440
3.80	2496.59	-435.39	211.15	-0.1744	0.0846	2347.19	-445.97	103.28	-0.1900	0.0440
3.90	2686.60	-465.92	234.00	-0.1734	0.0871	2082.29	-395.08	93.05	-0.1897	0.0447
4.00	2682.53	-460.91	244.83	-0.1718	0.0913	2207.51	-419.43	97.13	-0.1900	0.0440

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRACTOR REAR SUSPENSION TIRE FORCES
TRAILING TANDEM AXLE

	LEFT SIDE					RIGHT SIDE				
TIME (SEC)	VERTICAL (LB)	LONG. (LB)	LATERAL (LB)	MU-X	MU-Y	VERTICAL (LB)	LONG. (LB)	LATERAL (LB)	MU-X	MU-Y
0.0	2540.59	-0.0	0.0	0.0	0.0	2540.59	-0.0	0.0	0.0	0.0
0.10	2614.83	-22.26	6.25	-0.0085	0.0024	2491.76	-18.05	5.97	-0.0072	0.0024
0.20	2605.93	-30.71	73.99	-0.0118	0.0284	2303.82	-20.37	65.77	-0.0088	0.0285
0.30	2821.64	-36.55	189.70	-0.0130	0.0672	2300.11	-20.54	156.19	-0.0089	0.0679
0.40	2879.98	-38.08	283.63	-0.0132	0.0985	2173.76	-18.91	217.23	-0.0087	0.0999
0.50	2912.56	-38.17	378.56	-0.0131	0.1300	2152.03	-18.62	285.02	-0.0087	0.1324
0.60	2848.72	-36.21	434.43	-0.0127	0.1525	2165.75	-19.51	332.78	-0.0090	0.1537
0.70	2829.83	-34.65	446.42	-0.0122	0.1578	2200.00	-21.00	350.11	-0.0095	0.1591
0.80	2924.26	-34.94	481.65	-0.0119	0.1647	2074.41	-20.50	345.07	-0.0099	0.1663
0.90	2894.77	-33.99	500.44	-0.0117	0.1729	2240.34	-22.84	391.57	-0.0102	0.1748
1.00	2766.37	-32.04	474.68	-0.0116	0.1716	2212.53	-23.12	383.87	-0.0105	0.1735
1.10	3046.76	-34.88	523.13	-0.0114	0.1717	1995.97	-21.15	346.54	-0.0106	0.1736
1.20	2904.58	-33.35	529.39	-0.0115	0.1823	2164.41	-23.05	399.27	-0.0106	0.1845
1.30	2716.47	-31.04	486.17	-0.0114	0.1790	2165.55	-23.06	392.22	-0.0106	0.1811
1.40	3110.55	-35.30	532.66	-0.0113	0.1712	2023.60	-22.02	350.40	-0.0109	0.1732
1.50	3033.31	-34.61	561.46	-0.0114	0.1851	2174.14	-23.25	407.44	-0.0107	0.1874
1.60	2966.79	-33.64	539.45	-0.0113	0.1818	2265.59	-24.52	416.98	-0.0108	0.1840
1.70	3175.72	-35.86	540.78	-0.0113	0.1703	1965.62	-21.26	338.44	-0.0108	0.1722
1.80	2966.64	-33.89	549.57	-0.0114	0.1852	2185.47	-23.18	409.91	-0.0106	0.1876
1.90	2715.97	-31.03	502.26	-0.0114	0.1849	2157.91	-23.15	404.07	-0.0107	0.1873
2.00	3200.85	-36.06	537.79	-0.0113	0.1680	1909.91	-20.76	324.39	-0.0109	0.1698
2.10	3012.49	-34.17	553.12	-0.0113	0.1836	2173.06	-23.00	403.91	-0.0106	0.1859
2.20	2782.42	-556.48	330.74	-0.2000	0.1189	2382.12	-476.42	265.83	-0.2000	0.1116
2.30	3145.00	-629.00	242.17	-0.2000	0.0770	2240.82	-448.16	131.01	-0.2000	0.0585
2.40	2918.17	-583.63	190.44	-0.2000	0.0653	2433.24	-486.65	122.71	-0.2000	0.0504
2.50	2389.12	-472.20	147.30	-0.1976	0.0617	2470.78	-489.00	124.46	-0.1979	0.0504
2.60	3038.39	-592.25	196.69	-0.1949	0.0647	2304.18	-451.89	117.62	-0.1961	0.0510
2.70	2794.48	-526.37	211.38	-0.1884	0.0756	2280.85	-441.17	119.24	-0.1934	0.0523
2.80	2552.41	-461.86	216.64	-0.1809	0.0849	2525.11	-472.10	149.71	-0.1870	0.0593
2.90	2921.78	-509.65	272.05	-0.1744	0.0931	2237.14	-409.92	143.46	-0.1832	0.0641
3.00	2709.00	-445.51	280.28	-0.1645	0.1035	1993.94	-361.20	134.08	-0.1811	0.0672
3.10	2543.27	-400.78	277.31	-0.1576	0.1090	2531.24	-457.43	172.50	-0.1807	0.0681
3.20	2757.53	-433.84	301.41	-0.1573	0.1093	2340.16	-422.12	161.49	-0.1804	0.0690
3.30	2798.19	-431.63	314.89	-0.1543	0.1125	1969.37	-356.95	131.45	-0.1813	0.0667
3.40	2731.01	-413.66	315.32	-0.1515	0.1155	2593.33	-469.44	174.67	-0.1810	0.0674
3.50	2640.82	-401.85	302.97	-0.1522	0.1147	2336.28	-421.24	161.69	-0.1803	0.0692
3.60	3079.15	-456.48	365.93	-0.1482	0.1188	1981.69	-357.90	135.60	-0.1806	0.0684
3.70	2858.64	-415.03	348.91	-0.1452	0.1221	2355.20	-425.60	160.55	-0.1807	0.0682
3.80	2687.53	-391.48	326.67	-0.1457	0.1215	2405.72	-431.42	172.57	-0.1793	0.0717
3.90	2997.00	-429.98	371.19	-0.1435	0.1239	2216.27	-395.26	164.68	-0.1783	0.0743
4.00	3013.90	-420.78	385.49	-0.1396	0.1279	2321.02	-414.25	171.67	-0.1785	0.0740

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRACTOR FRONT SUSPENSION - BRAKE SUMMARY

		LEFT SIDE						RIGHT SIDE					
TIME (SEC)	TREADLE PRESSURE (PSI)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL. (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)
0.0	0.0	0.0	-0.00	-0.0	0.0	20.31	-0.0	0.0	-0.00	-0.0	0.0	20.31	-0.0
0.10	-0.0	0.0	1223.26	-62.15	0.0129	20.04	-0.11	0.0	1152.39	-55.61	0.0122	20.01	-0.66
0.20	-0.0	0.0	1274.19	-66.10	0.0131	20.05	0.14	0.0	1115.68	-53.35	0.0121	19.95	-0.73
0.30	-0.0	0.0	1308.25	-68.00	0.0132	20.06	0.17	0.0	1080.42	-50.91	0.0120	19.87	-0.85
0.40	-0.0	0.0	1318.48	-68.25	0.0131	20.08	0.12	0.0	1063.09	-49.85	0.0119	19.78	-0.88
0.50	-0.0	0.0	1327.99	-68.35	0.0130	20.09	0.05	0.0	1047.78	-49.32	0.0119	19.70	-0.83
0.60	-0.0	0.0	1324.19	-67.33	0.0129	20.09	-0.11	0.0	1056.38	-50.53	0.0121	19.63	-0.69
0.70	-0.0	0.0	1323.50	-66.69	0.0128	20.09	-0.22	0.0	1066.92	-51.46	0.0122	19.58	-0.62
0.80	-0.0	0.0	1325.14	-66.48	0.0127	20.07	-0.28	0.0	1061.44	-51.65	0.0123	19.53	-0.53
0.90	-0.0	0.0	1314.11	-65.57	0.0127	20.04	-0.35	0.0	1059.18	-51.83	0.0124	19.48	-0.47
1.00	-0.0	0.0	1300.46	-64.88	0.0126	20.02	-0.34	0.0	1079.58	-52.97	0.0124	19.45	-0.45
1.10	-0.0	0.0	1320.15	-65.59	0.0126	19.99	-0.40	0.0	1065.74	-52.47	0.0125	19.41	-0.41
1.20	-0.0	0.0	1334.25	-66.36	0.0126	19.94	-0.39	0.0	1055.44	-51.92	0.0125	19.36	-0.42
1.30	-0.0	0.0	1300.09	-64.72	0.0126	19.92	-0.37	0.0	1084.26	-53.25	0.0124	19.34	-0.45
1.40	-0.0	0.0	1310.26	-64.86	0.0125	19.88	-0.44	0.0	1068.50	-52.96	0.0126	19.31	-0.35
1.50	-0.0	0.0	1336.38	-66.30	0.0126	19.84	-0.42	0.0	1044.64	-51.49	0.0125	19.27	-0.39
1.60	-0.0	0.0	1300.27	-64.44	0.0126	19.81	-0.42	0.0	1082.75	-53.47	0.0125	19.23	-0.39
1.70	-0.0	0.0	1312.09	-64.92	0.0125	19.78	-0.45	0.0	1082.04	-53.51	0.0126	19.20	-0.38
1.80	-0.0	0.0	1341.50	-66.66	0.0126	19.74	-0.40	0.0	1042.62	-51.26	0.0125	19.16	-0.42
1.90	-0.0	0.0	1296.29	-64.63	0.0126	19.71	-0.35	0.0	1078.44	-52.93	0.0124	19.13	-0.45
2.00	0.05	0.0	1298.10	-64.05	0.0125	19.67	-0.48	0.0	1085.57	-53.81	0.0126	19.10	-0.35
2.10	2.00	0.11	1346.42	-66.81	0.0126	19.63	-0.42	0.11	1041.53	-51.19	0.0125	19.06	-0.42
2.20	2.00	0.67	1351.23	-62.37	0.0117	19.50	-1.31	0.67	1118.50	-46.22	0.0105	18.91	-2.11
2.30	2.00	1.11	1429.80	-67.83	0.0120	19.43	-1.04	1.11	1217.14	-52.33	0.0109	18.75	-1.91
2.40	2.00	1.40	1479.34	-69.59	0.0119	19.34	-1.19	1.40	1160.15	-46.14	0.0101	18.55	-2.53
2.50	2.00	1.60	1366.92	-65.79	0.0122	19.25	-0.82	1.60	1109.00	-42.64	0.0098	18.29	-2.69
2.60	2.00	1.73	1308.88	-60.71	0.0118	19.12	-1.21	1.73	1061.90	-40.67	0.0097	18.01	-2.61
2.70	2.00	1.82	1413.06	-67.33	0.0121	18.99	-0.97	1.82	1034.48	-38.70	0.0095	17.73	-2.72
2.80	2.00	1.88	1417.83	-67.64	0.0121	18.86	-0.96	1.88	1106.46	-40.61	0.0093	17.40	-3.05
2.90	2.00	1.92	1399.57	-65.36	0.0118	18.71	-1.21	1.92	1127.76	-42.33	0.0095	17.06	-2.94
3.00	2.00	1.95	1438.32	-66.60	0.0124	18.52	-1.36	1.95	1054.95	-38.43	0.0098	16.72	-2.97
3.10	2.00	1.96	1367.70	-61.03	0.0139	18.24	-1.72	1.96	1046.88	-35.48	0.0108	16.28	-3.45
3.20	2.00	1.98	1342.85	-59.54	0.0151	17.93	-1.77	1.98	1095.96	-38.51	0.0125	15.80	-3.35
3.30	2.00	1.98	1427.21	-62.18	0.0167	17.58	-2.08	1.98	1057.67	-36.01	0.0141	15.30	-3.45
3.40	2.00	1.99	1437.38	-58.80	0.0210	17.08	-2.82	1.99	1056.55	-32.84	0.0171	14.67	-4.04
3.50	2.00	1.99	1372.80	-58.06	0.0242	16.57	-2.34	1.99	1107.40	-35.69	0.0204	14.00	-4.00
3.60	2.00	2.00	1399.57	-57.98	0.0262	16.00	-2.61	2.00	1062.75	-36.33	0.0217	13.30	-3.44
3.70	2.00	2.00	1424.16	-61.29	0.0273	15.34	-2.22	2.00	1036.44	-33.63	0.0206	12.51	-3.70
3.80	2.00	2.00	1365.95	-57.82	0 0268	14.63	-2.32	2.00	1097.78	-34.64	0.0200	11.63	-4.10
3.90	2.00	2.00	1382.70	-57.51	0.0263	13.83	-2.54	2.00	1101.01	-35.41	0.0204	10.67	-3.99
4.00	2.00	2.00	1429.39	-59.30	0.0263	12.94	-2.65	2.00	1047.88	-32.00	0.0194	9.63	-4.12

HSRI/MVMA BRAKING AND HANDLING SIMULATION OF TRUCKS, TRACTOR-SEMITRAILERS, DOUBLES, AND TRIPLES - PHASE 4. OUTPUT PAGE NO. 1.09.1

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRACTOR REAR SUSPENSION - BRAKE SUMMARY
LEADING TANDEM AXLE

		LEFT SIDE						RIGHT SIDE					
TIME (SEC)	TREADLE PRESSURE (PSI)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL. (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)
0.0	0.0	0.0	-0.00	-0.0	0.0	20.31	-0.0	0.0	-0.00	-0.0	0.0	20.31	-0.0
0.10	-0.0	0.0	643.14	-21.47	0.0085	20.13	-0.98	0.0	633.24	-18.08	0.0072	20.11	-1.22
0.20	-0.0	0.0	648.55	-29.98	0.0117	20.07	-0.28	0.0	597.67	-20.91	0.0089	20.02	-0.83
0.30	-0.0	0.0	684.11	-34.91	0.0129	20.06	-0.01	0.0	611.87	-21.73	0.0090	19.94	-0.82
0.40	-0.0	0.0	681.89	-35.57	0.0132	20.06	0.05	0.0	591.30	-20.72	0.0089	19.86	-0.81
0.50	-0.0	0.0	676.72	-35.02	0.0131	20.07	0.03	0.0	595.09	-20.99	0.0089	19.78	-0.81
0.60	-0.0	0.0	656.77	-32.86	0.0127	20.07	-0.07	0.0	616.96	-22.89	0.0094	19.70	-0.74
0.70	-0.0	0.0	647.26	-31.19	0.0122	20.06	-0.17	0.0	612.70	-23.82	0.0099	19.64	-0.64
0.80	-0.0	0.0	692.40	-32.46	0.0119	20.05	-0.26	0.0	586.32	-23.53	0.0102	19.59	-0.55
0.90	-0.0	0.0	677.32	-31.10	0.0117	20.02	-0.31	0.0	607.35	-25.15	0.0105	19.53	-0.51
1.00	-0.0	0.0	643.06	-29.20	0.0115	20.00	-0.32	0.0	607.91	-25.63	0.0107	19.50	-0.47
1.10	-0.0	0.0	712.37	-31.82	0.0113	19.97	-0.40	0.0	553.25	-23.63	0.0108	19.46	-0.40
1.20	-0.0	0.0	692.09	-30.83	0.0114	19.93	-0.39	0.0	587.01	-25.24	0.0109	19.41	-0.41
1.30	-0.0	0.0	640.16	-28.57	0.0113	19.90	-0.36	0.0	594.40	-25.37	0.0108	19.39	-0.43
1.40	-0.0	0.0	735.71	-32.41	0.0112	19.87	-0.45	0.0	569.13	-24.61	0.0111	19.35	-0.39
1.50	-0.0	0.0	722.27	-32.12	0.0113	19.83	-0.42	0.0	583.83	-25.10	0.0109	19.32	-0.41
1.60	-0.0	0.0	700.50	-31.07	0.0112	19.80	-0.41	0.0	619.99	-26.69	0.0110	19.28	-0.43
1.70	-0.0	0.0	749.79	-33.14	C.0112	19.76	-0.45	0.0	554.28	-23.99	0.0110	19.24	-0.38
1.80	-0.0	0.0	705.17	-31.47	0.0113	19.73	-0.40	0.0	581.58	-24.89	0.0108	19.22	-0.42
1.90	-0.0	0.0	632.76	-28.37	0.0113	19.70	-0.35	0.0	578.58	-24.78	0.0109	19.18	-0.41
2.00	0.05	0.0	755.14	-33.08	0.0111	19.66	-0.48	0.0	554.28	-24.09	0.0110	19.14	-0.37
2.10	2.00	0.03	706.21	-31.31	0.0112	19.62	-0.42	0.03	587.77	-25.09	0.0108	19.11	-0.43
2.20	2.00	0.53	20953.38	-379.12	0.3586	12.63	-58.96	0.53	20849.00	-345.10	0.3656	12.14	-61.39
2.30	2.00	1.01	15139.88	-521.36	0.5452	8.92	-21.62	1.01	14893.80	-337.59	0.5932	7.72	-36.13
2.40	2.00	1.34	12342.45	-497.02	0.6237	7.35	-11.52	1.34	12230.96	-422.32	0.7252	5.16	-17.37
2.50	2.00	1.56	10795.57	-407.31	0.6834	6.15	-12.40	1.56	10833.84	-444.72	0.7837	4.01	-9.40
2.60	2.00	1.70	10202.39	-533.63	0.7059	5.67	0.88	1.70	10044.84	-399.77	0.8277	3.14	-9.78
2.70	2.00	1.80	9635.23	-488.49	0.7023	5.71	-0.48	1.80	9529.79	-408.68	0.8857	2.06	-6.79
2.80	2.00	1.87	9262.74	-428.73	0.7149	5.43	-3.92	1.87	9300.24	-467.81	0.9041	1.69	-0.77
2.90	2.00	1.91	9190.61	-481.62	0.7154	5.38	0.87	1.91	9087.74	-402.45	0.9170	1.44	-5.39
3.00	2.00	1.94	8835.88	-447.50	0.6981	5.65	-0.48	1.94	8706.94	-358.47	0.9566	0.74	-7.46
3.10	2.00	1.96	8527.03	-399.39	0.6971	5.60	-3.21	1.96	8553.37	-437.88	0.9733	0.45	-0.06
3.20	2.00	1.97	8521.75	-427.25	0.6946	5.56	-0.83	1.97	8451.50	-399.79	0.9728	0.44	-2.85
3.30	2.00	1.98	8279.39	-437.71	0.6793	5.74	1.11	1.98	8103.05	-341.14	1.0045	-0.07	-6.31
3.40	2.00	1.99	8254.89	-404.45	0.6613	5.93	-1.60	1.99	8236.68	-430.61	1.0114	-0.17	0.70
3.50	2.00	1.99	8183.19	-417.75	0.6631	5.75	-0.16	1.99	8135.26	-416.47	1.0025	-0.04	-0.06
3.60	2.00	1.99	8213.88	-495.08	0.6383	5.98	6.26	1.99	7973.38	-353.64	1.0156	-0.22	-4.68
3.70	2.00	2.00	8020.22	-445.14	0.6105	6.19	2.87	2.00	7927.82	-419.87	1.0298	-0.39	1.13
3.80	2.00	2.00	7902.30	-435.39	0.6098	5.93	2.56	2.00	7863.09	-445.97	1.0100	-0.12	3.62
3.90	2.00	2.00	7917.34	-465.92	0.5856	5.96	5.08	2.00	7773.98	-395.08	0.9934	0.08	-0.30
4.00	2.00	2.00	7674.33	-460.91	0.5455	6.13	5.71	2.00	7556.13	-419.43	1.0069	-0.07	2.71

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRACTOR REAR SUSPENSION - BRAKE SUMMARY
TRAILING TANDEM AXLE

		LEFT SIDE						RIGHT SIDE					
TIME (SEC)	TREADLE PRESSURE (PSI)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL. (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)
0.0	0.0	0.0	-0.00	-0.0	0.0	20.31	-0.0	0.0	-0.00	-0.0	0.0	20.31	-0.0
0.10	-0.0	0.0	662.11	-22.26	0.0085	20.12	-0.99	0.0	631.67	-18.05	0.0072	20.11	-1.22
0.20	-0.0	0.0	660.46	-30.71	0.0118	20.07	-0.27	0.0	584.72	-20.37	0.0088	20.02	-0.82
0.30	-0.0	0.0	714.14	-36.55	0.0130	20.06	-0.01	0.0	584.58	-20.54	0.0089	19.94	-0.80
0.40	-0.0	0.0	729.80	-38.08	0.0132	20.06	0.06	0.0	551.47	-18.91	0.0087	19.86	-0.79
0.50	-0.0	0.0	738.28	-38.17	0.0131	20.07	0.03	0.0	545.45	-18.62	0.0087	19.78	-0.79
0.60	-0.0	0.0	723.59	-36.21	0.0127	20.07	-0.08	0.0	547.13	-19.51	0.0090	19.71	-0.72
0.70	-0.0	0.0	716.38	-34.65	0.0122	20.06	-0.18	0.0	559.18	-21.00	0.0095	19.64	-0.65
0.80	-0.0	0.0	740.29	-34.94	0.0119	20.05	-0.26	0.0	526.58	-20.50	0.0099	19.59	-0.55
0.90	-0.0	0.0	734.69	-33.99	0.0117	20.02	-0.31	0.0	566.20	-22.84	0.0102	19.54	-0.53
1.00	-0.0	0.0	698.64	-32.04	0.0116	20.00	-0.32	0.0	560.80	-23.12	0.0105	19.50	-0.48
1.10	-0.0	0.0	772.47	-34.88	0.0114	19.97	-0.40	0.0	506.01	-21.15	0.0106	19.46	-0.41
1.20	-0.0	0.0	740.52	-33.35	0.0115	19.92	-0.39	0.0	546.99	-23.05	0.0106	19.42	-0.42
1.30	-0.0	0.0	688.41	-31.04	0.0114	19.90	-0.36	0.0	549.60	-23.06	0.0106	19.39	-0.43
1.40	-0.0	0.0	793.74	-35.30	0.0113	19.87	-0.46	0.0	517.20	-22.02	0.0109	19.35	-0.38
1.50	-0.0	0.0	769.28	-34.61	0.0114	19.83	-0.41	0.0	549.06	-23.25	0.0107	19.32	-0.42
1.60	-0.0	0.0	750.59	-33.64	0.0113	19.80	-0.41	0.0	577.23	-24.52	0.0108	19.28	-0.43
1.70	-0.0	0.0	802.71	-35.86	0.0113	19.76	-0.45	0.0	498.86	-21.26	0.0108	19.25	-0.37
1.80	-0.0	0.0	751.54	-33.89	0.0114	19.73	-0.39	0.0	550.59	-23.18	0.0106	19.22	-0.43
1.90	-0.0	0.0	684.55	-31.03	0.0114	19.69	-0.35	0.0	548.37	-23.15	0.0107	19.18	-0.42
2.00	0.05	-0.0	815.57	-36.06	0.0113	19.65	-0.49	-0.0	487.97	-20.76	0.0109	19.15	-0.36
2.10	2.00	0.03	764.33	-34.17	0.0113	19.62	-0.43	0.03	546.81	-23.00	0.0106	19.12	-0.43
2.20	2.00	0.53	21054.29	-556.48	0.3038	13.71	-44.36	0.53	20903.53	-476.42	0.3280	12.86	-50.49
2.30	2.00	1.01	15221.90	-629.00	0.4433	10.92	-12.85	1.01	14988.69	-448.16	0.5192	9.12	-27.17
2.40	2.00	1.34	12422.73	-583.63	0.4825	10.10	-4.53	1.34	12292.51	-486.65	0.6196	7.14	-12.19
2.50	2.00	1.56	10863.46	-472.20	0.5091	9.54	-7.20	1.56	10880.26	-489.00	0.6533	6.42	-5.85
2.60	2.00	1.70	10286.52	-592.25	0.5047	9.56	5.49	1.70	10114.09	-451.89	0.6763	5.90	-5.66
2.70	2.00	1.80	9710.60	-526.37	0.4779	10.01	2.41	1.80	9584.15	-441.17	0.7120	5.18	-4.27
2.80	2.00	1.87	9349.63	-461.86	0.4717	10.07	-1.49	1.87	9345.27	-472.10	0.7173	5.00	-0.61
2.90	2.00	1.91	9290.74	-509.65	0.4604	10.19	2.82	1.91	9126.33	-409.92	0.7236	4.79	-4.93
3.00	2.00	1.94	8907.75	-445.51	0.4408	10.47	-0.96	1.94	8720.70	-361.20	0.7604	4.08	-7.29
3.10	2.00	1.96	8612.93	-400.78	0.4379	10.40	-3.47	1.96	8601.32	-457.43	0.7678	3.87	1.38
3.20	2.00	1.97	8609.03	-433.84	0.4366	10.26	-0.65	1.97	8504.33	-422.12	0.7595	3.90	-1.19
3.30	2.00	1.98	8357.12	-431.63	0.4213	10.36	0.26	1.98	8139.74	-356.95	0.7813	3.45	-5.13
3.40	2.00	1.99	8362.37	-413.66	0.4073	10.37	-1.29	1.99	8316.07	-469.44	0.7755	3.42	3.64
3.50	2.00	1.99	8248.24	-401.85	0.4108	10.05	-1.79	1.99	8167.95	-421.24	0.7576	3.55	0.20
3.60	2.00	1.99	8281.77	-456.48	0.3912	10.06	2.69	1.99	7995.47	-357.90	0.7651	3.28	-4.42
3.70	2.00	2.00	8099.86	-415.03	0.3759	9.92	-0.03	2.00	7962.29	-425.60	0.7676	3.07	1.46
3.80	2.00	2.00	7953.38	-391.48	0.3783	9.45	-1.39	2.00	7880.00	-431.42	0.7333	3.29	2.32
3.90	2.00	2.00	7998.29	-429.98	0.3674	9.10	1.68	2.00	7807.96	-395.26	0.7086	3.32	-0.44
4.00	2.00	2.00	7761.79	-420.78	0.3481	8.80	1.93	2.00	7584.12	-414.25	0.7119	2.98	2.15

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR FRONT SUSPENSION - LATERAL TIRE FORCE AND MOMENT SUMMARY

	LEFT SIDE				RIGHT SIDE			
TIME (SEC)	TIRE SIDESLIP ANGLE (DEG)	TIRE LATERAL FORCE (LB)	MU-Y	ALIGNING TORQUE (IN-LB)	TIRE SIDESLIP ANGLE (DEG)	TIRE LATERAL FORCE (LB)	MU-Y	ALIGNING TORQUE (IN-LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.10	-0.3776	273.4478	0.0566	-273.3218	-0.3483	237.4240	0.0522	-237.3146
0.20	-0.6773	511.0461	0.1016	-510.8108	-0.6138	404.8948	0.0921	-404.7083
0.30	-0.9694	750.7024	0.1454	-750.3567	-0.8707	556.3127	0.1306	-556.0566
0.40	-1.2148	836.1086	0.1607	-835.7236	-1.0873	647.1309	0.1544	-646.8330
0.50	-1.5254	923.6084	0.1763	-923.1833	-1.3745	697.1658	0.1687	-696.8447
0.60	-1.3273	869.1260	0.1664	-868.7258	-1.1722	661.0911	0.1586	-660.7866
0.70	-1.1656	826.3794	0.1583	-825.9990	-1.0070	632.7407	0.1504	-632.4492
0.80	-1.1332	819.0029	0.1567	-818.6257	-0.9742	611.5896	0.1461	-611.3079
0.90	-1.2216	834.7058	0.1611	-834.3215	-1.0585	639.2712	0.1529	-638.9768
1.00	-1.1003	795.2456	0.1550	-794.8794	-0.9397	600.4163	0.1409	-600.1399
1.10	-1.0658	798.7395	0.1533	-798.3718	-0.9082	572.4006	0.1362	-572.1372
1.20	-1.3097	870.5339	0.1655	-870.1333	-1.1449	655.1130	0.1572	-654.8115
1.30	-1.1894	817.4104	0.1595	-817.0342	-1.0222	646.5618	0.1511	-646.2642
1.40	-1.0263	782.8457	0.1513	-782.4854	-0.8715	550.4663	0.1307	-550.2129
1.50	-1.3347	878.6841	0.1667	-878.2795	-1.1704	653.4797	0.1585	-653.1790
1.60	-1.2646	836.9622	0.1632	-836.5769	-1.0969	661.8691	0.1548	-661.5645
1.70	-0.9890	768.6421	0.1484	-768.2883	-0.8359	534.4697	0.1254	-534.2236
1.80	-1.3252	879.5010	0.1663	-879.0959	-1.1611	649.9026	0.1581	-649.6033
1.90	-1.3144	846.8767	0.1657	-846.4868	-1.1465	669.7129	0.1573	-669.4045
2.00	-0.9486	729.5950	0.1423	-729.2590	-0.7981	512.0730	0.1197	-511.8372
2.10	-1.2945	874.9973	0.1647	-874.5945	-1.1308	642.9702	0.1565	-642.6741
2.20	-1.3564	895.6917	0.1678	-895.2793	-1.1793	702.9954	0.1590	-702.6716
2.30	-0.9395	795.7253	0.1409	-795.3589	-0.7654	551.6760	0.1148	-551.4221
2.40	-1.2930	960.6028	0.1647	-960.1604	-1.0920	706.4290	0.1546	-706.1038
2.50	-1.7113	999.3735	0.1856	-998.9136	-1.5012	765.3901	0.1751	-765.0378
2.60	-1.6110	932.8362	0.1806	-932.4067	-1.3871	708.6106	0.1694	-708.2842
2.70	-2.2940	1115.8779	0.2000	-1115.3643	-2.0890	816.0549	0.2000	-815.6792
2.80	-3.4759	1117.0115	0.2000	-1116.4973	-3.3533	873.9116	0.2000	-873.5093
2.90	-3.7634	1104.5576	0.2000	-1104.0491	-3.6705	889.0647	0.2000	-888.6555
3.00	-4.8346	1134.6169	0.2000	-1134.0947	-4.8755	831.8396	0.2000	-831.4565
3.10	-6.9899	1077.0349	0.2000	-1076.5393	-7.3150	827.9912	0.2000	-827.6101
3.20	-8.1151	1059.3069	0.2000	-1058.8191	-8.6379	865.3911	0.2000	-864.9927
3.30	-9.4393	1126.3999	0.2000	-1125.8813	-10.2295	834.0068	0.2000	-833.6228
3.40	-12.2241	1132.4333	0.2000	-1131.9121	-13.5617	835.0786	0.2000	-834.6943
3.50	-14.2931	1082.6460	0.2000	-1082.1475	-16.1493	874.0935	0.2000	-873.6912
3.60	-16.0549	1105.9521	0.2000	-1105.4431	-18.4508	836.9585	0.2000	-836.5732
3.70	-19.3767	1123.2913	0.2000	-1122.7742	-22.7113	817.6548	0.2000	-817.2783
3.80	-22.5461	1077.3560	0.2000	-1076.8601	-26.9451	866.3694	0.2000	-865.9705
3.90	-24.9014	1092.9575	0.2000	-1092.4543	-30.3627	866.9607	0.2000	-866.5615
4.00	-28.5706	1128.1421	0.2000	-1127.6228	-35.5394	826.1865	0.2000	-825.8062

HSRI/MVMA BRAKING AND HANDLING SIMULATION OF TRUCKS, TRACTOR-SEMITRAILERS, DOUBLES, AND TRIPLES - PHASE 4. OUTPUT PAGE NO. 1.13.1

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR REAR SUSPENSION - LATERAL TIRE FORCE AND MOMENT SUMMARY

LEADING TANDEM AXLE

TIME (SEC)	LEFT SIDE TIRE SIDESLIP ANGLE (DEG)	TIRE LATERAL FORCE (LB)	MU-Y	ALIGNING TORQUE (IN-LB)	RIGHT SIDE TIRE SIDESLIP ANGLE (DEG)	TIRE LATERAL FORCE (LB)	MU-Y	ALIGNING TORQUE (IN-LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.10	0.0518	-19.7222	-0.0078	31.0513	0.0519	-19.4179	-0.0078	30.5722
0.20	0.0171	-6.5781	-0.0026	10.3568	0.0172	-6.0991	-0.0026	9.6027
0.30	-0.0695	28.1583	0.0104	-44.3335	-0.0702	25.3706	0.0105	-39.9443
0.40	-0.1015	40.9484	0.0152	-64.4705	-0.1030	36.0422	0.0155	-56.7461
0.50	-0.1551	62.1072	0.0233	-97.7837	-0.1581	55.7413	0.0237	-87.7611
0.60	-0.2272	88.1108	0.0341	-138.7248	-0.2322	85.0950	0.0348	-133.9766
0.70	-0.2596	99.5403	0.0389	-156.7197	-0.2658	96.0895	0.0399	-151.2866
0.80	-0.3504	143.6289	0.0526	-226.1343	-0.3593	124.1815	0.0539	-195.5156
0.90	-0.4861	194.5902	0.0729	-306.3694	-0.4988	179.7272	0.0748	-282.9688
1.00	-0.4401	167.9827	0.0660	-264.4775	-0.4519	162.6828	0.0678	-256.1333
1.10	-0.4391	185.1024	0.0659	-291.4316	-0.4509	147.7800	0.0676	-232.6699
1.20	-0.6459	262.9639	0.0969	-414.0193	-0.6632	231.2828	0.0995	-364.1396
1.30	-0.5690	215.5596	0.0853	-339.3845	-0.5845	205.3407	0.0877	-323.2954
1.40	-0.4248	184.0602	0.0637	-289.7908	-0.4362	145.5660	0.0654	-229.1841
1.50	-0.6948	296.6707	0.1042	-467.0886	-0.7136	247.1928	0.1070	-389.1890
1.60	-0.6276	260.8411	0.0941	-410.6770	-0.6446	235.3765	0.0967	-370.5850
1.70	-0.4019	178.8947	0.0603	-281.6580	-0.4128	135.2120	0.0619	-212.8824
1.80	-0.6951	290.4158	0.1043	-457.2407	-0.7140	247.0086	0.1071	-388.8989
1.90	-0.6819	256.5789	0.1023	-403.9666	-0.7005	239.4303	0.1051	-376.9673
2.00	-0.3580	159.3909	0.0537	-250.9506	-0.3676	120.3744	0.0551	-189.5216
2.10	-0.6654	278.8950	0.0998	-439.1021	-0.6835	238.6629	0.1025	-375.7590
2.20	-0.9160	133.3709	0.0704	-209.9837	-0.9430	122.4350	0.0710	-192.7659
2.30	-1.0397	111.6983	0.0428	-175.8618	-1.0751	68.1883	0.0404	-107.3580
2.40	-1.9482	122.8952	0.0495	-193.4905	-2.0262	88.6546	0.0420	-139.5808
2.50	-3.1710	92.3193	0.0453	-145.3508	-3.3272	82.9492	0.0373	-130.5981
2.60	-3.9784	116.1475	0.0435	-182.8667	-4.2077	68.3611	0.0342	-107.6301
2.70	-5.4585	115.7388	0.0469	-182.2233	-5.8198	66.3319	0.0323	-104.4352
2.80	-7.4810	109.9385	0.0500	-173.0910	-8.0569	81.6980	0.0346	-128.6281
2.90	-8.8606	134.0940	0.0535	-211.1223	-9.6336	76.6061	0.0370	-120.6113
3.00	-10.7741	145.0622	0.0606	-228.3909	-11.8132	71.7436	0.0379	-112.9557
3.10	-13.5620	151.0321	0.0687	-237.7901	-15.0000	102.4959	0.0443	-161.3732
3.20	-15.6740	179.3570	0.0748	-282.3860	-17.4869	99.0944	0.0468	-156.0177
3.30	-17.9186	191.1048	0.0774	-300.8818	-20.1497	79.0015	0.0440	-124.3827
3.40	-21.2707	181.5861	0.0792	-285.8953	-24.1089	99.7214	0.0440	-157.0049
3.50	-24.2305	187.0557	0.0790	-294.5068	-27.7004	96.4466	0.0440	-151.8489
3.60	-26.9636	230.1973	0.0816	-362.4307	-31.0622	81.8967	0.0440	-128.9410
3.70	-30.7477	215.6587	0.0845	-339.5405	-35.6472	97.2320	0.0440	-153.0855
3.80	-34.5125	211.1535	0.0846	-332.4473	-40.2826	103.2765	0.0440	-162.6022
3.90	-37.8068	234.0044	0.0871	-368.4246	-44.4386	93.0505	0.0447	-146.5020
4.00	-41.8180	244.8291	0.0913	-385.4673	-49.3778	97.1302	0.0440	-152.9252

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRACTOR REAR SUSPENSION - LATERAL TIRE FORCE AND MOMENT SUMMARY
TRAILING TANDEM AXLE

TIME (SEC)	LEFT SIDE: TIRE SIDESLIP ANGLE (DEG)	LEFT SIDE: TIRE LATERAL FORCE (LB)	LEFT SIDE: MU-Y	LEFT SIDE: ALIGNING TORQUE (IN-LB)	RIGHT SIDE: TIRE SIDESLIP ANGLE (DEG)	RIGHT SIDE: TIRE LATERAL FORCE (LB)	RIGHT SIDE: MU-Y	RIGHT SIDE: ALIGNING TORQUE (IN-LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.10	-0.0159	6.2498	0.0024	-9.8400	-0.0160	5.9663	0.0024	-9.3935
0.20	-0.1893	73.9892	0.0284	-116.4912	-0.1903	65.7669	0.0285	-103.5457
0.30	-0.4482	189.7008	0.0672	-298.6714	-0.4527	156.1866	0.0679	-245.9057
0.40	-0.6565	283.6272	0.0985	-446.5525	-0.6662	217.2338	0.0999	-342.0205
0.50	-0.8665	378.5615	0.1300	-596.0205	-0.8829	285.0190	0.1324	-448.7439
0.60	-1.0500	434.4292	0.1525	-683.9805	-1.0731	332.7795	0.1537	-523.9397
0.70	-1.1551	446.4216	0.1578	-702.8618	-1.1828	350.1135	0.1591	-551.2310
0.80	-1.2942	481.6519	0.1647	-758.3296	-1.3270	345.0735	0.1663	-543.2957
0.90	-1.4576	500.4436	0.1729	-787.9160	-1.4956	391.5667	0.1748	-616.4961
1.00	-1.4318	474.6812	0.1716	-747.3545	-1.4700	383.8687	0.1735	-604.3762
1.10	-1.4340	523.1338	0.1717	-823.6401	-1.4724	346.5386	0.1736	-545.6023
1.20	-1.6452	529.3933	0.1823	-833.4954	-1.6894	399.2712	0.1845	-628.6265
1.30	-1.5794	486.1714	0.1790	-765.4453	-1.6224	392.2183	0.1811	-617.5220
1.40	-1.4248	532.6567	0.1712	-838.6333	-1.4631	350.4004	0.1732	-551.6826
1.50	-1.7019	561.4561	0.1851	-883.9761	-1.7480	407.4365	0.1874	-641.4822
1.60	-1.6366	539.4468	0.1818	-849.3237	-1.6810	416.9780	0.1840	-656.5049
1.70	-1.4057	540.7771	0.1703	-851.4185	-1.4436	338.4434	0.1722	-532.8569
1.80	-1.7050	549.5652	0.1852	-865.2546	-1.7513	409.9136	0.1876	-645.3823
1.90	-1.6986	502.2607	0.1849	-790.7769	-1.7450	404.0706	0.1873	-636.1826
2.00	-1.3603	537.7891	0.1680	-846.7139	-1.3969	324.3923	0.1698	-510.7346
2.10	-1.6722	553.1243	0.1836	-870.8582	-1.7175	403.9133	0.1859	-635.9353
2.20	-2.0076	330.7422	0.1189	-520.7319	-2.0667	265.8318	0.1116	-418.5347
2.30	-2.2972	242.1664	0.0770	-381.2751	-2.3754	131.0112	0.0585	-206.2687
2.40	-3.4162	190.4395	0.0653	-299.8345	-3.5527	122.7140	0.0504	-193.2052
2.50	-4.9592	147.3037	0.0617	-231.9199	-5.2028	124.4554	0.0504	-195.9468
2.60	-6.0509	196.6885	0.0647	-309.6731	-6.3981	117.6169	0.0510	-185.1802
2.70	-7.8124	211.3774	0.0756	-332.7998	-8.3259	119.2382	0.0523	-187.7328
2.80	-10.1782	216.6364	0.0849	-341.0798	-10.9533	149.7098	0.0593	-235.7084
2.90	-11.8756	272.0510	0.0931	-428.3264	-12.8968	143.4628	0.0641	-225.8729
3.00	-14.0581	280.2825	0.1035	-441.2864	-15.3880	134.0802	0.0672	-211.1005
3.10	-17.1040	277.3149	0.1090	-436.6143	-18.8709	172.4984	0.0681	-271.5874
3.20	-19.4683	301.4084	0.1093	-474.5479	-21.6479	161.4908	0.0690	-254.2568
3.30	-21.9263	314.8899	0.1125	-495.7734	-24.5502	131.4550	0.0667	-206.9672
3.40	-25.4552	315.3228	0.1155	-496.4551	-28.6873	174.6674	0.0674	-275.0024
3.50	-28.6012	302.9651	0.1147	-476.9988	-32.4588	161.6932	0.0692	-254.5754
3.60	-31.4807	365.9277	0.1188	-576.1294	-35.9428	135.5996	0.0684	-213.4927
3.70	-35.3199	348.9114	0.1221	-549.3381	-40.5048	160.5499	0.0682	-252.7753
3.80	-39.1252	326.6689	0.1215	-514.3191	-45.0746	172.5709	0.0717	-271.7014
3.90	-42.4601	371.1921	0.1239	-584.4177	-49.1507	164.6756	0.0743	-259.2708
4.00	-46.3895	385.4946	0.1279	-606.9360	-53.8304	171.6695	0.0740	-270.2822

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRACTOR FRONT SUSPENSION - UNSPRUNG MASS SUMMARY

	AXLE MOTION					DYNAMIC SUSPENSION MOTIONS AND FORCES					
	POSITION		VELOCITY			LEFT SIDE			RIGHT SIDE		
TIME (SEC)	VERTICAL (FT)	ROLL (DEG)	VERTICAL (FT/SEC)	ROLL (DEG/SEC)	AUXILIARY ROLL TORQUE (IN-LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0	0.0	0.0	-0.0
0.10	0.0003	-0.0443	0.0055	-0.2369	40.5	-0.0117	-0.5228	-40.97	0.0011	0.3108	5.60
0.20	0.0008	-0.0990	0.0019	-0.4423	277.4	-0.0672	-0.5064	-191.69	0.0339	0.3539	107.80
0.30	0.0008	-0.1427	-0.0028	-0.2644	388.0	-0.0905	-0.0358	-241.66	0.0540	0.0808	158.72
0.40	0.0005	-0.1602	-0.0032	-0.1249	416.0	-0.0904	-0.0260	-239.27	0.0646	0.1515	182.75
0.50	0.0003	-0.1757	-0.0010	-0.1567	458.1	-0.0936	-0.0260	-246.35	0.0775	0.0603	210.47
0.60	0.0005	-0.1681	0.0049	0.0074	465.1	-0.0978	0.0485	-248.97	0.0767	-0.1180	195.38
0.70	0.0009	-0.1610	-0.0006	-0.0363	482.6	-0.1062	-0.2438	-267.43	0.0735	0.1023	175.32
0.80	0.0007	-0.1654	-0.0047	-0.1480	616.9	-0.1299	-0.0651	-313.03	0.1001	0.2069	236.39
0.90	0.0002	-0.1603	-0.0002	0.2487	536.6	-0.1117	0.3926	-212.13	0.0914	-0.3848	180.34
1.00	0.0005	-0.1388	0.0044	0.0750	435.4	-0.0944	-0.2762	-132.03	0.0675	0.2231	80.46
1.10	0.0007	-0.1593	0.0015	-0.3458	756.6	-0.1580	-0.6666	-310.96	0.1214	0.6248	237.36
1.20	0.0008	-0.1754	-0.0001	0.3213	774.4	-0.1681	0.5356	-291.42	0.1251	-0.6619	209.38
1.30	0.0006	-0.1359	-0.0044	0.2844	445.3	-0.1070	0.1509	-57.59	0.0607	-0.0747	-6.48
1.40	0.0004	-0.1511	0.0039	-0.5674	778.9	-0.1625	-0.8724	-264.66	0.1234	1.0104	214.34
1.50	0.0005	-0.1833	-0.0006	0.1637	926.8	-0.1939	0.5629	-319.61	0.1562	-0.6548	266.19
1.60	0.0006	-0.1370	0.0047	0.3260	472.8	-0.1160	0.3804	-40.06	0.0638	-0.5485	-28.23
1.70	0.0010	-0.1436	-0.0011	-0.6909	764.3	-0.1714	-1.1088	-270.68	0.1082	1.0798	166.14
1.80	0.0006	-0.1875	-0.0105	0.0105	1008.9	-0.2143	0.6406	-353.97	0.1662	-0.5446	299.55
1.90	0.0003	-0.1372	-0.0021	0.3857	451.8	-0.1071	0.7443	-2.82	0.0666	-0.8428	-22.12
2.00	0.0006	-0.1326	0.0074	-0.7247	703.3	-0.1525	-1.3012	-223.97	0.1033	1.2810	155.55
2.10	0.0008	-0.1911	-0.0018	-0.1501	1084.2	-0.2282	0.4457	-406.22	0.1793	-0.4196	333.44
2.20	0.0037	-0.1464	0.0645	0.2184	463.6	-0.1898	-0.5373	-223.40	-0.0099	-2.9297	-174.96
2.30	0.0102	-0.1335	0.0394	-0.1010	551.9	-0.3775	-2.8085	-652.73	-0.1778	-0.0801	-412.41
2.40	0.0100	-0.1998	-0.0307	-0.4082	1073.9	-0.5362	0.4957	-860.02	-0.1351	0.5195	-181.58
2.50	0.0040	-0.1624	-0.0347	0.2840	589.2	-0.3595	2.8059	-251.14	-0.1321	0.2733	-174.71
2.60	0.0002	-0.1547	-0.0092	-0.4590	562.1	-0.2500	-0.8637	-144.82	-0.0464	1.6365	69.81
2.70	0.0029	-0.2371	0.0168	-0.4076	1247.3	-0.3811	-1.2157	-607.20	0.0823	-0.1429	273.75
2.80	0.0058	-0.1965	-0.0103	0.8212	779.2	-0.3558	0.9127	-408.39	-0.0543	-2.5638	-195.30
2.90	0.0059	-0.1704	-0.0052	-0.2806	400.4	-0.3057	-0.9705	-289.94	-0.1609	1.0225	-328.72
3.00	0.0046	-0.2405	-0.0111	-0.1104	1323.1	-0.4454	-0.6917	-708.04	0.0422	2.2102	219.06
3.10	0.0018	-0.2030	-0.0040	1.3048	1086.6	-0.3607	2.3149	-327.33	0.0572	-1.4797	74.75
3.20	0.0026	-0.1555	0.0092	0.3059	262.2	-0.1906	-0.4144	-36.32	-0.0923	-0.2272	-275.03
3.30	0.0043	-0.2314	-0.0010	-0.3336	1043.7	-0.3591	-2.4000	-601.88	0.0204	1.8071	136.04
3.40	0.0046	-0.2399	-0.0012	0.8904	1277.5	-0.4261	1.1714	-606.35	0.0597	-1.4768	113.75
3.50	0.0041	-0.1669	-0.0004	0.2494	356.1	-0.2575	1.0925	-128.88	-0.1190	-0.7820	-314.78
3.60	0.0035	-0.2100	0.0040	-1.0879	788.5	-0.3147	-1.5524	-438.84	-0.0305	2.2344	53.21
3.70	0.0034	-0.2433	-0.0060	0.0256	1354.9	-0.4073	0.6721	-633.54	0.1029	-0.6704	275.53
3.80	0.0035	-0.1687	-0.0008	0.2033	472.5	-0.2556	1.5179	-141.86	-0.0693	-2.0781	-238.36
3.90	0.0042	-0.1756	0.0077	-1.1399	446.3	-0.2559	-1.5500	-292.45	-0.0978	1.4452	-160.86
4.00	0.0040	-0.2392	-0.0026	-0.2969	1347.0	-0.4206	-0.4293	-698.42	0.0793	0.9938	260.22

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRACTOR REAR SUSPENSION - UNSPRUNG MASS SUMMARY
LEADING TANDEM AXLE

	AXLE MOTION					DYNAMIC SUSPENSION MOTIONS AND FORCES					
	POSITION		VELOCITY			LEFT SIDE			RIGHT SIDE		
TIME (SEC)	VERTICAL (FT)	ROLL (DEG)	VERTICAL (FT/SEC)	ROLL (DEG/SEC)	AUXILIARY ROLL TORQUE (IN-LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0	0.0	0.0	-0.0
0.10	-0.0002	-0.0033	0.0014	-0.1475	-37.5	0.0045	-0.3248	-71.77	0.0042	0.7245	96.09
0.20	-0.0007	-0.0177	-0.0054	0.0335	-253.7	0.0326	-0.8303	-209.78	0.0006	0.5068	267.41
0.30	0.0001	-0.0249	-0.0011	-0.2383	-127.2	0.0148	-0.1098	-264.87	-0.0075	0.0459	271.92
0.40	-0.0003	-0.0316	-0.0006	0.0071	26.5	0.0117	-0.0510	-285.02	0.0039	0.2473	344.57
0.50	-0.0003	-0.0284	0.0038	0.0860	-148.4	0.0171	-0.2326	-232.78	-0.0112	0.0309	276.18
0.60	-0.0003	-0.0148	0.0039	0.6051	185.6	-0.0102	-0.0076	-44.77	0.0034	0.1911	140.90
0.70	-0.0005	-0.0116	-0.0088	-0.3668	796.0	-0.0457	-0.1706	5.69	0.0467	0.0214	45.32
0.80	-0.0002	-0.0368	-0.0105	-0.3046	423.6	-0.0211	-0.4443	-245.10	0.0188	-0.2252	225.95
0.90	-0.0001	-0.0246	0.0022	0.2949	90.6	0.0020	0.9922	-62.88	0.0042	0.0997	65.96
1.00	-0.0007	-0.0121	0.0129	-0.1741	1084.1	-0.0389	-0.2978	122.73	0.0688	0.1298	-1.58
1.10	-0.0004	-0.0553	0.0001	-0.0012	744.3	-0.0537	-1.3554	-345.16	0.0099	0.4066	390.10
1.20	-0.0001	-0.0373	-0.0176	0.7743	29.3	0.0001	1.1613	-53.25	-0.0056	0.0397	67.57
1.30	-0.0010	-0.0158	-0.0031	-0.1073	1412.0	-0.0451	0.0179	58.06	0.1131	-0.5098	21.86
1.40	0.0003	-0.0581	-0.0541	-0.1534	1068.8	0.0067	-2.0000	-398.40	0.1031	0.5105	602.77
1.50	0.0003	-0.0483	0.0106	0.2096	-79.5	0.0244	0.6620	-74.46	0.0040	-0.7535	136.91
1.60	0.0006	-0.0271	-0.0028	-0.7307	1524.5	-0.0989	0.8557	-77.93	0.0804	-0.9483	-2.54
1.70	0.0003	-0.0680	0.0096	-0.3473	1336.8	-0.0402	-0.7761	-312.51	0.1040	2.0508	542.15
1.80	-0.0001	-0.0435	0.0283	0.3083	-221.5	0.0323	0.9058	-150.50	0.0021	-0.3041	115.67
1.90	-0.0014	-0.0184	0.0086	-0.5315	1523.7	-0.0790	1.1964	-60.18	0.0973	-1.2966	-47.41
2.00	0.0004	-0.0700	-0.0195	0.1413	1620.5	-0.0304	-1.7770	-501.49	0.1276	1.8636	510.07
2.10	0.0001	-0.0413	0.0335	0.0348	-290.2	0.0243	0.7500	-133.65	-0.0185	-0.1550	66.98
2.20	-0.0071	-0.0113	0.0904	-1.0411	1442.3	-0.0246	3.7749	629.15	0.1322	0.0986	685.07
2.30	-0.0037	-0.0772	0.0129	-1.1105	1549.8	-0.0038	-1.5806	-235.21	0.1274	0.9899	1067.26
2.40	-0.0023	-0.0354	0.0076	0.6556	-546.2	0.0723	-0.4282	193.38	-0.0091	0.3056	505.44
2.50	-0.0037	0.0176	-0.0324	-0.2863	1144.8	-0.0273	0.8310	503.00*	0.1049	-2.5548	130.13
2.60	-0.0019	-0.0537	-0.0063	-1.4558	2107.5	-0.0695	0.0074	-211.36	0.1495	2.3153	733.82
2.70	-0.0026	-0.0370	0.0145	0.0706	-162.3	0.0712	-0.9353	-17.12	0.0276	0.6558	500.40
2.80	-0.0026	0.0144	0.0550	0.0452	648.1	-0.0350	2.5448	449.90	0.0391	-2.0982	-140.66
2.90	-0.0023	-0.0354	-0.0014	-0.8426	2199.8	-0.1112	-0.0980	-141.06	0.1072	1.8959	494.78
3.00	-0.0036	-0.0452	-0.0175	0.2224	180.3	0.0433	-2.0891	-141.28	0.0587	1.5775	497.52
3.10	-0.0027	0.0102	0.0199	0.0361	454.5	-0.0450	2.8210	374.69	0.0367	-2.5265	-9.41
3.20	-0.0025	-0.0240	-0.0328	-0.2047	2221.1	-0.1016	0.3253	175.42	0.1411	0.2091	359.46
3.30	-0.0037	-0.0625	-0.0175	0.7605	369.7	-0.0050	-3.5426	-243.37	0.0284	2.1789	670.31
3.40	-0.0022	-0.0070	-0.0502	1.2947	-119.3	0.0142	1.3056	361.23	-0.0044	-1.5710	80.79
3.50	-0.0023	-0.0168	-0.0381	0.3836	1947.9	-0.0888	0.5079	226.26	0.1310	-1.6290	203.39
3.60	-0.0017	-0.0854	-0.0488	0.1740	793.3	-0.0033	-3.2079	-338.22	0.0672	2.1258	812.88
3.70	-0.0015	-0.0338	-0.0027	0.9634	-528.1	0.0625	1.0517	102.92	-0.0023	0.0794	358.71
3.80	-0.0013	-0.0138	0.0639	0.1645	1040.2	-0.0481	3.2527	376.30	0.0960	-1.0432	56.96
3.90	-0.0015	-0.0493	0.0145	-1.1315	1200.0	-0.0165	-0.8015	-146.36	0.1173	2.7607	562.51
4.00	-0.0010	-0.0424	0.0244	0.0976	-204.8	0.0194	-1.5548	-66.95	-0.0045	0.3968	530.30

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRACTOR REAR SUSPENSION - UNSPRUNG MASS SUMMARY
TRAILING TANDEM AXLE

	AXLE MOTION					DYNAMIC SUSPENSION MOTIONS AND FORCES					
	POSITION		VELOCITY			LEFT SIDE			RIGHT SIDE		
TIME (SEC)	VERTICAL (FT)	ROLL (DEG)	VERTICAL (FT/SEC)	ROLL (DEG/SEC)	AUXILIARY ROLL TORQUE (IN-LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.10	0.0001	-0.0105	0.0047	-0.0924	-80.6	0.0175	-0.3040	-118.75	-0.0009	0.7818	86.94
0.20	-0.0008	-0.0266	-0.0076	-0.0343	-306.7	0.0328	-0.8409	-227.28	-0.0042	0.4512	206.36
0.30	0.0002	-0.0448	-0.0024	-0.3526	-246.1	0.0196	-0.1062	-285.20	-0.0011	-0.0262	249.57
0.40	-0.0001	-0.0621	-0.0015	-0.1034	-155.6	0.0167	-0.0551	-306.31	0.0088	0.1699	325.10
0.50	-0.0001	-0.0671	0.0002	-0.0265	-379.4	0.0298	-0.2802	-252.01	-0.0016	-0.0914	233.10
0.60	-0.0003	-0.0622	-0.0008	0.5029	-97.6	0.0057	-0.0780	-176.31	0.0028	0.0529	148.56
0.70	-0.0002	-0.0543	-0.0056	-0.3928	541.5	-0.0047	-0.1758	-5.84	0.0494	-0.0012	5.90
0.80	-0.0004	-0.0744	0.0034	-0.1923	198.7	-0.0103	-0.3806	-214.69	0.0167	-0.0870	217.30
0.90	0.0002	-0.0591	0.0030	0.3273	-114.8	0.0110	0.9298	-84.54	0.0115	0.0588	37.40
1.00	-0.0005	-0.0478	0.0152	-0.3190	871.1	-0.0337	-0.2738	110.49	0.0734	0.0577	-19.55
1.10	-0.0002	-0.0930	0.0012	0.0373	518.8	-0.0493	-1.4345	-364.62	0.0185	0.3531	350.16
1.20	0.0000	-0.0685	-0.0163	0.8528	-157.5	0.0014	1.0676	-72.01	0.0009	-0.0019	14.31
1.30	-0.0009	-0.0484	0.0003	-0.0751	1217.3	-0.0442	-0.0050	44.21	0.0923	-0.5113	26.02
1.40	0.0005	-0.0967	-0.0607	0.1763	838.4	-0.0141	-2.2678	-365.54	0.0884	0.4613	521.53
1.50	0.0005	-0.0771	0.0147	0.2995	-251.3	0.0147	0.5846	-163.06	0.0057	-0.7713	124.77
1.60	0.0007	-0.0594	-0.0070	-0.7146	1331.7	-0.0757	0.7455	26.88	0.0691	-1.0478	34.81
1.70	0.0002	-0.1057	0.0102	-0.3524	1111.7	-0.0279	-0.8435	-312.41	0.0848	1.9800	494.02
1.80	0.0002	-0.0708	0.0274	0.4623	-384.3	0.0303	0.7400	-188.48	-0.0001	-0.3678	107.10
1.90	-0.0010	-0.0466	0.0171	-0.7607	1355.6	-0.0572	1.3201	17.45	0.0975	-1.3249	-62.46
2.00	-0.0003	-0.1138	-0.0438	-0.1064	1359.2	-0.0424	-2.0567	-456.49	0.1129	1.4197	662.35
2.10	0.0004	-0.0761	0.0205	0.5260	-497.9	0.0220	0.3218	-192.97	-0.0186	-0.2574	-17.12
2.20	0.0006	-0.0345	-0.0588	-0.2342	1303.3	-0.0078	1.6565	33.56	0.1556	-1.4847	-131.32
2.30	0.0014	-0.0762	-0.0019	-1.0291	1555.7	-0.0228	-1.8570	-629.96	0.1747	0.7674	639.65
2.40	0.0013	-0.0437	-0.0098	0.2181	-595.4	0.0711	-0.6483	-208.92	0.0238	-0.2047	146.39
2.50	-0.0009	0.0083	-0.0339	-0.3050	1089.6	-0.0276	0.7012	185.01	0.1046	-2.6969	-188.64
2.60	0.0012	-0.0607	0.0163	-1.1544	2065.7	-0.0676	0.0535	-503.47	0.1611	2.5614	288.85
2.70	-0.0001	-0.0458	0.0205	0.1008	-214.9	0.0712	-1.1634	-298.62	0.0646	0.4478	312.96
2.80	-0.0000	-0.0004	0.0016	-0.5510	559.4	-0.0281	1.8716	203.83	0.0554	-3.1669	-266.47
2.90	0.0004	-0.0573	0.0016	-0.8825	2068.7	-0.1083	-0.1983	-547.00	0.1355	1.7692	204.23
3.00	-0.0018	-0.0657	0.0115	0.6879	57.7	0.0442	-2.3214	-397.15	0.0372	1.6540	451.67
3.10	-0.0000	-0.0038	0.0006	0.7493	371.1	-0.0299	1.9548	96.18	0.0067	-2.9197	-364.28
3.20	0.0002	-0.0358	-0.0346	-0.3081	2151.0	-0.1014	0.1885	-72.33	0.1423	0.0036	96.00
3.30	-0.0014	-0.0764	-0.0173	0.8604	286.3	0.0156	-4.0132	-465.83	0.0287	1.7745	434.42
3.40	0.0012	-0.0162	-0.0298	1.1019	-174.2	0.0349	1.0405	125.43	0.0392	-1.9639	-263.09
3.50	-0.0004	-0.0270	-0.0135	0.0271	1887.0	-0.0870	0.6923	-6.91	0.1319	-1.6811	-31.15
3.60	0.0000	-0.1010	-0.0340	1.0808	700.6	-0.0035	-3.7497	-579.37	0.0659	2.1854	574.84
3.70	0.0006	-0.0485	0.0100	1.0905	-615.9	0.0617	0.4504	-183.16	0.0068	-0.4376	5.12
3.80	-0.0001	-0.0236	0.0475	-0.3739	982.0	-0.0091	2.9070	126.99	0.0938	-1.7460	-181.39
3.90	0.0006	-0.0647	-0.0024	-1.2001	1108.4	0.0183	-1.2941	-413.58	0.1198	2.2227	307.56
4.00	0.0010	-0.0607	0.0365	-0.1496	-314.4	0.0401	-2.1355	-282.04	-0.0036	-0.3479	225.91

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRAILER NO. 1 SPRUNG MASS POSITION

TIME (SEC)	FORWARD (FT)	LATERAL (FT)	VERTICAL (FT)	ROLL (DEG)	PITCH (DEG)	HEADING (DEG)	TURN RADIUS (FT)	SIDE SLIP (DEG)	ARTICULATION ANGLE (DEG)
0.0	-27.9938	0.0	0.0	0.0	0.0	0.0	************	0.0	0.0
0.10	-24.6133	-0.0001	-0.0001	0.0030	0.0006	-0.0003	-17337.3008	-0.0040	0.0210
0.20	-21.3199	-0.0004	-0.0010	0.0248	0.0039	-0.0023	5950.4180	0.0028	0.1327
0.30	-18.0316	0.0013	0.0002	-0.0036	-0.0002	0.0057	1748.4229	0.0654	0.3648
0.40	-14.7492	0.0090	-0.0005	-0.0360	0.0012	0.0417	1101.4365	0.1694	0.7153
0.50	-11.4730	0.0265	-0.0004	-0.0036	0.0020	0.1132	786.7097	0.3026	1.1683
0.60	-8.2034	0.0575	-0.0002	-0.0459	0.0005	0.2305	623.9995	0.4573	1.6883
0.70	-4.9403	0.1054	-0.0005	-0.1451	0.0021	0.4012	547.6152	0.6067	2.2286
0.80	-1.6840	0.1726	-0.0004	-0.1079	0.0010	0.6204	454.1594	0.7614	2.7695
0.90	1.5651	0.2629	-0.0000	-0.0399	0.0001	0.8874	404.1294	0.9360	3.2925
1.00	4.8059	0.3786	-0.0013	-0.1942	0.0039	1.2104	414.3481	1.0671	3.7771
1.10	8.0386	0.5201	0.0003	-0.1804	-0.0018	1.5763	350.1750	1.1873	4.2269
1.20	11.2630	0.6909	0.0003	-0.0423	-0.0011	1.9787	314.0503	1.3525	4.6418
1.30	14.4787	0.8938	-0.0021	-0.2533	0.0065	2.4335	334.5862	1.4683	5.0093
1.40	17.6854	1.1277	-0.0009	-0.2382	0.0050	2.9245	296.2427	1.5523	5.3415
1.50	20.8830	1.3950	-0.0010	-0.0351	0.0003	3.4353	278.0149	1.6719	5.6506
1.60	24.0703	1.6980	0.0008	-0.2840	-0.0030	3.9893	282.3748	1.7813	5.9184
1.70	27.2473	2.0361	-0.0011	-0.2937	0.0028	4.5760	288.7944	1.8226	6.1507
1.80	30.4136	2.4091	-0.0010	-0.0064	0.0021	5.1692	252.9472	1.9090	6.3733
1.90	33.5686	2.8206	-0.0012	-0.2755	0.0046	5.7964	270.4082	2.0070	6.5643
2.00	36.7121	3.2687	-0.0013	-0.3438	0.0035	6.4519	271.4404	2.0051	6.7271
2.10	39.8432	3.7529	-0.0008	0.0073	-0.0004	7.1050	240.3148	2.0551	6.8840
2.20	42.9559	4.2757	-0.0026	-0.2548	0.0129	7.7809	323.4116	2.0914	7.0373
2.30	46.0408	4.8262	-0.0027	-0.3396	0.0049	8.4431	350.2251	1.9198	7.3158
2.40	49.0983	5.3994	0.0005	0.0566	-0.0004	9.0505	343.3752	1.8561	7.7833
2.50	52.1264	5.9952	-0.0019	-0.1761	0.0078	9.6182	463.5330	1.7349	8.5038
2.60	55.1274	6.6075	-0.0013	-0.4125	0.0035	10.1486	396.6692	1.5997	9.5071
2.70	58.0995	7.2379	-0.0030	-0.0100	0.0107	10.6295	403.9546	1.5809	10.7659
2.80	61.0460	7.8856	-0.0005	-0.0963	0.0009	11.0815	534.4705	1.5051	12.3094
2.90	63.9677	8.5461	0.0004	-0.4165	-0.0020	11.5196	467.2866	1.3997	14.1402
3.00	66.8625	9.2206	-0.0034	-0.0785	0.0124	11.9254	412.8350	1.4028	16.2372
3.10	69.7350	9.9109	-0.0007	-0.0696	0.0013	12.3151	491.1792	1.3941	18.5870
3.20	72.5859	10.6142	-0.0007	-0.4248	0.0024	12.7094	488.1963	1.3276	21.1721
3.30	75.4130	11.3304	-0.0027	-0.1361	0.0094	13.0829	416.4465	1.3291	23.9919
3.40	78.2183	12.0611	-0.0004	0.0146	0.0022	13.4400	480.6948	1.3479	27.0492
3.50	81.0060	12.8042	-0.0019	-0.3976	0.0038	13.8076	540.0081	1.2841	30.3436
3.60	83.7728	13.5587	-0.0012	-0.2630	0.0058	14.1638	409.7681	1.2761	33.8746
3.70	86.5192	14.3272	-0.0022	0.0691	0.0053	14.5001	442.5867	1.3250	37.6343
3.80	89.2502	15.1089	-0.0017	-0.2516	0.0035	14.8495	526.0752	1.3025	41.6162
3.90	91.9632	15.9024	-0.0013	-0.3592	0.0060	15.2039	446.2126	1.2802	45.8182
4.00	94.6555	16.7090	-0.0019	-0.0126	0.0024	15.5409	391.1423	1.3374	50.2433

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRAILER NO. 1 SPRUNG MASS VELOCITY (BODY AXES)

TIME (SEC)	FORWARD (FT/SEC)	LATERAL (FT/SEC)	VERTICAL (FT/SEC)	ROLL (DEG/SEC)	PITCH (DEG/SEC)	HEADING (DEG/SEC)	ARTICULATION RATE (DEG/SEC)
0.0	33.00	0.0	0.0	0.0	0.0	0.0	0.0
0.10	32.97	-0.00	-0.00	0.11	0.02	-0.01	0.57
0.20	32.91	0.00	0.00	0.14	-0.03	-0.00	1.71
0.30	32.85	0.04	0.01	-0.61	-0.01	0.20	2.93
0.40	32.80	0.10	-0.01	0.16	0.02	0.53	4.06
0.50	32.73	0.17	0.01	0.11	-0.03	0.92	4.96
0.60	32.67	0.26	0.00	-0.88	-0.01	1.44	5.36
0.70	32.61	0.35	-0.00	-0.67	0.00	1.96	5.43
0.80	32.54	0.43	0.01	1.21	-0.04	2.42	5.36
0.90	32.47	0.53	-0.01	-0.53	0.04	2.95	5.05
1.00	32.40	0.60	0.01	-1.62	-0.05	3.48	4.67
1.10	32.34	0.67	0.02	1.95	-0.09	3.82	4.34
1.20	32.27	0.76	-0.02	-0.52	0.10	4.27	3.92
1.30	32.20	0.83	0.01	-2.25	-0.07	4.79	3.48
1.40	32.13	0.87	-0.00	2.55	0.06	5.00	3.17
1.50	32.06	0.94	0.02	-0.16	-0.06	5.28	2.93
1.60	31.99	0.99	-0.01	-3.03	-0.03	5.77	2.44
1.70	31.92	1.02	-0.01	3.01	0.11	5.89	2.26
1.80	31.85	1.06	0.02	0.54	-0.08	6.04	2.15
1.90	31.78	1.11	-0.00	-3.97	-0.08	6.49	1.74
2.00	31.72	1.11	0.00	3.22	0.09	6.56	1.54
2.10	31.66	1.14	0.03	1.15	-0.12	6.59	1.54
2.20	31.52	1.15	-0.05	-4.20	0.12	6.84	1.92
2.30	31.22	1.05	0.06	3.32	-0.07	6.36	3.68
2.40	30.98	1.00	-0.01	1.82	-0.04	5.84	5.82
2.50	30.74	0.93	0.00	-4.94	0.01	5.53	8.66
2.60	30.51	0.85	0.00	1.78	0.05	5.06	11.31
2.70	30.28	0.84	0.01	3.38	-0.08	4.61	13.99
2.80	30.06	0.79	0.04	-4.54	-0.13	4.48	16.91
2.90	29.85	0.73	-0.02	0.29	0.07	4.25	19.68
3.00	29.63	0.73	-0.00	3.84	-0.05	3.92	22.27
3.10	29.44	0.72	0.04	-3.82	-0.16	3.94	24.69
3.20	29.26	0.68	-0.03	-0.83	0.08	3.89	27.01
3.30	29.09	0.67	0.03	4.63	-0.14	3.60	29.39
3.40	28.91	0.68	-0.00	-2.68	0.03	3.62	31.73
3.50	28.76	0.64	0.01	-2.74	-0.06	3.69	34.12
3.60	28.61	0.64	-0.00	4.73	0.03	3.42	36.43
3.70	28.45	0.66	0.00	0.00	0.00	3.39	38.71
3.80	28.32	0.64	0.02	-4.12	-0.06	3.58	40.93
3.90	28.20	0.63	-0.02	2.46	0.12	3.46	43.15
4.00	28.06	0.66	0.03	2.30	-0.13	3.36	45.35

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TIME (SEC)	TRAILER NO. 1 SPRUNG MASS ACCELERATION (BODY AXES) FORWARD (FT/SEC**2)	LATERAL (FT/SEC**2)	VERTICAL (FT/SEC**2)	ROLL (DEG/SEC**2)	PITCH (DEG/SEC**2)	HEADING (DEG/SEC**2)	INERTIAL ACCEL. ALONG BODY AXES LONGITUDINAL (FT/SEC**2)	LATERAL (FT/SEC**2)
0.0	-0.1638	0.0	0.0	0.0	0.0192	0.0	-0.1638	0.0
0.10	-0.4682	-0.0551	-0.0716	2.5004	0.4442	-0.3384	-0.4682	-0.0626
0.20	-0.5394	0.1888	0.3554	-7.1087	-1.2460	0.9215	-0.5394	0.1861
0.30	-0.5563	0.5047	-0.3499	-0.9574	1.3206	2.9734	-0.5565	0.6196
0.40	-0.5687	0.6754	0.2870	9.8464	0.4901	3.4610	-0.5696	0.9770
0.50	-0.6346	0.8336	-0.0423	-11.4132	-0.9273	4.6012	-0.6374	1.3600
0.60	-0.6318	0.8818	0.0443	-5.4606	0.6237	5.4604	-0.6384	1.7034
0.70	-0.6051	0.8168	0.0554	17.2334	-0.9195	4.7934	-0.6169	1.9344
0.80	-0.6602	0.9524	-0.0015	5.6591	-0.5211	4.6159	-0.6784	2.3249
0.90	-0.6382	0.9241	-0.3680	-30.8887	2.0019	5.9029	-0.6655	2.5952
1.00	-0.6682	0.5531	0.4830	19.1255	-1.5273	4.1375	-0.7048	2.5205
1.10	-0.6600	0.8175	-0.0643	20.4842	0.3207	3.1860	-0.7047	2.9750
1.20	-0.6998	0.8874	-0.3841	-53.9301	1.4082	5.7636	-0.7567	3.2937
1.30	-0.6770	0.3864	0.6442	31.4497	-2.4421	3.5944	-0.7460	3.0778
1.40	-0.6544	0.6632	-0.0648	33.2661	-1.5309	1.5711	-0.7304	3.4671
1.50	-0.6856	0.7281	0.1890	-65.7585	2.2215	5.0120	-0.7718	3.6812
1.60	-0.7038	0.3781	-0.4343	36.3950	-0.6218	3.5781	-0.8040	3.6007
1.70	-0.6393	0.2314	0.0572	40.5468	-1.3789	-0.0888	-0.7438	3.5158
1.80	-0.7098	0.6394	-0.0554	-78.6486	1.9158	3.8053	-0.8217	3.9961
1.90	-0.6737	0.1003	0.1084	32.8809	-2.8682	2.8418	-0.7999	3.7008
2.00	-0.5440	0.0616	-0.3042	60.4960	-0.7490	-0.9435	-0.6710	3.6912
2.10	-0.6964	0.5182	0.0154	-88.5996	3.9170	3.1942	-0.8270	4.1564
2.20	-2.5684	-0.8009	0.3628	29.2832	-5.9489	-2.0800	-2.7058	2.9556
2.30	-2.8261	-0.7515	0.1519	74.0295	1.7038	-5.9059	-2.9422	2.7085
2.40	-2.2714	-0.4393	-0.7407	-86.9935	0.6035	-3.8064	-2.3737	2.7183
2.50	-2.3373	-1.0010	0.7654	2.9661	-7.4342	-3.5749	-2.4271	1.9647
2.60	-2.3240	-0.3991	-1.1457	88.1432	7.1969	-5.3185	-2.3992	2.2956
2.70	-2.2458	-0.2285	0.7338	-69.5469	-3.1292	-2.9154	-2.3130	2.2066
2.80	-2.0924	-0.7144	-0.3543	-36.5090	0.1585	-0.9873	-2.1541	1.6364
2.90	-2.1253	-0.3475	-0.6748	98.2173	3.9428	-3.7696	-2.1794	1.8648
3.00	-2.0528	0.0475	0.9952	-50.2282	-4.0575	-1.7825	-2.1024	2.0740
3.10	-1.8013	-0.3225	-0.9258	-55.6333	1.9829	1.0909	-1.8507	1.7058
3.20	-1.7981	-0.2745	-0.1502	86.9532	-0.1476	-2.4289	-1.8442	1.7136
3.30	-1.7964	0.1622	0.8319	-23.4366	-3.6738	-1.9188	-1.8389	1.9877
3.40	-1.6719	-0.1386	-0.4948	-81.1610	1.6390	1.8508	-1.7149	1.6879
3.50	-1.4286	-0.3417	0.6784	72.6539	-1.0463	-1.2338	-1.4701	1.5088
3.60	-1.6806	0.2615	-0.3083	25.7583	-3.0002	-2.4420	-1.7186	1.9716
3.70	-1.4385	0.1060	0.0089	-89.2219	1.5647	1.9504	-1.4774	1.7880
3.80	-1.1202	-0.2838	-0.1239	33.4141	2.9112	0.6702	-1.1605	1.4893
3.90	-1.3461	0.0554	-1.0809	61.7379	-1.1106	-2.5917	-1.3842	1.7577
4.00	-1.3087	0.3452	0.9086	-57.6095	-0.5892	1.3337	-1.3472	1.9902

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRAILER NO. 1 REAR SUSPENSION TIRE FORCES
LEADING TANDEM AXLE

	LEFT SIDE					RIGHT SIDE				
TIME (SEC)	VERTICAL (LB)	LONG. (LB)	LATERAL (LB)	MU-X	MU-Y	VERTICAL (LB)	LONG. (LB)	LATERAL (LB)	MU-X	MU-Y
0.0	2177.50	-0.0	0.0	0.0	0.0	2177.50	-0.0	0.0	0.0	0.0
0.10	2165.04	-15.50	0.79	-0.0072	0.0004	2173.82	-15.64	0.80	-0.0072	0.0004
0.20	2100.35	-20.16	-0.19	-0.0096	-0.0001	2223.16	-21.44	-0.21	-0.0096	-0.0001
0.30	2200.98	-23.60	-4.19	-0.0107	-0.0019	2163.07	-22.42	-4.12	-0.0104	-0.0019
0.40	2258.46	-25.66	6.40	-0.0114	0.0028	2045.93	-21.37	5.81	-0.0104	0.0028
0.50	2184.96	-25.30	7.43	-0.0116	0.0034	2171.49	-22.39	7.41	-0.0103	0.0034
0.60	2282.05	-26.71	7.82	-0.0117	0.0034	2048.09	-20.63	7.05	-0.0101	0.0034
0.70	2514.81	-29.81	23.99	-0.0119	0.0095	1822.63	-17.98	17.50	-0.0099	0.0096
0.80	2379.09	-28.16	43.63	-0.0118	0.0183	1953.35	-18.91	36.10	-0.0097	0.0185
0.90	2170.31	-25.54	28.52	-0.0118	0.0131	2172.66	-21.09	28.82	-0.0097	0.0133
1.00	2547.62	-29.82	43.88	-0.0117	0.0172	1756.20	-16.86	30.59	-0.0096	0.0174
1.10	2487.07	-28.96	81.97	-0.0116	0.0330	1879.21	-17.82	62.70	-0.0095	0.0334
1.20	2090.27	-24.04	46.19	-0.0115	0.0221	2264.05	-21.74	50.72	-0.0096	0.0224
1.30	2620.94	-30.13	66.22	-0.0115	0.0253	1659.23	-15.74	42.58	-0.0095	0.0257
1.40	2572.76	-29.21	115.32	-0.0114	0.0448	1861.90	-17.36	84.82	-0.0093	0.0456
1.50	1968.77	-22.02	60.74	-0.0112	0.0309	2263.07	-21.94	71.03	-0.0097	0.0314
1.60	2718.52	-30.49	79.77	-0.0112	0.0293	1667.42	-15.76	49.85	-0.0095	0.0299
1.70	2604.78	-29.25	145.89	-0.0112	0.0560	1721.40	-16.10	98.28	-0.0094	0.0571
1.80	1942.24	-21.34	79.55	-0.0110	0.0410	2355.34	-23.13	98.39	-0.0098	0.0418
1.90	2694.82	-29.66	86.25	-0.0110	0.0320	1649.22	-15.73	53.92	-0.0095	0.0327
2.00	2736.79	-30.42	184.18	-0.0111	0.0673	1631.57	-15.25	112.19	-0.0093	0.0688
2.10	1911.58	-20.88	101.78	-0.0109	0.0532	2346.01	-23.38	127.64	-0.0100	0.0544
2.20	2725.62	-24.90	108.42	-0.0091	0.0398	1713.19	-14.01	69.70	-0.0082	0.0407
2.30	2700.55	-15.68	203.40	-0.0058	0.0753	1556.60	-5.78	119.75	-0.0037	0.0769
2.40	1911.19	-8.91	100.78	-0.0047	0.0527	2463.78	-11.98	132.50	-0.0049	0.0538
2.50	2564.55	-11.09	66.87	-0.0043	0.0261	1778.47	-9.48	47.25	-0.0053	0.0266
2.60	2931.39	-17.05	153.33	-0.0058	0.0523	1409.57	-5.65	75.01	-0.0040	0.0532
2.70	1926.10	-10.11	75.44	-0.0052	0.0392	2355.59	-11.07	93.73	-0.0047	0.0398
2.80	2358.08	-11.39	21.24	-0.0048	0.0090	2003.36	-11.49	18.32	-0.0057	0.0091
2.90	2946.29	-19.03	104.06	-0.0065	0.0353	1432.49	-6.82	51.35	-0.0048	0.0358
3.00	2024.01	-12.66	69.01	-0.0063	0.0341	2257.61	-11.24	78.04	-0.0050	0.0346
3.10	2208.58	-13.27	6.24	-0.0060	0.0028	2137.77	-13.49	6.12	-0.0063	0.0029
3.20	2940.28	-22.00	73.87	-0.0075	0.0251	1439.11	-8.27	36.66	-0.0057	0.0255
3.30	2124.70	-15.92	73.97	-0.0075	0.0348	2167.75	-12.73	76.44	-0.0059	0.0353
3.40	1974.06	-13.49	-0.01	-0.0068	-0.0000	2404.48	-17.01	-0.01	-0.0071	-0.0000
3.50	2845.51	-23.17	40.28	-0.0081	0.0142	1441.62	-9.94	20.68	-0.0069	0.0143
3.60	2441.40	-20.73	89.28	-0.0085	0.0366	1977.86	-13.09	73.24	-0.0066	0.0370
3.70	1782.84	-13.73	9.99	-0.0077	0.0056	2470.18	-18.79	14.01	-0.0076	0.0057
3.80	2635.75	-22.65	4.76	-0.0086	0.0018	1640.72	-13.17	3.00	-0.0080	0.0018
3.90	2794.68	-25.86	84.52	-0.0093	0.0302	1604.33	-12.13	49.14	-0.0076	0.0306
4.00	1885.16	-16.45	30.54	-0.0087	0.0162	2330.35	-18.70	38.23	-0.0080	0.0164

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRAILER NO. 1 REAR SUSPENSION TIRE FORCES
TRAILING TANDEM AXLE

	LEFT SIDE					RIGHT SIDE				
TIME (SEC)	VERTICAL (LB)	LONG. (LB)	LATERAL (LB)	MU-X	MU-Y	VERTICAL (LB)	LONG. (LB)	LATERAL (LB)	MU-X	MU-Y
0.0	2177.50	-0.0	0.0	0.0	0.0	2177.50	-0.0	0.0	0.0	0.0
0.10	2178.65	-15.45	0.28	-0.0071	0.0001	2189.34	-15.60	0.28	-0.0071	0.0001
0.20	2115.99	-20.18	-0.38	-0.0095	-0.0002	2239.40	-21.47	-0.40	-0.0096	-0.0002
0.30	2223.03	-23.73	3.90	-0.0107	0.0018	2172.72	-22.41	3.81	-0.0103	0.0018
0.40	2291.81	-25.98	28.56	-0.0113	0.0125	2044.91	-21.26	25.53	-0.0104	0.0125
0.50	2229.63	-25.78	45.19	-0.0116	0.0203	2159.06	-22.14	43.89	-0.0103	0.0203
0.60	2342.03	-27.40	69.87	-0.0117	0.0298	2019.88	-20.20	60.53	-0.0100	0.0300
0.70	2592.01	-30.74	118.11	-0.0119	0.0456	1776.93	-17.35	81.48	-0.0098	0.0459
0.80	2468.35	-29.24	154.85	-0.0118	0.0627	1896.38	-18.11	119.89	-0.0095	0.0632
0.90	2276.59	-26.83	153.36	-0.0118	0.0674	2099.04	-20.05	142.74	-0.0095	0.0680
1.00	2669.36	-31.32	216.93	-0.0117	0.0813	1665.38	-15.67	136.86	-0.0094	0.0822
1.10	2621.03	-30.60	271.21	-0.0117	0.1035	1778.04	-16.44	186.26	-0.0092	0.1048
1.20	2237.73	-25.84	226.01	-0.0115	0.1010	2149.38	-20.11	220.10	-0.0094	0.1024
1.30	2782.06	-32.14	316.65	-0.0116	0.1138	1528.59	-14.07	176.69	-0.0092	0.1156
1.40	2744.35	-31.32	377.17	-0.0114	0.1374	1722.42	-15.48	240.58	-0.0090	0.1397
1.50	2140.32	-24.11	275.64	-0.0113	0.1288	2122.50	-19.89	278.07	-0.0094	0.1310
1.60	2915.61	-32.97	398.34	-0.0113	0.1366	1502.04	-13.68	209.10	-0.0091	0.1392
1.70	2785.91	-31.52	432.48	-0.0113	0.1552	1573.54	-14.06	245.96	-0.0089	0.1563
1.80	2134.71	-23.67	322.74	-0.0111	0.1512	2193.95	-20.74	333.94	-0.0095	0.1522
1.90	2912.10	-32.39	439.97	-0.0111	0.1511	1463.58	-13.41	222.73	-0.0092	0.1522
2.00	2916.01	-32.69	476.25	-0.0112	0.1633	1486.46	-13.23	244.82	-0.0089	0.1647
2.10	2094.45	-23.09	332.82	-0.0110	0.1589	2193.91	-21.07	351.45	-0.0096	0.1602
2.20	2942.33	-27.31	459.41	-0.0093	0.1561	1529.17	-11.91	240.72	-0.0078	0.1574
2.30	2866.51	-17.29	474.08	-0.0060	0.1654	1427.36	-4.35	238.06	-0.0030	0.1668
2.40	2090.14	-10.46	323.79	-0.0050	0.1549	2315.60	-9.57	361.23	-0.0041	0.1560
2.50	2756.10	-13.22	366.41	-0.0048	0.1329	1618.54	-7.41	219.24	-0.0046	0.1355
2.60	3109.96	-19.21	467.47	-0.0062	0.1503	1264.90	-3.88	191.24	-0.0031	0.1512
2.70	2086.07	-11.70	270.72	-0.0056	0.1298	2226.98	-8.48	293.61	-0.0038	0.1318
2.80	2519.22	-13.21	246.04	-0.0052	0.0977	1873.63	-9.40	185.84	-0.0050	0.0992
2.90	3104.54	-20.96	372.66	-0.0068	0.1200	1308.43	-5.19	159.40	-0.0040	0.1218
3.00	2166.59	-14.13	244.57	-0.0065	0.1129	2146.71	-9.04	245.68	-0.0042	0.1144
3.10	2353.53	-14.87	194.40	-0.0063	0.0826	2024.38	-11.56	169.56	-0.0057	0.0838
3.20	3088.50	-23.81	322.38	-0.0077	0.1044	1323.12	-6.74	140.03	-0.0051	0.1058
3.30	2260.17	-17.36	245.51	-0.0077	0.1086	2064.02	-10.77	227.11	-0.0052	0.1100
3.40	2111.96	-14.95	157.63	-0.0071	0.0746	2298.37	-15.11	173.79	-0.0066	0.0756
3.50	2986.26	-24.90	270.38	-0.0083	0.0905	1332.27	-8.50	122.24	-0.0064	0.0918
3.60	2578.34	-22.26	278.31	-0.0086	0.1079	1873.72	-11.35	204.79	-0.0061	0.1093
3.70	1912.68	-15.09	146.52	-0.0079	0.0766	2371.77	-16.99	183.95	-0.0072	0.0776
3.80	2774.92	-24.36	214.32	-0.0088	0.0772	1532.98	-11.68	119.97	-0.0076	0.0783
3.90	2934.27	-27.52	303.19	-0.0094	0.1033	1497.32	-10.62	156.70	-0.0071	0.1047
4.00	2010.80	-17.83	176.22	-0.0089	0.0876	2235.42	-17.01	198.36	-0.0076	0.0887

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRAILER NO. 1 REAR SUSPENSION - BRAKE SUMMARY
LEADING TANDEM AXLE

		LEFT SIDE						RIGHT SIDE					
TIME (SEC)	TREADLE PRESSURE (PSI)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL. (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)
0.0	0.0	0.0	-0.00	-0.0	0.0	20.31	-0.0	0.0	-0.00	-0.0	0.0	20.31	-0.0
0.10	-0.0	0.0	548.97	-15.50	0.0072	20.14	-1.07	0.0	550.89	-15.64	0.0072	20.14	-1.07
0.20	-0.0	0.0	533.09	-20.16	0.0096	20.06	-0.61	0.0	563.88	-21.44	0.0096	20.06	-0.63
0.30	-0.0	0.0	556.52	-23.60	0.0107	20.01	-0.42	0.0	549.00	-22.42	0.0104	20.00	-0.49
0.40	-0.0	0.0	573.04	-25.66	0.0114	19.97	-0.32	0.0	518.61	-21.37	0.0104	19.96	-0.44
0.50	-0.0	0.0	554.29	-25.30	0.0116	19.94	-0.26	0.0	550.27	-22.39	0.0103	19.91	-0.49
0.60	-0.0	0.0	577.10	-26.71	0.0117	19.91	-0.24	0.0	520.53	-20.63	0.0101	19.86	-0.51
0.70	-0.0	0.0	636.80	-29.81	0.0119	19.89	-0.24	0.0	463.24	-17.98	0.0099	19.80	-0.49
0.80	-0.0	0.0	605.18	-28.16	0.0118	19.86	-0.24	0.0	492.60	-18.91	0.0097	19.75	-0.54
0.90	-0.0	0.0	549.51	-25.54	0.0118	19.84	-0.22	0.0	551.75	-21.09	0.0097	19.70	-0.61
1.00	-0.0	0.0	643.73	-29.82	0.0117	19.82	-0.27	0.0	447.61	-16.86	0.0096	19.64	-0.52
1.10	-0.0	0.0	634.37	-28.96	0.0116	19.79	-0.30	0.0	472.14	-17.82	0.0095	19.59	-0.54
1.20	-0.0	0.0	529.25	-24.04	0.0115	19.77	-0.26	0.0	574.28	-21.74	0.0096	19.53	-0.65
1.30	-0.0	0.0	661.44	-30.13	0.0115	19.74	-0.32	0.0	424.14	-15.74	0.0095	19.47	-0.51
1.40	-0.0	0.0	657.09	-29.21	0.0114	19.71	-0.38	0.0	466.26	-17.36	0.0093	19.43	-0.56
1.50	-0.0	0.0	498.45	-22.02	0.0112	19.67	-0.30	0.0	573.13	-21.94	0.0097	19.37	-0.63
1.60	-0.0	0.0	685.54	-30.49	0.0112	19.65	-0.40	0.0	427.60	-15.76	0.0095	19.31	-0.52
1.70	-0.0	0.0	666.11	-29.25	0.0112	19.61	-0.42	0.0	428.97	-16.10	0.0094	19.28	-0.50
1.80	-0.0	0.0	493.00	-21.34	0.0110	19.58	-0.33	0.0	596.49	-23.13	0.0098	19.22	-0.63
1.90	-0.0	0.0	678.67	-29.66	0.0110	19.55	-0.44	0.0	423.79	-15.73	0.0095	19.16	-0.51
2.00	0.05	0.0	700.07	-30.42	0.0111	19.51	-0.46	0.0	405.09	-15.25	0.0093	19.13	-0.47
2.10	2.00	0.06	485.75	-20.88	0.0109	19.47	-0.34	0.06	593.60	-23.38	0.0100	19.08	-0.60
2.20	2.00	0.73	686.79	-24.90	0.0091	19.44	-0.88	0.73	440.74	-14.01	0.0082	19.02	-0.73
2.30	2.00	1.27	689.73	-15.68	0.0058	19.30	-1.67	1.27	385.51	-5.78	0.0037	18.94	-1.19
2.40	2.00	1.58	487.35	-8.91	0.0047	19.16	-1.36	1.58	622.78	-11.98	0.0049	18.78	-1.69
2.50	2.00	1.76	643.63	-11.09	0.0043	19.01	-1.86	1.76	457.31	-9.48	0.0053	18.64	-1.18
2.60	2.00	1.86	745.22	-17.05	0.0058	18.83	-1.79	1.86	353.89	-5.65	0.0040	18.54	-1.06
2.70	2.00	1.92	491.58	-10.11	0.0052	18.68	-1.28	1.92	594.56	-11.07	0.0047	18.40	-1.65
2.80	2.00	1.96	590.35	-11.39	0.0048	18.55	-1.60	1.96	515.49	-11.49	0.0057	18.25	-1.27
2.90	2.00	1.97	746.69	-19.03	0.0065	18.39	-1.63	1.97	363.62	-6.82	0.0048	18.15	-1.00
3.00	2.00	1.99	518.36	-12.66	0.0063	18.25	-1.18	1.99	568.84	-11.24	0.0050	18.02	-1.52
3.10	2.00	1.99	551.23	-13.27	0.0060	18.13	-1.27	1.99	549.39	-13.49	0.0063	17.88	-1.24
3.20	2.00	2.00	744.30	-22.00	0.0075	18.00	-1.37	2.00	365.73	-8.27	0.0057	17.78	-0.89
3.30	2.00	2.00	544.55	-15.92	0.0075	17.88	-1.02	2.00	544.36	-12.73	0.0059	17.68	-1.29
3.40	2.00	2.00	494.94	-13.49	0.0068	17.79	-1.01	2.00	615.84	-17.01	0.0071	17.55	-1.24
3.50	2.00	2.00	718.95	-23.17	0.0081	17.67	-1.16	2.00	367.74	-9.94	0.0069	17.46	-0.76
3.60	2.00	2.00	626.59	-20.73	0.0085	17.56	-0.97	2.00	494.29	-13.09	0.0066	17.38	-1.04
3.70	2.00	2.00	453.11	-13.73	0.0077	17.48	-0.81	2.00	626.00	-18.79	0.0076	17.27	-1.13
3.80	2.00	2.00	663.62	-22.65	0.0086	17.39	-0.97	2.00	420.71	-13.17	0.0080	17.17	-0.71
3.90	2.00	2.00	713.45	-25.86	0.0093	17.30	-0.91	2.00	400.54	-12.13	0.0076	17.11	-0.71
4.00	2.00	2.00	479.11	-16.45	0.0087	17.22	-0.69	2.00	588.25	-18.70	0.0080	17.02	-0.97

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRAILER NO. 1 REAR SUSPENSION - BRAKE SUMMARY
TRAILING TANDEM AXLE

		LEFT SIDE						RIGHT SIDE					
TIME (SEC)	TREADLE PRESSURE (PSI)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL. (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)	BRAKE PRESSURE (PSI)	BRAKE TORQUE (IN-LB)	TIRE BRAKE FORCE (LB)	WHEEL SLIP	ANGULAR WHEEL VEL (RAD/SEC)	ANGULAR WHEEL ACCEL. (RAD/S**2)
0.0	0.0	0.0	-0.00	-0.0	0.0	20.52	-0.0	0.0	-0.00	-0.0	0.0	20.52	-0.0
0.10	-0.0	0.0	546.67	-15.45	0.0071	20.35	-1.08	0.0	549.12	-15.60	0.0071	20.35	-1.08
0.20	-0.0	0.0	531.52	-20.18	0.0095	20.27	-0.62	0.0	562.20	-21.47	0.0096	20.27	-0.64
0.30	-0.0	0.0	556.27	-23.73	0.0107	20.22	-0.43	0.0	545.86	-22.41	0.0103	20.21	-0.49
0.40	-0.0	0.0	575.50	-25.98	0.0113	20.18	-0.32	0.0	513.11	-21.26	0.0104	20.16	-0.45
0.50	-0.0	0.0	559.67	-25.78	0.0116	20.15	-0.27	0.0	541.59	-22.14	0.0103	20.11	-0.50
0.60	-0.0	0.0	586.12	-27.40	0.0117	20.12	-0.25	0.0	508.23	-20.20	0.0100	20.06	-0.51
0.70	-0.0	0.0	649.55	-30.74	0.0119	20.10	-0.24	0.0	447.11	-17.35	0.0098	20.01	-0.49
0.80	-0.0	0.0	621.28	-29.24	0.0118	20.07	-0.25	0.0	473.35	-18.11	0.0095	19.96	-0.54
0.90	-0.0	0.0	570.44	-26.83	0.0118	20.05	-0.23	0.0	527.74	-20.05	0.0095	19.90	-0.61
1.00	-0.0	0.0	667.61	-31.32	0.0117	20.02	-0.27	0.0	420.30	-15.67	0.0094	19.85	-0.51
1.10	-0.0	0.0	661.46	-30.60	0.0117	19.99	-0.31	0.0	442.04	-16.44	0.0092	19.80	-0.54
1.20	-0.0	0.0	560.70	-25.84	0.0115	19.97	-0.27	0.0	539.72	-20.11	0.0094	19.74	-0.66
1.30	-0.0	0.0	695.03	-32.14	0.0116	19.94	-0.32	0.0	387.06	-14.07	0.0092	19.68	-0.50
1.40	-0.0	0.0	693.37	-31.32	0.0114	19.91	-0.39	0.0	426.61	-15.48	0.0090	19.64	-0.56
1.50	-0.0	0.0	536.23	-24.11	0.0113	19.88	-0.31	0.0	532.10	-19.89	0.0094	19.58	-0.64
1.60	-0.0	0.0	727.92	-32.97	0.0113	19.85	-0.40	0.0	381.78	-13.68	0.0091	19.52	-0.51
1.70	-0.0	0.0	704.92	-31.52	0.0113	19.81	-0.42	0.0	387.42	-14.06	0.0089	19.48	-0.51
1.80	-0.0	0.0	535.98	-23.67	0.0111	19.78	-0.34	0.0	550.13	-20.74	0.0095	19.42	-0.65
1.90	-0.0	0.0	726.32	-32.39	0.0111	19.75	-0.44	0.0	372.77	-13.41	0.0092	19.37	-0.50
2.00	0.05	0.0	737.89	-32.69	0.0112	19.71	-0.46	0.0	364.42	-13.23	0.0089	19.34	-0.47
2.10	2.00	0.06	526.38	-23.09	0.0110	19.67	-0.35	0.06	549.61	-21.07	0.0096	19.28	-0.62
2.20	2.00	0.73	734.31	-27.31	0.0093	19.64	-0.90	0.73	389.90	-11.91	0.0078	19.23	-0.70
2.30	2.00	1.27	724.33	-17.29	0.0060	19.50	-1.70	1.27	348.90	-4.35	0.0030	19.15	-1.15
2.40	2.00	1.58	527.02	-10.46	0.0050	19.35	-1.41	1.58	579.40	-9.57	0.0041	18.99	-1.72
2.50	2.00	1.76	685.09	-13.22	0.0048	19.20	-1.87	1.76	412.55	-7.41	0.0046	18.85	-1.17
2.60	2.00	1.86	782.47	-19.21	0.0062	19.02	-1.79	1.86	313.94	-3.88	0.0031	18.75	-1.04
2.70	2.00	1.92	526.87	-11.70	0.0056	18.87	-1.31	1.92	556.00	-8.48	0.0038	18.60	-1.71
2.80	2.00	1.96	624.69	-13.21	0.0052	18.73	-1.61	1.96	477.72	-9.40	0.0050	18.45	-1.29
2.90	2.00	1.97	778.68	-20.96	0.0068	18.57	-1.63	1.97	328.56	-5.19	0.0040	18.35	-0.99
3.00	2.00	1.99	548.94	-14.13	0.0065	18.43	-1.20	1.99	535.08	-9.04	0.0042	18.22	-1.57
3.10	2.00	1.99	581.85	-14.87	0.0063	18.31	-1.28	1.99	515.38	-11.56	0.0057	18.07	-1.27
3.20	2.00	2.00	773.91	-23.81	0.0077	18.18	-1.37	2.00	332.83	-6.74	0.0051	17.98	-0.88
3.30	2.00	2.00	573.07	-17.36	0.0077	18.06	-1.03	2.00	512.68	-10.77	0.0052	17.87	-1.33
3.40	2.00	2.00	524.42	-14.95	0.0071	17.97	-1.03	2.00	582.93	-15.11	0.0066	17.74	-1.27
3.50	2.00	2.00	746.83	-24.90	0.0083	17.85	-1.16	2.00	336.57	-8.50	0.0064	17.65	-0.75
3.60	2.00	2.00	654.55	-22.26	0.0086	17.74	-0.98	2.00	462.96	-11.35	0.0061	17.57	-1.06
3.70	2.00	2.00	480.97	-15.09	0.0079	17.66	-0.82	2.00	594.96	-16.99	0.0072	17.45	-1.16
3.80	2.00	2.00	691.70	-24.36	0.0088	17.57	-0.96	2.00	389.40	-11.68	0.0076	17.36	-0.71
3.90	2.00	2.00	741.16	-27.52	0.0094	17.48	-0.91	2.00	369.50	-10.62	0.0071	17.30	-0.72
4.00	2.00	2.00	505.66	-17.83	0.0089	17.40	-0.70	2.00	558.47	-17.01	0.0076	17.20	-1.00

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRAILER NO. 1 REAR SUSPENSION - LATERAL TIRE FORCE AND MOMENT SUMMARY

LEADING TANDEM AXLE

TIME (SEC)	LEFT SIDE: TIRE SIDESLIP ANGLE (DEG)	LEFT SIDE: TIRE LATERAL FORCE (LB)	LEFT SIDE: MU-Y	LEFT SIDE: ALIGNING TORQUE (IN-LB)	RIGHT SIDE: TIRE SIDESLIP ANGLE (DEG)	RIGHT SIDE: TIRE LATERAL FORCE (LB)	RIGHT SIDE: MU-Y	RIGHT SIDE: ALIGNING TORQUE (IN-LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.10	-0.0024	0.7935	0.0004	-1.4576	-0.0024	0.7966	0.0004	-1.4634
0.20	0.0006	-0.1939	-0.0001	0.3562	0.0006	-0.2053	-0.0001	0.3771
0.30	0.0127	-4.1875	-0.0019	7.6923	0.0127	-4.1180	-0.0019	7.5646
0.40	-0.0189	6.4004	0.0028	-11.7574	-0.0189	5.8078	0.0028	-10.6688
0.50	-0.0227	7.4338	0.0034	-13.6556	-0.0227	7.4096	0.0034	-13.6112
0.60	-0.0228	7.8209	0.0034	-14.3668	-0.0230	7.0514	0.0034	-12.9532
0.70	-0.0636	23.9893	0.0095	-44.0676	-0.0640	17.4957	0.0096	-32.1390
0.80	-0.1223	43.6278	0.0183	-80.1430	-0.1232	36.0983	0.0185	-66.3116
0.90	-0.0876	28.5197	0.0131	-52.3898	-0.0884	28.8214	0.0133	-52.9441
1.00	-0.1148	43.8761	0.0172	-80.5991	-0.1161	30.5855	0.0174	-56.1847
1.10	-0.2197	81.9714	0.0330	-150.5790	-0.2224	62.7033	0.0334	-115.1840
1.20	-0.1473	46.1909	0.0221	-84.8512	-0.1494	50.7247	0.0224	-93.1798
1.30	-0.1684	66.2245	0.0253	-121.6523	-0.1711	42.5781	0.0257	-78.2146
1.40	-0.2988	115.3233	0.0448	-211.8453	-0.3037	84.8210	0.0456	-155.8136
1.50	-0.2057	60.7424	0.0309	-111.5819	-0.2092	71.0282	0.0314	-130.4767
1.60	-0.1956	79.7668	0.0293	-146.5293	-0.1993	49.8526	0.0299	-91.5776
1.70	-0.3734	145.8873	0.0560	-267.9902	-0.3806	98.2804	0.0571	-180.5381
1.80	-0.2730	79.5467	0.0410	-146.1248	-0.2785	98.3865	0.0418	-180.7329
1.90	-0.2134	86.2494	0.0320	-158.4376	-0.2180	53.9176	0.0327	-99.0450
2.00	-0.4487	184.1823	0.0673	-338.3372	-0.4584	112.1879	0.0688	-206.0858
2.10	-0.3550	101.7786	0.0532	-186.9642	-0.3627	127.6407	0.0544	-234.4720
2.20	-0.2652	108.4199	0.0398	-199.1640	-0.2712	69.7017	0.0407	-128.0400
2.30	-0.5021	203.4001	0.0753	-373.6396	-0.5129	119.7484	0.0769	-219.9741
2.40	-0.3516	100.7843	0.0527	-185.1378	-0.3585	132.4973	0.0538	-243.3935
2.50	-0.1738	66.8737	0.0261	-122.8450	-0.1771	47.2511	0.0266	-86.7989
2.60	-0.3487	153.3268	0.0523	-281.6565	-0.3548	75.0103	0.0532	-137.7916
2.70	-0.2611	75.4373	0.0392	-138.5760	-0.2653	93.7305	0.0398	-172.1801
2.80	-0.0600	21.2351	0.0090	-39.0083	-0.0610	18.3224	0.0091	-33.6576
2.90	-0.2354	104.0552	0.0353	-191.1463	-0.2390	51.3457	0.0358	-94.3206
3.00	-0.2273	69.0129	0.0341	-126.7745	-0.2305	78.0437	0.0346	-143.3639
3.10	-0.0188	6.2391	0.0028	-11.4610	-0.0191	6.1237	0.0029	-11.2491
3.20	-0.1675	73.8706	0.0251	-135.6980	-0.1698	36.6591	0.0255	-67.3418
3.30	-0.2321	73.9660	0.0348	-135.8732	-0.2351	76.4427	0.0353	-140.4229
3.40	0.0000	-0.0095	-0.0000	0.0174	0.0000	-0.0117	-0.0000	0.0215
3.50	-0.0944	40.2792	0.0142	-73.9916	-0.0956	20.6804	0.0143	-37.9892
3.60	-0.2438	89.2826	0.0366	-164.0094	-0.2469	73.2370	0.0370	-134.5342
3.70	-0.0374	9.9899	0.0056	-18.3511	-0.0378	14.0137	0.0057	-25.7428
3.80	-0.0120	4.7567	0.0018	-8.7379	-0.0122	3.0002	0.0018	-5.5113
3.90	-0.2016	84.5172	0.0302	-155.2554	-0.2042	49.1409	0.0306	-90.2704
4.00	-0.1080	30.5442	0.0162	-56.1087	-0.1094	38.2308	0.0164	-70.2288

HSRI/MVMA BRAKING AND HANDLING SIMULATION OF TRUCKS, TRACTOR-SEMITRAILERS, DOUBLES, AND TRIPLES - PHASE 4. OUTPUT PAGE NO. 1.14.2

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRAILER NO. 1 REAR SUSPENSION - LATERAL TIRE FORCE AND MOMENT SUMMARY

TRAILING TANDEM AXLE

TIME (SEC)	LEFT SIDE TIRE SIDESLIP ANGLE (DEG)	LEFT SIDE TIRE LATERAL FORCE (LB)	LEFT SIDE MU-Y	LEFT SIDE ALIGNING TORQUE (IN-LB)	RIGHT SIDE TIRE SIDESLIP ANGLE (DEG)	RIGHT SIDE TIRE LATERAL FORCE (LB)	RIGHT SIDE MU-Y	RIGHT SIDE ALIGNING TORQUE (IN-LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.10	-0.0009	0.2825	0.0001	-0.5190	-0.0009	0.2839	0.0001	-0.5215
0.20	0.0012	-0.3793	-0.0002	0.6968	0.0012	-0.4014	-0.0002	0.7374
0.30	-0.0117	3.8969	0.0018	-7.1585	-0.0117	3.8111	0.0018	-7.0010
0.40	-0.0831	28.5625	0.0125	-52.4684	-0.0832	25.5280	0.0125	-46.8941
0.50	-0.1351	45.1893	0.0203	-83.0114	-0.1355	43.8873	0.0203	-80.6196
0.60	-0.1989	69.8680	0.0298	-128.3455	-0.1998	60.5346	0.0300	-111.2002
0.70	-0.3038	118.1090	0.0456	-216.9626	-0.3057	81.4773	0.0459	-149.6713
0.80	-0.4182	154.8514	0.0627	-284.4573	-0.4215	119.8916	0.0632	-220.2371
0.90	-0.4491	153.3623	0.0674	-281.7217	-0.4534	142.7433	0.0680	-262.2151
1.00	-0.5418	216.9340	0.0813	-398.5012	-0.5479	136.8612	0.0822	-251.4099
1.10	-0.6898	271.2063	0.1035	-498.1978	-0.6984	186.2565	0.1048	-342.1475
1.20	-0.6733	226.0107	0.1010	-415.1748	-0.6827	220.0970	0.1024	-404.3113
1.30	-0.7588	316.6465	0.1138	-581.6699	-0.7706	176.6920	0.1156	-324.5779
1.40	-0.9162	377.1726	0.1374	-692.8545	-0.9312	240.5840	0.1397	-441.9456
1.50	-0.8586	275.6423	0.1288	-506.3464	-0.8734	278.0669	0.1310	-510.8003
1.60	-0.9108	398.3362	0.1366	-731.7312	-0.9281	209.0992	0.1392	-384.1089
1.70	-1.1048	432.4778	0.1552	-794.4485	-1.1262	245.9568	0.1563	-451.8149
1.80	-1.0238	322.7437	0.1512	-592.8701	-1.0441	333.9360	0.1522	-613.4304
1.90	-1.0217	439.9719	0.1511	-808.2151	-1.0436	222.7296	0.1522	-409.1475
2.00	-1.2665	476.2534	0.1633	-874.8630	-1.2940	244.8193	0.1647	-449.7253
2.10	-1.1781	332.8169	0.1589	-611.3745	-1.2039	351.4480	0.1602	-645.5991
2.20	-1.1227	459.4077	0.1561	-843.9180	-1.1483	240.7184	0.1574	-442.1924
2.30	-1.3077	474.0840	0.1654	-870.8777	-1.3357	238.0639	0.1668	-437.3159
2.40	-1.0982	323.7856	0.1549	-594.7844	-1.1200	361.2292	0.1560	-663.5669
2.50	-0.8863	366.4082	0.1329	-673.0806	-0.9030	219.2367	0.1355	-402.7310
2.60	-1.0063	467.4709	0.1503	-858.7297	-1.0238	191.2385	0.1512	-351.2993
2.70	-0.8652	270.7170	0.1298	-497.2988	-0.8790	293.6145	0.1318	-539.3608
2.80	-0.6511	246.0378	0.0977	-451.9639	-0.6613	185.8423	0.0992	-341.3865
2.90	-0.8002	372.6602	0.1200	-684.5654	-0.8122	159.4014	0.1218	-292.8154
3.00	-0.7525	244.5653	0.1129	-449.2588	-0.7630	245.6761	0.1144	-451.2993
3.10	-0.5507	194.3991	0.0826	-357.1052	-0.5584	169.5564	0.0838	-311.4697
3.20	-0.6959	322.3789	0.1044	-592.2002	-0.7056	140.0318	0.1058	-257.2339
3.30	-0.7242	245.5130	0.1086	-450.9998	-0.7336	227.1122	0.1100	-417.1982
3.40	-0.4976	157.6295	0.0746	-289.5603	-0.5041	173.7914	0.0756	-319.2493
3.50	-0.6036	270.3760	0.0905	-496.6724	-0.6117	122.2425	0.0918	-224.5558
3.60	-0.7196	278.3103	0.1079	-511.2473	-0.7286	204.7858	0.1093	-376.1851
3.70	-0.5107	146.5214	0.0766	-269.1553	-0.5171	183.9536	0.0776	-337.9170
3.80	-0.5149	214.3223	0.0772	-393.7034	-0.5217	119.9687	0.0783	-220.3788
3.90	-0.6889	303.1914	0.1033	-556.9534	-0.6977	156.6997	0.1047	-287.8523
4.00	-0.5842	176.2202	0.0876	-323.7109	-0.5916	198.3615	0.0887	-364.3840

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER

TRAILER NO. 1 REAR SUSPENSION - UNSPRUNG MASS SUMMARY

LEADING TANDEM AXLE

	AXLE MOTION					DYNAMIC SUSPENSION MOTIONS AND FORCES					
	POSITION		VELOCITY			LEFT SIDE			RIGHT SIDE		
TIME (SEC)	VERTICAL (FT)	ROLL (DEG)	VERTICAL (FT/SEC)	ROLL (DEG/SEC)	AUXILIARY ROLL TORQUE (IN-LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.0	0.0	0.0	-0.0
0.10	-0.0001	0.0007	0.0005	0.0454	-75.7	0.0003	0.0154	18.27	-0.0010	-0.0246	-2.86
0.20	-0.0001	0.0118	-0.0073	0.0589	-438.6	0.0038	0.0285	118.42	-0.0043	-0.0223	-81.24
0.30	0.0000	-0.0027	0.0067	-0.3237	30.5	-0.0001	-0.1172	-41.55	-0.0010	0.0660	44.94
0.40	-0.0002	-0.0210	-0.0040	0.0774	507.0	-0.0041	0.0485	-153.18	0.0044	-0.0052	201.47
0.50	0.0000	-0.0016	-0.0008	0.1042	66.1	-0.0002	-0.0027	-15.85	-0.0006	-0.0085	21.43
0.60	-0.0001	-0.0216	0.0009	-0.4155	822.6	-0.0055	-0.1468	-194.52	0.0057	0.1471	225.06
0.70	-0.0001	-0.0667	-0.0039	-0.3088	2652.0	-0.0222	-0.0969	-559.33	0.0227	0.1316	573.19
0.80	-0.0001	-0.0438	0.0030	0.7141	2166.2	-0.0184	0.1580	-299.06	0.0198	-0.1578	314.08
0.90	-0.0001	0.0009	-0.0024	-0.2227	1380.3	-0.0092	-0.1268	33.33	0.0103	0.0721	-24.38
1.00	-0.0003	-0.0751	-0.0023	-0.7119	4026.0	-0.0312	-0.2242	-581.01	0.0353	0.3542	628.45
1.10	0.0000	-0.0633	0.0029	1.2432	3964.0	-0.0336	0.2414	-382.55	0.0370	-0.2075	399.36
1.20	-0.0000	0.0173	0.0021	-0.1074	2016.5	-0.0140	-0.1047	221.75	0.0155	0.1557	-223.70
1.30	-0.0004	-0.0908	-0.0059	-1.0269	5497.9	-0.0428	-0.3212	-673.37	0.0484	0.4555	725.18
1.40	0.0004	-0.0745	0.0073	1.6320	5537.4	-0.0466	0.2742	-425.37	0.0522	-0.3081	415.52
1.50	-0.0006	0.0287	0.0074	0.0162	2159.1	-0.0121	-0.0854	417.18	0.0190	0.0261	-347.08
1.60	0.0002	-0.0986	-0.0099	-1.3421	6273.1	-0.0490	-0.4822	-762.15	0.0532	0.5919	737.93
1.70	-0.0002	-0.0925	0.0116	1.9959	6803.4	-0.0562	0.2905	-494.56	0.0664	-0.3586	493.50
1.80	-0.0003	0.0397	-0.0008	0.2296	1558.2	-0.0075	0.1166	525.24	0.0122	-0.0835	-479.81
1.90	-0.0000	-0.0972	-0.0110	-1.6044	6029.9	-0.0451	-0.6298	-739.97	0.0498	0.8780	741.35
2.00	0.0000	-0.1148	0.0174	2.1933	7746.5	-0.0631	0.2775	-599.01	0.0773	-0.3762	577.26
2.10	-0.0005	0.0412	-0.0015	0.3936	1146.5	-0.0022	0.2542	585.23	0.0112	-0.2276	-507.08
2.20	0.0005	-0.0938	-0.0153	-1.6722	5447.4	-0.0395	-0.6657	-709.12	0.0440	0.9429	677.28
2.30	-0.0006	-0.1182	0.0294	2.0727	7488.2	-0.0568	0.1978	-548.92	0.0803	-0.5976	591.23
2.40	0.0001	0.0517	-0.0092	0.7572	-167.5	0.0025	0.4916	608.76	-0.0073	-0.1828	-649.69
2.50	-0.0001	-0.0705	-0.0015	-2.0457	3574.0	-0.0232	-0.9270	-554.26	0.0253	0.9139	551.38
2.60	-0.0001	-0.1509	0.0092	0.7033	8847.1	-0.0732	0.2748	-921.54	0.0857	-0.4124	899.64
2.70	-0.0004	0.0390	-0.0068	0.9656	1655.0	-0.0115	0.9047	524.12	0.0159	-0.6308	-473.32
2.80	0.0000	-0.0273	-0.0013	-2.3656	2334.4	-0.0100	-0.7992	-219.09	0.0177	0.5838	219.00
2.90	0.0001	-0.1475	-0.0016	-0.1387	9099.3	-0.0773	0.1005	-1102.53	0.0854	-0.1725	1088.35
3.00	-0.0003	0.0185	-0.0145	1.3949	3282.1	-0.0275	0.8484	377.42	0.0324	-0.7081	-311.12
3.10	-0.0001	0.0007	0.0087	-2.4621	2378.2	-0.0112	-0.4016	-34.78	0.0196	0.4606	22.17
3.20	0.0001	-0.1457	0.0016	-0.3343	9442.0	-0.0797	-0.0189	-1121.15	0.0883	0.2983	1111.35
3.30	-0.0003	-0.0012	-0.0067	1.7505	4563.9	-0.0400	0.9225	239.66	0.0457	-0.9102	-181.41
3.40	0.0001	0.0472	-0.0004	-1.6582	1103.0	-0.0038	-0.3467	272.87	0.0054	0.3064	-240.34
3.50	-0.0003	-0.1349	0.0009	-0.7483	8887.8	-0.0690	-0.5544	-1038.35	0.0863	0.7159	1108.69
3.60	0.0003	-0.0525	-0.0039	2.3160	7120.1	-0.0631	0.6931	-231.72	0.0709	-0.8452	176.62
3.70	-0.0005	0.0664	-0.0078	0.2402	-89.8	0.0103	-0.1683	669.33	0.0018	-0.0156	-584.40
3.80	-0.0004	-0.0926	-0.0021	-1.4884	5375.9	-0.0369	-0.9184	-742.09	0.0501	0.7596	812.65
3.90	0.0002	-0.1213	0.0069	1.6132	8046.4	-0.0704	0.2933	-796.07	0.0772	-0.2475	693.06
4.00	-0.0007	0.0416	0.0104	0.6129	1833.2	-0.0086	0.6677	545.15	0.0229	-0.4101	-400.86

RETARDER THREE-AXLE TRACTOR / TWO-AXLE SEMITRAILER
TRAILER NO. 1 REAR SUSPENSION - UNSPRUNG MASS SUMMARY
TRAILING TANDEM AXLE

	AXLE MOTION					DYNAMIC SUSPENSION MOTIONS AND FORCES					
	POSITION		VELOCITY			LEFT SIDE			RIGHT SIDE		
TIME (SEC)	VERTICAL (FT)	ROLL (DEG)	VERTICAL (FT/SEC)	ROLL (DEG/SEC)	AUXILIARY ROLL TORQUE (IN-LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)	SUSP. DEFLECT. (IN)	SUSP. VELOCITY (IN/SEC)	SUSP. FORCE (LB)
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.10	0.0001	0.0009	0.0011	0.0334	-68.1	0.0009	0.0265	3.62	-0.0002	-0.0211	-18.51
0.20	0.0000	0.0119	-0.0074	0.0523	-435.9	0.0044	0.0300	103.36	-0.0035	-0.0250	-97.99
0.30	0.0002	-0.0039	0.0068	-0.3437	-8.4	0.0005	-0.1105	-55.63	-0.0002	0.0600	26.90
0.40	-0.0001	-0.0243	-0.0044	0.0592	395.3	-0.0036	0.0500	-168.90	0.0053	-0.0154	185.89
0.50	0.0002	-0.0071	-0.0007	0.0693	-119.0	0.0004	0.0101	-31.04	0.0002	-0.0180	5.17
0.60	0.0000	-0.0301	0.0009	-0.4531	535.0	-0.0051	-0.1364	-208.01	0.0065	0.1336	206.82
0.70	0.0001	-0.0786	-0.0039	-0.3367	2248.7	-0.0219	-0.0920	-576.33	0.0233	0.1187	558.65
0.80	0.0000	-0.0580	0.0029	0.6853	1685.8	-0.0179	0.1620	-312.87	0.0204	-0.1721	296.22
0.90	0.0001	-0.0166	-0.0024	-0.2578	789.3	-0.0086	-0.1173	21.38	0.0111	0.0592	-44.15
1.00	-0.0001	-0.0958	-0.0024	-0.7335	3325.7	-0.0308	-0.2277	-598.40	0.0359	0.3369	614.85
1.10	0.0002	-0.0862	0.0026	1.2224	3188.9	-0.0328	0.2348	-394.63	0.0375	-0.2274	386.91
1.20	0.0002	-0.0082	0.0023	-0.1451	1154.0	-0.0130	-0.0924	212.23	0.0158	0.1439	-242.48
1.30	-0.0002	-0.1193	-0.0060	-1.0434	4535.3	-0.0420	-0.3345	-691.11	0.0486	0.4317	712.14
1.40	0.0005	-0.1048	0.0071	1.6049	4512.0	-0.0459	0.2622	-440.16	0.0525	-0.3373	399.82
1.50	-0.0005	-0.0017	0.0076	-0.0210	1131.3	-0.0115	-0.0738	399.92	0.0191	0.0140	-364.12
1.60	0.0003	-0.1339	-0.0100	-1.3607	5077.0	-0.0485	-0.5001	-780.29	0.0532	0.5622	724.55
1.70	-0.0000	-0.1248	0.0115	2.0359	5711.8	-0.0558	0.2497	-520.43	0.0668	-0.3740	489.87
1.80	-0.0001	0.0053	-0.0008	0.1515	396.7	-0.0070	0.1417	512.60	0.0121	-0.1082	-498.41
1.90	0.0001	-0.1366	-0.0110	-1.5849	4696.0	-0.0447	-0.6620	-758.94	0.0496	0.8582	728.30
2.00	0.0002	-0.1466	0.0175	2.2132	6672.4	-0.0630	0.2386	-627.47	0.0781	-0.4025	566.18
2.10	-0.0003	0.0088	-0.0014	0.3118	47.9	-0.0019	0.2817	572.30	0.0112	-0.2522	-525.25
2.20	0.0006	-0.1330	-0.0154	-1.6300	4118.4	-0.0392	-0.7044	-728.38	0.0439	0.9311	665.02
2.30	-0.0004	-0.1472	0.0293	2.1142	6508.1	-0.0558	0.1509	-585.79	0.0810	-0.6180	578.50
2.40	0.0003	0.0199	-0.0089	0.6924	-1242.0	0.0033	0.5205	596.54	-0.0074	-0.1952	-668.28
2.50	0.0001	-0.1048	-0.0017	-2.0570	2413.4	-0.0231	-0.9381	-572.38	0.0254	0.8956	537.96
2.60	0.0001	-0.1825	0.0087	0.7205	7776.8	-0.0732	0.2325	-946.10	0.0863	-0.4437	894.38
2.70	-0.0002	0.0106	-0.0069	1.0285	694.5	-0.0117	0.8822	507.36	0.0162	-0.6132	-488.10
2.80	0.0002	-0.0557	-0.0011	-2.3818	1374.6	-0.0101	-0.7979	-233.07	0.0178	0.5746	204.85
2.90	0.0003	-0.1752	-0.0000	-0.1185	8164.1	-0.0772	0.0871	-1124.14	0.0857	-0.1729	1073.74
3.00	-0.0002	-0.0064	-0.0147	1.4319	2440.4	-0.0276	0.8291	359.94	0.0327	-0.7038	-325.67
3.10	0.0001	-0.0245	0.0089	-2.4856	1526.7	-0.0111	-0.3959	-47.56	0.0197	0.4514	4.78
3.20	0.0003	-0.1715	0.0016	-0.3159	8566.8	-0.0797	-0.0486	-1143.68	0.0884	0.2803	1101.58
3.30	-0.0001	-0.0247	-0.0069	1.7802	3770.1	-0.0401	0.9025	221.33	0.0460	-0.9113	-195.17
3.40	0.0003	0.0234	-0.0004	-1.6677	297.5	-0.0036	-0.3436	258.34	0.0053	0.3035	-253.88
3.50	-0.0002	-0.1593	0.0010	-0.7632	8062.6	-0.0688	-0.5692	-1058.90	0.0862	0.6916	1098.07
3.60	0.0005	-0.0761	-0.0037	2.3395	6320.8	-0.0631	0.6743	-251.74	0.0710	-0.8490	164.65
3.70	-0.0003	0.0442	-0.0078	0.2164	-841.8	0.0104	-0.1574	657.54	0.0018	-0.0198	-602.74
3.80	-0.0002	-0.1167	-0.0021	-1.4987	4560.8	-0.0368	-0.9278	-760.93	0.0500	0.7436	799.98
3.90	0.0004	-0.1455	0.0070	1.6264	7229.9	-0.0704	0.2715	-821.85	0.0773	-0.2609	682.40
4.00	-0.0006	0.0201	0.0103	0.5986	1105.6	-0.0086	0.6699	530.37	0.0229	-0.4170	-417.44