COMPUTER PREDICTION OF THE BRAKING AND STEERING PERFORMANCE OF THE AM GENERAL TRANSBUS

A SUMMARY REPORT

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1.0 INTRODUCTION

This document is intended to give a quick overall view of the program of computer analysis and tire testing which the Highway Safety Research Institute (HSRI) is conducting to aid AM General in predicting the steering and braking response of a new and innovative bus design. This bus, called the Transbus, is being developed within a program sponsored by the Urban Mass Transit Administration. By design, the Transbus should be a large step forward with respect to passenger comfort and convenience. In addition, the bus should handle easily and be able to meet all applicable Federal Motor Vehicle Safety Standards. The objective of HSRI's work is to insure that the steering and braking performance achieved by the Transbus will be judged adequate for safe, easily controlled operation on the road.

Up to this time, HSRI has provided two preliminary reports to AM General. These reports are entitled:

1. Ride and Handling Analysis of the AM General Transbus, and
2. Computer Prediction of the Braking and Steering Performance of the AM General Transbus (an Interim Report).

The first report contained discussions of (1) the applicability of limit maneuver measures to the motor coach, (2) a simplified procedure for predicting vehicle braking performance, (3) an initial analysis of the steady turning behavior of the projected Transbus, (4) the factors involved in an analysis of ride quality, and (5) the simulation programs available at HSRI which may be used to predict the performance of the Transbus. Preliminary computer predictions of the braking and steering performance of the Transbus in severe maneuvers were presented in the second report.

In the future, HSRI will use its flat bed machine to test the special cantilevered tires which are being developed for the Transbus. Once the tires are available, tire shear force properties will be measured and more computations will be made to predict the performance of the prototype vehicle and to serve as a guide for planning the vehicle testing activity.

In the next section of this report the computer programs which have been (and will be) used for predicting the braking and/or steering response of the Transbus are described. In the following section, the equipment and methodology to be used to obtain the required tire data are discussed. Then, the currently available predictions of Transbus performance in test maneuvers are summarized and the implications of the preliminary predictions are discussed in a final section.

A bibliography, listing pertinent HSRI research publications, is included to provide reference sources containing detailed treatments of the simulation, tire testing and vehicle testing methodology discussed in this report.

2.0 COMPUTER PROGRAMS FOR PREDICTING THE STEERING AND BRAKING PERFORMANCE OF THE TRANSBUS

The simulation programs which have been used to predict the braking and handling performance of the AM General bus are described in this section.

Two computer programs are available for predicting the performance of the Transbus—a straight-line and a directional response program. These programs were obtained by making minor adaptations in programs which were developed by HSRI to simulate heavy trucks [1, 2, 3]*. An example showing the correspondence between test results and computer prediction, is illustrated in Figure 1. In this example the truck was first steered into a turn, then at two seconds after the steering input was applied, the brakes were applied. As shown in Figure 1, there is very good agreement between test results and computer prediction in this case.

2.1 THE UNIT VEHICLE STRAIGHT-LINE PERFORMANCE PROGRAM

This dynamic simulation program is based upon a mathematical model that represents a three-axle unit vehicle. Motions are constrained to the plane of symmetry (vertical plane). Specifically, the wheels can bounce and spin, the chassis can heave and pitch, and the vehicle can accelerate (decelerate) in straight-line motion. The braking system is modeled in a manner such that the brake torque-line pressure characteristic can be specified for each brake and variable time lags and delays in torque response can be introduced. Thus, any desired brake force distribution can be specified. Simulation of antiskid devices may be added by the user if desired.

The model has nine degrees of freedom, which are listed in Table 1.

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*Numbers in square brackets denote references listed in the Bibliography.

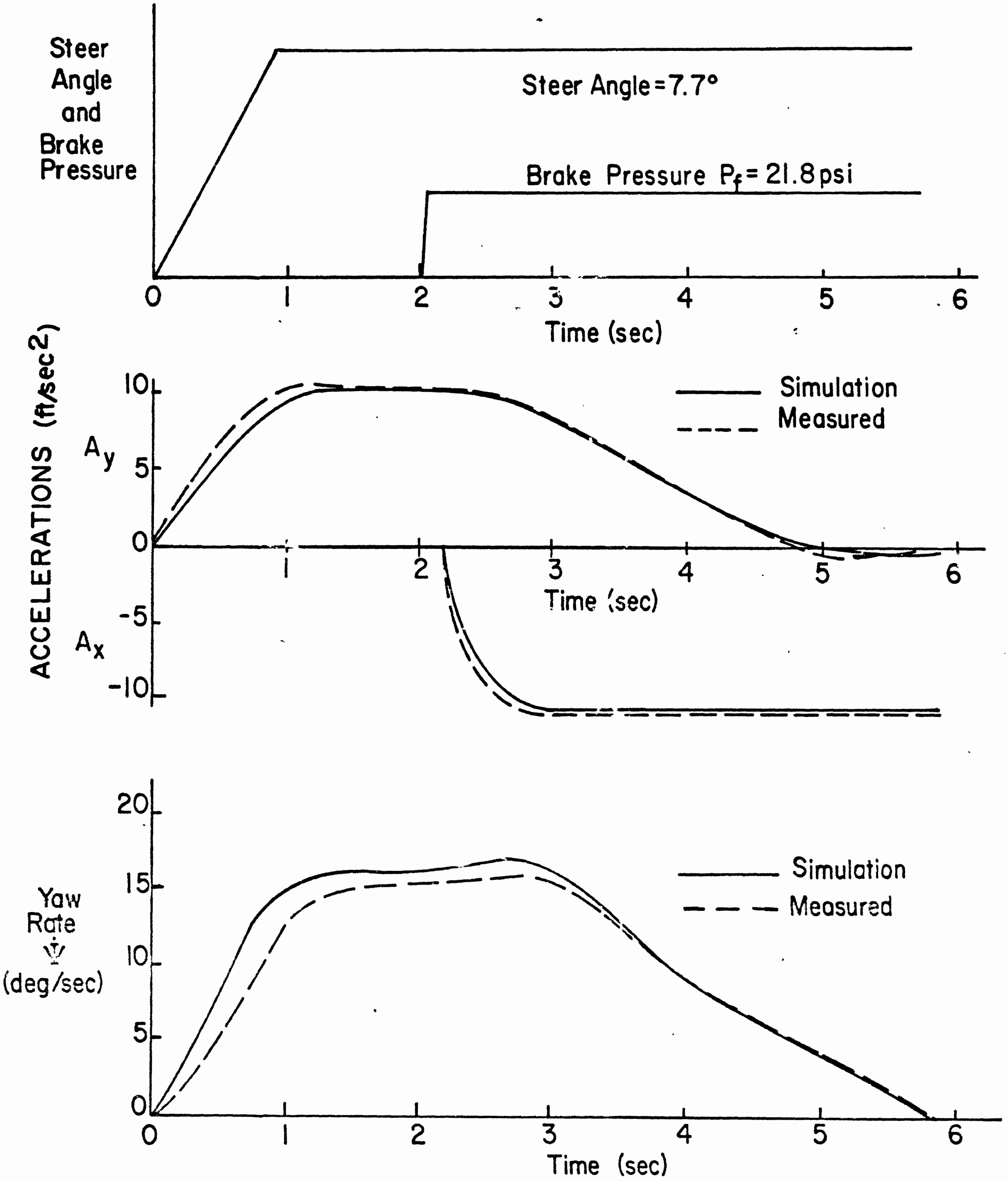


Figure 1. Validation of a braking-in-a-turn maneuver for a truck.

TABLE 1

DEGREES OF FREEDOM—STRAIGHT-LINE PERFORMANCE MODEL

Variable	Description
X	vehicle forward displacement
Z	vertical displacement of c.g.
θ	pitch angle of the sprung mass
ZS1	vertical displacement of front axle (or both independently suspended front wheels)
ZS2	vertical displacement of leading rear axle
ZS3	vertical displacement of trailing rear axle
$\Omega 1$	angular velocity of front wheels
$\Omega 2$	angular velocity of wheels on leading rear axle
$\Omega 3$	angular velocity of wheels on trailing rear axle

To determine the values of these variables as functions of time, nine differential equations of motion are solved simultaneously, along with ancillary equations defining intermediate variables such as suspension deflections, tire-road interface forces, normal forces on the tires, and horizontal forces acting on the sprung masses. The subroutine used to accomplish the major portion of the integration of the equations of motion is based upon Hamming's predictor-corrector method. Some optional features are listed below:

1. The user may input brake dynamometer pressure-torque curves.

2. Shock absorber characteristics are generally characterized by C, the slope of the force-velocity curve. To make the model more accurate, a two-slope shock absorber can be specified, characterized by jounce slope, CJ, and rebound slope, CR.

3. The spring force-deflection relation may be characterized by the slope K of the force-deflection curve, or by table lookup of deflection-force points.

4. Rough road coordinate points or a user-supplied road algorithm may be conveniently entered as input.

2.2 THE DIRECTIONAL RESPONSE (BRAKING AND HANDLING) MODEL

This dynamic simulation contains eighteen degrees of freedom, which are listed in Table 2. (Note X, Y and Z are fixed axes; x, y and z are body axes.)

TABLE 2

DEGREES OF FREEDOM, UNIT VEHICLE
BRAKING AND HANDLING MODEL

Variable	Description
X	longitudinal position of sprung mass center
Y	lateral position of sprung mass center
Z	vertical position of the sprung mass center
p	sprung mass rotation rate about x axis
q	sprung mass rotation rate about y axis
r	sprung mass rotation rate about z axis
$ZS_{i,j}$ (i=1,2;j=1,2,3)	vertical position of wheel i on axle j
$\Omega_{i,j}$ (i=1,2;j=1,2,3)	rotation rate of wheel i on axle j

This model has all the features of the pitch plane unit vehicle model including:

1. Tandem axles may be specified
2. Optional table lookup for force-deflection at each suspension
3. Two-slope shock absorber
4. Brake characteristics may be specified by dynamometer curves
5. Option rough road input.

2.3 REQUIRED PARAMETER DATA

A copy of the printout of the input parameters for a typical run of the Transbus Directional Response program is given in Appendix 1. As can be seen by inspection of this parameter list, a sizeable amount of information describing the vehicle and its tires is needed to analyze the performance of the vehicle over its entire operating range including emergency maneuvers. Steering inputs may be specified by a table of up to 25 steering angle-time pairs. Braking inputs are specified by a similar table for the pressure output of the treadle valve as a function of time. The torque-line pressure characteristics may be specified for the brakes on each wheel

3.0 TESTING OF THE AM GENERAL TRANSBUS TIRES

The HSRI flat bed tire tester [4], shown in Figure 2, will be used to measure the shear force characteristics of the bus tire. All three forces and all three moments acting between the tire and the road (bed surface) are measured. Frequently, however, flat bed data are used to make the type of side force carpet plot shown in Figure 3. This example plot, which shows the dependence of lateral force capability on inflation pressure, was part of a large study of truck tire performance characteristics [2, 5]. It should be noted that the flat bed machine has the capability to apply and measure tire forces up to 10,000 lbs. This large force range is needed for studying bus tires.

An extensive program of testing is planned for the Transbus tires. Clearly, this is warranted since the tire is the prime source of force for stopping and/or turning the vehicle. Examination of the proposed tire test program, presented in Appendix 2 of this report. shows that shear force data will be obtained in the following ranges of operating conditions:

Vertical load:	1800 to 9000 lbs.
Slip angle:	0 to 30 degrees
Camber angle:	0 to 5 degrees
Braking force:	up to 1500 lbs.

To predict vehicle performance on a given test surface, it is necessary to supplement laboratory tire measurements with data describing the frictional characteristics of the particular tire/road interface involved in the vehicle tests. At this point in time, the state of the art in predicting the shear force performance of a particular tire on a given surface is such that these predictions cannot be made easily and reliably. Accordingly, tire tests on a specified surface may be required to obtain accurate predictions

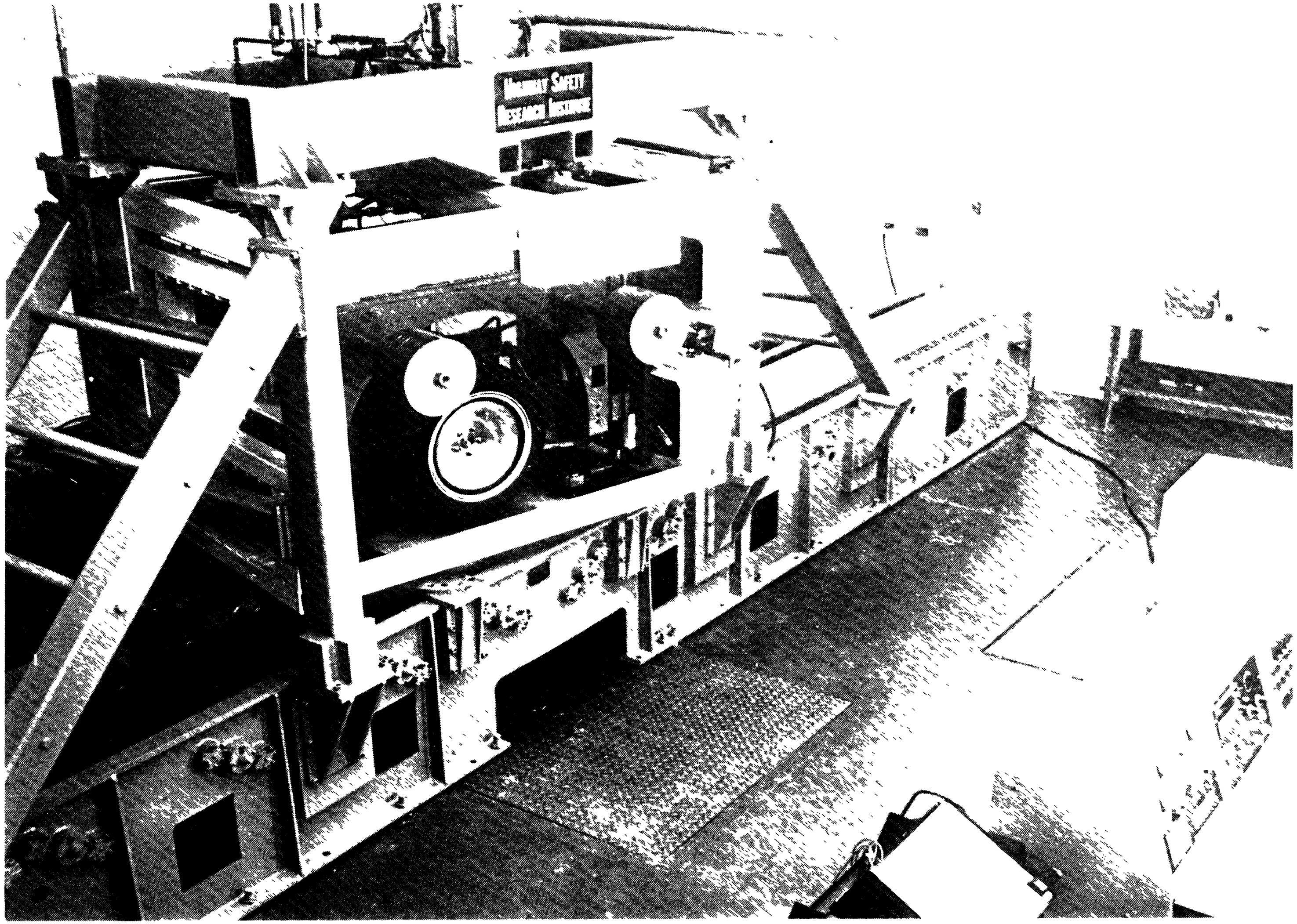


Figure 2. Flat Bed Tire Tester

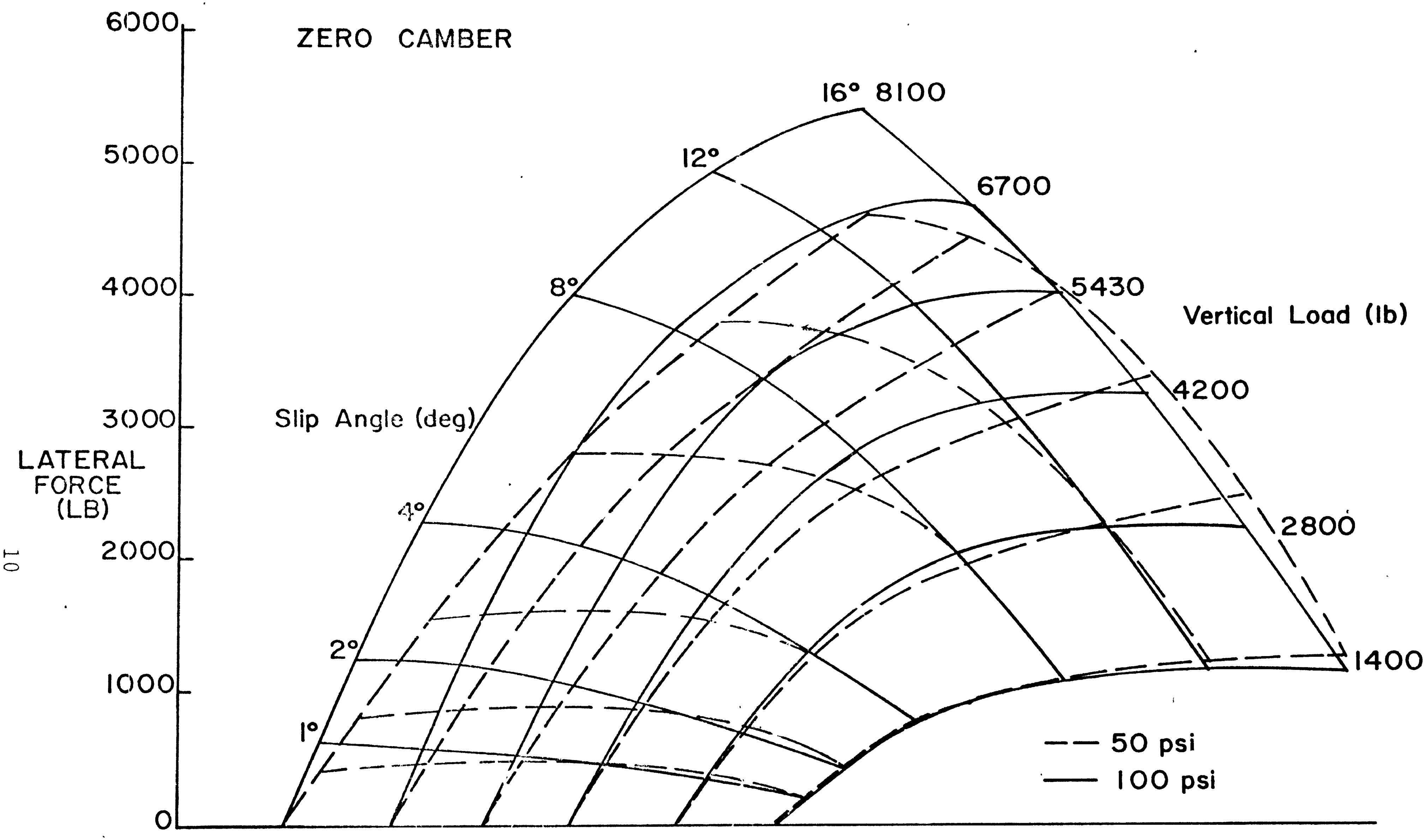


Figure 3. Lateral force vs. slip angle and vertical load on 10.00-20/G truck tire at 100 psi and 50 psi.

of vehicle performance on that surface. In making computer studies to date, we have simply postulated reasonable values of parameters representing the frictional characteristics of the tire-road interface. At some time in the future when a specific test surface is identified, it may be desirable to test the bus tire on the selected test surface. A device that can be used for on-the-road measurement of the longitudinal forces produced by large tires is shown in Figure 4.

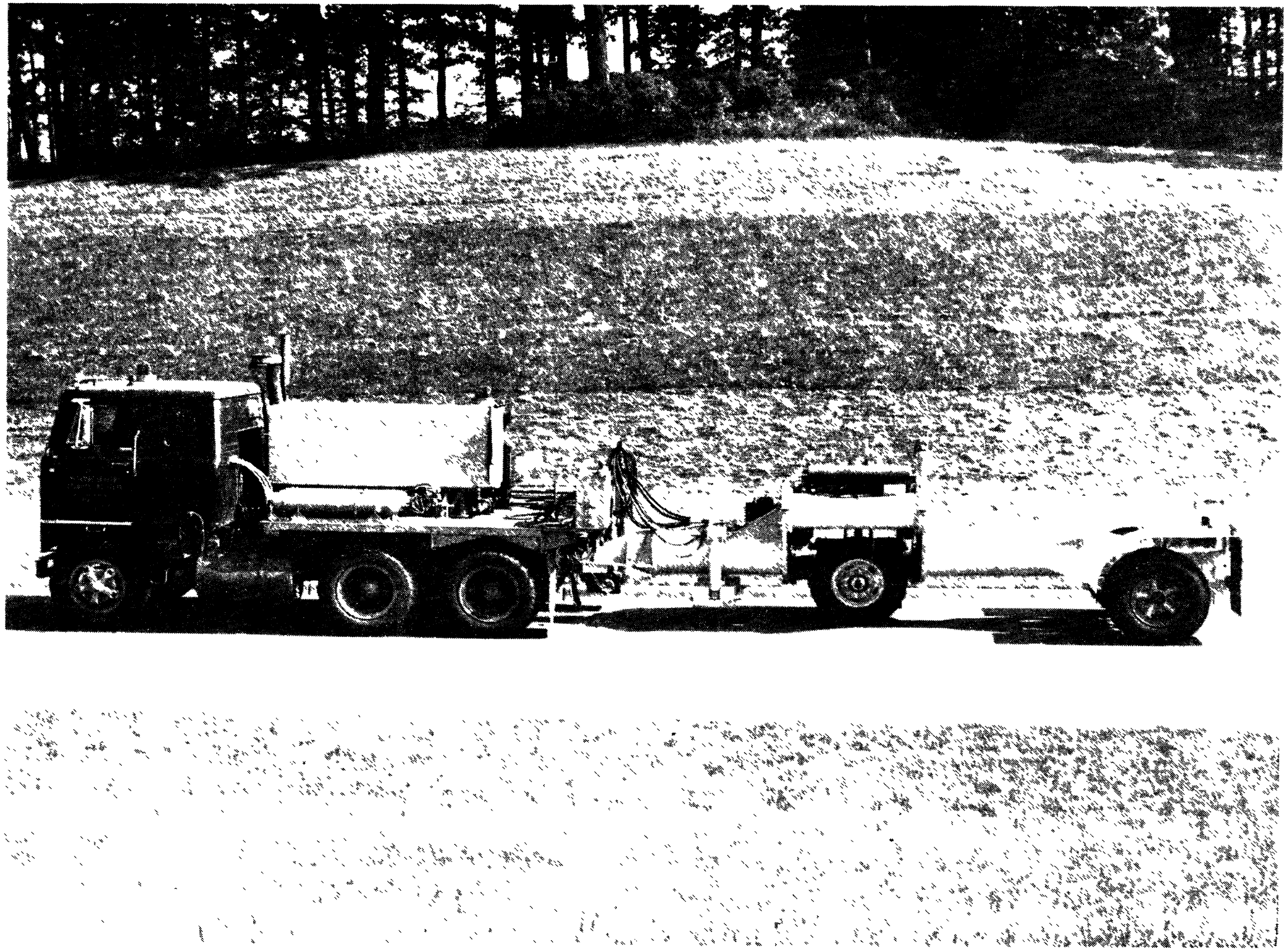


Figure 4. HSRI Tractor-Trailer Device for Measuring Tire Braking Force

4.0 PRELIMINARY PREDICTIONS OF TRANSBUS PERFORMANCE

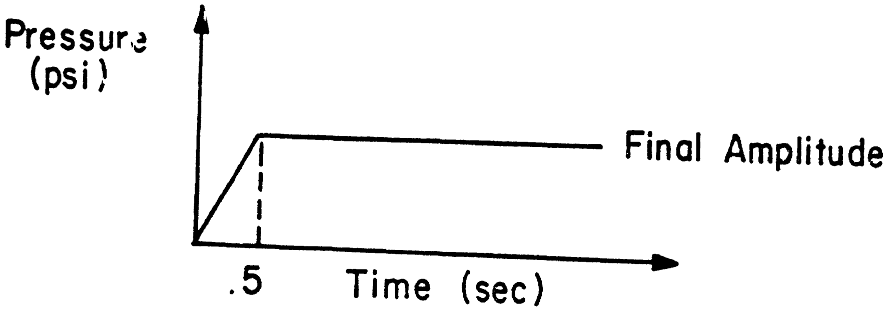
Four vehicle maneuvers have been selected for use in the preliminary simulation of the Transbus. These maneuvers are straight-line braking, trapezoidal steer (J-turn), sinusoidal steer (lane change) and braking-in-a-turn. The range of input steering and braking levels used in these simulated tests were chosen to represent control actions which might be taken during severe, emergency maneuvers.

While these maneuvers have been selected from maneuvers developed in previous vehicle handling research projects [6, 7, 8], they are not intended to be used to find the limit performance of the Transbus. Rather, they are intended to be used to predict whether or not the emergency response of the vehicle will be acceptable. As pointed out in the first report from HSRI to AM General, the limit performance methodology as applied to passenger cars may not be entirely satisfactory for the study of motor coach performance. Accordingly, we have chosen maneuvers which should provide useful information on emergency performance without imposing unnecessary requirements on the initial testing of the motor coach.

It should be emphasized that the simulation results, which are presented in the following paragraphs, are based on predicted tire performance characteristics. Engineering estimates of tire shear force performance were obtained from the Goodyear Tire and Rubber Company. These estimates were based on past experience and not on actual measurements of the Transbus tire since a tire had not been constructed at that time. Consequently, the following simulation results must be viewed as preliminary predictions. Nevertheless, they are believed to be qualitatively correct.

4.1 STRAIGHT STOP SIMULATIONS

Simulation runs were made at various brake line pressure levels. All lags and delays in the braking system were assumed to be negligible. However, the form of the rise of pressure at the foot valve (shown in the following figure) is such that 0.5 seconds is required to develop the desired pressure level.



In the sample results which follow, the simulated vehicle has every seat filled but no standing passengers (i.e., GVW 32,000 lbs). Each stop was made from an initial velocity of 30 mph. Results for wet and dry surfaces are tabulated below.

DRY

(BUS TIRE 30 MPH SKID NUMBER = 65)

Brake Line Pressure (Psi	Steady State Deceleration (ft/sec^2)	Stopping Distance (ft)
750	14.6	77.3
850	16.5	69.5
900	17.5	66.3
950	18.5	63.4
1000 (axle 3 lock)	19.6	61.8
1050 (axle 2 & 3 lock)	20.1	61.7

WET

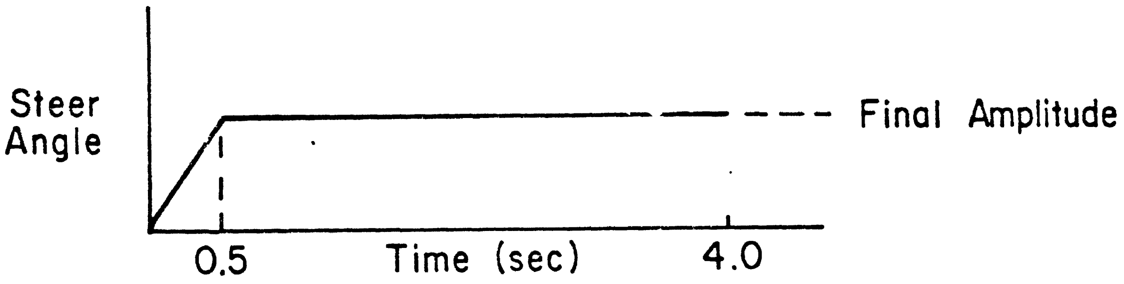
(BUS TIRE 30 MPH SKID NUMBER = 30)

Brake Line Pressure (Psi)	Steady State Deceleration (ft/sec^2)
600	11.7
650	12.6
700	13.6
750	14.6

These initial computer calculations indicate that the stopping distance performance of the AM General Transbus (as simulated) may be satisfactory for passing impending federal motor vehicle safety standards.* However, this will be highly dependent upon the shear force performance of the Transbus tires. If needed, the wheels unlocked braking performance could be improved by providing proportionately greater brake torque to the front wheels.

4.2 TRAPEZOIDAL STEER SIMULATIONS - 30 MPH

The purpose of these computer runs is to assess the performance of the transbus in rapid turns. Five simulation runs were performed at an initial speed of 30 mph. In each, the front wheel steer angle was prescribed to have the following type of time history:



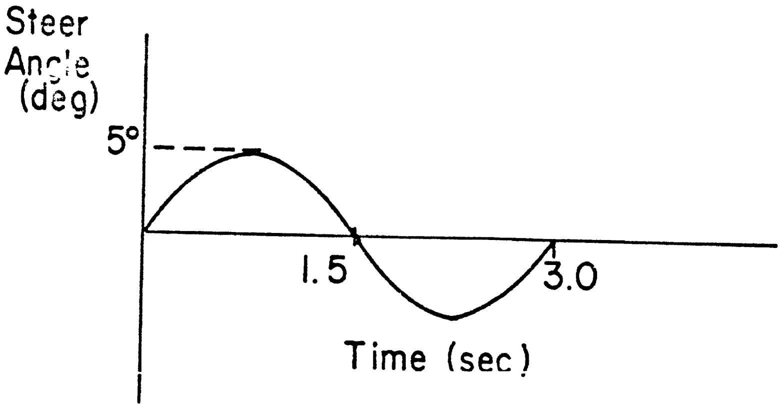
The trapezoidal steer results (given below) show that the vehicle can make drastic turns with greater than 0.5g lateral acceleration without suffering bump stop contact. (Bump stop contact occurs at approximately 5° roll angle.) These preliminary results indicate that the vehicle should be able to perform sharp turns without having a propensity to roll over. A summary of the trapezoidal steer results follows.

At 4.0 Seconds After the Initiation of Steering

Amplitude of Steer Angle	Lateral Accel-eration (ft/sec^2)	Turn Radius (ft)	Vehicle Side Slip Angle (deg)	Yaw Rate (deg/sec)	Longi-tudinal Velocity (ft/sec)	Max. Roll Angle (deg)
5	6.7	278.3	0.4	8.9	43.3	1.9
10	12.4	138.1	1.0	17.1	41.5	3.6
15	16.6	88.6	1.5	24.3	38.3	4.9
20	19.0	62.5	1.8	29.9	34.5	5.5
25	19.2	45.9	4.4	35.4	29.8	5.4

4.3 SINUSOIDAL STEER

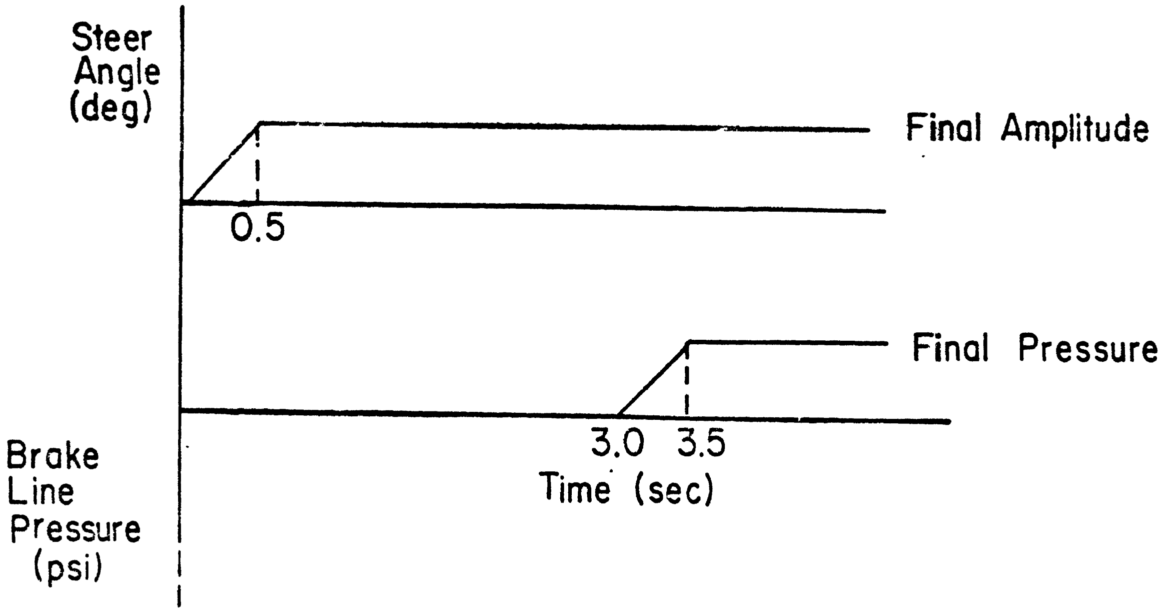
The following steering waveform was used to approximate a lane change type maneuver starting with initial speeds of 30, 40, and 50 mph.

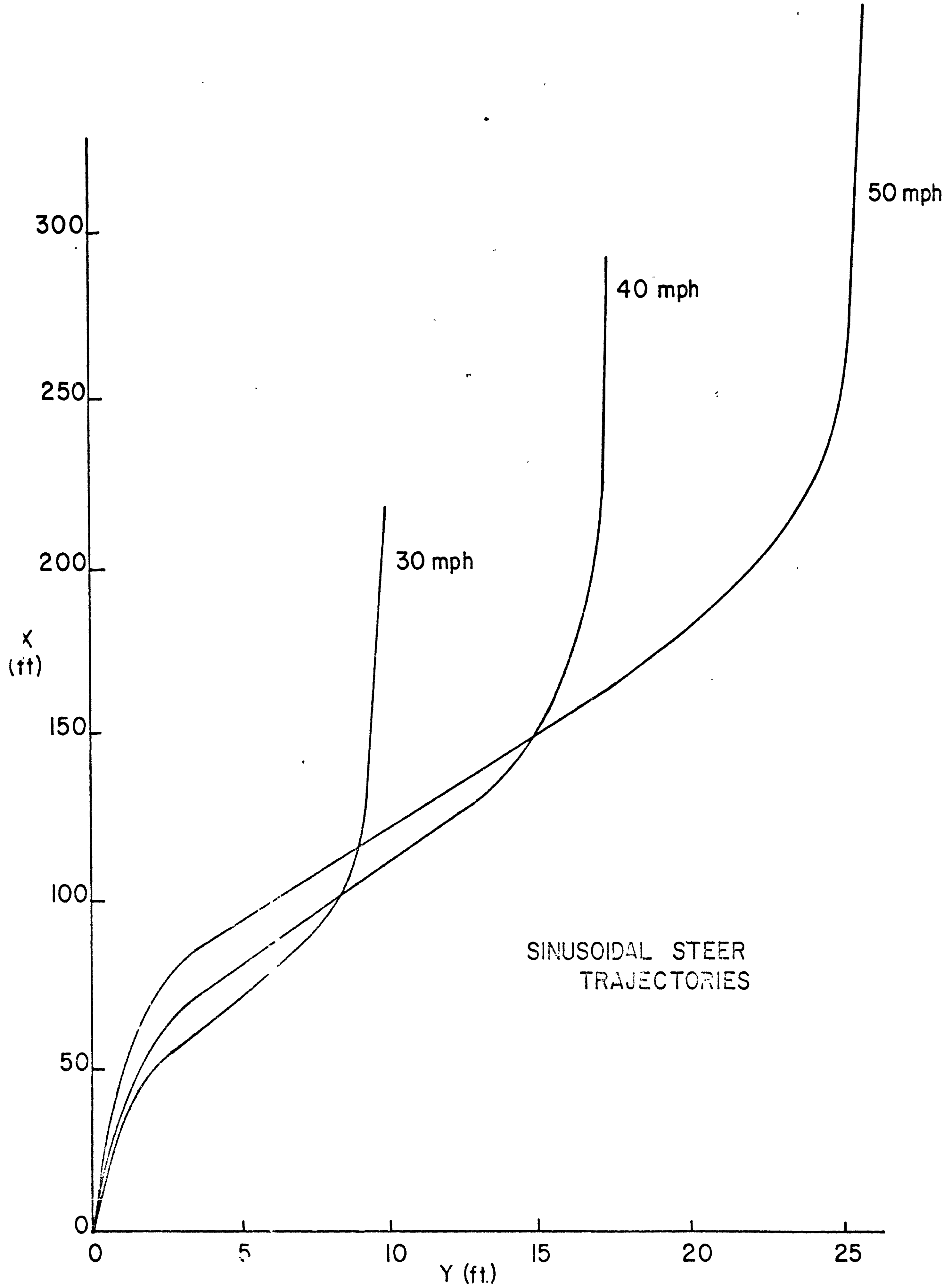


A sketch of the trajectories obtained from the simulation is given in Figure 5. These results demonstrate that this bus should be able to perform rapid lane changes, returning to the original heading, in response to symmetric steering inputs.

4.4 BRAKING-IN-A-TURN

In each of these simulation runs, the steer angle was applied as usual, i.e., a 0.5-second ramp input starting at the beginning of the run. At three seconds into the run, brakes were applied in the same fashion as in the straight-line braking simulations, i.e., a 0.5-second ramp. This is shown schematically in the following figure.





300
250
200
150
100
50
0
X (ft)
0
5
10
15
20
25
Y (ft.)
30 mph
40 mph
50 mph
SINUSOIDAL STEER TRAJECTORIES

Figure 5

The following two maneuvers were simulated from an initial velocity of 30 mph.

Final Amplitude of Steer Angle (deg)	Final Value of Brake Line Pressure (Psi)
10	700
20	800

In the more severe maneuver, the inside wheels on the rear axles locked, resulting in a loss of cornering force and thus much reduced lateral acceleration. The trajectories of the center of mass are shown in Figure 6. These runs were terminated at 5.0 seconds after the start of the steering input.

The braking-in-a-turn trajectories show that the bus will have a substantial directional response due to braking. Further calculations and analysis are needed to assess the importance of this phenomenon.

4.5 CONCLUDING REMARKS

Clearly, more work is needed to specify vehicle tests and to provide final quantitative predictions of the steering and braking performance of the Transbus. Nevertheless, the results obtained to date are encouraging and they tend to indicate that this vehicle will be able to turn rapidly in a controlled manner. Once tire parametric data has been measured, calculations, like those presented in the previous section, will be repeated for a comprehensive set of conditions. Ranges of input steering and braking levels suitable for vehicle test will be selected from the computer results. Other factors which will be determined from the simulated maneuvers are:

(1) test area needed to perform each maneuver

(2) magnitude of accelerations and angular velocities obtained by the vehicle during each maneuver

(3) influence of surface friction characteristics on vehicle response.

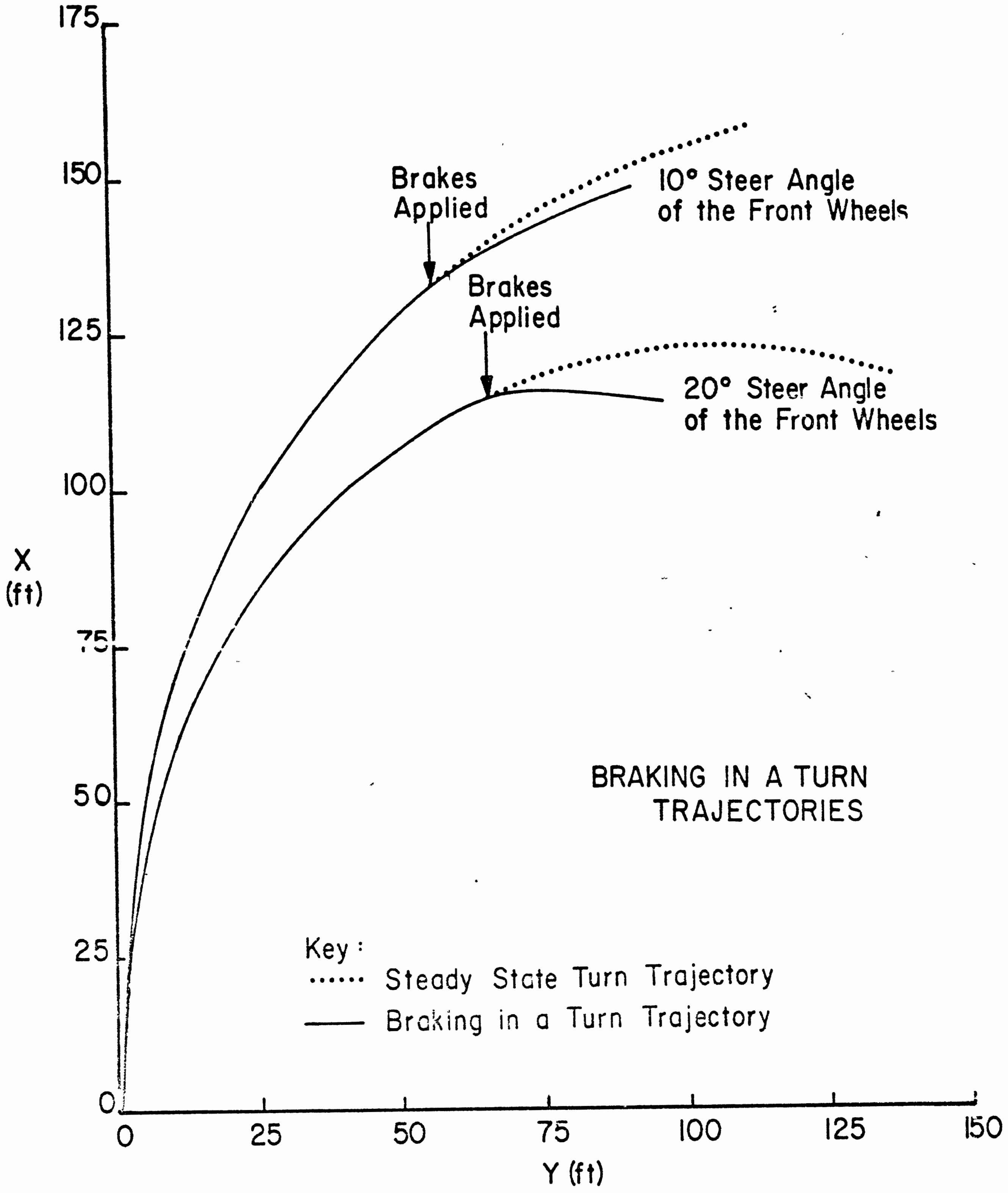

175
150
125
100
75
50
25
0
X (ft)
0
25
50
75
100
125
150
Y (ft)
Brakes Applied
Brakes Applied
10° Steer Angle of the Front Wheels
20° Steer Angle of the Front Wheels
BRAKING IN A TURN TRAJECTORIES
Key:
...... Steady State Turn Trajectory
—— Braking in a Turn Trajectory

Figure 6.

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APPENDIX 1

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                                        HSRI UMTA BUS SIMULATION

                               BRAKING IN A TURN, 700 PSI, 10 DEGREES

                                                           PAGE 1


INPUT PARAMETER TABLE

SYMBOL      DESCRIPTION                                 INITIAL VALUE
AA1         HORIZONTAL DISTANCE BETWEEN REAR AXLES (IN)       44.00
A1          HORIZONTAL DISTANCE FROM CG TO MIDPOINT OF
            FRONT SUSPENSION (IN)                            183.06
A2          HORIZONTAL DISTANCE FROM CG TO MIDPOINT
            BETWEEN REAR AXLES (IN)                           99.70
ALPHA1      STATIC DISTANCE, FRONT AXLE TO GROUND IN)         15.20
ALPHA2      STATIC DISTANCE, REAR AXLES TO GROUND (IN)        15.20
C1          VISCOUS DAMPING: JOUNCE ON FRONT AXLE
            (LB-SEC/IN.)                                      18.00
C2          VISCOUS DAMPING: REBOUND ON FRONT AXLE
            (LB-SEC/IN.)                                     120.00
C3          VISCOUS DAMPING: JOUNCE ON FRONT TANDEM AXLE
            (LB-SEC/IN.)                                      18.00
C4          VISCOUS DAMPING: REBOUND ON FRONT TANDEM
            AXLE (LB-SEC/IN.)                                120.00
CALF1       LATERAL STIFFNESS, FRONT TIRES (LBS/DEG)          -1.00
CALF2       LATERAL STIFFNESS, FRONT TANDEM TIRES
            (LBS/DEG)                                         -1.00
CALF3       LATERAL STIFFNESS, REAR TANDEM TIRES
            (LBS/DEG)                                         -1.00
CF1         MAX. COULOMB FRICTION, FRONT SUSPENSION
            (LB)                                               0.0
CF2         MAX. COULOMB FRICTION, REAR SUSPENSION (LB)        0.0
CGAMMA      CAMBER STIFFNESS (LBS/DEG)                        70.00
CS1         LONGITUDINAL STIFFNESS, FRONT TIRES (LBS)      91950.00
CS2         LONGITUDINAL STIFFNESS, FRONT TANDEM TIRES
            (LBS)                                          91950.00
CS3         LONGITUDINAL STIFFNESS, REAR TANDEM TIRES
            (LBS)                                          91950.00
DELTA1      STATIC VERTICAL DISTANCE, FRONT AXLE TO
            BUS CG (IN)                                       27.00
FA1         FRICTION REDUCTION PARAMETER ON FRONT TIRES        0.01
FA2         FRICTION REDUCTION PARAMETER ON FRONT
            TANDEM TIRES                                       0.01
FA3         FRICTION REDUCTION PARAMETER ON REAR TANDEM
            TIRES                                              0.01
J1          SPRUNG MASS ROLL MOMENT OF INERTIA
            (IN-LB-SEC**2)                                102500.00
J2          SPRUNG MASS PITCH MOMENT OF INERTIA
            (IN-LB-SEC**2)                               1240000.00
J3          YAW MOMENT OF INERTIA (IN-LB-SEC**2)         1540000.00
JA2         ROLL MOMENT OF FRONT TANDEM AXLE
            (IN-LB-SEC**2)                                  5000.00
JS1         POLAR MOMENT OF FRONT WHEELS (IN-LB-SEC**2)      100.00
JS2         POLAR MOMENT OF FRONT TANDEM WHEELS
            (IN-LB-SEC**2)                                   100.00
JS3         POLAR MOMENT OF REAR TANDEM WHEELS
            (IN-LB-SEC**2)                                   100.00
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                                                  HSRI UMTA BUS SIMULATION

                                       BRAKING IN A TURN, 700 PSI, 10 DEGREES

                                                            PAGE 2


K1             SPRING RATE, FRONT SUSPENSION (LB/IN)              943.00
K2             SPRING RATE, FRONT TANDEM AXLE (LB/IN)             752.00
KT1            SPRING RATE, FRONT TIRES (LB/IN)                  5200.00
KT2            SPRING RATE, FRONT TANDEM TIRES (LB/IN)           5200.00
KT3            SPRING RATE, REAR TANDEM TIRES (LB/IN)            5200.00
MUZERO1        COEFFICIENT OF FRICTION, FRONT WHEELS                0.86
MUZERO2        COEFFICIENT OF FRICTION, FRONT TANDEM WHEELS         0.86
MUZERO3        COEFFICIENT OF FRICTION, REAR TANDEM WHEELS          0.86
PW             WEIGHT OF PAYLOAD (LBS)                             0.0
RCH1           ROLL CENTER HEIGHT, FRONT SUSPENSION (IN)           10.56
RCH2           ROLL CENTER HEIGHT, REAR SUSPENSION (IN)             7.38
SY1            HORIZONTAL DISTANCE FROM BODY X-AXIS TO
               FRONT SUSPENSION (IN)                               43.40
SY2            HORIZONTAL DISTANCE FROM BODY X-AXIS TO
               REAR SUSPENSION (IN)                                34.00
TIMF           MAXIMUM REAL TIME FOR SIMULATION (SEC)               5.00
TRA1           HALF TRACK OF FRONT AXLE (IN)                       43.40
TRA2           HALF TRACK OF FRONT TANDEM AXLE (IN)                43.56
VEL            INITIAL VELOCITY (FPS)                              44.00
W              SPRUNG WEIGHT OF TRUCK (LBS)                     26440.00
WS1            WEIGHT OF FRONT SUSPENSION (LBS)                  1245.00
WS2            WEIGHT OF FRONT TANDEM (LBS)                      2157.00
WS3            WEIGHT OF REAR TANDEM (LBS)                       2157.00
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                                                            HSRI UMTA BUS SIMULATION

                                                  BRAKING IN A TURN, 700 PSI, 10 DEGREES

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BRAKE PARAMETERS: TQ(1,1,1) = 0.0   TQ(1,1,2) = 0.001
                  TQ(1,2,1) = 0.0   TQ(1,2,2) = 0.001
                  TQ(2,1,1) = 0.0   TQ(2,1,2) = 0.001
                  TQ(2,2,1) = 0.0   TQ(2,2,2) = 0.001
                  TQ(3,1,1) = 0.0   TQ(3,1,2) = 0.001
                  TQ(3,2,1) = 0.0   TQ(3,2,2) = 0.001

    TABLE 1: TIME VS PRESSURE (PSI)
             NO. OF POINTS:  3
          0.0            0.0
          3.0000         0.0
          3.5000       700.0000

    TABLE 2: PRESSURE (PSI) VS TORQUE (IN-LBS)
             FRONT BRAKES, LEFT SIDE
             NO. OF POINTS: 11
          0.0            0.0
        127.0000      3988.0000
        249.0000      7831.0000
        367.0000     11548.0000
        481.0000     15139.0000
        591.0000     18604.0000
        697.0000     21959.0000
        800.0000     25203.0000
        900.0000     28353.0000
        996.0000     31377.0000
       1090.0000     34322.0000

    TABLE 3: PRESSURE (PSI) VS TORQUE (IN-LBS)
             FRONT BRAKE, RIGHT SIDE
             NO. OF POINTS: 11
          0.0            0.0
        127.0000      3988.0000
        249.0000      7831.0000
        367.0000     11548.0000
        481.0000     15139.0000
        591.0000     18604.0000
        697.0000     21959.0000
        800.0000     25203.0000
        900.0000     28353.0000
        996.0000     31377.0000
       1090.0000     34322.0000
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                                        HSRI LMTA BUS SIMULATION

                                  BRAKING IN A TURN, 700 PSI, 10 DEGREES

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      TABLE 4: PRESSURE (PSI) VS TORQUE (IN-LBS)
               FRONT TANDEM BRAKES, LEFT SIDE
               NO. OF POINTS: 11
          0.0              0.0
        127.0000        7596.0000
        249.0000       14916.0000
        367.0000       21996.0000
        481.0000       28836.0000
        591.0000       35436.0000
        697.0000       41826.0000
        800.0000       48006.0000
        900.0000       54006.0000
        996.0000       59766.0000
       1090.0000       65376.0000

      TABLE 5: PRESSURE (PSI) VS TORQUE (IN-LBS)
               FRONT TANDEM BRAKES, RIGHT SIDE
               NO. OF POINTS: 11
          0.0              0.0
        127.0000        7596.0000
        249.0000       14916.0000
        367.0000       21996.0000
        481.0000       28836.0000
        591.0000       35436.0000
        697.0000       41826.0000
        800.0000       48006.0000
        900.0000       54006.0000
        996.0000       59766.0000
       1090.0000       65376.0000

      TABLE 6: PRESSURE (PSI) VS TORQUE (IN-LBS)
               REAR TANDEM BRAKES, LEFT SIDE
               NO. OF POINTS: 11
          0.0              0.0
        127.0000        7596.0000
        249.0000       14916.0000
        367.0000       21996.0000
        481.0000       28836.0000
        591.0000       35436.0000
        697.0000       41826.0000
        800.0000       48006.0000
        900.0000       54006.0000
        996.0000       59766.0000
       1090.0000       65376.0000
```

```
TABLE 7: PRESSURE (PSI) VS TORQUE (IN-LBS)
         REAR TANDEM BRAKES, RIGHT SIDE
         NO. OF POINTS: 11
      0.0             0.0
    127.0000       7596.0000
    249.0000      14916.0000
    367.0000      21936.0000
    481.0000      28836.0000
    591.0000      35436.0000
    697.0000      41826.0000
    800.0000      48006.0000
    900.0000      54006.0000
    996.0000      59766.0000
   1090.0000      65376.0000

TABLE  8: TIME VS STEER ANGLE (DEG)
          NO. OF POINTS:  2
      0.0             0.0
      0.5000         10.0000

TABLE  9: SUSPENSION DEFLECTION (IN) VS CAMBER (DEG)
          NO. OF POINTS:  9
     -4.0000         -2.0000
     -3.0000         -1.0000
     -2.0000         -0.4000
     -1.0000          0.1000
      0.0             0.5000
      1.0000          0.7000
      2.0000          0.8000
      3.0000          0.9000
      4.0000          1.0000

TABLE. 9: VERTICAL LOAD VS LATERAL STIFFNESS (LBS/DEG)
          FRONT TIRES
          NO. OF POINTS:  7
      0.0             0.0
   1800.0000        690.0000
   3300.0000        786.0000
   4770.0000        791.0000
   5430.0000        824.0000
   6900.0000        963.0000
   9840.0000       1097.0000
```

```
TABLE  9: VERTICAL LOAD VS LATERAL STIFFNESS (LBS/DEG)
          FRONT TANDEM TIRES
          NO. OF POINTS:  7
    0.0            0.0
 1800.0000       690.0000
 3300.0000       786.0000
 4770.0000       791.0000
 5430.0000       824.0000
 6900.0000       963.0000
 9840.0000      1097.0000

TABLE  9: VERTICAL LOAD VS LATERAL STIFFNESS 'LBS/DEG)
          REAR TANDEM TIRES
          NO. OF POINTS:  7
    0.0            0.0
 1800.0000       690.0000
 3300.0000       786.0000
 4770.0000       791.0000
 5430.0000       824.0000
 6900.0000       963.0000
 9840.0000      1097.0000

*** END INPUT ***
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APPENDIX 2

Testing of the AM General bus tires is described in this appendix. Several tires will be supplied by AM General. A series of screening tests will be performed at one load and three slip angles to ensure that all tires perform uniformly.

Tire tests will be performed to obtain shear force data at specified inflation pressure and at loads of 1800, 3600, 5430, 7200, and 9000 lbs. The following tests will be run:

Test 1. Sideslip Angles: 0 ±(1, 2, 4, 8, 12, 16, 20, 24, and 30) at 0° camber angle.

Measure: lateral force, normal load, aligning torque, overturning moment, loaded radius, effective radius

Test 2. Camber Angles: 0, ±(1, 2, 3, 4, 5) degrees at 0° steer angle.

Measure: Same as in Test 1

NOTE: Data from Tests 1 and 2 at zero slip and zero camber angle will be used to calculate the rolling and static spring rates of the tires.

Test 3. Longitudinal Slip: 0° steer angle and 0° camber angle.

Approximate longitudinal force, braking and driving, $(0.1, 0.2, 0.3, 0.4, \ldots)F_z$ up to 1500 lbs.

Measure: bed velocity, longitudinal slip, and braking or driving force

Test 4. Combined Side and Longitudinal Slip: 0° camber at steer angles of 4, 8, and 12°, for braking and driving forces as in Test 3. Rated load and tire pressure.

Measure: bed velocity, longitudinal slip, lateral force, and braking or driving force.