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Aberdeen Proving Ground, MD 21005-5059

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14. ABSTRACT
This Test Operations Procedure (TOP) describes use of the Roadway Simulator (RWS) when conducting standardized automotive performance tests of two- and three-axle wheeled vehicles. Objective tests are performed on the RWS in accordance with industry standards, other U.S. Army Test and Evaluation Command (ATEC) TOPs, or unique tests described in test plans. In all cases, the vehicle is controlled by an autopilot and the RWS is operated in the Road Load or Road Speed mode.

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U.S. ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure 02-2-514 — 25 August 2020
DTIC AD No.

ROADWAY SIMULATOR

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1. SCOPE.

This Test Operations Procedure (TOP) describes use of the Roadway Simulator (RWS) when conducting standardized automotive performance tests of two- and three-axle wheeled vehicles. Objective performance tests, including those listed in Table 1, are conducted on the RWS in accordance with industry standards, other U.S. Army Test and Evaluation Command (ATEC) TOPs, or unique tests described in test plans. In all cases, the vehicle is controlled by an autopilot and the RWS is operated in the Road Load or Road Speed mode. The RWS Setup and Operation Manual[1**] provides additional guidance needed to setup and operate the simulator during test conduct.

TABLE 1. TYPICAL PERFORMANCE TESTS CONDUCTED ON THE RWS

SUBTEST	REFERENCE STANDARDS (Appendix B)	RWS CONTROL METHOD
Steady-state circular steer	TOP 02-2-002A[2], SAE J266[3], SAE J2181[4], ISO 4138[5], ISO 14792[6]	Road Load
On-center handling	TOP 02-2-600[7], TOP 02-2-002A, ISO 13674-1[8], ISO 13674-2[9], ISO 11012[10]	Road Load
Response gain	TOP 02-2-002A, SAE J266	Road Load
Transient response	TOP 02-2-002A, ISO 7401[11]	Road Load
Electronic stability control	TOP 02-2-718A[12], TOP 02-2-002A	Road Load
Steering effort	TOP 02-2-002A, AVTP 03-30[13]	Road Load
Emergency lane change	TOP 02-2-002A, AVTP 03-160W[14]	Road Load
Self-steer during braking	TOP 02-2-002A	Road Load or Road Speed
Mountain braking	TOP 02-2-608[15]	Road Load
Resistance-to-motion	SAE J2263[16], SAE J1263[17], ISO 10521-1[18]	Road Load
Resistance-to-tow	TOP 02-2-605[19]	Road Speed
Drawbar pull	TOP 02-2-604[20]	Road Speed
Acceleration; maximum and minimum speeds	TOP 02-2-602A[21], SAE J1491[22]	Road Load
Longitudinal slope speeds	TOP 02-2-610A[23]	Road Load
Vehicle fuel consumption	TOP 02-2-603A[24]	Road Load
Full-load cooling	TOP 02-2-607[25]	Road Speed
Road-load cooling	TOP 02-2-607	Road Load
Controlled damage experiments	Per relevant test plan	Road Load or Road Speed

AVTP = Allied Vehicle Testing Publication
ISO = International Organization for Standardization
SAE = SAE International (Formerly Society of Automotive Engineers)

** Superscript numbers correspond to Appendix B, References.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

Item	Requirement
RWS	Treadmill-type roadway simulator capable of testing two- and three-axle wheeled vehicles up to 27,216 kilogram (kg) (60,000 pound (lb)) gross vehicle weight (GVW).

2.2 Instrumentation.

Devices for Measuring	Permissible Measurement Error
Force	± 0.01% of full scale
Velocity	± 0.1 miles per hour (mph)
Angle	± 0.05 degrees

3. ROADWAY SIMULATOR (RWS) DESCRIPTION.

The RWS is a vehicle-in-the-loop simulator used to test the safety and performance of wheeled vehicles in a laboratory environment. The RWS consists of four treadmill actuator sets (known as Flat-trac units), an autopilot, and restraint towers with integrated bi-axial load cells. Two-axle vehicles up to 15,876-kg (35,000-lb) GVW and three-axle vehicles up to approximately 27,216-kg (60,000-lb) GVW may be tested. Figure 1 shows an image of the RWS with a two-axle vehicle and side-to-side restraints, and Figure 2 shows a three-axle vehicle being tested. The Flat-trac units, autopilot, vehicle restraints with bi-axial loads, and motion control modes are described in paragraph 3.1.

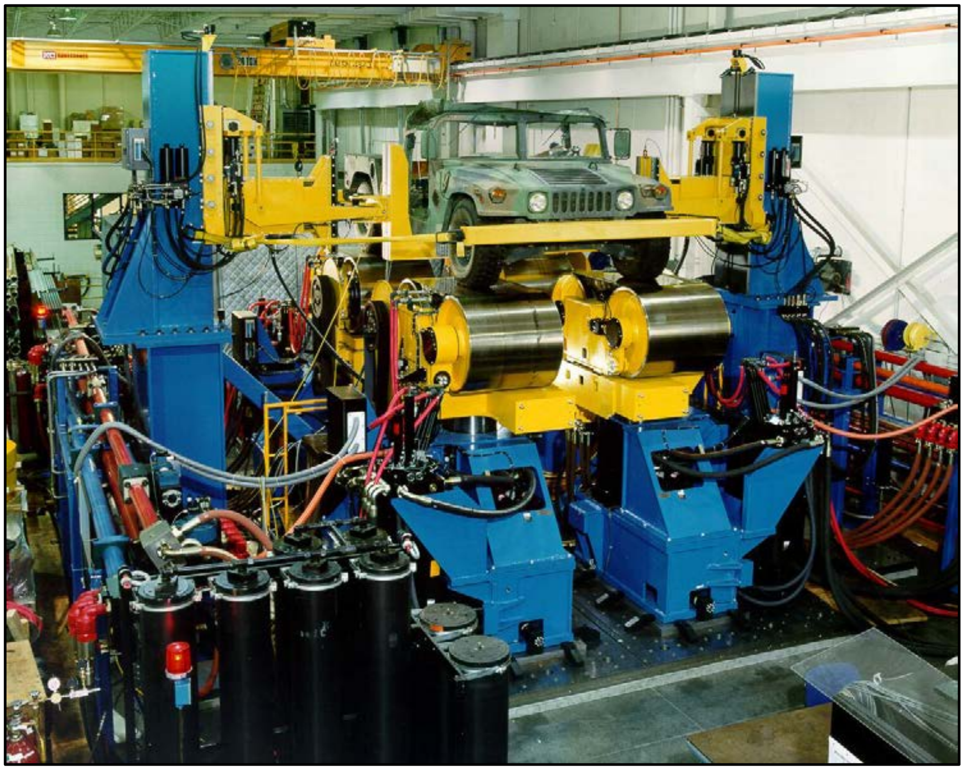
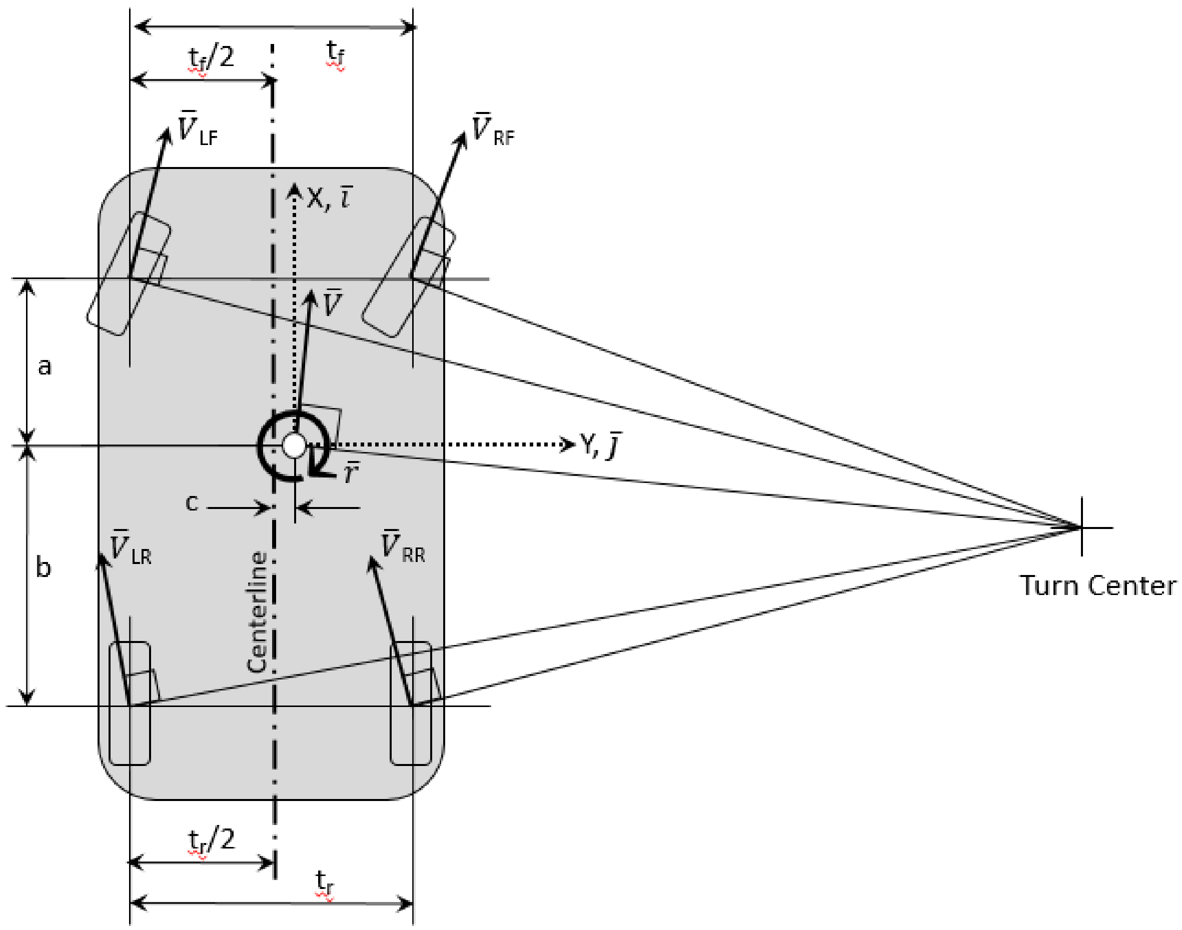


Figure 1. RWS with High Mobility Multi-Purpose Wheeled Vehicle (HMMWV).

Figure 2. RWS with 3-axle vehicle, tandem rear axle.

3.1 Roadway Simulator (RWS) Flat-trac Units.

a. Test vehicles are driven on a set of Flat-trac units, which simulate tire trajectory velocity vectors as defined in the 2008 version of SAE J670[26]. The tire trajectory velocity vectors, $\bar{V}_{LF}$, $\bar{V}_{RF}$, $\bar{V}_{LR}$, *and* $\bar{V}_{RR}$, for a two-axle vehicle while cornering are illustrated in Figure 3. $\bar{V}$ and $\bar{r}$ represent the vehicle velocity and yaw rate at the vehicle center of gravity (CG) while cornering ($\bar{r}$ is actually a free vector). Two types of Flat-trac units exist, single-axle units (Figure 4) and tandem-axle units (Figure 5). Revolving belts provide velocity vector magnitude and steer actuators provide velocity vector direction. Coordinated movement of the actuator sets produces a coherent roadway beneath the test vehicle.



a = distance from the CG to the front axle.
b = distance from the CG to the rear axle.
c = lateral CG offset.
t_f = front axle track.
t_r = rear axle track.
$\bar{\imath},\bar{\jmath}$ = unit vectors of the X and Y axes.

Figure 3. Vehicle cornering geometry.

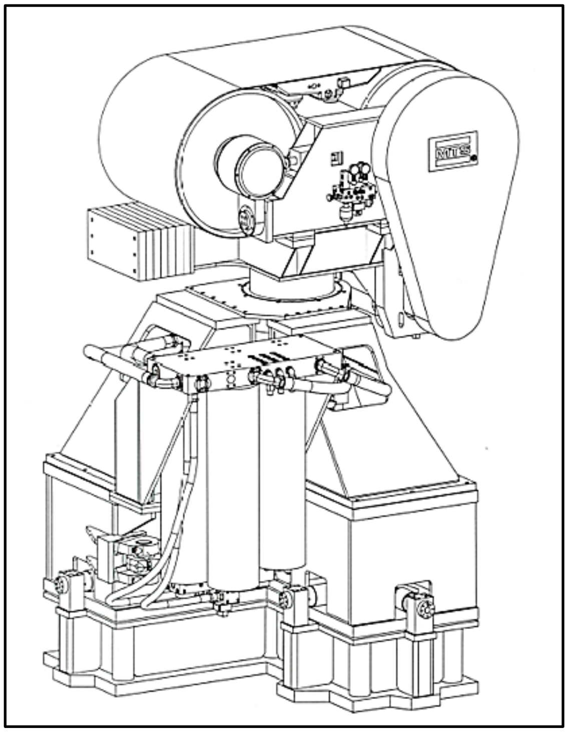


Figure 4. Single-axle Flat-trac unit.

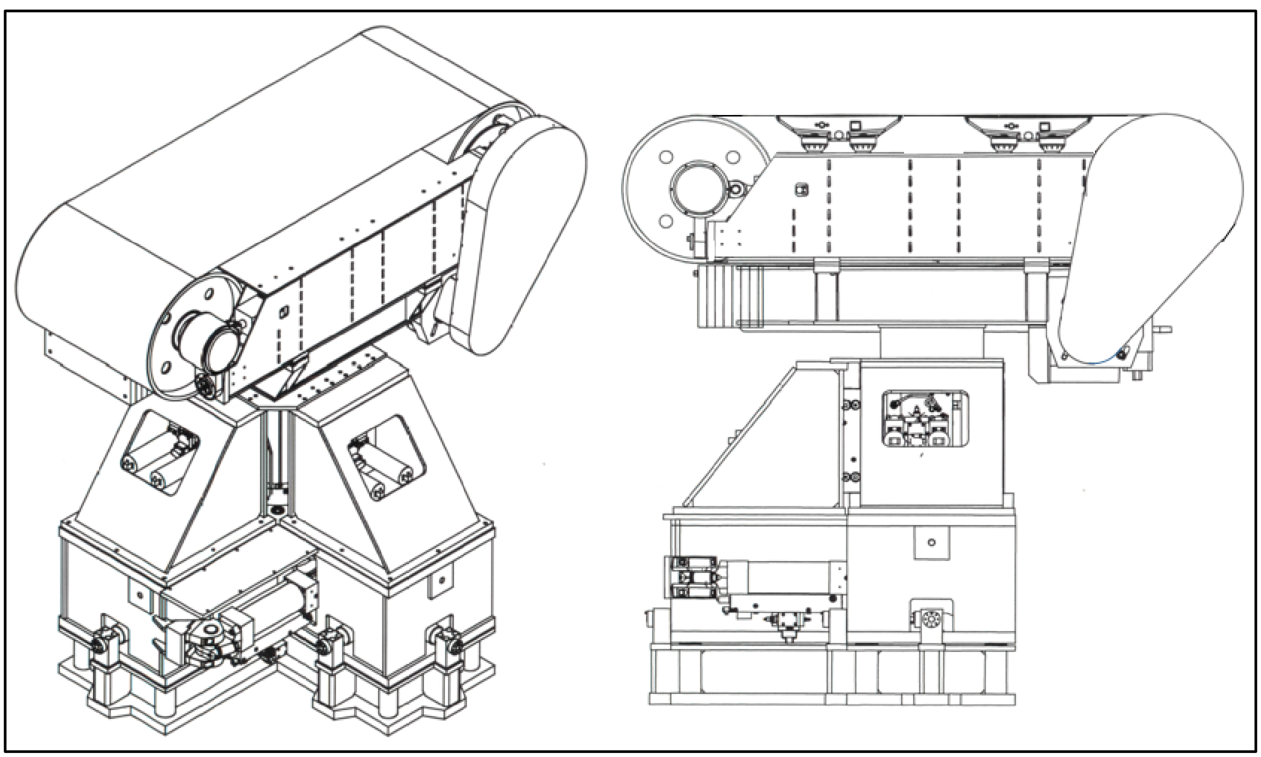


Figure 5. Tandem-axle Flat-trac unit with two hydrodynamic bearings.

b. Each servo-hydraulic actuator set consists of a driven drum, an idler drum, a continuous steel belt, a vertical actuator, a steer actuator, hydrodynamic (water) bearings, and load cells beneath the hydrodynamic bearings. The hydrodynamic bearings support the vehicle at the tire/road interface and are located directly beneath the belt. Drive pulleys connect the driven drum to the drive motor. Two different drive pulley ratios are available to match the speed and torque capability of the test vehicle.

c. Table 2 lists speed, steer, and vertical motion capabilities of the single-axle and tandem-axle units.

TABLE 2. ACTUATOR SET PERFORMANCE CAPABILITY

CAPABILITY		SINGLE-AXLE UNIT	TANDEM-AXLE UNIT
Belt speed (mph)	Pulley ratio 1.40:1	120	120
	Pulley ratio 2.67:1	64	64
Steer angle (degrees)		±20	±16
Vertical displacement (inches (in.))		±6	±6
Vertical rate (inches per second (in./sec))		80	80
Vertical acceleration (*g*)		10	10

d. The combined rotating inertia for four single-axle units matches the kinetic energy of a moving 12,701-kg (28,000-lb) wheeled vehicle, assuming 0.9-meter (m) (36-in.) tire rolling radius and 0.9-m (36-in.) drum radius. The hydraulic motors provide additional power to accelerate vehicles of different weights, compensate for vehicle weight transfer during acceleration, and compensate for aerodynamic and other motion resistances. The combined rotating inertia for two single-axle units and two tandem-axle units matches the kinetic energy of a 14,569-kg (32,120-lb) vehicle.

e. Dynamic responses of the servo-hydraulic actuators are adjustable with proportional, integral, differential (PID) control, incorporating actuator delta pressure and feedforward gain when appropriate. Actuator gain, lag, and frequency bandwidth are monitored and periodically adjusted to ensure phase lag is minimal, overshoot is within acceptable bounds, and steady-state error is minimal. Adjustments are infrequent. Engineering judgement of skilled operators ensures gain calibration is optimal.

f. Since the tandem-axle Flat-trac units only apply a single tire trajectory velocity vector for each pair of tandem rear tires of a vehicle, tests performed with the tandem rear axle vehicles are generally limited to powertrain and mountain brake performance. Large radius turns may be driven when the slip angles on each side of the tandem rear axles of a vehicle are similar.

3.2 Restraint Towers with Bi-axial Load Cells.

a. The purpose of the restraint towers, illustrated in Figures 6 and 7, is to constrain the vehicle in the longitudinal (*X*), lateral (*Y*), and yaw directions (ψ), while allowing the vehicle to move freely in the vertical (*Z*), pitch (θ), and roll (ϕ) directions. Two restraint configurations may be used: side-to-side and front-to-back. In either case, the axis extending between the bi-axial load cell centers is configured to pass through the vehicle CG. Bi-axial load cells measure the vehicle reaction forces (or body forces) in the longitudinal (F_x), lateral (F_y), and yaw (M_z) constrained degrees-of-freedom, and are available in 2,268-kg (5,000-lb), 5,897-kg (13,000-lb), and 11,793-kg (26,000-lb) capacities.

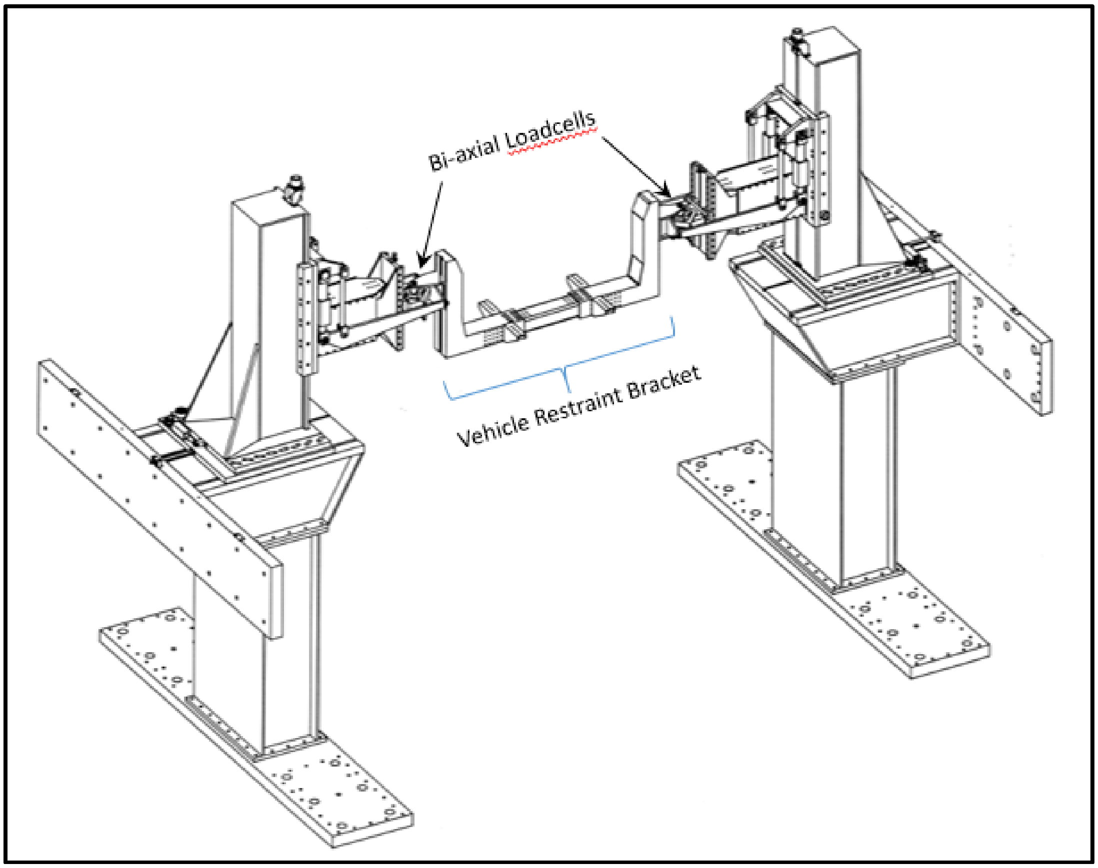


Figure 6. Restraint towers in side-to-side configuration.

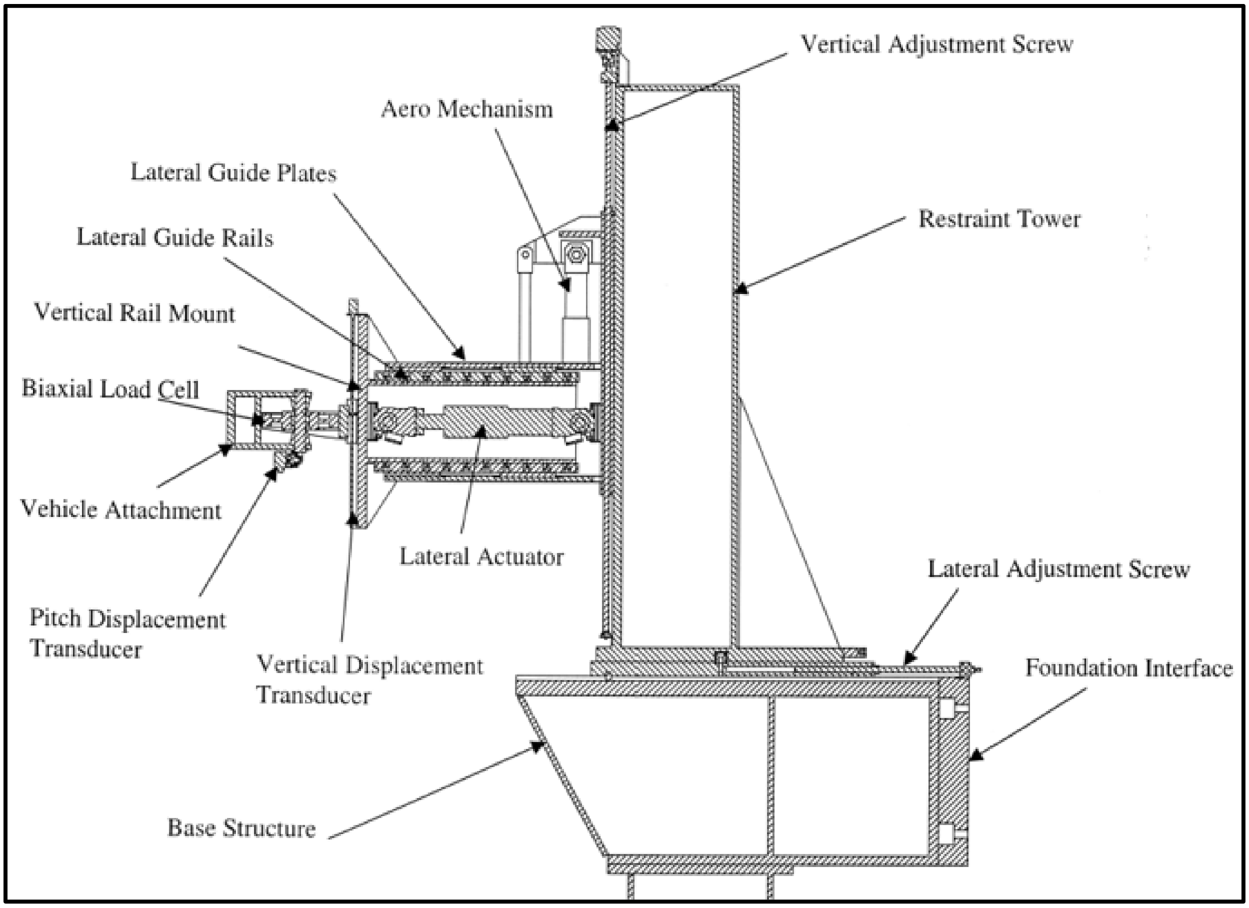


Figure 7. Components of a single restraint tower.

b. The restraint tower mechanisms move spherically about the vehicle CG in two ways. First, the load cells contain a spherical joint at the center, allowing free rotation about the axis between the load cells. This rotation is limited to ±20 degrees. Second, the restraint towers include vertical and lateral guides (or linear bearings) with passive lateral actuators positioned inside the lateral guides. The outer oil column in one actuator (on one side of the vehicle) is hydraulically coupled to the inner oil column on the other actuator (on the other side of the vehicle), and vice versa. As the vehicle rolls or pitches during testing, depending on the configuration, the combined action of the vertical guide, lateral guide, and lateral actuators allows spherical roll and pitch motion, as well as lateral motion, without constraining the vehicle. The restraint towers also include aero-actuators to simulate aerodynamic downforce, if needed for testing.

c. The front-to-back configuration is generally used when steering and handling tests are conducted, to minimize increases in vehicle roll inertia. The side-to-side configuration is generally used during powertrain performance tests to improve the ability to force cooling air to the vehicle radiator and to ensure pitch motion is not restricted.

3.3 Autopilot.

The RWS autopilot consists of steering, brake actuator, accelerator actuator, gear shift, and clutch actuators and a controller unit. Figure 8 shows a typical installation in a test vehicle. Stiffening brackets are often used near actuator reaction points to eliminate unwanted deflection and inaccurate position feedback signals. The autopilot controller is supervised by the RWS controller.

Figure 8. RWS autopilot mounted in a HMMWV.

3.4 Control Modes.

Two supervisory motion control modes are used in testing, Road Load control (closed-loop) and Road Speed control (open-loop). Belt-speed mode is also provided for setup, calibration, and actuator tuning. The following descriptions of Road Load and Road Speed control supplement pages 54 and 55 of the Roadway Simulator Setup and Operation Manual.

3.4.1 Road Load Control.

a. Road Load is the most common motion control method. Feedback from the bi-axial load cells is used to automatically control Flat-trac belt speed and steer actuators. For many tests, the RWS operator sends open-loop control commands to the autopilot to execute a test maneuver and the RWS responds accordingly. However, additional control loops may be applied to the autopilot for automatic control of a maneuver (e.g., executing a constant radius turn or following a velocity profile).

b. Road Load control is based on the application of Newton's second law. The sum of the forces acting on the vehicle and the mass properties of the vehicle determine the acceleration of the vehicle. For the RWS, Newton's law is applied in the constrained degrees of freedom, *X*, *Y*, and yaw. Accelerations in the remaining degrees of freedom are not computed because the vehicle is free to move in those directions and control is not required.

c. The vehicle velocity vector $\bar{V}$ is represented as $u\bar{\imath} + v\bar{\jmath}$, where *u* and *v* are the *X* and *Y* direction components of *V*, respectively. The $\bar{\imath}$ and $\bar{\jmath}$ unit vectors are shown in Figure 3 at the CG position. The yaw velocity (rate) vector is expressed as $r\bar{k}$, where the unit vector $\bar{k}$ is orthogonal to $\bar{\imath}$ and $\bar{\jmath}$, directed downward. This notation is consistent with the 1976 version of SAE J670[27]. The 2008 version of SAE J670 uses V_x, V_y, and ω_z instead of *u*, *v*, and *r*.

d. Using this notation, the RWS equations of motion for control are the following.

$$\dot{u} = vr + \frac{(F_x + F_{AERO} + F_{GRADE})}{m} \qquad \text{(Equation 1)}$$

$$\dot{v} = -ur + \frac{F_y}{m} \qquad \text{(Equation 2)}$$

$$\dot{r} = \frac{M_z}{(I_{zz} + 2\theta I_{xz})} \qquad \text{(Equation 3)}$$

where:

$\dot{u}$ is the vehicle longitudinal acceleration at the CG.
$\dot{v}$ is the vehicle lateral acceleration at the CG.
$\dot{r}$ is the vehicle yaw acceleration.
m is the vehicle mass.
I_{zz} is the vehicle yaw mass moment of inertia about the CG.
I_{xz} is the vehicle xz product of inertia about the CG.
θ is the vehicle pitch angle.
F_{AERO} is the aerodynamic drag force.
F_{GRADE} is the grade force.

e. Aerodynamic drag and grade forces may be applied in the lateral direction as well, but this is not typically done. Grade can be constant or commanded based on distance or time.

f. The simulation basic period is 1000 Hertz (Hz). The terms on the left side of the equations are computed at discrete time t, while the terms on the right side of the equations are computed from feedback data available at discrete time t-1. The accelerations, $\dot{u}$, $\dot{v}$, and $\dot{r}$, are numerically integrated at the simulation basic period to compute u, v, and r at the vehicle CG.

g. Finally, the velocity vector magnitudes at the CG position, *u* and *v*, the yaw rate magnitude r, and the Flat-trac steer center position vectors relative to the vehicle CG position are used to compute the tire trajectory velocity vectors for each Flat-trac unit. The position vectors of the Flat-trac steer centers from the vehicle CG position (see Figure 3) are calculated by:

$$\bar{P}_{LF}(i,j) = \begin{Bmatrix} +a \\ -(t/2 + c) \end{Bmatrix} \qquad \textit{(Equation 4)}$$

$$\bar{P}_{RF}(i,j) = \begin{Bmatrix} +a \\ (t/2 - c) \end{Bmatrix} \qquad \text{(}\textit{Equation 5)}$$

$$\bar{P}_{LR}(i,j) = \begin{Bmatrix} -b \\ -(t/2 + c) \end{Bmatrix} \qquad \textit{(Equation 6)}$$

$$\bar{P}_{RR}(i,j) = \begin{Bmatrix} -b \\ (t/2 - c) \end{Bmatrix} \qquad \text{(Equation 7)}$$

where the upper term in each vector is in the $\bar{\imath}$ direction and the lower term is in the $\bar{\jmath}$ direction. The tire trajectory velocity vectors are then computed using the following equations.

$$\bar{V}_{LF} = u\bar{\imath} + v\bar{\jmath} + r\bar{k} \times \bar{P}_{LF} \qquad \textit{(Equation 8)}$$

$$\bar{V}_{RF} = u\bar{\imath} + v\bar{\jmath} + r\bar{k} \times \bar{P}_{RF} \qquad \textit{(Equation 9)}$$

$$\bar{V}_{LR} = u\bar{\imath} + v\bar{\jmath} + r\bar{k} \times \bar{P}_{LR} \qquad \textit{(Equation 10)}$$

$$\bar{V}_{RR} = u\bar{\imath} + v\bar{\jmath} + r\bar{k} \times \bar{P}_{RR} \qquad \textit{(Equation 11)}$$

h. The magnitude and direction of each velocity vector are then computed as command signals to the Flat-trac unit belt speed (vector magnitude) and steering (vector angle) actuators.

3.4.2 Road Speed Control.

Road Speed control is open-loop, where the longitudinal, lateral, and yaw velocity or vehicle velocity, side-slip, and yaw velocity are directly controlled by the RWS operator. For example, the operator could command the road speed to effectively tow the vehicle down the road to measure resistance-to-tow forces. Road speed control may also be used during full-load cooling tests where the vehicle speed is regulated to achieve maximum power of the engine at wide-open throttle.

4. REQUIRED TEST CONDITIONS.

4.1 Vehicle Preparation.

Prior to testing, ensure the following:

a. The vehicle has been prepared and equipped in accordance with standard use and/or within the specifications presented in the test plan, with particular attention being given to the engine, transmission, brakes, running gear, and fuel and oil levels.

b. The vehicle is payloaded in accordance with the test plan and the payload is secured in a safe and proper manner.

c. The vehicle has received the proper break-in operation.

d. Vehicle tires are in good serviceable condition, and the tire pressure is adjusted to the proper settings.

e. Prior to any full-load tractive effort operations (drawbar bar pull and full-load cooling tests) the tire and wheel at the bead interface should be marked to allow a visual check of bead slip and possible loss of traction during testing.

f. The vehicle has been thoroughly cleaned and is free of dirt and debris that could damage Flat-trac belts.

g. A means shall also be provided on the vehicle for the RWS test operator to remotely shut down the vehicle engine in the event of an emergency.

4.2 On-Board Vehicle Instrumentation.

Install the appropriate on-board vehicle instrumentation in accordance with the relevant TOP or test plan for the test to be performed. Instrumentation should include a means for recording the vehicle data buses, if the vehicle is so equipped, and a means for the test operator to monitor engine speed.

4.3 Basic Vehicle Measurements.

Prior to installation of the RWS vehicle restraint hardware, obtain the following static vehicle measurements at the test payload conditions:

a. Track at each axle, as defined in SAE J670.

b. Wheelbase per axle, as defined in SAE J670.

c. Vehicle weight distribution and total weight, in accordance with TOP 02-2-801[28].

d. CG position, measured in accordance with TOP 02-2-800[29], ISO 19385[30], or ISO 10392[31].

e. I_{zz} yaw mass moment of inertia and I_{xz} product of inertia measured in accordance with TOP 01-2-520[32].

4.4 Field Test Measurements.

Obtain any dynamic field test measurements needed for test replication on the RWS (e.g., dynamic velocity profiles for fuel consumption testing with associated grade data), based on the specific tests to be performed. Follow pertinent test standards and TOPs. Perform a resistance-to-motion test of the vehicle at the desired payload configuration in accordance with SAE J2263. The resistance-to-motion data is used with resistance-to-tow data collected on the RWS to estimate the aerodynamic drag coefficient of the vehicle. The aerodynamic drag coefficient is required as an input to the Simulator Parameters window in the RWS software.

4.5 Roadway Simulator (RWS) Preparation.

a. The Roadway Simulator Setup and Operation Manual provides key information needed for hardware and software configuration and test preparation and should be used as the primary guide in addition to the following procedures.

b. Prior to executing any step below that requires the RWS hydraulics, autopilot, or system software to be active, follow the System Startup Procedures described on pages 207 through 214 of the Roadway Simulator Setup and Operation Manual.

Note: The Roadway Simulator Setup and Operation Manual only references use of the side-to-side orientation of the vehicle restraints. Provisions were installed by MTS Systems Corporation in the RWS Test Controller software for use of front-to-back restraints after the manual was published. The same general procedure applies to both configurations.

4.5.1 Installation of Vehicle Restraints.

a. Install the vehicle restraint bracketry and mounting plates, either to the front and rear or sides of the vehicle as appropriate. Examples of front and rear restraints are shown in Figures 9 and 10. For planning purposes, the load cell axis should pass through the vehicle *X*, *Y*, and *Z* CG position. Offsets can be programmed into the RWS configuration software if necessary.

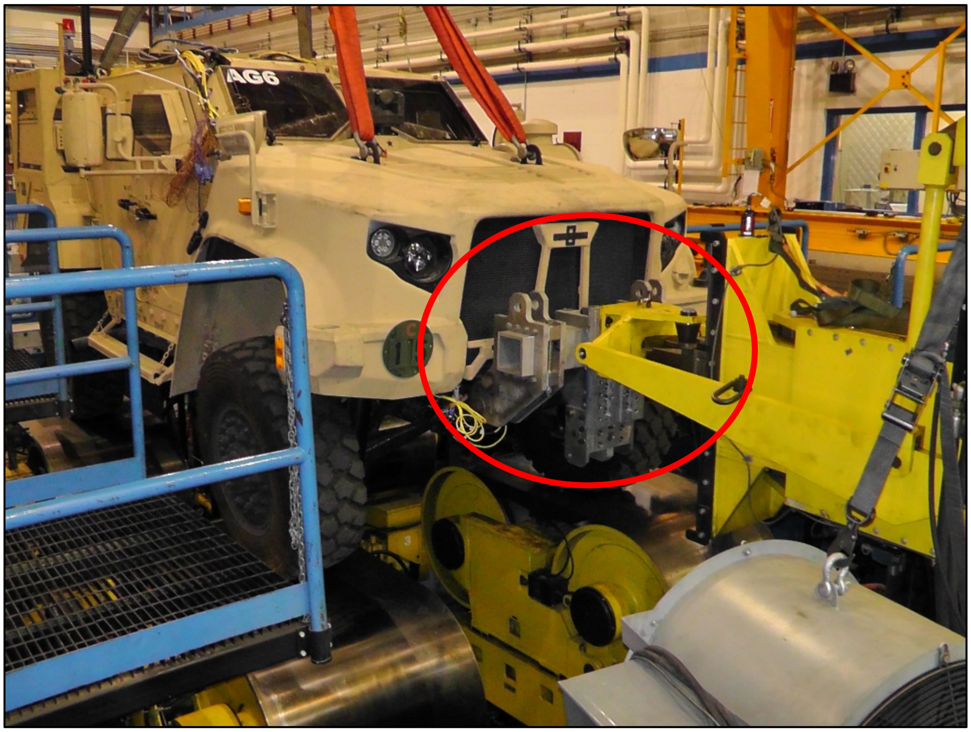


Figure 9. Front vehicle restraint bracketry and plate.

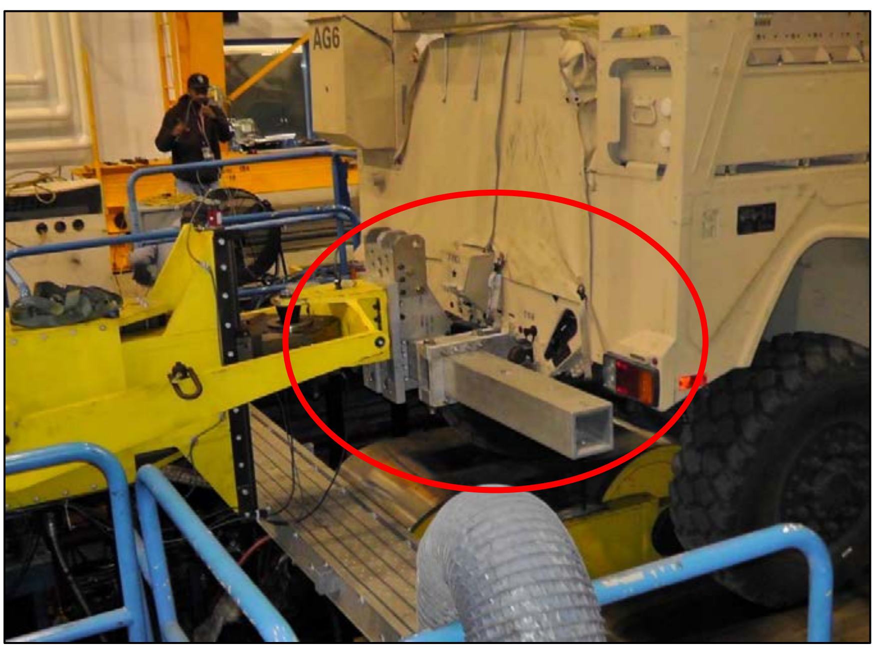


Figure 10. Rear vehicle restraint bracketry and plate.

b. Install temporary load cell mass simulator weights to the restraint/load cell attachment plates, consistent with the load cells (2,268-kg (5,000-lb), 5,897-kg (13,000-lb), or 11,793-kg (26,000-lb) capacity) used during testing. An example mass simulator weight is shown in Figure 11.

Figure 11. Test vehicle restraint bracketry with mass simulator.

c. Ensure the restraint hardware attachment to the test vehicle is structurally sufficient for anticipated test loads.

d. Perform new weight distribution and CG measurements of the vehicle with the restraints and compare to the original vehicle weight distribution and CG data.

e. Adjust vehicle payload and ballast as appropriate to obtain the target test weight distribution. Compensate for the autopilot weight versus the human driver.

f. After the weight distribution measurements are completed, remove the load cell mass simulator weights and measure and record the following for later use during simulator software configuration:

(1) Distances across the outer faces of the load cell attachment plates.

(2) Location of the restraint axis relative to the vehicle *X* or *Y* axis (based on the CG position and restraint configuration) and Z axis.

(3) Offsets of the midpoint of the load cell attachment points from the vehicle *X* or *Y* axis (based on the CG position and restraint configuration).

g. All required vehicle parameters for test simulation are listed on pages 50 and 51 of the Roadway Simulator Setup and Operation Manual.

4.5.2 Installation of Autopilot.

Install the autopilot system following the guidance provided on pages 237 through 253 of the Roadway Simulator Setup and Operation Manual. Ensure the autopilot actuator restraint hardware is sufficiently stiff as installed to permit accurate control and feedback of the throttle, brake, steering wheel, and shifter.

4.5.3 RWS Hardware Configuration.

Position the RWS restraint towers as needed based on the restraint configuration, restraint measurements, and vehicle CG position. Follow the guidance provided on pages 219 through 227 of the Roadway Simulator Setup and Operation Manual. Select the appropriate RWS Flat-trac units for the test vehicle (i.e., single or tandem rear axles). Position the RWS Flat-trac units at the centers of the wheelbase and track positions relative to the vehicle CG position and restraints. Install the desired load cells on the restraint towers. Ensure the load cell transducer *X* and *Y* output connections are consistent with the restraint configuration. The positive *X* direction is forward and the positive *Y* direction is to the right of the vehicle.

4.5.4 Initial RWS Checks.

a. Prior to vehicle installation and operations, ensure the RWS bi-axial loads cells used during testing are calibrated in accordance with ATEC policy and U.S. Army Aberdeen Test Center (ATC) guidelines. Also, ensure the Flat-trac unit belt speed encoders/tachometers are functioning properly and reporting accurate speed readings.

b. Verify that the correct biaxial load cell and water bearing load cell calibration factors are loaded into the Real-time Controls Panel, Main Panel, Calibration Menu, as described on pages 112 through 144 of the Roadway Simulator Setup and Operation Manual. The load cells are serialized. The water bearing load cell data is not a necessary measurement for most tests.

c. Zero the biaxial and water bearing load cells by removing any voltage offsets observed on the direct current (DC) conditioner window, page 130, of the Roadway Simulator Setup and Operation Manual. Perform this operation for each load cell used. To properly zero the biaxial load cells, lift the load cells with the RWS crane at the center of the spherical joint and level the adjacent restraint mounting bracket that attaches the load cell spherical joint to the vehicle restraint bracketry. To properly zero the water bearing load cells (if the data is desired for the test), the water bearings shall be powered up with water flowing through the bearings.

d. Prior to installing the vehicle on the RWS verify the following:

(1) Flat-trac unit belts are clean.

(2) Hydraulic Power Units (HPUs) are functioning properly.

(3) Water bearing chiller is functioning properly and water temperature is set appropriately.

(4) Evaporative cooling tower and pumps are functioning properly.

(5) Load cell cabling is connected properly.

(6) RWS Flat-trac unit cabling is connected properly.

(7) The RWS Flat-trac units are properly secured to the inertial mass floor plates.

(8) Restraint towers are properly secured to the inertial mass.

e. Operate the Flat-trac units in Belt-speed mode (or Individual mode), varying speed and steer angles, in accordance with pages 281 through 287 of the Roadway Simulator Setup and Operation Manual. Ensure the corners are under control and no problematic leaks occur. Adjust the zero offsets of the Flat-trac unit steer actuators to ensure alignment with the *X* axis of the vehicle.

4.5.5 Vehicle Installation.

a. Ensure the test vehicle is configured at the test payload condition and configuration, including tire pressure, drivetrain settings, and suspension settings.

b. Following safe lifting procedures and instructions on pages 228 through 234 of the Roadway Simulator Setup and Operations Manual, lift the vehicle onto the RWS and secure the vehicle restraint fasteners. Ensure that the number of fasteners are sufficient for the test loads.

c. Install safety straps from the test vehicle to the inertial mass, leaving the minimal amount of slack to not inhibit test motions of the vehicle but still provide a means to constrain the vehicle in the event of restraint hardware failure.

d. Re-connect the autopilot cabling (if removed during vehicle installation) and verify connection to the autopilot control computer.

e. Ensure the RWS pitch and roll sensors are configured and functioning properly.

4.5.6 Vehicle Parameters File Configuration.

a. Follow the instructions for loading, modifying, and selecting the RWS Parameter file provided on page 217 of the Roadway Simulator Setup and Operation Manual. This step loads key vehicle and restraint data into the RWS controller software, including measurement data collected for Sections 4.3, 4.4, and 4.5 of this TOP. Select the appropriate parameter window for either two-axle or tandem rear-axle vehicles. An example two-axle vehicle window is shown in Figure 12.

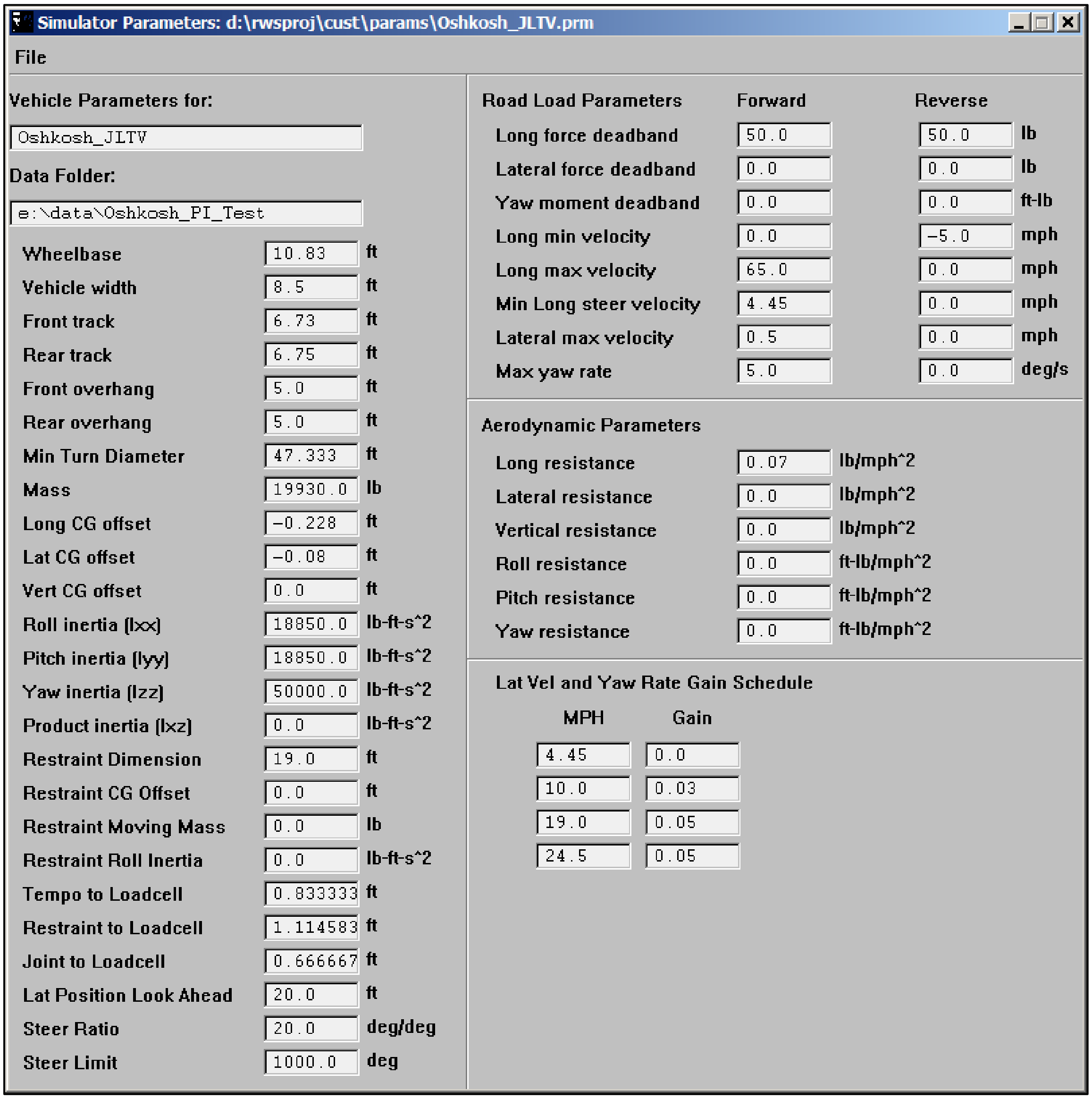


Figure 12. Simulator Parameters Window example.

b. Precise values for I_{xx}, I_{yy}, I_{zz}, and I_{xz} vehicle inertia parameter data are only critical for transient maneuver tests, as vehicle inertia is not a factor in steady-state tests. When these data are not critical, the vehicle inertia values can be approximated from previous measurements or the vehicle weight distribution.

c. If the longitudinal aerodynamic parameters coefficient is not known prior to testing, the coefficient will need to be updated following measurement of resistance-to-tow force, as described in Section 5. The remaining aerodynamic parameter values are generally not used.

d. The lateral velocity and yaw rate gain schedule was implemented to improve RWS control during low speed driving in Road Load mode, due to machine limitations for angle generation and the likelihood of small offsets in F_y and M_z measurements. The integral solutions for lateral velocity *v* and yaw velocity *r* are forced to zero until longitudinal velocity *u* exceeds a threshold of approximately 8 kilometers per hour (km/hr) (5 mph) (7.16 km/hr (4.45 mph) in the example shown). Generally, cornering tests are not performed below 8 km/hr (5 mph). The gains are gradually increased as vehicle speed is increased.

4.5.7 System Startup Procedures.

a. Prior to operating the RWS, warm up the hydraulic oil to at least 27 °Celsius (°C) (80 °Fahrenheit (°F)).

b. Prepare the RWS and autopilot for test operations by following the System Startup Procedures described on pages 207 through 212 of the Roadway Simulator Setup and Operation Manual. The Main ATC Roadway Simulator Window shown in Figure 13 will be visible to the operator.

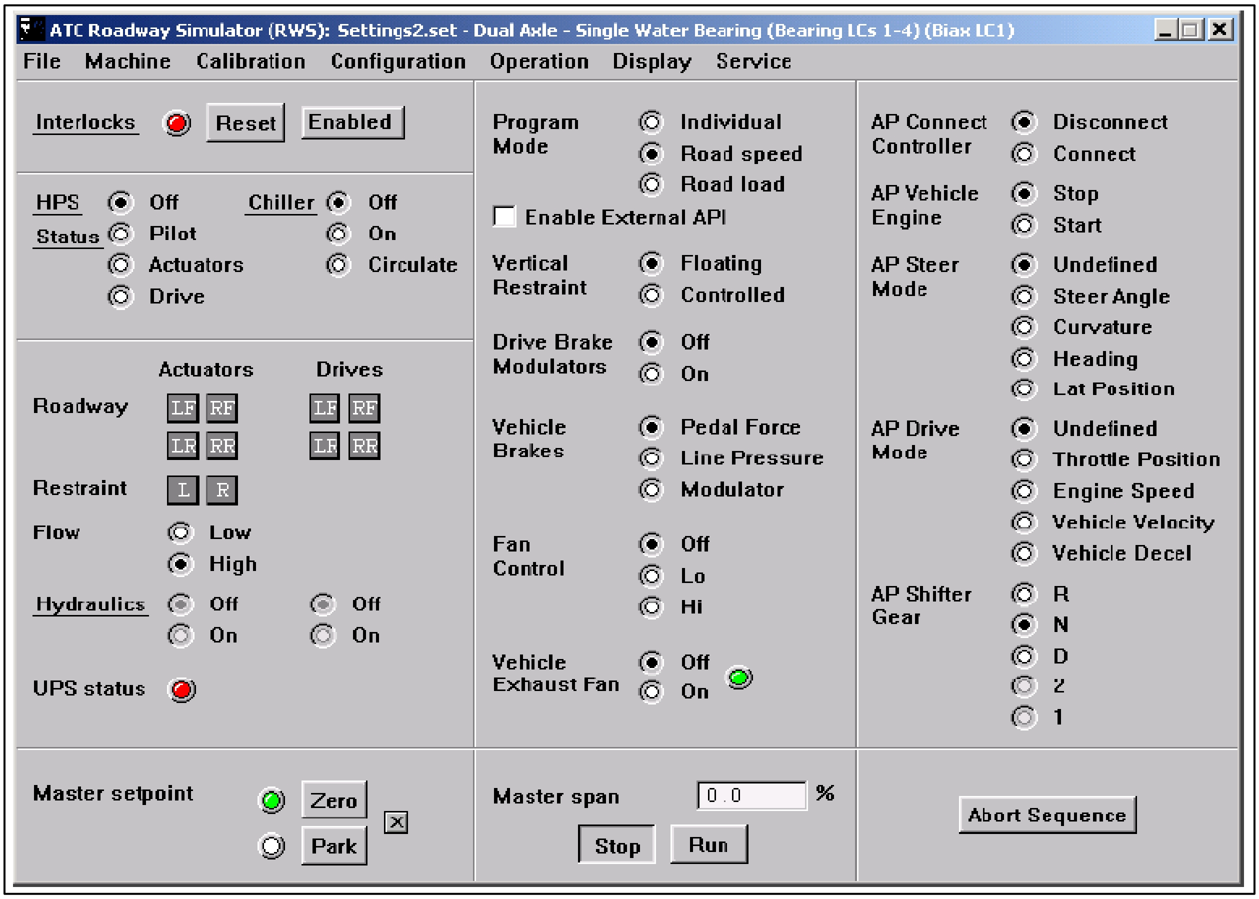


Figure 13. Main ATC Roadway Simulator Window.

c. Click on the HPS (Hydraulic Power Supply) label near the top left of the window to enable a sufficient number of hydraulic pumps for the test being conducted. The number of pilot pumps, actuator pumps, and drive pumps to use is based on experience of the test operators. At this point, the hydraulic pumps and autopilot are powered up and active. Do not enable actuator and drive pressure to the Flat-track units at this point (this is done later on the bottom left under the Actuators and Drives columns).

d. Enable the chiller system (on) and set it to circulate. This step turns on the water bearing supply, so that the water bearings are functional.

e. The following menu settings should also be selected:

(1) Flow: High.

(2) Vertical Restraint: Floating.

(3) Drive Brake Modulators: Off.

(4) Vehicle Brakes: Pedal Force.

(5) Fan Control: Off, Lo, or Hi (depending on test requirement- for vehicle cooling).

(6) Vehicle Exhaust Fan: On.

(7) AP Shifter Gear: N.

f. Start the vehicle engine, either using the “AP Vehicle Engine” button in the right column or manually.

g. Connect to the autopilot (AP) at the upper right column. Verify that the RWS controller connects to the autopilot without error.

h. Enable the actuator corner hydraulics for the RWS (Figure 13, bottom left under Actuators column) and select the “Zero” button under master setpoint (bottom left). The master zero will bring the RWS treadmills up to the operational height and zero out any command channels. The zero point is the midpoint of the vertical stroke for the RWS Flat-trac units.

i. In the ATC RWS Control Software Main Window, verify the Program Mode is set to Road Speed mode (Figure 13, center column top) and enable the drive hydraulics (Figure 13, bottom left under Drives column).

j. Verify that the selected autopilot Drive Mode (Figure 13, bottom right) is “Vehicle Velocity”. Set the “AP Velocity” to 10 mph and verify that the vehicle accelerates and then holds the targeted speed. Adjust the zero of the autopilot steering encoder to eliminate any lateral force acting on the vehicle from steered wheels. The intent is to drive the vehicle straight down the road by setting the neutral steer point for the vehicle and to settle the vehicle suspension.

k. While driving, zero the pitch and roll sensors by removing any voltage offsets observed on the DC conditioner window, page 130, of the Roadway Simulator Setup and Operation Manual.

l. Bring the vehicle to a stop by applying force to the brake pedal with the autopilot brake actuator.

m. Once the vehicle is stopped, place the vehicle in "Park" using the autopilot and place the RWS in "Park" (Figure 13, bottom left of the Main ATC Roadway Simulator Window) until testing is ready to commence.

4.6 Restrictions.

Humans are not permitted inside the vehicle or on any components of the RWS during test operations. The RWS is not man-rated due to the use of powerful electro-hydraulic actuators.

5. TEST PROCEDURES.

a. This TOP provides general test procedure guidance for any wheeled vehicle test conducted on the RWS, including those listed in Table 1. Refer to relevant TOPs, other industry test standards, or the test plan for specific guidance on executing a test. Many of the tests listed in Table 1 are automated in the RWS software, as described on pages 319 through 397 of the Roadway Simulator Setup and Operation Manual. Tests may also be executed manually depending on the skill and experience of the test operator.

b. Example test procedures are provided below for tests conducted using Road Speed control and Road Load control. The resistance-to-tow test procedure was selected as the example for Road Speed control because the test results are used with the field-based resistance-to-motion test (paragraph 4.7) to determine the longitudinal aerodynamic drag coefficient needed for Road Load control tests. The Road Load fuel consumption test procedure was selected for the Road Load control example.

5.1 Pre-test Vehicle Settings.

Prior to commencing a test, ensure the following:

a. Vehicle tires are in good serviceable condition, and the tire pressure is adjusted to the proper settings.

b. The vehicle suspension settings are correct for the test to be performed.

c. The vehicle drivetrain settings are correct for the test to be performed.

5.2 Roadway Simulator (RWS) Pre-test Operations.

Follow the system startup procedures described in paragraph 4.5.7 to warm the test vehicle up to normal operating temperatures and prepare for the tests described below.

5.3 Resistance-to-Tow Test Procedure (Road Speed Control Example).

a. Use SAE J2263 and TOP 02-2-605 as a guide for conducting the resistance-to-tow test. The goal is to characterize mechanical drag at various vehicle speeds as described in Section 11 of SAE J2263. Select a sufficient number of vehicle test speeds to effectively characterize mechanical drag up to the maximum test speed from the resistance-to-motion test described in paragraph 4.4.

b. Enable the actuator corner hydraulics for the RWS (Figure 13, bottom left under Actuators column) and select the “Zero” button under master setpoint (bottom left). The master zero will bring the RWS treadmills up to the operational height and zero out any command channels. The zero point is the midpoint of the vertical stroke for the RWS Flat-trac units.

c. Verify the Program Mode is set to Road Speed mode (Figure 13, center column top) and enable the drive hydraulics (Figure 13, bottom left under Drives column).

d. Verify that the transmission and differential oil sump temperatures are within ±3 °C (5 °F) of the coast down runs performed in paragraph 4.4. If the transmission and differentials are not at the desired operating temperature, drive the vehicle on the simulator until the temperatures are within the tolerance stated above. Oil temperature has a significant impact on vehicle motion resistance.

e. Under “AP Gear Shifter” label (Figure 13, bottom right), verify the vehicle transmission selection is set to “N” (neutral). If not, select “N” and the autopilot will shift the transmission to neutral.

f. Select the “Long velocity” channel on the function generator (see page 163 of the Roadway Simulator Setup and Operations Manual[1]).

g. At a minimum, set the RWS data recorder (see page 161 of the Roadway Simulator Setup and Operations Manual) to capture the data channels listed in Table 3. Also set the on-board vehicle data acquisition system to record the required vehicle data channels listed in Table 4. The data can be synchronized using vehicle speed if necessary.

TABLE 3. REQUIRED DATA FROM SIMULATOR
FOR RESISTANCE-TO-TOW TEST

Vehicle velocity (mph)
Long force feedback (fbk) (lbf)
Net long force fbk (lbf)

TABLE 4. REQUIRED DATA FROM VEHICLE FOR RESISTANCE-TO-TOW TEST

Vehicle speed (J1939)
Transmission gear (J1939)
Torque converter lock state (J1939)
Front differential sump temperature (analog)
Transmission sump temperature (analog)
Rear transaxle sump temperature (analog)

h. Using the function generator, tow the vehicle to the initial test velocity. Hold the velocity for 30 seconds and then enter the next test speed in the function generator. Repeat the process in regular intervals until the maximum vehicle test speed is reached. Set the last speed point at or above the maximum vehicle speed achieved in the coast down test.

i. Once testing is complete at the last speed test point, slowly adjust the vehicle speed settings in the function generator to decelerate the vehicle and bring the vehicle to a standstill. Park the vehicle and Flat-Trac units and shut down the RWS in accordance with the RWS Setup and Operation Manual.

j. Use the test data to determine the resistance-to-tow characteristics of the test vehicle (force versus road speed), per SAE J2263.

5.4 Determination of the Longitudinal Aerodynamic Drag Coefficient.

a. Use the definitions of Mechanical drag, Aerodynamic drag, and Grade correction provided in SAE J1163 for the following calculations.

b. Use Equation 1 in SAE J2263 along with the resistance-to-motion and resistance-to-tow data to estimate the aerodynamic drag force versus relative wind speed. The yaw coefficients can generally be ignored if testing is conducted in accordance with TOP 02-2-605. Fit a second order curve to the resulting drag force data of the form $D_{aero} = C \times V_r^2$ (units lb/mph^2), where V_r is the road speed.

c. Insert the coefficient C into the *Aerodynamic Parameters*, *Long Resistance* item of the RWS Simulator Parameters window (Figure 11). The coefficient is multiplied by the square of vehicle speed to determine the aerodynamic drag force versus speed when in Road Load control.

5.5 Road Load Fuel Consumption Test Procedure (Road Load Control Example).

a. TOP 02-2-603A is used as a guide for the RWS testing steps described below. Paragraph 4.1 in TOP 02-2-603A discusses use of the RWS.

b. Prior to testing, prepare the vehicle with test instrumentation to measure and record the data channels listed in Table 5. Prepare the RWS data recorder to record the data channels listed in Table 6. The vehicle speed channel will be used to synchronize the vehicle data file with the simulator data file. Record data at 100 Hz, minimum.

TABLE 5. DATA REQUIRED FROM VEHICLE
FOR FUEL CONSUMPTION TEST

Front differential sump temperature (analog)
Transmission sump temperature (analog)
Rear transaxle sump temperature (analog)
Vehicle speed (J1939)
Engine coolant temperature (J1939)
Engine speed (J1939)
Transmission gear (J1939)
Torque converter lock state (J1939)
Accelerator pedal position (J1939)
Brake switch (J1939)
Brake pedal effort (analog)
Voltage at alternator (analog)
Alternator current (analog)
Fuel flow (analog)
Fuel temperature (analog)

TABLE 6. DATA REQUIRED FROM RWS
FOR FUEL CONSUMPTION TEST

Vehicle velocity (mph)
Long force fbk (lbf)
Net long force fbk (lbf)

c. Enable the actuator corner hydraulics for the RWS (Figure 13, bottom left under Actuators column) and select the “Zero” button under master setpoint (bottom left). The master zero will bring the RWS treadmills up to the operational height and zero out any command channels. The zero point is the midpoint of the vertical stroke for the RWS Flat-trac units.

d. Verify the Program Mode is set to Road Load mode (Figure 13, center column top) and enable the drive hydraulics (Figure 13, bottom left under Drives column).

e. Under “AP Gear Shifter” (Figure 13, bottom right), set the vehicle transmission to “Drive”.

f. Verify that the selected autopilot Drive Mode (Figure 13, bottom right) is “Vehicle Velocity”. Set the “AP Velocity” to 10 mph and verify that the vehicle accelerates and then holds the targeted speed. Ensure the vehicle is up to the standard operating temperature before starting fuel consumption testing. Follow the precondition procedure specified in SAE J2263, Section 8.2, if necessary. The procedure recommends driving the vehicle at 80 km/hr (50 mph) for 30 minutes to warm up the drivetrain and tires.

g. After the preconditioning, set the “AP Velocity” to the initial target vehicle speed (in mph) for the test and verify that the vehicle accelerates to and then holds the targeted speed.

h. Once a steady-state vehicle speed is achieved, start the data recorders. Stay at the targeted speed for at least 30 seconds.

i. Set the “AP Velocity” to the next desired test speed, and once achieved hold for at least 30 seconds.

j. Repeat this procedure until all of the desired vehicle speeds have been sampled at least three times.

k. Once the testing is complete, stop the data recorders, apply the vehicle brakes using the autopilot to bring the vehicle to a full stop, and set the Master Control Point to park (Figure 12, bottom left).

6. <u>DATA REQUIRED</u>.

The data required for a specific test performed on the RWS is determined by the applicable TOP, industry test standard, or the test plan, as appropriate. General guidance for basic vehicle and test characterization data, data available from the RWS, and on-board vehicle data are described below.

a. General Vehicle and Test Characterization.

(1) Vehicle identification: manufacturer, type, registration number, serial number.

(2) Odometer mileage.

(3) Vehicle payload distribution (amount of payload and location).

(4) Wheelbase and track.

(5) Vehicle weight distribution.

(6) Vehicle CG location (longitudinal, lateral, and vertical).

(7) Mass moment of inertia properties (I_{zz} and I_{xz}).

(8) Tire selection, tire pressures, central tire inflation system setting, tire condition, and tread depth.

(9) Suspension configuration (highway, off-road, etc.) and suspension or vehicle trim heights.

(10) Drivetrain configuration (2x4, 4x4, driveline locks, etc.).

(11) Vehicle wheel alignment data (if available).

(12) Suspension and steering system condition.

(13) Ambient weather conditions (temperature and humidity).

(14) Test instrumentation description.

b. RWS Data Available. There are 174 data channels available for recording from the RWS, as listed on pages 313 through 317 of the Roadway Simulator Setup and Operation Manual. The data channels may be viewed in the RWS Data Recorder Window (see page 161 of the Roadway Simulator Setup and Operations Manual). The test operator should determine which data channels to record and the appropriate sample rate for the test to be conducted. The list includes the vehicle motion parameters (see page 47 of the manual), the restraint force and displacement parameters (see page 48 of the manual), the autopilot steer angle, steer torque, throttle position, and brake position, and the Flat-trac steer angle, velocity, and height parameters.

c. On-board Vehicle Data. On-board vehicle data generally consists of parameters not included with the RWS system, and may include engine cooling system temperatures, drive shaft torque, engine speed, fuel consumed, fuel temperature, and the J1939 data bus. On-board vehicle data may be recorded separately from the RWS system, but should be synchronized with the RWS data. Review the relevant TOPs, industry standards, or the test plan for on-board vehicle data guidance.

7. PRESENTATION OF DATA.

Data for specific tests conducted on the RWS should be presented in accordance with guidance in the relevant TOPs, industry standards, or test plan. Presentation generally consists of tabular and graphical summaries.

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APPENDIX A. ACRONYMS AND ABBREVIATIONS.

AP	autopilot
ATC	U.S. Army Aberdeen Test Center
ATEC	U.S. Army Test and Evaluation Command
AVTP	Allied Vehicle Testing Publication
°C	degrees Celsius
CG	center of gravity
DC	direct current
DTIC	Defense Technical Information Center
°F	degrees Fahrenheit
fbk	feedback
g	gravitational acceleration
GVW	gross vehicle weight
HMMWV	High Mobility Multi-Purpose Wheeled Vehicle
HPS	Hydraulic Power Supply
HPU	Hydraulic Power Unit
Hz	Hertz
in.	inch
in./sec	inches per second
ISO	International Organization for Standardization
kg	kilogram
km/hr	kilometers per hour
lb	pound
lbf	pound force
m	meter
mph	miles per hour
N	neutral
PID	proportional, integral, differential
RWS	Roadway Simulator
SAE	SAE International
TOP	Test Operations Procedure

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APPENDIX B. REFERENCES.

1. Roadway Simulator Setup and Operation, Document No. 100-116-570 A, MTS System Corporation, August 2003.

2. TOP 02-2-002A, Steering and Cornering Behavior, 25 September 2019.

3. SAE International Surface Vehicle Recommended Practice J266, Steady-State Directional Control Test Procedures for Passenger Cars and Light Trucks, January 1996.

4. SAE International Surface Vehicle Recommended Practice J2181, Steady-State Circular Test Procedure for Trucks and Buses, September 2011.

5. ISO 4138, Passenger cars- Steady-state circular driving behavior- Open-loop test methods, June 2012.

6. ISO 14792, Road vehicles- Heavy commercial vehicles and buses - Steady-state circular tests, March 2011.

7. TOP 02-2-600, Steering Performance Tactical Vehicles, 29 July, 2015.

8. ISO 13674-1, Road vehicles- Test method for the quantification of on-centre handling- Part 1 Weave test, May 2010.

9. ISO 13674-2, ISO 13674-2, Road vehicles- Test method for the quantification of on-centre handling-Part 2 Transition test, April 2016.

10. ISO 11012, Heavy commercial vehicles and buses- Open-loop test methods for the quantification of on-centre handling- Weave and transition test, September 2009.

11. ISO 7401, Road vehicles- Lateral transient response test methods-Open-loop test methods, April 2011.

12. TOP 02-2-718A, Electronic Stability Control, 1 October, 2018.

13. AVTP 03-30, Steering and Maneuverability, September 1991.

14. AVTP 03-160W, Dynamic Stability, September 1991.

15. TOP 02-2-608, Braking, Wheeled Vehicles, 20 May 2008.

16. SAE International Surface Vehicle Recommended Practice J2263, Road Load Measurement Using Onboard Anemometry and Coastdown Techniques, December 2008.

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17. SAE International Surface Vehicle Recommended Practice J1263, Road Load Measurement and Dynamometer Simulation Using Coastdown Techniques, March 2010.

18. ISO 10521-1, Road Vehicles- Road Load- Part1: Determination Under Reference Atmospheric Conditions, 01 October 2006.

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24. TOP 02-2-603A, Vehicle Fuel Consumption, 10 May 2012.

25. TOP 02-2-607, Cooling Systems (Automotive), 27 September 2006.

26. SAE International Recommended Practice J670, Vehicle Dynamics Terminology, January 2008.

27. SAE International Recommended Practice J670, Vehicle Dynamics Terminology, July 1976.

28. TOP 02-2-801, Weight Distribution and Ground Pressure, 26 September 2006.

29. TOP 02-2-800, Center of Gravity, 26 September 2006.

30. ISO 19385, Heavy commercial vehicles and buses- Centre of gravity measurements- Axle lift, tilt-table and stable pendulum test methods, August 2019.

31. ISO 10392, Road vehicles- Determination of centre of gravity, 15 March 2011.

32. TOP 01-2-520, Moments of Inertia, 3 August 2017.

APPENDIX C. APPROVAL AUTHORITY.

CSTE-CI 25 August 2020

MEMORANDUM FOR

Commander, U.S. Army Operational Test Command
Director, U.S. Army Evaluation Center
Commanders, ATEC Test Centers
Technical Directors, ATEC Test Centers

SUBJECT: Test Operations Procedure 02-2-514, Roadway Simulator, Approved for Publication

1. Test Operations Procedure (TOP) 02-2-514, Roadway Simulator, has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency.

2. Scope of the document. This TOP describes the use of the Roadway Simulator when conducting standardized automotive performance tests of two- and three-axle wheeled vehicles. Objective tests are performed on the Roadway Simulator in accordance with industry standards, other U.S. Army Test and Evaluation Command TOPs, or unique tests described in test plans. In all cases, the vehicle is controlled by an autopilot and the Roadway Simulator is operated in the Road Load or Road Speed mode.

3. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at https://vdls.atc.army.mil/.

4. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-CI), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to usarmy.apg.atec.mbx.atec-standards@mail.mil.

ZWIEBEL.MICHA
EL.J.1229197289

MICHAEL J. ZWIEBEL
Director, Directorate for Capabilities
Integration (DCI)

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-TM), U.S. Army Test and Evaluation Command, 6617 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Instrumentation Division (TEAT-ADI), U.S. Army Aberdeen Test Center, 6943 Colleran Road, Aberdeen Proving Ground, MD 21005-5059. Additional copies can be requested through the following website: https://www.atec.army.mil/publications/documents.html, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.