

9/14/06

**MEMORANDUM REPORT VRTC-DCD-6097
PE06-010**

Investigation of Tire Pressure Monitoring System in 2004 -2005 Toyota Sienna Vehicles

1.0 Introduction

This program was performed at the Vehicle Research and Test Center (VRTC) at the request of the Office of Defects Investigation (ODI) of the National Highway Traffic Safety Administration. ODI opened a Preliminary Evaluation (PE06-010) on 2004 - 2005 Toyota Sienna vehicles equipped with all-wheel-drive (AWD). Original equipment on subject vehicles included run flat tires but no spare tire or jack. Consumer complaints to ODI have indicated that the Tire Pressure Warning System (TPWS) warning light did not illuminate when the tire pressure was low or the tire was deflated.

2.0 Background

The TPWS on this vehicle monitors the four Antilock Brake System (ABS) speed sensors. As a tire deflates and deforms, the resulting decreased effective tire diameter will result in an increased wheel speed compared to the other non-deflated tires. The TPWS is designed to detect this difference in wheel speed, interpret it as a low-pressure tire, and trigger the TPWS warning light.

3.0 Objective

The objective of this testing was to assess the performance of the TPWS on the subject vehicle using both run flat and standard tires.

4.0 Test Preparation

A 2005 Toyota Sienna (VIN: 5TDBA23CX[REDACTED]) was procured and prepared as follows:

- Instrumentation was installed that allowed the measurement and recording of individual tire pressures and wheel speeds. Individual wheel speeds were determined by monitoring the ABS wheel speed sensor output signals. Individual tire pressures were monitored through the use of a rotary union mounted on each wheel and plastic tubing that ran from each rotary valve to individual calibrated pressure transducers. A detailed description and diagram of the

rotary union is provided in Appendix 1. The instrumentation was also able to monitor brake-light activation and a manual switch that was operated by the driver when the TPWS warning lamp illuminated.

- A manifold, valves, and an air tank were installed that allowed adjustment of individual tire pressures, both up and down, while the vehicle was in motion. A variable orifice was installed in each air line that allowed the air pressure in each tire to be bled off at the desired rate. By proper manipulation of the valves, the tire pressure of the three non-test tires could be equalized to maintain the same tire pressure between them. A photo of the manifold, valves, and pressure transducers is provided in Appendix 2.
- Late in the program, an infrared remote temperature detection device was added, the output of which was also recorded. At the same time, a video camera, video recorder, remote video monitor and an aftermarket direct-measurement Tire Pressure Warning System (TPWS) were installed to visually monitor the condition and internal and external temperature of the right rear tire. The aftermarket TPWS and video system were monitored by the driver and results were annotated manually on the test logs.

5.0 Photographic Documentation of Tires at Different Inflation Pressures

With the vehicle at Lightly Loaded Vehicle Weight¹ (LLVW) and Gross Vehicle Weight (GVW), the visual appearance of both run flat and standard tires was photographically documented at 35 and 15 psi. These inflation pressures were chosen because the Sienna owner's manual lists 35 psi as the maximum recommended pressure of the standard equipment run flat tires and 15 psi as the minimum pressure before permanent tire degradation begins to occur.

6.0 Test Procedures

Unless otherwise noted in the Results section of this report, each condition listed below was tested at slow speed (20-40 mph) on the Transportation Research Center of Ohio's (TRC) Winding Road Course (WRC) and at high speed (55 – 60 mph) on TRC's 7½ Mile (High Speed) Test Track (HSTT). Descriptions of these test courses are provided in Appendix 3. Testing was performed at both LLVW and at GVW using both standard and run flat tires. All four wheel

¹ LLVW = Empty vehicle + driver + instrumentation [Curb weight + 500 lb

positions were tested individually at each loading/tire configuration. Three tests were performed on each tire for each condition unless otherwise noted. Detailed test procedures are provided in Appendix 4.

6.1 Determine Tire Pressure Required to Illuminate the TPWS Warning Light

Starting with all tires set at 35 psi, one tire was deflated per test at a rate of 2 psi/min while operating the vehicle. The vehicle was operated at low speed on the WRC and at high speed on the HSTT. The test was terminated when the TPWS warning light illuminated or at 15 psi for run flat tires and 10 psi for standard tires.

6.2 Determine Time and Distance Required for the TPWS Warning Light to Illuminate

With the tire pressure of the test tire adjusted to the “reduced pressure” setting, (15 psi for run flat tires, 10 psi for standard tires) the vehicle was operated at low speed on the WRC and at high speed on the HSTT. Initial tests were terminated when the TPWS warning light illuminated or after twenty (20) minutes on either course. Later tests were terminated when the TPWS warning light illuminated or after thirty-five (35) minutes on either course.

6.3 Determine Speed Range at Which the TPWS Will Function Properly

These tests were performed in an attempt to verify the range of speeds (19 – 61 mph) listed in the subject vehicle’s owner’s manual.

6.3.1 Determine Low Speed Operating Threshold

At the WRC, all tires were adjusted to the recommended operating pressure of 35 psi. The test tire was then adjusted to the “reduced pressure” setting. The vehicle was operated at 17 mph. The test was terminated if the TPWS warning was observed. If the TPWS warning was not observed within 20 minutes, the test was repeated with a speed increase of one mph. The 1-mph speed increases were repeated until the TPWS warning light illuminated or until the test speed reached 21 mph.

6.3.2 Determine High Speed Operating Threshold

At the HSTT, all tires were adjusted to the recommended operating pressure of 35 psi. The test tire was then adjusted to the “reduced pressure” setting. The vehicle was operated at 63 mph.

The test was terminated if the TPWS warning was observed. If the TPWS warning was not observed within 20 minutes, the test was repeated with a speed reduction of one mph. The 1-mph speed reductions were repeated until the TPWS warning light illuminated or until the test speed reached 58 mph.

6.4 Determine Braking Distance with One Tire at 15 PSI

With the inflation pressure in all tires adjusted to the recommended operating pressure, high-effort (100 lb pedal force) brake stops were performed from 60 mph. Testing was repeated with each tire, in turn, adjusted to the reduced pressure of 10 psi for standard tires and 15 psi for run flat tires.

6.5 Determine Run Flat Endurance

Only two tests were performed, both on run flat tires. With the vehicle at GVW and the right rear tire adjusted to the test pressure, the vehicle was operated at 55 mph. The test was to be terminated after driving 125 miles following observation of the TPWS warning, or after one hour if the TPWS warning did not illuminate, or when a tire failure occurred. Tire temperature was monitored throughout the test. The test tire pressure was adjusted to 10 psi for the first test and to zero (0) psi for the second test.

7.0 Test Results

7.1 Photographic Documentation of Tires at Different Inflation Pressures

Comparison of the visual appearance of the run flat tires at 35 and 15 psi showed very little discernable difference between the two pressure settings, either at LLVW or at GVW. Figures 1 and 2 show the appearance of the right front tire at both pressures at LLVW. Figures 3 and 4 show the appearance of the right front tire at both pressures at GVW.

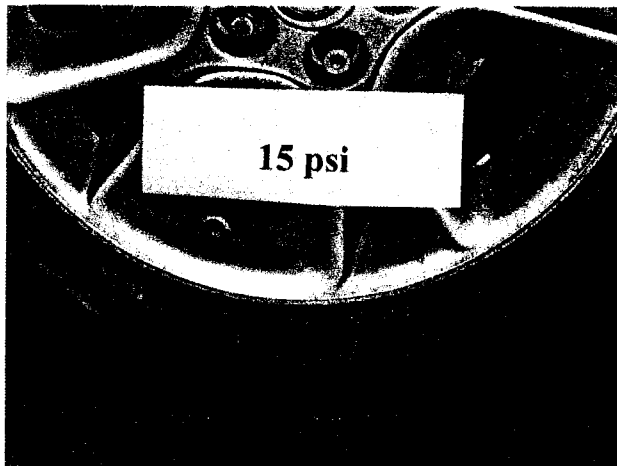


Figure 1
Run Flat Tire at 15 psi (LLVW)

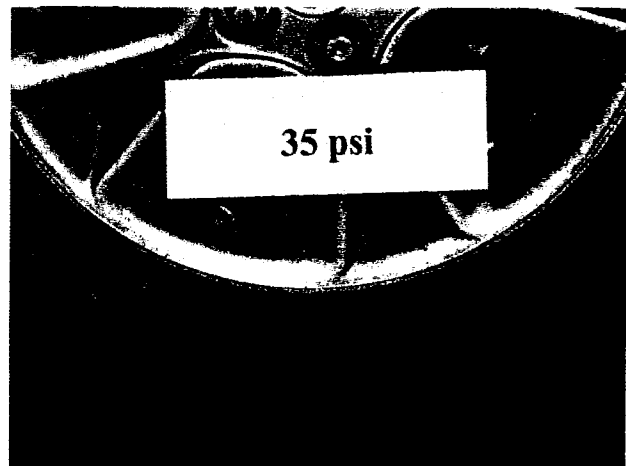


Figure 2
Run Flat Tire at 35 psi (LLVW)

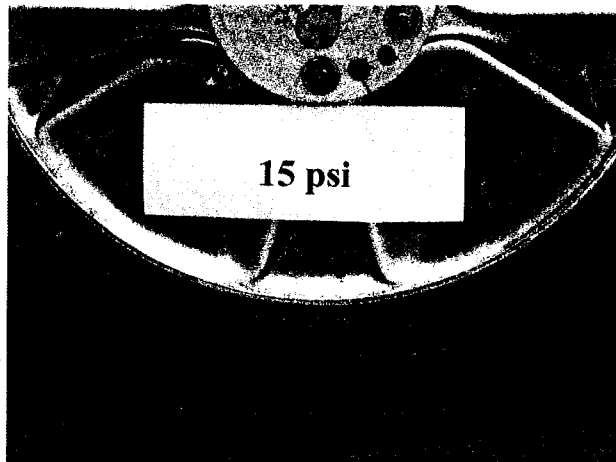


Figure 3
Run Flat Tire at 15 psi (GVW)

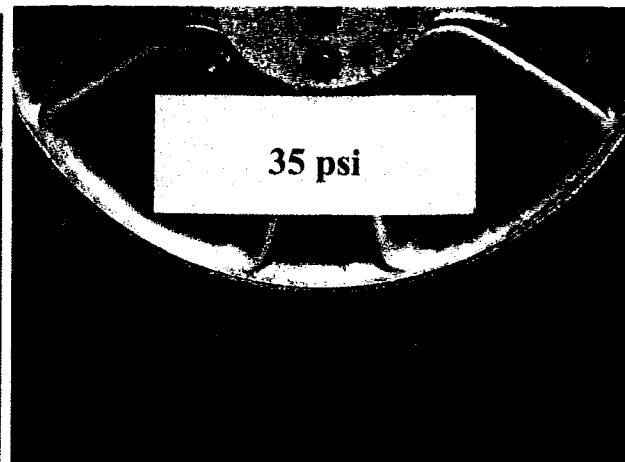


Figure 4
Run Flat Tire at 35 psi (GVW)

Comparison of the visual appearance of the standard tires at 35 and 15 psi showed a marked difference between the two pressure settings, at both LLVW and at GVW. Figures 5 and 6 show the appearance of the right rear tire under both conditions at LLVW. Figures 7 and 8 show the appearance of the right rear tire under both conditions at GVW.

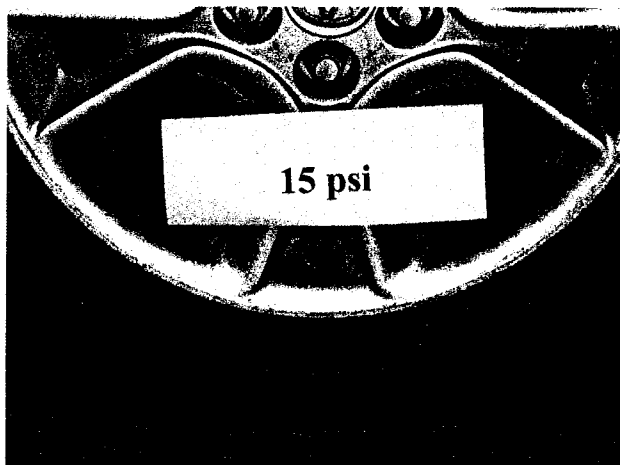


Figure 5
Standard Tire at 15 psi (LLVW)

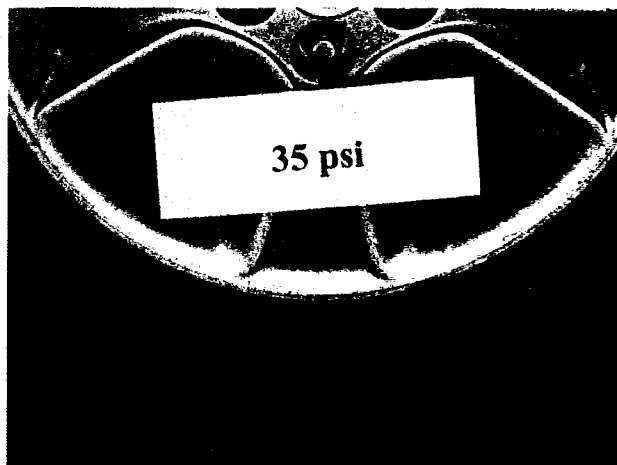


Figure 6
Standard Tire at 35 psi (LLVW)

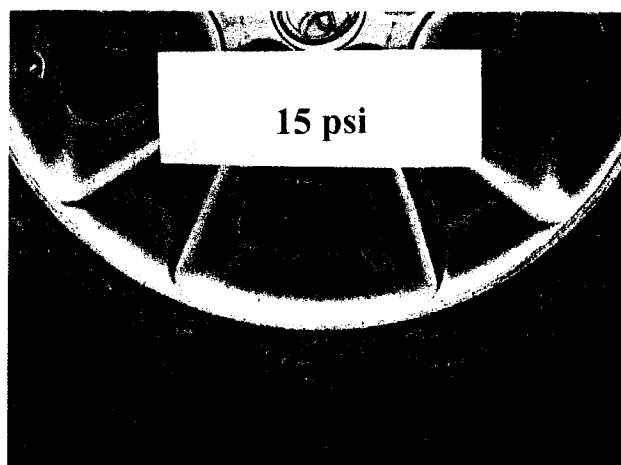


Figure 7
Standard Tire at 15 psi (GVW)

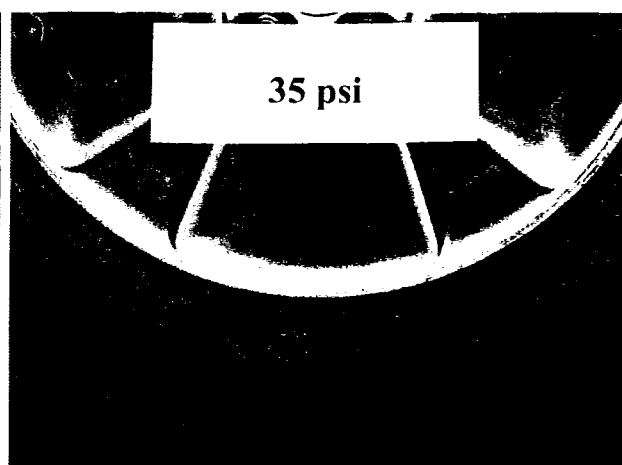


Figure 8
Standard Tire at 35 psi (GVW)

7.2 Tire Pressure Required to Illuminate the TPWS Warning Light

Tabulated averaged test results for this series of tests are presented in Table 1.

Test Tire	TPWS Warning Pressure (psi)							
	Standard Tires				Run Flat Tires			
	LLVW		GVW		LLVW		GVW	
	WRC	HSTT	WRC	HSTT	WRC	HSTT	WRC	HSTT
LF	14	12**	18	15*	***	16*	***	***
RF	16	15*	18	***	***	17*	***	***
LR	11	13**	17*	21*	***	15*	***	20*
RR	12	12	16	15*	***	26*	***	***
* = Only one of three tests activated the TPWS								
** = Only two of three tests activated the TPWS								
*** = No activation of TPWS in three tests.								

Table 1
Averaged Results of Leak-Down Tests on Standard Tires

7.2.1 Standard Tires, LLVW

The TPWS activated during all three tests of all four tires on the WRC. When averaged for each position, the range of tire pressures at which the TPWS activated was 11 to 16 psi. On the HSTT, the TPWS activated during only one of the three tests of the right front tire, during only two of the three tests on both left side tires, and during all three tests of the right rear tire. For the tests where the TPWS warning activated, when averaged for each position, the range of tire pressures at which the system activated was 12 to 15 psi.

7.2.2 Standard Tires, GVW

On the WRC, the TPWS activated during all three tests of both front tires as well as during the test of the right rear tire. The system activated during only one of the three tests of the left rear tire. When averaged for each position, the range of tire pressures at which the TPWS activated was 16 to 18 psi. On the HSTT, the TPWS activated during only one of the three tests of the left front tire and both rear tires. The TPWS did not activate during any of the three tests of the right front tire. When averaged for each position, the range of tire pressures at which the system activated was 15 to 21 psi.

7.2.3 Run Flat Tires, LLVW

On the WRC, the TPWS did not activate during any of the tests. On the HSTT, the TPWS activated during only one of three tests of each tire. For the tests that the TPWS activated, the range of tire pressures was 15 to 26 psi.

7.2.4 Run Flat Tires, GVW

On the WRC, the TPWS did not activate during any of the tests. On the HSTT, the TPWS activated during only one of the three tests of the left rear tire. This single warning event occurred at 20 psi. The system did not activate during any of the other tests in this configuration.

7.3 Time and Distance Required for the TPWS Warning Light to Illuminate

7.3.1 Test Results of Standard Tires

Tabulated test results of tests using standard tires are presented in Table 2.

Test Tire	Standard Tires							
	Time for TPWS Warning (min)				Distance for TPWS Warning (mi)			
	LLVW		GVW		LLVW		GVW	
	WRC	HSTT	WRC	HSTT	WRC	HSTT	WRC	HSTT
LF	9.5	11.7**	3.8	***	5.1	12.0**	1.9	***
RF	6.6	13.2**	3.9	10.0*	3.5	11.0**	1.9	9.1*
LR	7.3	12.7*	2.9	9.7*	3.8	11.7*	1.4	9.1*
RR	5.6	13.3**	3.0	***	2.9	12.3**	1.5	***
* = Only one of three tests activated the TPWS								
** = Only two of three tests activated the TPWS								
*** = No activation of TPWS in three tests.								

Table 2
Results of Time and Distance Testing Using Standard Tires

7.3.1.1 Standard Tires, LLVW

On the WRC, the TPWS activated during all three tests of all four tires. When averaged for each position, the activations occurred between 5.6 and 9.5 minutes and 2.9 and 5.1 miles. On the HSTT, the TPWS activated during only one of three tests of the left rear tire, and during only two of the three tests on the remaining three tires. For the tests where the TPWS activated, when averaged for each position, the activations occurred between 11.7 and 13.3 minutes and 11.0 and 12.3 miles.

7.3.1.2 Standard Tires, GVW

On the WRC, the TPWS activated during all three tests of all four tires. When averaged for each position, the warnings occurred between 2.9 and 3.9 minutes and 1.4 and 1.9 miles. On the HSTT, the TPWS activated during only one of three tests of the right front and left rear tires. The system did not activate at all during tests of the left front and right rear tires. For the tests where the TPWS activated, both warnings occurred at 9.1 miles and required 9.7 and 10.0 minutes.

7.3.2 Test Results of Run Flat Tires

Tabulated results of tests using run flat tires are presented in Table 3.

Test Tire	Run Flat Tires							
	Time for TPWS Warning (min)				Distance for TPWS Warning (mi)			
	LLVW		GVW		LLVW		GVW	
	WRC	HSTT	WRC	HSTT	WRC	HSTT	WRC	HSTT
LF	N/T	*	N/T	**	N/T	*	N/T	**
RF	N/T	*	N/T	**	N/T	*	N/T	**
LR	N/T	*	N/T	**	N/T	*	N/T	**
RR	N/T	*	N/T	**	N/T	*	N/T	**
* = No activation of TPWS in three tests.								
** = No activation of TPWS in one test.								
N/T = Not Tested								

Table 3
Results of Time and Distance Testing Using Run Flat Tires

7.3.2.1 Run Flat Tires, LLVW

Because the TPWS failed to activate on the WRC during any of the 24 Leak-Down tests performed at LLVW, Time and Distance testing was not performed on the WRC. Because the LLVW Leak-Down testing resulted in one TPWS activation on each tire on the HSTT, a full series of twelve Time and Distance tests was performed on the HSTT. The TPWS did not activate during any of these twelve tests.

7.3.2.2 Run Flat Tires, GVW

Because the TPWS failed to activate on the WRC during any of the 24 Leak-Down tests performed at GVW, Time and Distance testing was not performed on the WRC. Because the GVW Leak-Down testing resulted in one TPWS warning activation of one tire on the HSTT, a

limited Time and Distance test series of one test per tire was performed on each tire on the HSTT. The TPWS did not activate during any of these four tests.

7.4 Speed Threshold Testing

Tabulated test results are presented in Table 4.

Test Tire	TPWS Speed Thresholds (mph)			
	LLVW		GVW	
	WRC	HSTT	WRC	HSTT
LF	**	**	N/T	N/T
RF	23*	**	N/T	N/T
LR	20*	63*	N/T	N/T
RR	21*	**	N/T	N/T
* = Only one of three tests activated the TPWS				
** = No activation of TPWS in three tests.				
N/T = Not Tested				

Table 4
Results of Speed Threshold Testing Using Standard Tires

Fifty tests were performed using standard tires in an attempt to determine the speed threshold of the TPWS at LLVW. On the WRC, the TPWS activated during only one of three series of the right front and both rear wheels. There was never any warning from the left front wheel. When warnings occurred, the warning range on the WRC was between 21 and 23 mph. On the HSTT, only one of three tests produced a warning on only the left rear tire. This occurred at 63 mph. The remaining three wheels failed to activate the TPWS during any of these tests. Due to the lack of repeatable results and results that were outside of the speed range specified by Toyota, speed threshold testing was not performed on run flat tires or on standard tires with the vehicle loaded to GVW.

7.5 Brake Testing

Tabulated test results are presented in Table 5.

Test Position	Stopping Dist. (ft)			
	Run Flat Tires		Standard Tires	
	LLVW	GVW	LLVW	GVW
LF	153	188	161	179
RF	159	190	165	185
LR	153	171	162	173
RR	152	180	164	179
all @ 35 psi	153	183	165	187

Table 5 - Braking Distances

With standard tires, stopping distances were the same as or shorter with one tire at reduced inflation pressure than stopping distances with all four tires fully inflated, regardless of vehicle loading. With run flat tires, stopping distances were slightly shorter with either rear tire at reduced inflation pressure and slightly longer with either front tire reduced when tested at GVW. When tested at LLVW, stopping distances were approximately equal, both with fully inflated tires and with any one tire at reduced inflation pressure.

7.6 Run Flat Endurance Testing

Results of the endurance testing are documented below. Tests were performed using the Original Equipment tires provided from the factory. The odometer reading was approximately 5,300 miles and the tires had approximately 7/32 inch of tread.

7.6.1 Right Rear Tire at 10 PSI

The test was aborted after one hour because the TPWS warning light did not illuminate. At the conclusion of the test, the external rubber temperature of the test tire was 170 deg. F. The external rubber temperatures of the three non-test tires were between 105 and 110 deg. F.

7.6.2 Right Rear Tire at 0 PSI

This test was performed using a different tire from the tire used in the test described in Section 7.6.1 above. At approximately 20 minutes into the test, the internal tire temperature was 239 deg. F. At approximately 40 minutes into the test, the internal tire temperature was at least 248 deg. F. (it is suspected that this was the limit of the measuring device) At this point, the tire had developed a severe vibration and the driver stated he could smell something but did not observe any smoke. The test was terminated at that point. Total distance traveled was 36.6 miles. The total time of the test was 42 minutes. The TPWS warning light never illuminated.

Upon return to the lab, the appearance of the tire, as shown in figures 9 through 15 was that of a deflated standard tire. The external tire temperature was 229 deg. F. The tire appeared to be somewhat debaded.

Approximately 15 minutes after the test vehicle was returned to the lab, the tire was reinflated to 35 psi. It held pressure for approximately 1½ minutes, at which point it experienced catastrophic sidewall failure (blow-out) as shown in Figure 16.

After dismounting the tire from the wheel, examination of the interior of the tire showed a large quantity of small pieces of brittle rubber. Some of these are shown in Figure 17.



Figure 9
Tire at End of 0-PSI Endurance Test
Front View

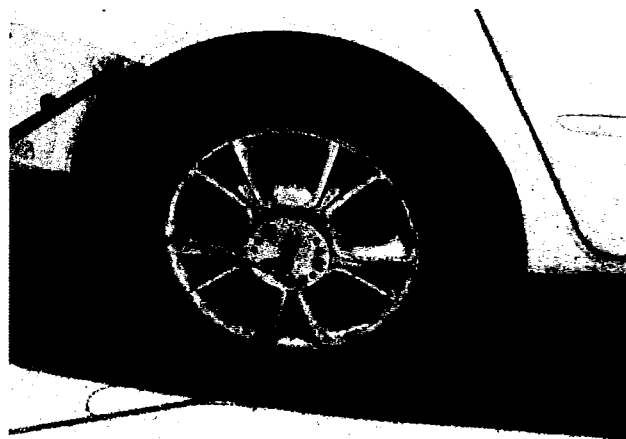


Figure 10
Tire at End of 0-PSI Endurance Test
Side View

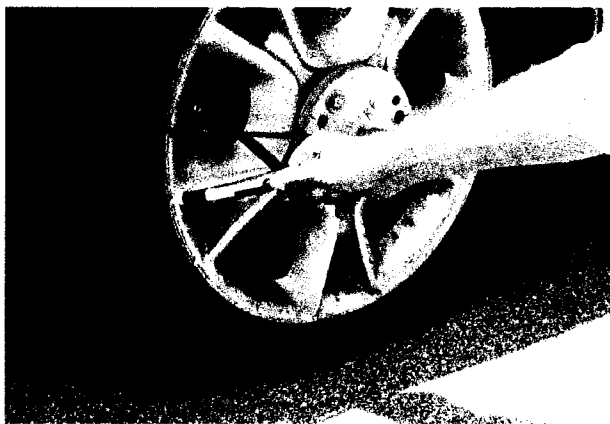


Figure 11
Tire at End of 0-PSI Endurance Test
Rear View



Figure 12
Possible Debanding at Conclusion
of 0-PSI Endurance Test



Figure 13
Internal Tire Temperature Readout
at Conclusion of 0-PSI Endurance Test

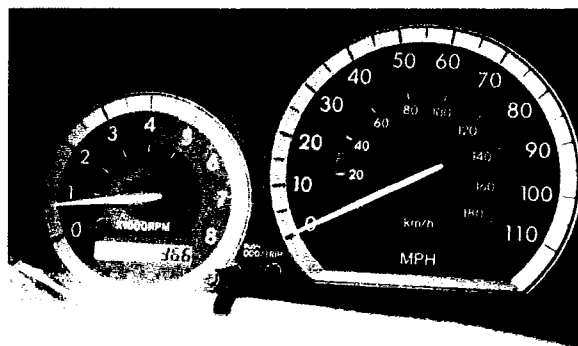


Figure 14
Trip Odometer Reading
at Conclusion of 0-PSI Endurance Test

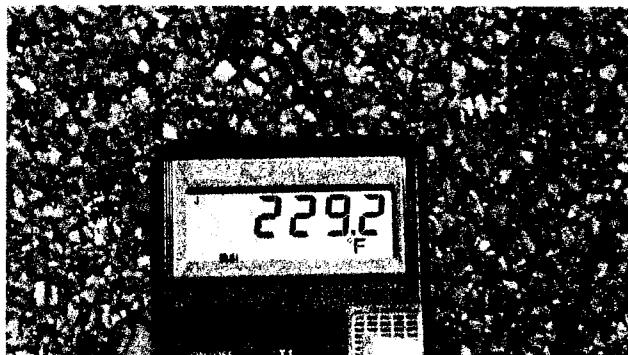


Figure 15
External Tire Temperature at Conclusion
of 0-PSI Endurance Test



Figure 16
Sidewall Failure at Conclusion
of 0-PSI Endurance Test

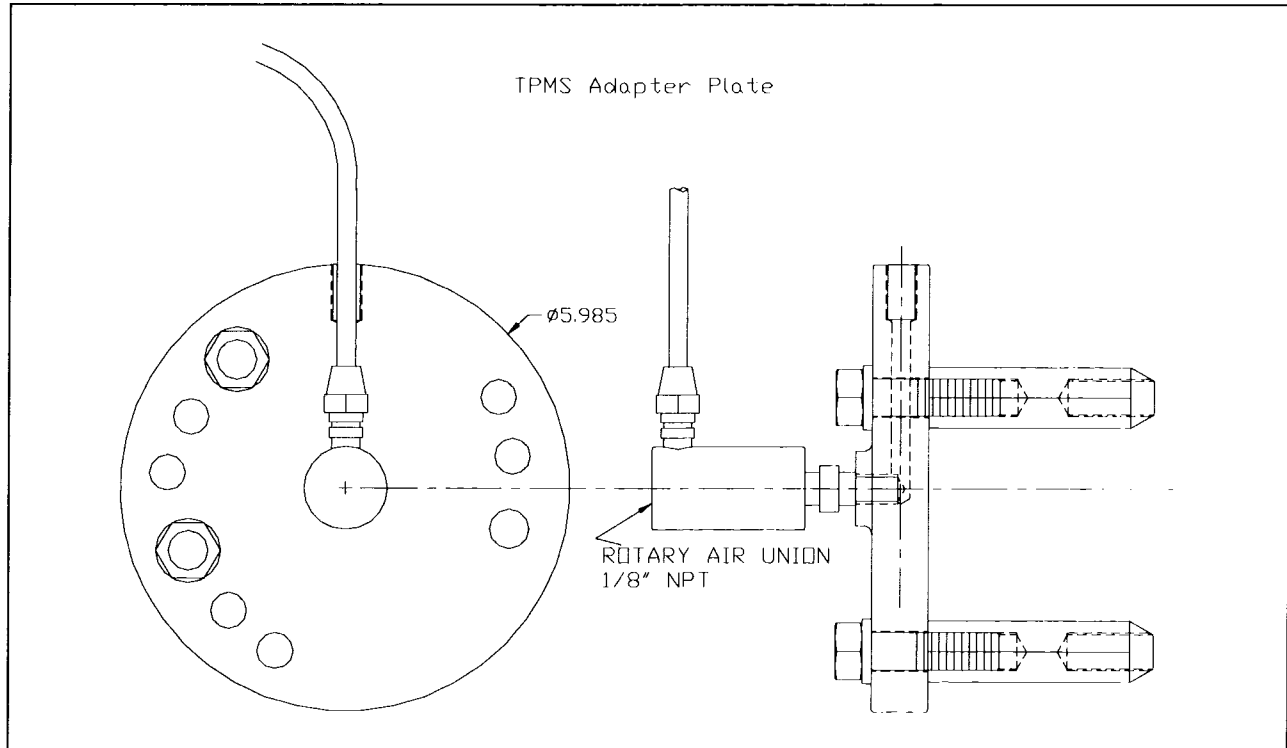


Figure 17
Loose Pieces of Interior Rubber
at Conclusion of 0-PSI Endurance Test

Appendix 1

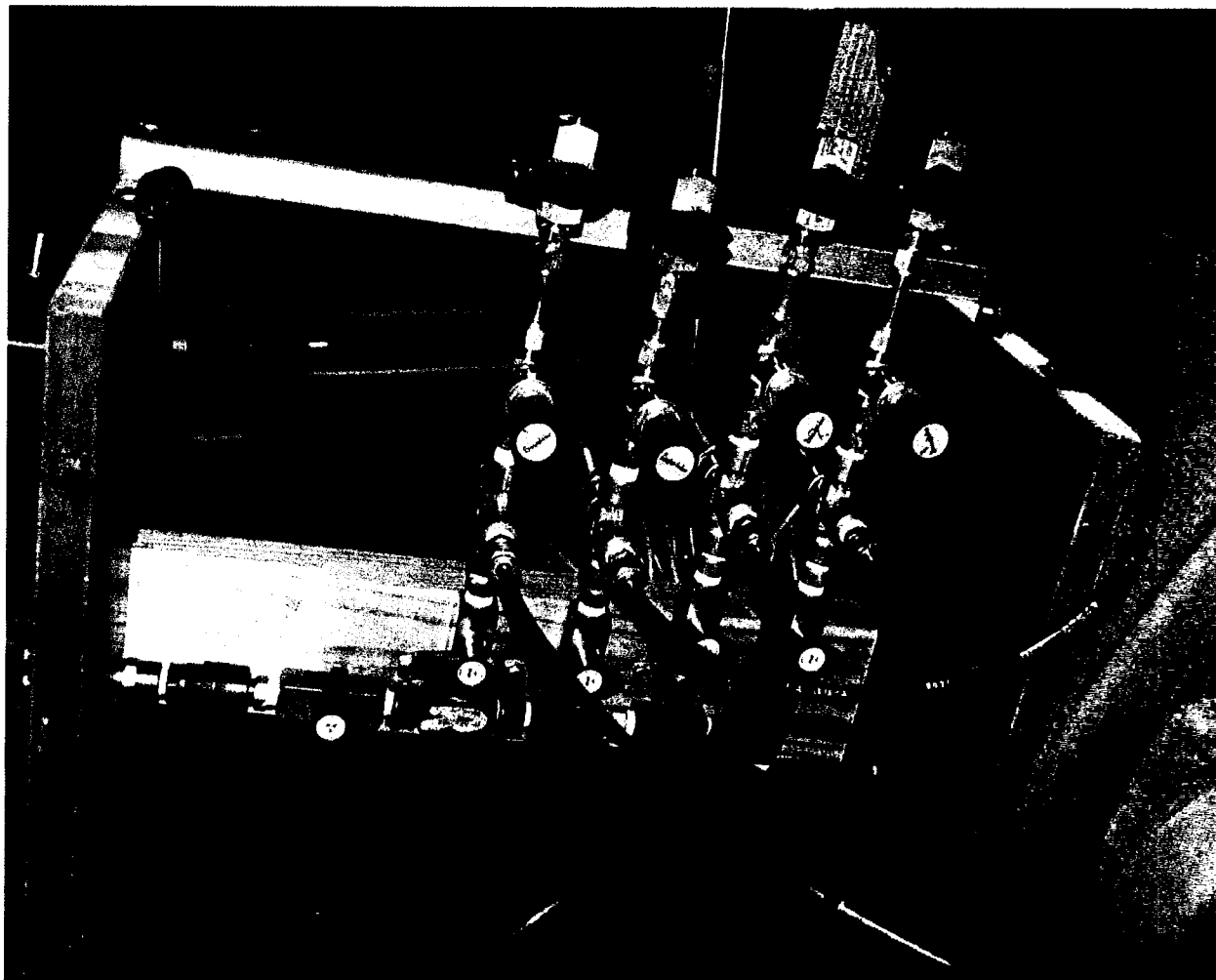
TPMS Adapter Plate Assembly

A rubber hose is threaded into the hole in the top of the adapter plate. The other end of this hose is connected to the tire's valve stem. Three extra-long stainless steel lug nuts replace the normal nuts and attach the plate to the wheel. The plate and the hose connecting it to the valve stem rotate with the wheel. On the other side of the rotary union, a plastic hose connects the union to the pressure manifold inside the vehicle. The plastic hose is taped to the car to prevent it and the outside piece of the rotary union from rotating.



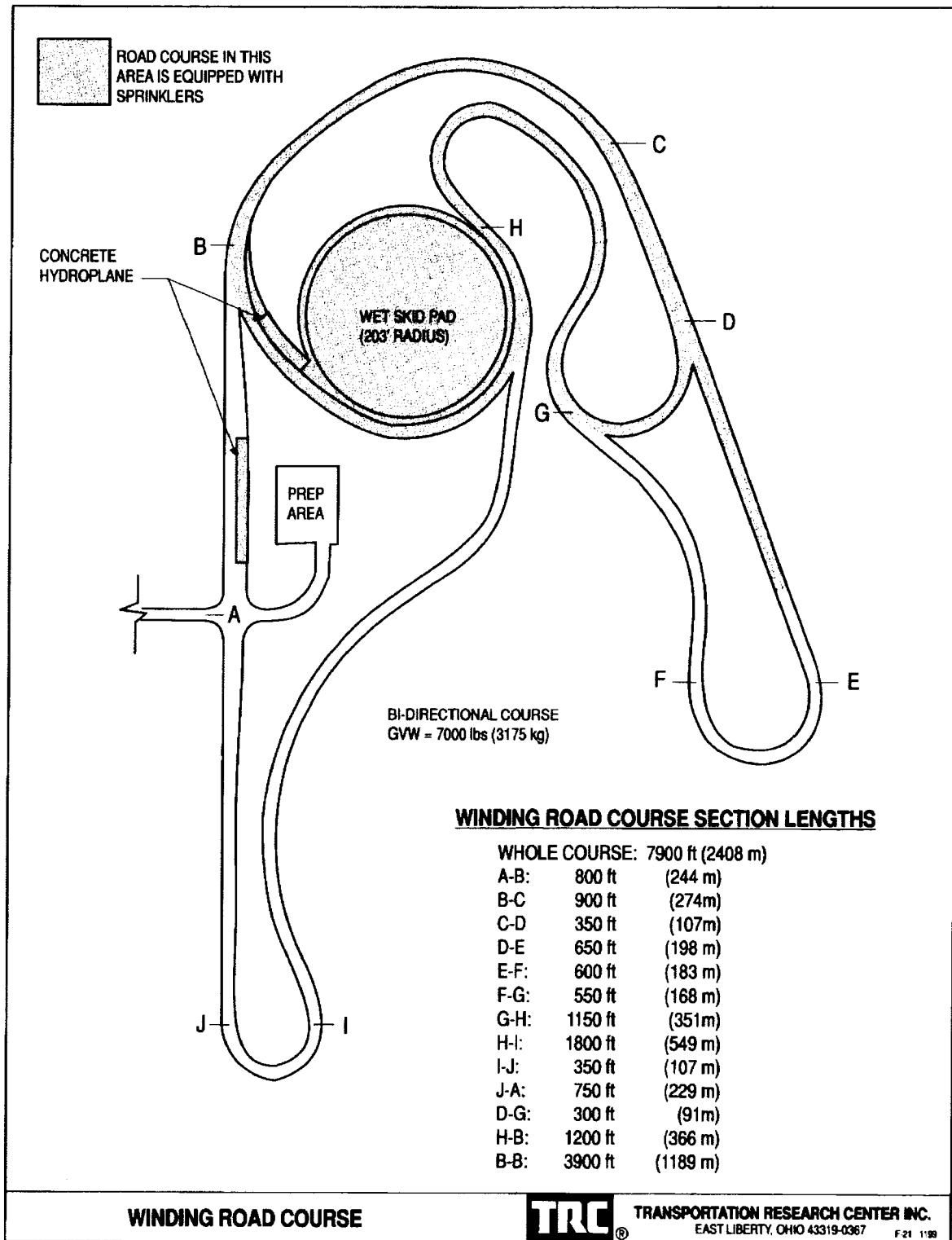
Appendix 2

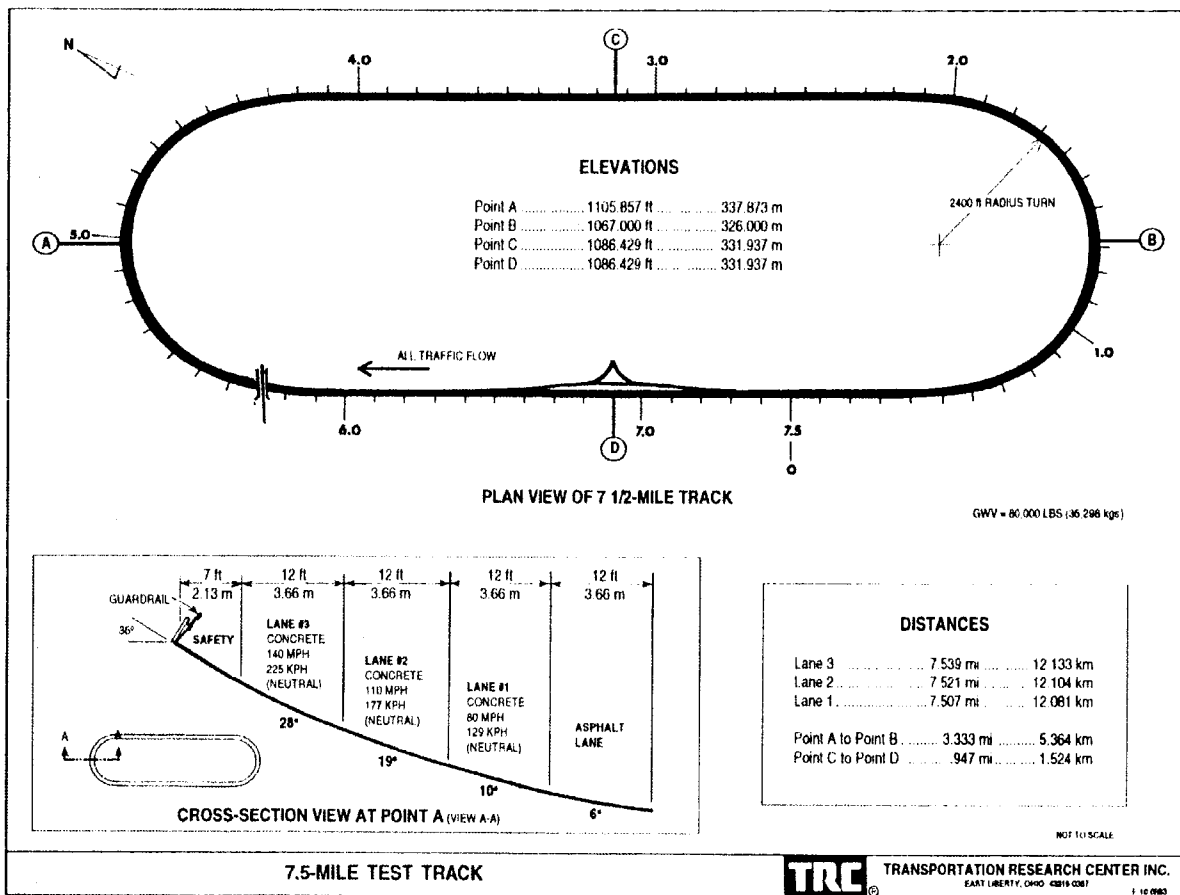
Air Pressure Adjustment Manifold



Appendix 3

Test Courses





Appendix 4

Detailed Test Procedures

Toyota Sienna TPWS Test Procedure Test No. 1

Objective: Determine the air pressure required to illuminate the TPWS warning light on low-speed winding road.

The following test procedure is to be performed three times for each tire under each of the four conditions listed. Testing may be performed in any order.

- LLVW – Standard tires
 - GVWR – Standard tires
 - GVWR – Run flat tires
 - LLVW – Run flat tires
1. Load vehicle to desired loading/tire combination. (TPMS must be recalibrated when changing tires. This is not required when changing loading)
 2. Set tire pressure to placard recommendations for given load
 3. Record ambient weather conditions
 4. Drive vehicle on **WRC (CAUTION: MAINTAIN SPEED ABOVE 20 MPH)**
 5. reset trip odometer, open valves to balance three non-test tires
 6. start data acquisition
 7. start stopwatch, and begin leaking **RF** tire pressure at 2 psi/min
 - a. if warning is observed, stop the air leak, note time and distance traveled and tire pressure
 - b. if warning is not observed, stop leaking tire pressure at 15 psi for run flat tires, 10 psi for standard tires.
 8. stop DAQ, return to pit area
 9. refill tested tire to match current pressure of other tire on same axle (use only compressed air)
 10. reset TPMS warning (do not recalibrate)
 11. Repeat for **LF** tire
 12. Repeat for **RR** tire
 13. Repeat for **LR** tire

Variable: Tire Pressure

Toyota Sienna TPWS Test Procedure Test No. 2

Objective: Determine length of time the vehicle must be driven before the TPWS light will illuminate on low-speed winding road.

The following test procedure is to be performed three times for each tire under each of the four conditions listed. Testing may be performed in any order.

- LLVW – Standard tires
 - GVWR – Standard tires
 - GVWR – Run flat tires
 - LLVW – Run flat tires
1. Load vehicle to desired loading/tire combination. (TPMS must be recalibrated when changing tires. This is not required when changing loading)
 2. Set tire pressure to placard recommendations for given load
 3. Record ambient weather conditions
 4. At **WRC** - drive 2 laps (3.0 miles) with all tires properly inflated
 5. Stop and adjust **RF** tire to 5 psi below the pressure determined in Test 1 above or 15 psi minimum for run flat tires, 10 psi for standard tires.
 6. Open valves to balance three non-test tires.
 7. Start data acquisition
 8. Reset trip odometer, start stopwatch
 9. Maintain vehicle speed **above 20 mph**
 - a. If warning is observed, stop DAQ, record time and distance to activation, close balance valves.
 - b. If warning is not observed, drive for 20 minutes and terminate test.
 10. Stop vehicle, stop engine.
 11. Refill tested tire to match current pressure of other tire on same axle (use compressed air)
 12. Wait 5 minutes in pit area
 13. Restart engine.
 14. Repeat for **LF** tire
 15. Repeat for **RR** tire
 16. Repeat for **LR** tire

Variable: Time

Toyota Sienna TPWS Test Procedure

Test No. 3

Objective: Determine the operating range (speed) at which the TPWS will function properly and illuminate the TPWS light on low-speed curving road.

The following test procedure is to be performed three times for each tire under each of the four conditions listed. Testing may be performed in any order.

- LLVW – Standard tires
 - GVWR – Standard tires
 - GVWR – Run flat tires
 - LLVW – Run flat tires
1. Load vehicle to desired loading/tire combination. (TPMS must be recalibrated when changing tires. This is not required when changing loading)
 2. Set tire pressure to placard recommendations for given load
 3. Record ambient weather conditions
 4. At **WRC**, stop and adjust tire pressure of **RF** tire to the pressure as Test 2 above or 15 psi minimum for run flat tires, 10 psi for standard tires.
 5. Open valves to balance three non-test tires
 6. Zero the trip odometer, start stopwatch, start DAQ
 7. Drive at **15 mph**
 - a. If warning is observed, stop DAQ, record time and distance to activation.
 - b. If warning is not observed within 1 lap beyond time/distance determined in test 2 above, **increase speed by 1 mph**, repeat step 6.
 - c. Repeat **1 mph speed increases** until system alarm or until speed reaches **22 mph**.
 8. Return to pit area, stop engine, refill tire to original recorded tire pressure with air (do not use nitrogen)
 9. Restart engine.
 10. Repeat for **LF** tire
 11. Repeat for **RR** tire
 12. Repeat for **LR** tire

Variable: Speed

Toyota Sienna TPWS Test Procedure

Test No. 4

Objective: Determine the air pressure required to illuminate the TPWS warning light on high-speed straight road.

The following test procedure is to be performed three times on each tire under each of the four conditions listed. Testing may be performed in any order.

- LLVW – Standard tires
 - GVWR – Standard tires
 - GVWR – Run flat tires
 - LLVW – Run flat tires
1. Load vehicle to desired loading/tire combination. (TPMS must be recalibrated when changing tires. This is not required when changing loading)
 2. Set tire pressure to placard recommendations for given load
 3. Record ambient weather conditions
 4. At **HSTT**:
 - a. open valves to balance three non-test tires
 - b. reset trip odometer
 - c. start data acquisition, begin leaking **RF** tire pressure at 2 psi/min
 - d. Accelerate to 55-60 mph (**CAUTION: DO NOT EXCEED 60 MPH**)
 - e. if warning is observed, stop the air leak, note distance traveled
 - f. if warning is not observed, stop leaking tire pressure at 15 psi. for run flat tires, 10 psi for standard tires
 - g. stop DAQ, return to pit area, stop engine.
 5. Refill tested tire to match current pressure of other tire on same axle
 6. Restart engine
 7. Repeat for **LF** tire
 8. Repeat for **RR** tire
 9. Repeat for **LR** tire

Variable: Tire Pressure

Toyota Sienna TPWS Test Procedure
Test No. 5

Objective: Determine length of time the vehicle must be driven before the TPWS light will illuminate on high-speed straight road.

The following test procedure is to be performed under each of the four conditions listed. Testing may be performed in any order.

- LLVW – Standard tires
 - GVWR – Standard tires
 - GVWR – Run flat tires
 - LLVW – Run flat tires
1. Load vehicle to desired loading/tire combination. (TPMS must be recalibrated when changing tires. This is not required when changing loading)
 2. Set tire pressure to placard recommendations for given load
 3. Record ambient weather conditions
 4. At **HSTT**:
 - a. drive 1 lap (7.5 miles) at 60 mph with all tires properly inflated
 - b. Stop and:
 - i. adjust **RF** tire to 5 psi below pressure determined in Test 4 above or 15 psi minimum for run flat tires, 10 psi for standard tires.
 - ii. open valves to balance three non-test tires
 - iii. zero the trip odometer, start DAQ
 - c. drive 55-60 mph (**CAUTION: DO NOT EXCEED 60 MPH**)
 - i. if warning is observed, stop DAQ, record distance to activation
 - ii. terminate test if warning does not activate after 20 minutes
 5. return to pit area, turn off engine
 6. refill tested tire, wait 5 minutes in pit area
 7. Repeat for **LF** tire
 8. Repeat for **RR** tire
 9. Repeat for **LR** tire

Variable: Time

Toyota Sienna TPWS Test Procedure

Test No. 6

Objective: Determine the operating range (speed) at which the TPWS will function properly and illuminate the TPWS light on high-speed straight road.

The following test procedure is to be performed under each of the four conditions listed. Testing may be performed in any order.

- LLVW – Standard tires
 - GVWR – Standard tires
 - GVWR – Run flat tires
 - LLVW – Run flat tires
1. Load vehicle to desired loading/tire combination. (TPMS must be recalibrated when changing tires. This is not required when changing loading)
 2. Set tire pressure to placard recommendations for given load
 3. Record ambient weather conditions
 4. At **HSTT**:
 - a. Open valves to balance the three non-test tires.
 - b. Drive 1 lap (7.5 miles) at **65 mph** with all tires properly inflated
 - c. **Without stopping**, zero the trip odometer, start DAQ, rapidly reduce tire pressure of **RF** tire to the pressure as Test 5 above or 15 psi minimum.
 5. Maintain test speed.
 - a. If warning is observed, stop DAQ, record distance to activation.
 - b. If warning is not observed within 4 miles (½ lap) of the distance determined in test 5 above, **reduce speed by 1 mph without stopping** and continue.
 6. Repeat 1 mph speed reductions until system alarms or until speed reaches **59 mph**.
 7. Return to pit area, stop engine.
 8. Refill tested tire to match current pressure of other tire on same axle
 9. Restart engine
 10. Repeat for **LF** tire
 11. Repeat for **RR** tire
 12. Repeat for **LR** tire

Variable: Speed

Toyota Sienna TPWS Test Procedure
Test No. 7

Objective: Compare stopping distances: all tires fully inflated tires vs. each tire deflated to 15 psi.

The following test procedure is to be performed three times for each tire under each of the four conditions listed. Testing may be performed in any order.

- LLVW – Standard tires
 - GVWR – Standard tires
 - GVWR – Run flat tires
 - LLVW – Run flat tires
1. Load vehicle to desired loading/tire combination. (TPMS must be recalibrated when changing tires. This is not required when changing loading)
 2. Set tire pressure to placard recommendations for given load
 3. Record ambient weather conditions
 4. At **Skid Pad** – Perform one high-effort brake stop (100 lb pedal force) from 60 mph with functional ABS.
 5. Allow brakes to cool for 5minutes.
 6. For each tire, one at a time, reduce tire pressure to 15 psi for run flat tires, 10 psi for standard tires, with other three tire pressures balanced.
 7. Repeat steps 4 – 6

Toyota Sienna TPWS Test Procedure
Test No. 8

Objective: Determine if run flat tires can achieve the endurance with low air pressure claimed by the manufacturer.

The following test procedure is to be performed under the conditions listed below.

- GVWR – Run flat tires
 1. Set all tire pressures to 35 psi
 2. Ensure sufficient fuel onboard to drive for 4 hours.
 3. Ensure at least two fire extinguishers are onboard test vehicle and readily accessible
 4. Record ambient weather conditions
 5. At **HSTT**, adjust right rear tire pressure to test pressure.
 6. Reset trip odometer to zero.
 7. Activate data recording device.
 8. Drive vehicle at **58 mph** (caution: do not exceed 61 mph) (slowing for construction zones is permissible but not preferred)
 9. End test if TPWS does not activate within one hour.
 10. If TPWS activates before 1 hour, manually record the trip odometer reading at point of activation, reset the trip odometer to zero without stopping, reduce speed to **55 mph**, and continue driving
 11. End test after traveling 125 miles from point of TPWS activation.
 12. Monitor condition of right rear tire using onboard video camera and infrared temperature measuring device. Abort test immediately if any of the following occur:
 - Infrared measurement of tire temperature reaches 240 deg. F
 - Contained air temperature reaches 240 deg. F
 - Flame or excessive smoke is observed from right rear tire
 - Tire failure