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Technical Report

No. 13521

MOTION BASE SIMULATION
TEST OF THE M840E1
DOLLY SET

December 1990

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13. ABSTRACT *(Maximum 200 words)*
This report describes the testing of the modified M840E1 dolly set in the Physical Simulation Laboratory at TACOM. A motion base simulator was designed, assembled, and utilized to produce motion on the dolly set. This motion represents typical terrain/speed scenarios encountered by dolly sets. The test plan executed followed the initial production test of the M840 dolly set.

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Preface

This report presents the full scale motion base simulation of an M840E1 dolly set. Questions regarding motion base simulation of vehicles and/or components are to be referred to the U.S. Army Tank-Automotive Command, ATTN: System Simulation and Technology Division, AMSTA-RY, Warren, MI 48397-5000, Telephone: AUTOVON/DSN 786-6228, Commercial (313) 574-6228.

1.0 Introduction

This report, prepared by the System Simulation and Technology Division of the Directorate for Tank-Automotive Technology; U.S. Army Tank Automotive Command (TACOM), describes the testing of the modified M840E1 dolly set which was performed at TACOM's full-scale Physical Simulation Laboratory.

In order to alleviate the present shortage of M720 dolly sets, a project was initiated to utilize and convert the M840 dolly set to fit the S280 shelter in order to perform the M720 mission. The resulting (modified) dolly set is to be designated the M840E1 unit. The modification was accomplished by AMSTA-TF (Fabrication Division) at TACOM.

The converted M840E1 dolly set then was loaded with 5000 pounds of dummy load to simulate the everyday average use. A motion base simulation test was then performed by the Analytical and Physical Simulation Branch (AMSTA-RYA) in the Physical Simulation Laboratory in building 215. See Figure 1.

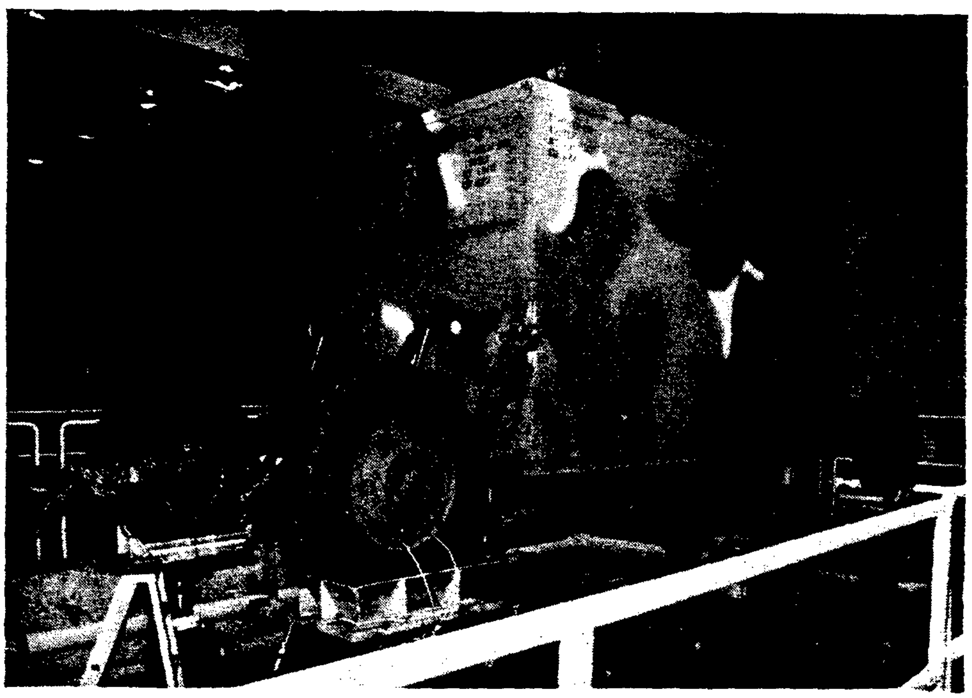


Figure 1 Dolly Set on Motion Base Simulator

2.0 Item Description

The M840 dolly set consists of one front and one rear, two-wheeled dollies designed to pick up and transport various shelters which are extensively used by the Air Force as repair, maintenance, and storage shops.

The dollies bolt to the front and rear of the shelter and, in effect, convert it into a full-size trailer which may then be towed by another vehicle such as a 2-1/2 or 5-ton truck. The front dolly uses wagon-tongue steering, and the rear dolly has a non steering axle.

The suspension system has two air springs and two automotive type shock absorbers to provide proper ride characteristics and to absorb shock when traveling over different trails and cross-country roads.

Each dolly is equipped with an independent hydraulically actuated lifting-leveling system. Two hydraulically operated lifting-leveling jacks are on each dolly for lifting and leveling a shelter. These jacks provide the means of installing the dolly set to the shelter when the shelter is resting on the ground and to lift the shelter to a height of 17 inches.

All technical data regarding weight, center-of-gravity position, moments of inertia, and suspension properties, such as vertical spring rate, roll rate, and tire properties are presented in the Addendum.

3.0 Test Objective

The objective of this test was to effectively test the durability of the modified M840E1 dolly set when traveling over selected terrain profiles, as recommended by the 3300 cross-country and secondary road miles in the Initial Production Test (IPT) plan. In addition, the objectives were to validate the conversion concept and design modification changes, manufacturing methods, conformance to safety requirements, compliance with applicable military requirements and to lay the grounds for the probable increase in payload weight limit.

In addition, this test provided valuable test data for concept evaluation, test methodology, dynamic model verification which was essential to the successful completion of the test.

4.0 Inspection

A visual inspection of the modified M840E1 dolly set, prior to testing, was performed and did not reveal any major problem or malfunction of the M840E1 dolly set.

During the test, the following inspections and tasks were conducted as required by TM 9-2330-275-14.

Initial.

1) Lubricated and prepared vehicle according to TM 9-2330- 275-14. Sec II, Fig 3-1.
2) Set airbag inflation pressure according to TM 9-2330-275-14 Sec IV, Fig 3-2.
3) Set tire air pressure to 25 psi.
4) Performed visual inspection of vehicle and search for cracks or any mechanical damage or abnormalities.

Ongoing.

1) Checked tire pressure every 300 miles.
2) Lubricated and checked vehicle approximately every 300 miles.
3) Visually inspected vehicle for cracks, abnormalities.
4) Performed simulator maintenance.
5) Checked payload.
6) Rotated tires every 300 miles.

5.0 Conclusions and Recommendations

There were no problems encountered throughout the test. The simulation did not reveal any degradation of any of the dolly set components. The modification to fit the S280 shelter is appropriate and of acceptable performance. Therefore, the M840E1 configuration can be expected to perform adequately throughout its mission scenario. Consequently, implementation of this concept is recommended. After completion of 2,850 miles with 5,000 pounds of dummy load inside the shelter and 300 miles without the payload, damage was done to the right-front shock bracket caused by an uncontrollable input spike in the front two actuators. The remaining 150 miles without payload was performed without any problems. The test was completed on November 27, 1990.

6.0 Discussion

6.1 Motion Simulator

6.1.1 Summary

The motion simulator constructed for this test is a high-performance three axis (roll, pitch, and vertical) simulator assembly capable of testing trailers and dolly sets or any other four wheeled vehicle not heavier than 25,000 pounds. The simulator uses electro-hydraulic actuators to produce motion on the test item. The simulator is controlled by an operator at a control console. The dolly set tires rest on platens attached to each actuator. The lunette is attached to a fixed beam for safety.

In operation, a Computer Automated Measurement and Control (CAMAC) system creates actuator commands which synergistically produce the vertical and rotational motion requirements. The CAMAC system is interfaced to the RDE Center Supercomputing Network and motion controllers that output a servo current drive signal to each actuator.

All simulator design, assembly, integration, and software development were accomplished within the RDE Center.

6.1.2 Performance Specification

Table 1 Performance Summary of Simulator

Parameter	Value
Payload	8700 pounds
Axes	Roll, Pitch, and Vertical
Maximum excursions	
Vertical	+- 6 inches
Pitch	+- 2 degrees
Roll	+- 4.5 degrees
Maximum acceleration (actuator)	9 g's
Positional bandwidth	10 hertz

6.1.3 Simulator Control System

The control system is made up of the CAMAC system, servo controllers and servo valves ported to the actuators. An overall system block diagram is given in figure 2. TACOM engineers write software on the CAMAC system which sends realtime, scaled actuator commands through four 12-bit digital to analog converters at a clock rate of 100 samples per second. The software is written such that actuator commands are provided continuously for 12 hours or more without replenishing the CAMAC system with additional road profile data.

These commands are received by four servo controllers which supply current signals to drive the servovalves on the actuators. They do this while maintaining actuator loop control.

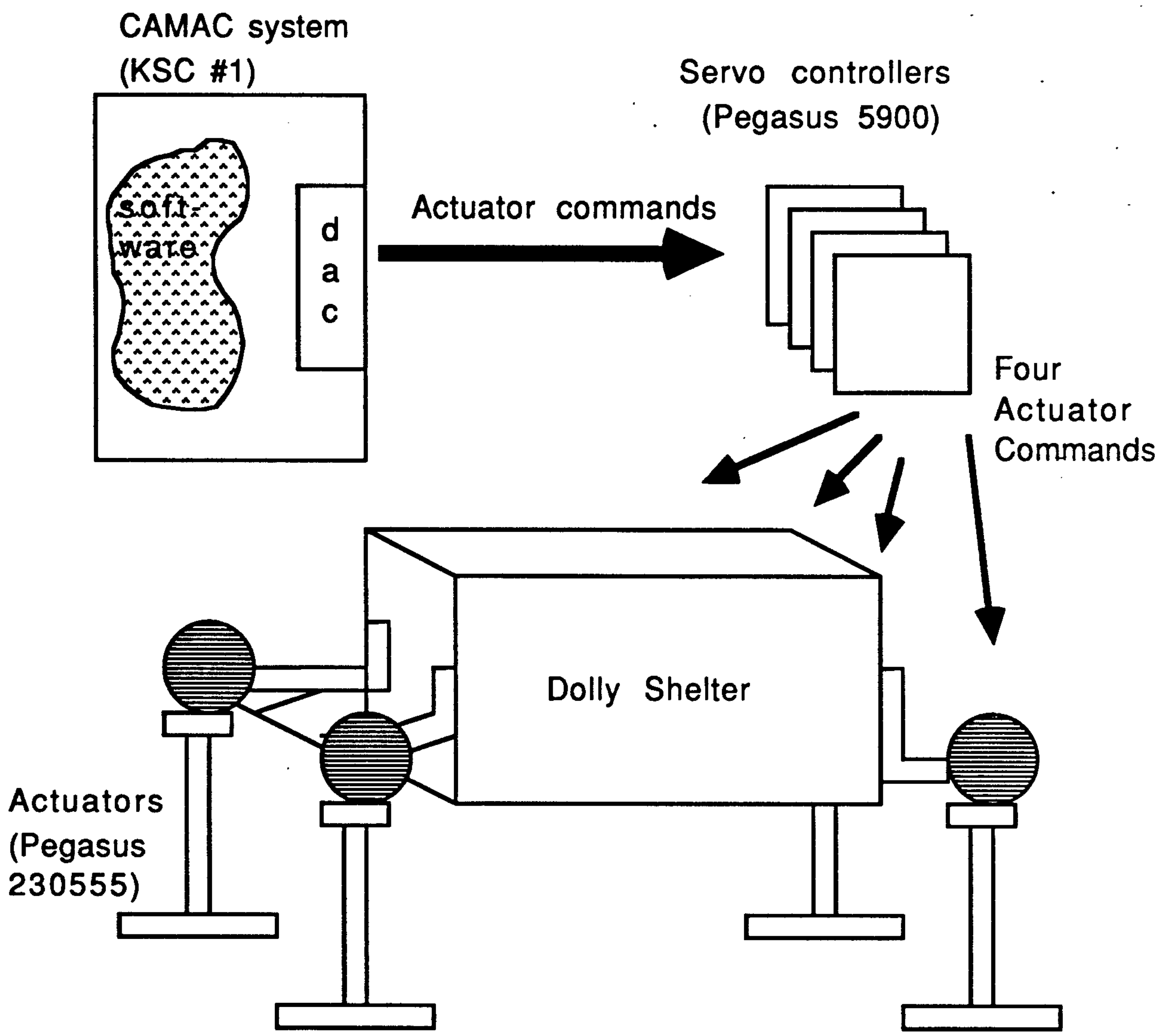


Figure 2 Motion Control System

6.2 Profile Selection

The motion simulator is supplied with actuator commands which reproduce the dynamic effects of a variety of secondary road and cross country terrains. The Initial Production Test (IPT) plan document details the type of profile and speeds at which the dolly set is tested for durability. The course/speed selection is based on the mission scenario of the vehicle which was followed as close as possible for this laboratory test, in order to reproduce and complement similar field tests.

The IPT plan calls for the road profile and speed scenario in Table 2.

Table 2 IPT Scenario

Course	Average speed
Paved	40 mph
Gravel	20 mph
Level cross country	15 mph
Hilly cross country	15 mph
Belgian block	15 mph

These profiles are further described here. Paved roads are hard surface roads and highways that contain little bump detail. This portion of the IPT plan was not (and cannot) be tested using the simulator as little dynamic input is present. Gravel roads are maintained dirt roads sometimes covered with crushed stone or bank gravel. Bumps and potholes are usually limited in depth to one to two inches. Level cross-country courses have a wide range of severity, but for trailer testing, the courses are limited to moderate severity. These courses usually have bumps detailed up to six inches. Hilly cross-country courses follow similar characteristics as level cross-country courses, but also contain steep hills. Belgian block is characterized by unevenly laid blocks that form an undulating surface which creates intense random vibration.

The System Simulation and Technology Division has in its computer system, a comprehensive library of terrains profiled from several areas throughout the United States. Courses were selected from this library which match characteristics of those in Table 2. These are specified in Table 3.

Table 3 Selected Courses

Course type	Bump max	Simulated Speed
Gravel		
- Churchville 6	1.8 inch pk-pk	20 mph
- Churchville 7	1.2 inch pk-pk	20 mph
Level Cross-Country		
- APG 37	4.4 inch pk-pk	15 mph
- Letourneau 5*	5.5 inch pk-pk	12 mph
Hilly Cross-Country		
- Letourneau 4*	3.5 inch pk-pk	15 mph
Belgian Block**		
- Churchville 7	1.2 inch pk-pk	20 mph

* Letourneau courses run were actually one half amplitude of the original Letourneau courses profiled at Waterways Experiment Station, Vicksburg, Miss.
** Belgian block profile not available on computer. Churchville 7 was used instead, as it contains a large frequency spectrum like Belgian block.

6.3 Test Execution

The IPT plan recommends a 6,000 mile test to prove the durability of the dolly set including 2,700 paved-road miles. Since motion simulators create little dynamic effect when simulating constant speed, paved-road travel, this portion was eliminated. It is recommended that effects of the paved-road portion of the IPT should be evaluated by means of the field test portion of the dolly set testing plans. The dolly set was subject to 3,300 miles of simulated road profile as detailed in Table 4.

Table 4 **Test Mileage Breakout**

Course	Miles with Payload	Miles no Payload	Speed
Gravel			
- Churchville 6	750	0	20 mph
- Churchville 7	750	0	20 mph
Level Cross Country			
- APG 37	450	150	15 mph
- Letourneau 5	450	150	12 mph
Hilly Cross Country			
- Letourneau 4	360	120	15 mph
Belgian Block			
- Churchville 7	90	30	20 mph
	-----	-----	
	2850	450	

Testing commenced Oct 11, 1990 and concluded on November 27, 1990. Simulator performance was monitored throughout the test. This ensured that the motion simulator produced the dynamics intended for each profile simulated.

6.4 Data Acquisition and Analysis

The motion simulator and dolly set were instrumented with a variety of transducers. The data collected provide the engineering community with position, velocity and acceleration information to evaluate test results. It is also used to provide the design and test engineer with the required parameters needed to diagnose simulator or vehicle failures, if they occur. The data collected are summarized in Table 5. The data are recorded digitally using the CAMAC system and were low- pass filtered at 50 hertz and recorded at 100 samples per second. The data are retained in the System Simulation and Technology Division computer archives.

Table 5 **Data Recorded**

Channel no	Signal	Location
1	RF acceleration	RF spindle
2	LF acceleration	LF spindle
3	RR acceleration	RR spindle
4	LR acceleration	LR spindle
5	Roll rate	Shelter CG
6	Pitch rate	Shelter CG
7	RF pos command	CAMAC dac 1
8	RF actuator pos	RF LVDT
9	LF actuator pos	LF LVDT
10	RR actuator pos	RR LVDT
11	LR actuator pos	LR LVDT
12	LF jounce accel	LF airbag bracket
13	LR jounce accel	LR airbagbracket
14	LF pos command	CAMAC dac 2
15	RR pos command	CAMAC dac 3
16	LR pos command	CAMAC dac 4

Analysis of the data quantifies the performance of the motion simulator and dynamic performance of the dolly set. Two plots of actuator position command and actuator position response versus time are shown in Figures 3 and 4. The response is typical of all profiles and actuators run in this test. It shows that the actuator tracks the commanded (desired) position extremely well. In fact, the simulator used in this test is the most dynamically accurate motion simulator ever assembled at TACOM. This is due in part to the recent acquisition of new servo controllers and careful calibration and compensation of the servo system by RDE personnel.

The spindle and jounce acceleration and angular velocity data recorded will be used for model validation and field-test comparison studies. This work is ongoing at this time.

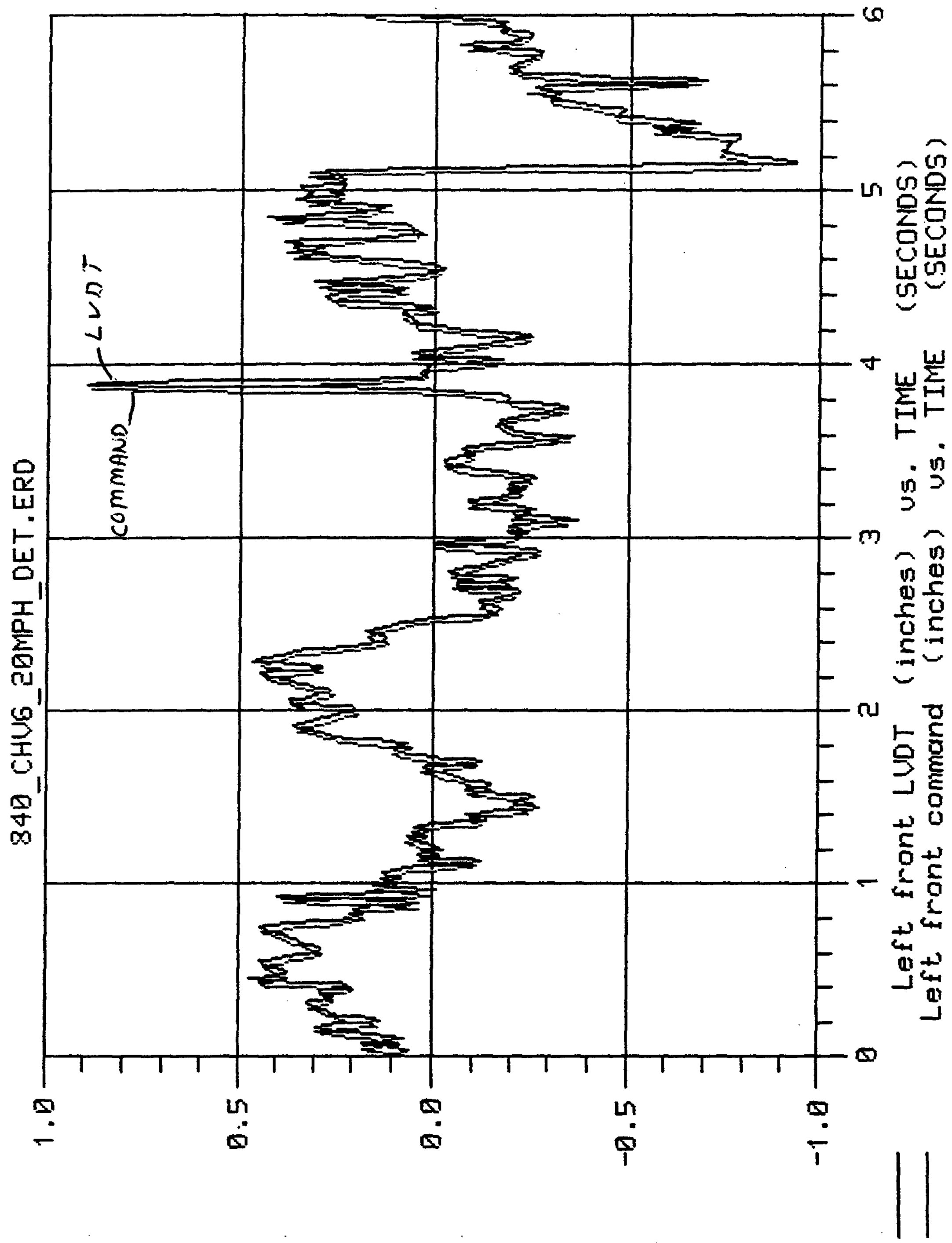


Figure 3. Churchville 6

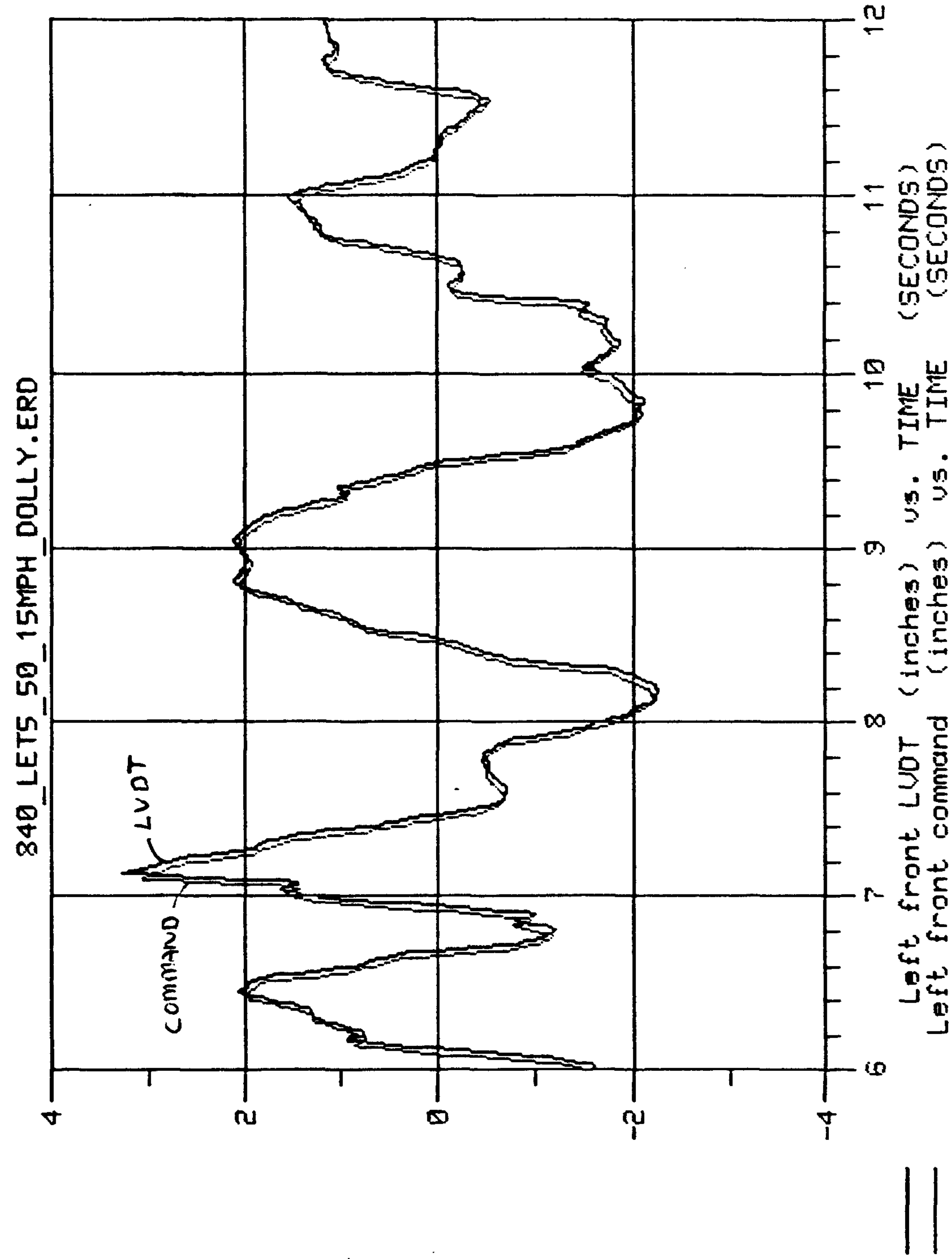


Figure 4. Letourneau 5_50

Addendum

M840 Dolly Set Characterization Report
University of Michigan Transportation
Research Institute

UMTRI The University of Michigan
Transportation Research Institute
2901 Baxter Road, Ann Arbor, Michigan 48109-2150

Wednesday, July 25, 1990

US ARMY TACOM
System Simulation and Tech. Division
Attn: AMSTRA-RYA
Mr. Aleksander Kurec
Warren, MI 48397-5000

Dear Mr. Kurec:

This letter is to report on the results of a series of parameter measurements which UMTRI has conducted for TACOM on the M840 Dolly Set. The M840 Dolly Set consists of one front and one rear, two-wheeled dollies, designed to pickup and transport various 8'x12' shelters. The dollies bolt to the "front" and "rear" of the shelter and in effect, convert it into a full trailer, which may then be towed by a five-ton truck.

The rear dolly has a non-steering axle; the front dolly uses wagon-tongue steering. Both dollies use trailing-arm air suspensions, and each is equipped with a hydraulic mechanism for raising the shelter structure to nominal ride height when first installing the dollies.

UMTRI has conducted a series of parameter measurements on the components of these dollies. Measurements covered (i) tire properties, (ii) suspension properties, and (iii) inertial properties.

Tire Properties

For one extra tire delivered by TACOM to UMTRI, we have measured:

1) The vertical force/deflection behavior of the tire over the zero-to-6000 pound range of vertical loads. Measurements were made at two inflation pressures, viz., 25 and 50 psi, as specified by TACOM.
2) Lateral force/deflection behavior over lateral loading from 0 lbs up to wheel slide on a concrete surface. These measurements were made at the three vertical loads of 1750, 3500, and 5250 pounds, specified by TACOM, and at the two inflation pressures of 25 and 50 psi. (for a total of six test conditions).

The tire test data are presented in Figures 1 through 4. Vertical deflection data are presented in Figures 1 and 2 for the 25 and 50 psi test conditions, respectively. These figures also include expressions for tire spring rate (dF_z/dZ) as a function of vertical load (F_z).

Similarly, lateral deflection data are in Figures 3 and 4. Slide friction (μ), and lateral spring rate (dF_y/dY) are given in these figures. The nominal spring rate is given for both increasing and decreasing lateral loading.

Table 1 and Figure 5 review the vertical response results. Table 2 reviews the lateral response results.

Suspension Properties

For both the front and rear dolly suspensions of the M840, the following properties were measure:

1) vertical spring rate (force/deflection properties)
2) Coulomb friction force with respect to vertical deflection
3) Roll rate
4) Roll steer behavior
5) Aligning moment steer behavior

The "raw" data graphs derived from testing the two suspensions are attached. Parameters derived from these data are presented in Table 3. This table shows the suspension parameters as a function of suspension (front or rear) and axle load (total load on the axle measured at the tire/ground interface). The first line in the table presents "corrected" axle load, that is, axle load with the weight of the sprung mass subtracted. (Note that the front unsprung mass is considerably greater than the rear because of the weight of the steering system hardware and the tongue.)

Vertical spring rate given in the table is the effective spring rate measured at the spindle, not at the air spring itself. The value in the table is the nominal, linear rate at the operating condition. Figure 6 plots these values against corrected load revealing that the spring rate is clearly a linear function of the spring load.

The raw data plots of vertical rate show that Coulomb friction of the suspension linkage is a function of the size of the suspension stroke. The table gives friction values for large and moderate strokes.

Table 3 shows that the rear axle roll center is slightly higher than the front axle roll center. This is as expected, due to differences in the suspension geometry. Lateral location of the axles is accomplished by both the main trailing arm and additional links located at an angle to the longitudinal center-line in the plan view. For the front suspension, this link attaches to the axle at very nearly the axle center-line. In the rear suspension, similar links attach to the axle several inches above the axle center-line.

The roll steer of both front and rear suspensions is small.

The roll stiffness of both suspensions is a strong function of load, as is clearly expected since the vertical rate of the air springs is a function of load. The rear suspension shows higher roll stiffness for two reasons. Most importantly, the rear springs are set at a greater lateral spacing (49.75") than are the front springs (38.5"). Also, at the rear, auxiliary roll stiffness is higher since the redundant lateral locating mechanisms (main trailing arms and suspension locating links) are set at different heights. These two restraints, together, tend to resist roll motions.

The aligning moment steer of the front axle is larger than that of the rear, due to the compliance of the steering system. The raw data plots also reveal the lash in the steering system.

Inertial Properties

UMTRI measured the significant "sprung" and "unsprung" mass properties of the dolly set. The axle was removed from each dolly, thus separating each into its sprung and unsprung mass segments. Inertial properties of the sprung mass (frame) portion were measured with this assembly configured "for travel." The wagon tongue was remove from the front axle and weighed separately. The following inertial properties were be measured:

For Each Sprung Mass (frame assembly)

1) weight
2) center of gravity position
3) yaw moment of inertia about the c.g.
4) pitch moment of inertia about the c.g.
5) roll moment of inertia about the c.g.

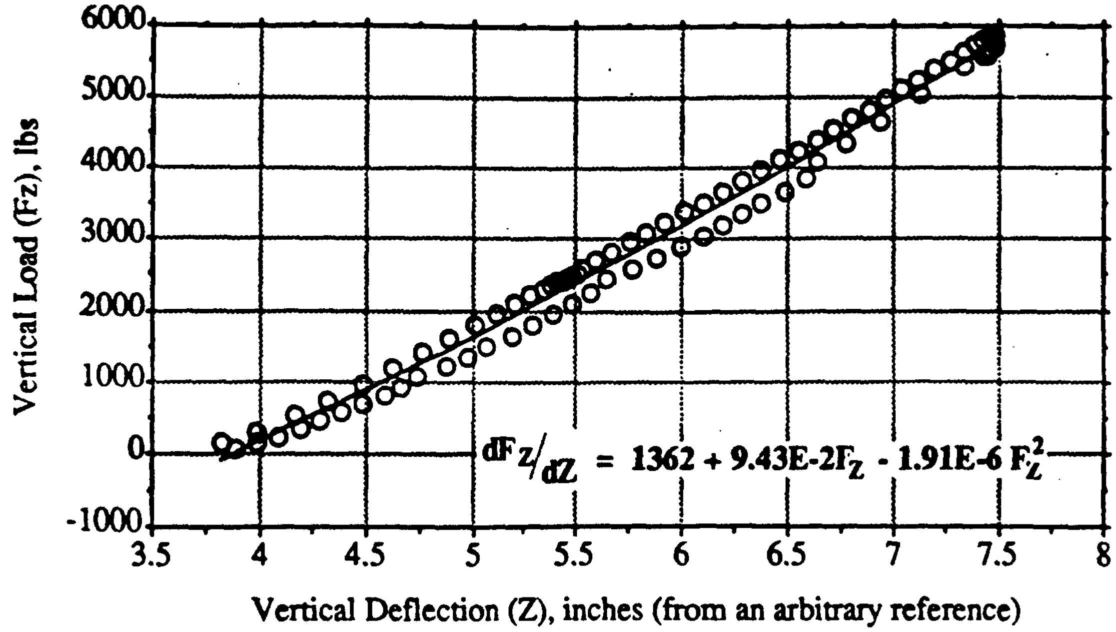
For Each Unsprung Mass (axle assembly)

1) weight
2) moment of inertia in roll and in yaw (assumed to be identical)

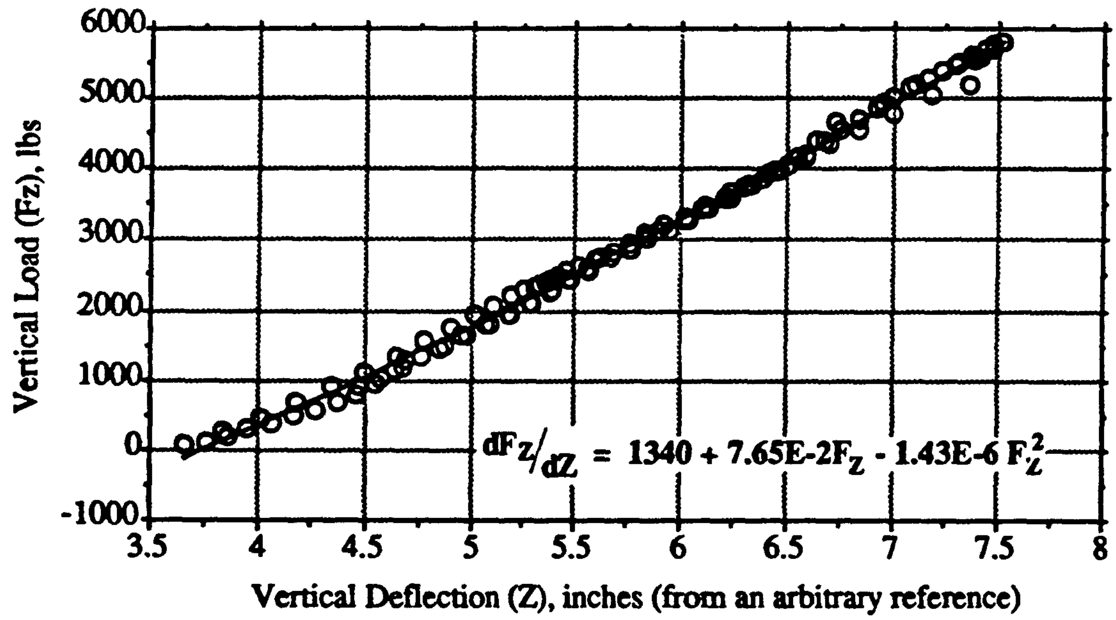
For One Tire/Wheel/Brake Drum Asymbly

1) weight
2) moment of inertia about the spindle of one tire/wheel/brake rotor assembly.

The weights and moments of inertias which were measured are shown in Table 4. The cg positions of the sprung masses are shown in Figure 7. The cg positions have also been marked on the actual parts.

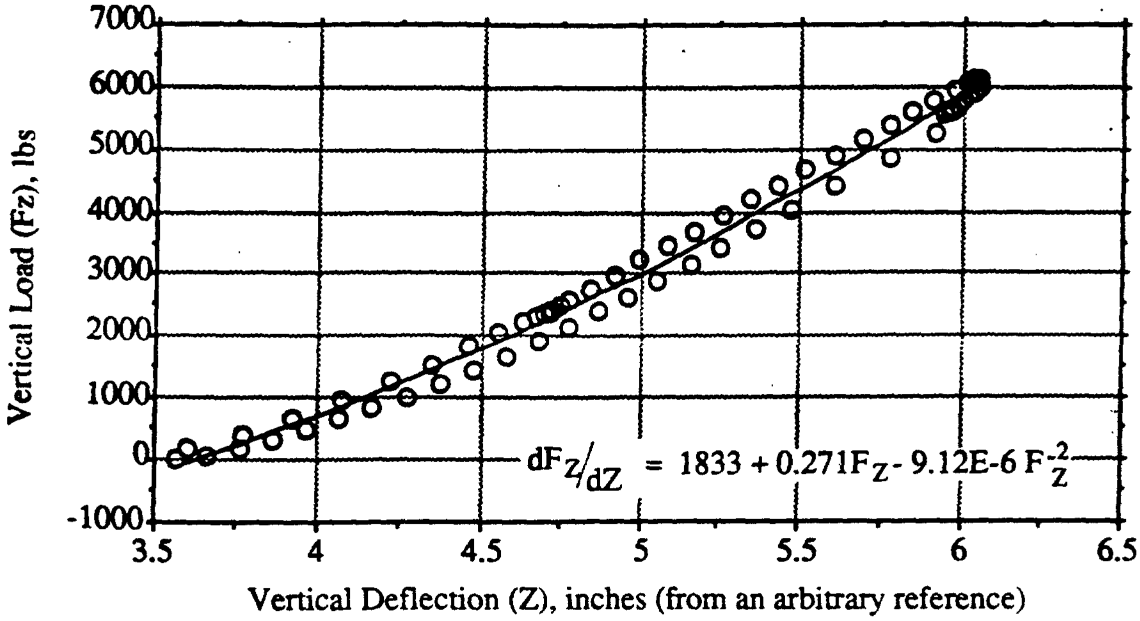


Vertical force deflection properties of the standing tire inflated to 25 psi.

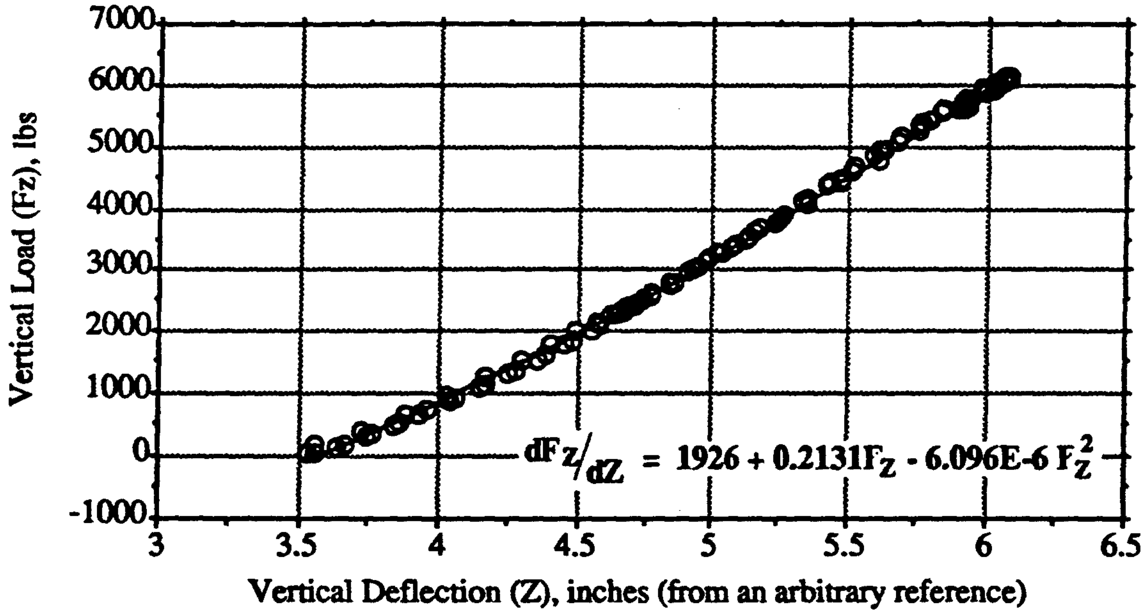


Vertical force deflection properties of the rolling tire inflated to 25 psi.

Figure 1. Vertical force deflection properties of a 9.00 x 20, bias, 8 ply, military tread tire inflated to 25 psi.

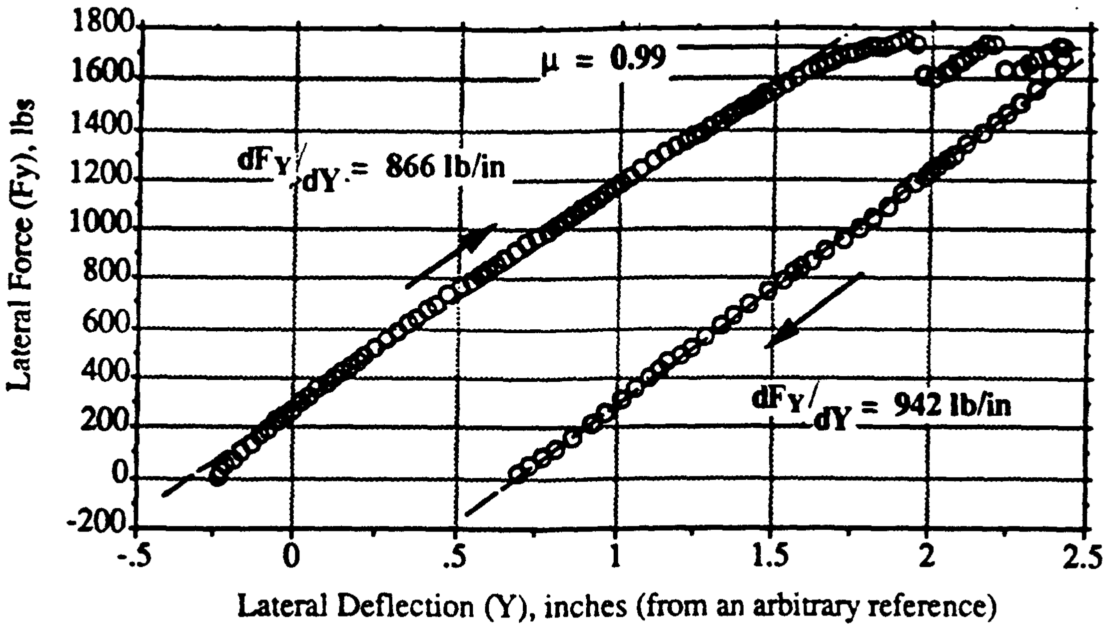


Vertical force deflection properties of the standing tire inflated to 50 psi.

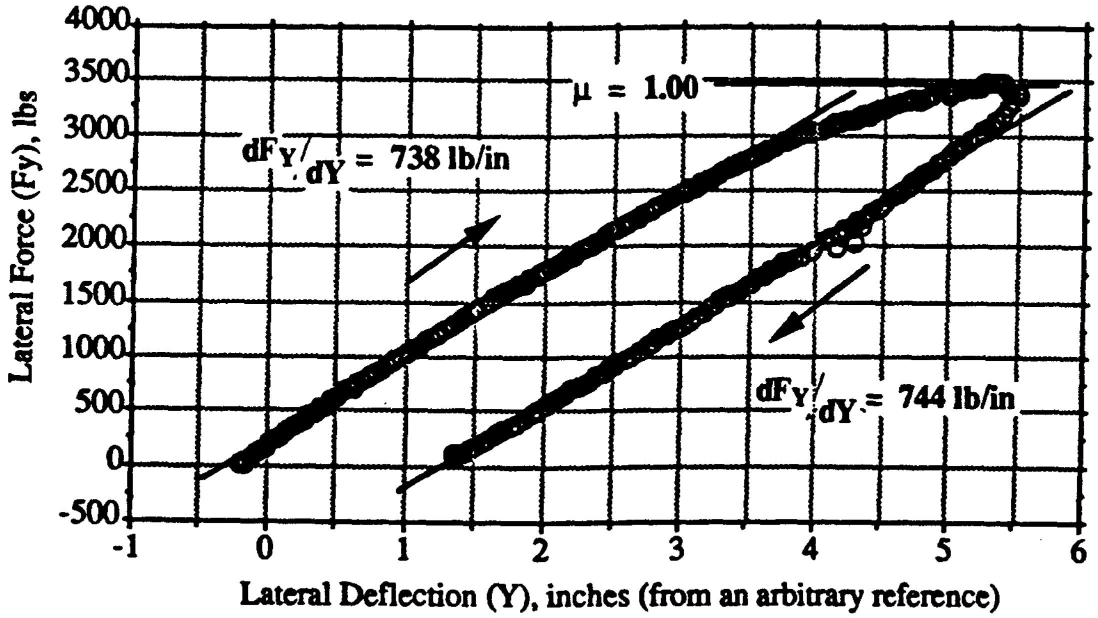


Vertical force deflection properties of the rolling tire inflated to 50 psi.

Figure 2. Vertical force deflection properties of a 9.00 x 20, bias, 8 ply, military tread tire inflated to 50 psi.

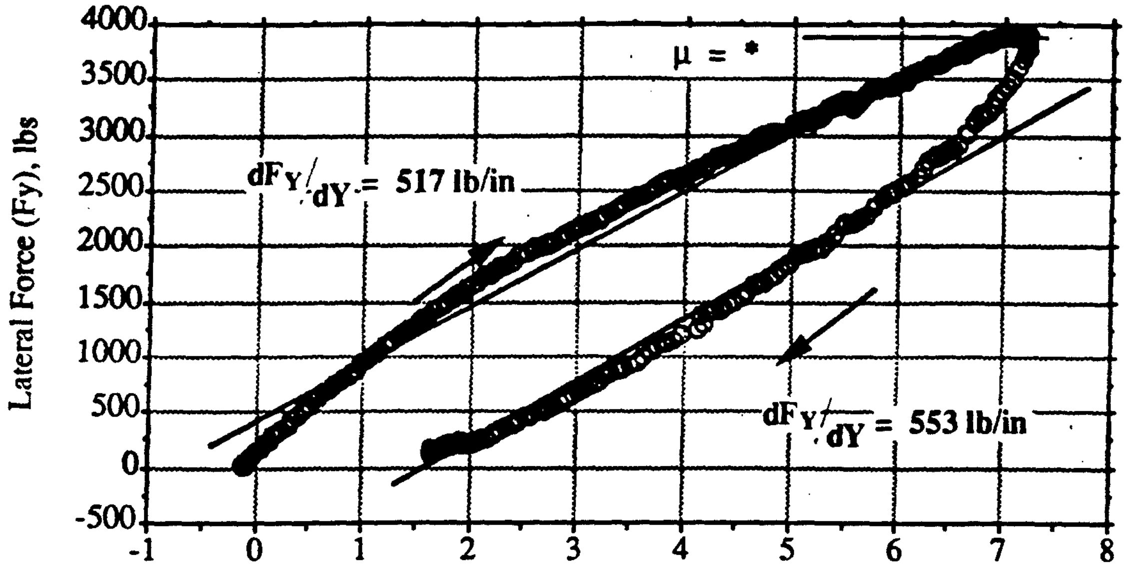


Lateral force deflection properties of the standing tire
at a nominal vertical load of 1750 pounds and inflated to 25 psi.



Lateral force deflection properties of the standing tire
at a nominal vertical load of 3500 pounds and inflated to 25 psi.

Figure 3. Lateral force deflection properties of a 9.00 x 20, bias, 8 ply, military tread tire inflated to 25 psi.

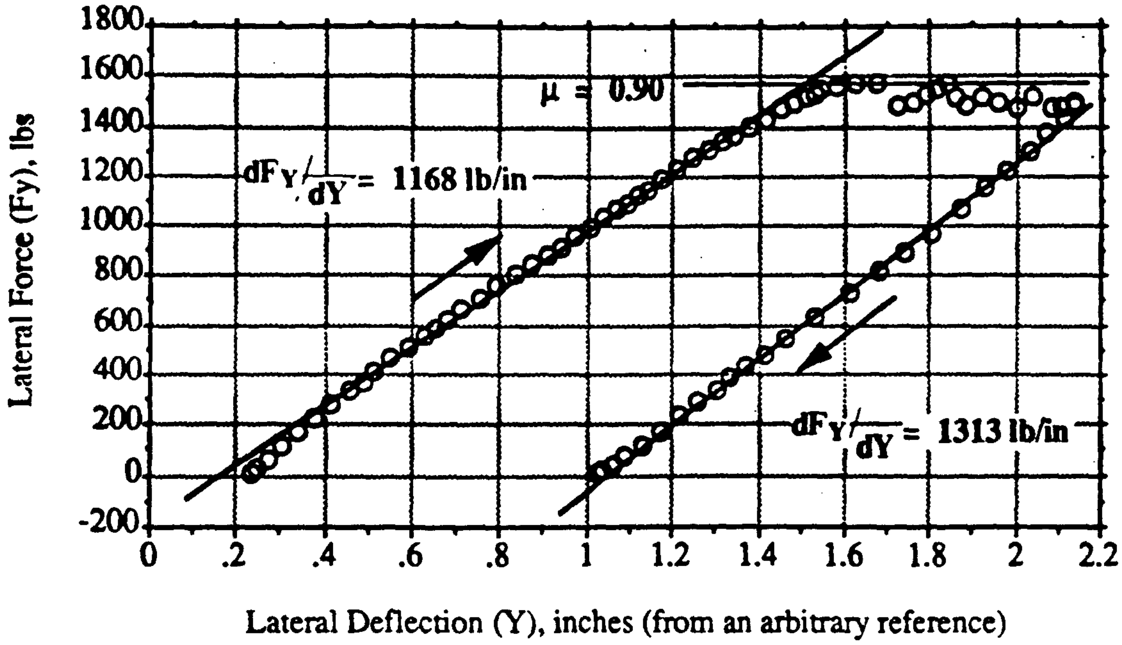


Lateral Deflection (Y), inches (from an arbitrary reference)

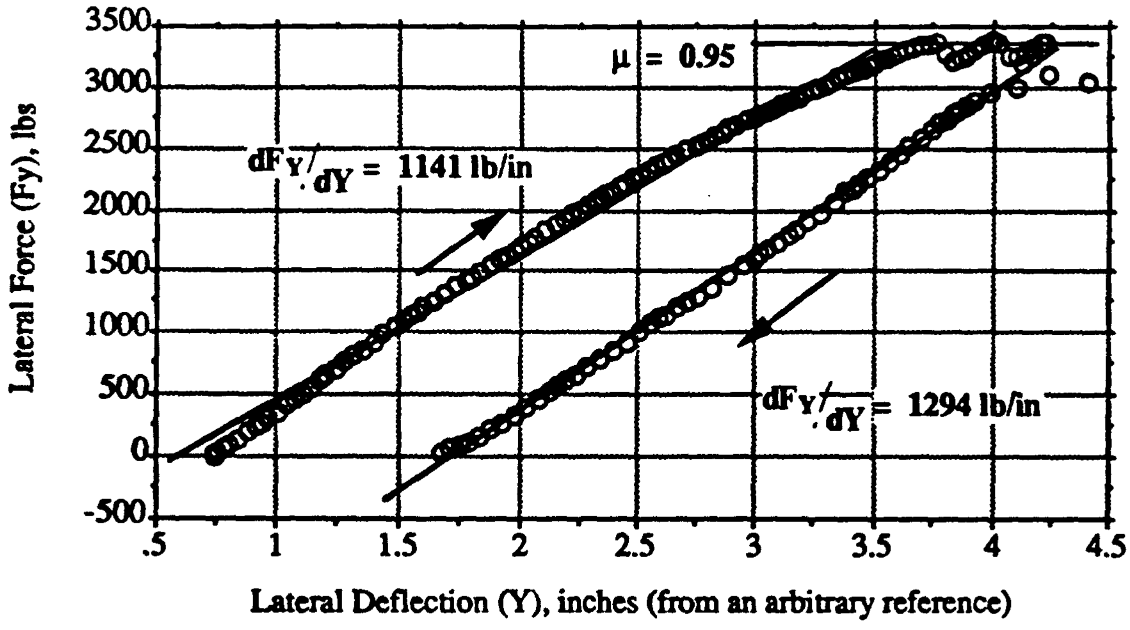
Lateral force deflection properties of the standing tire at a vertical load of 5250 pounds and inflated to 25 psi.

*Slide was not attained.
Lateral deflection of the tire carcass was excessive in this high load/low inflation configuration. The test was halted when bead separation appeared imminent.

Figure 3. (continued) Lateral force deflection properties of a 9.00 x 20, bias, 8 ply, military tread tire inflated to 25 psi.



Lateral force deflection properties of the standing tire
at a nominal vertical load of 1750 pounds and inflated to 50 psi.



Lateral force deflection properties of the standing tire
at a nominal vertical load of 3500 pounds and inflated to 50 psi.

Figure 4. Lateral force deflection properties of a 9.00 x 20, bias, 8 ply, military tread tire inflated to 50 psi.

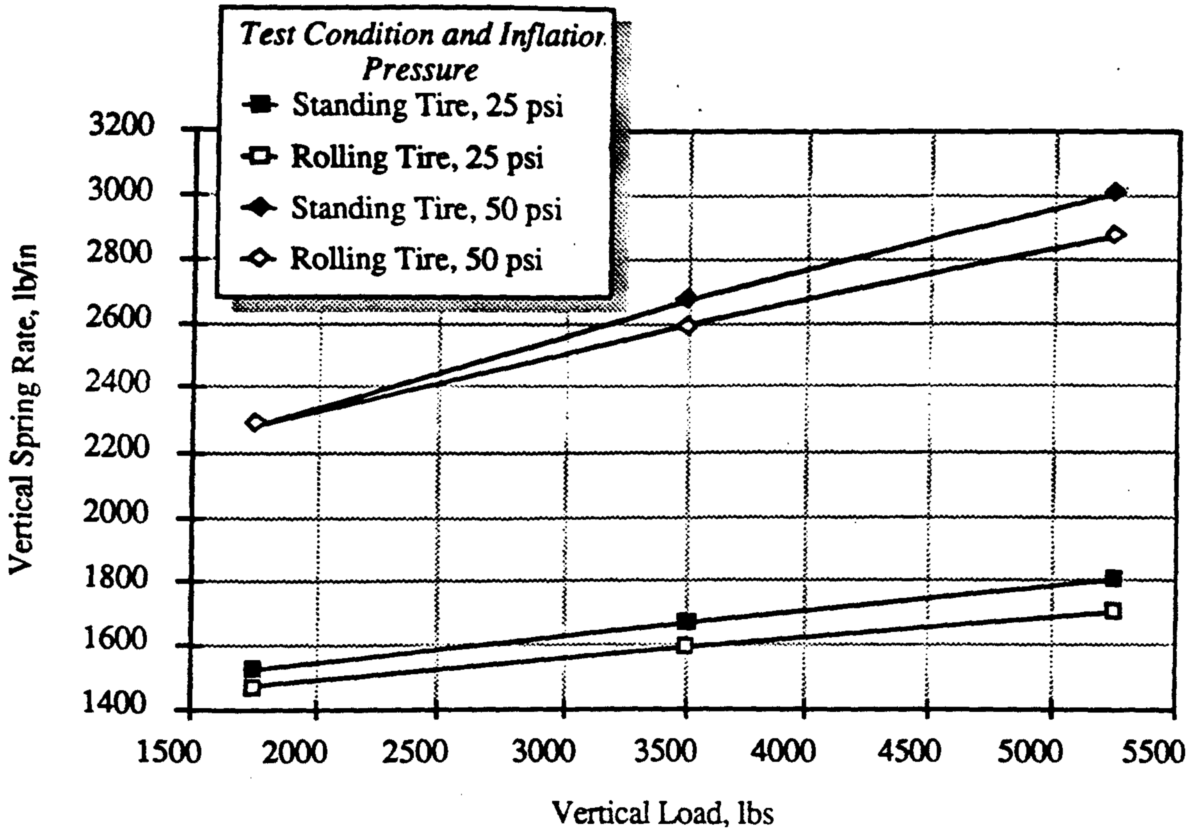


Figure 5. Vertical spring rate of a 9.00 x 20, bias, 8 ply, military tread tire.

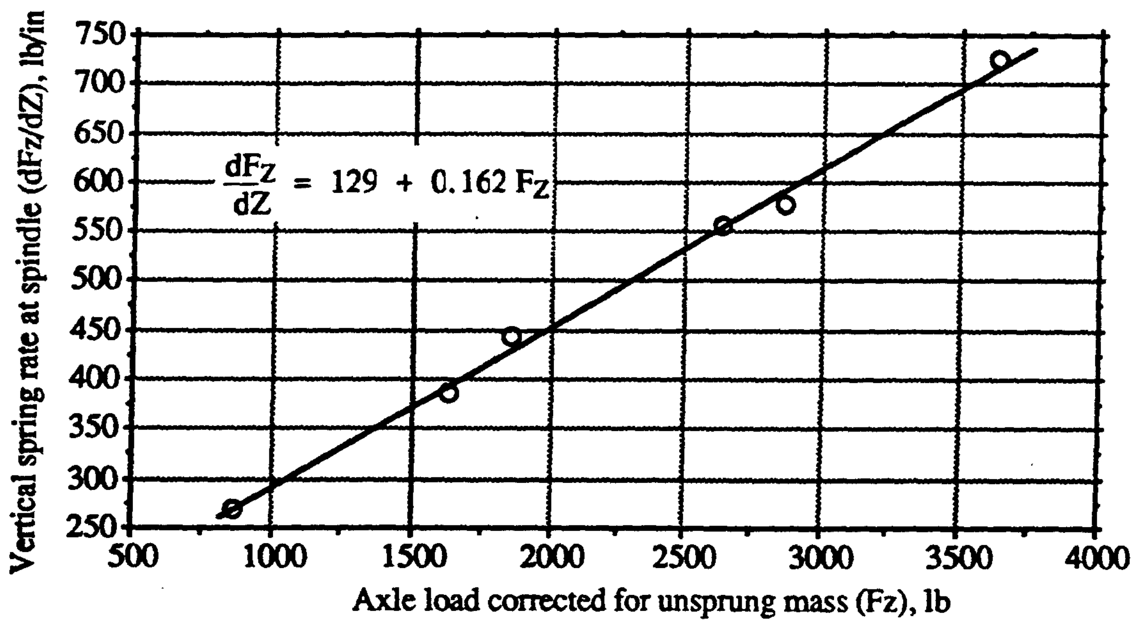


Figure 6. Vertical spring rate as a function of "corrected" axle load.

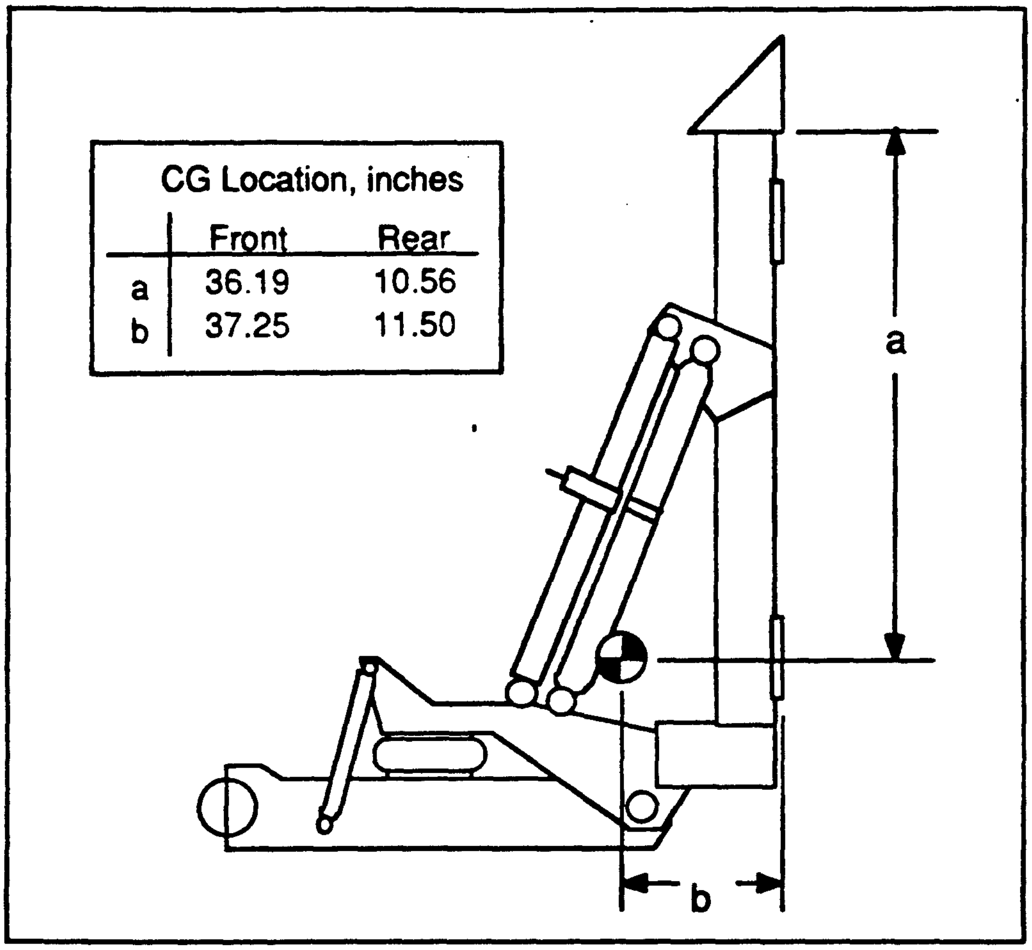


Figure 7. Location of the sprung mass center of gravity.

Table 4. Inertial Properties of the M840 Dolly Set				
		Moment of Inertia About the CG, in-lb-sec^2		
Component	Weight, pounds	Roll	Pitch	Yaw
Front Sprung Mass*	579	910	462	710
Front Unsprung Mass	988	3367		3367
Rear Sprung Mass*	567	1160	474	1044
Rear Unsprung Mass	870	3178		3188
Tire/Wheel/Drum Asym	252		81.3	
Tow Bar	152			
Single trailing arm	44			

* Includes trailing arms, locating links, and shocks.

Table 3. Suspension Parameters for the M840 Dolly Set

Dolly	Front			Rear		
Axle load, lb	*2000*	*3000*	*4000*	*2500*	*3500*	*4500*
Axle Load Corrected for Sprung Mass, lb	860	1860	2860	1630	2630	3630
Vertical Rate (at the Spindle), lb/in	269	445	577	386	556	725
Coulomb Friction, Large Motion, lb	133.5	145	165	125	135	150
Coulomb Friction, Moderate Motion, lb	75	90	85	50	85	80
Roll Center Height Above Ground, in	19.5	19.6	19.9	19.1	18.9	19.1
Roll Steer Coefficient, deg/deg	0.030	0.036	0.048	0.016	0.036	0.043
Roll Rate, in-lb/deg	5,720.	8,560.	11,100.	12,700.	16,300.	20,800.
Auxiliary Roll Stiffness, in-lb/deg	2,241.	2,804.	3,637.	4,363.	4,292.	5,142.
*Aligning Moment Steer Coef., deg/in-lb**	na	6.87E-5	7.54E-5	2.47E-5	2.30E-5	2.26E-5

* The change of the average of left and right wheel steer angles per unit change of the average of the left and right wheel aligning moments. Left and right aligning moment applied equally and simultaneously.

Table 1. Vertical Spring Rate of 9.00 x 20.00 Test Tire			
Inflation Pressure, psi	Test Condition	Vertical Load, lbs	Vertical Spring Rate, lb/in
25	Standing	1750	1521
25	Standing	3500	1669
25	Standing	5250	1806
25	Rolling	1750	1470
25	Rolling	3500	1591
25	Rolling	5250	1703
50	Standing	1750	2284
50	Standing	3500	2672
50	Standing	5250	3010
50	Rolling	1750	2283
50	Rolling	3500	2596
50	Rolling	5250	2875

Table 2. Lateral Spring Rate and Friction of 9.00 x 20.00 Test Tire				
Inflation Pressure, psi	Vertical Load, pounds	Standing Tire Lateral Spring Rate, lb/in		Sliding Friction Coefficient
		Rising	Falling	
25	1750	866	942	0.99
25	3500	738	744	1.00
25	5250	517	553	na
50	1750	1168	1313	0.90
50	3500	1141	1294	0.95
50	5250	990	1192	0.98

I hope that this report serves your needs. If I can answer any questions or be of futher service, please call.

Sincerely,

C. B. Winkler

cc.: R. Ervin
J. Thomson

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