FINAL REPORT ON
SPECIAL STUDY OF VEHICLE STABILITY TESTS
OF
TRUCK, UTILITY, 1/4-TON, 4X4,
M151 AND TRUCK, CARGO,
3/4-TON, 4X4, M37

BY
T. COOKE
FEBRUARY 1968

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SPECIAL STUDY OF VEHICLE STABILITY TESTS OF
TRUCK, UTILITY, 1/4-TON, 4X4, M151
AND TRUCK, CARGO, 3/4-TON, 4X4
M37.

FINAL REPORT, Nov 68 - Oct 69

BY

T. COOKE
FEB 68

45p.

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ABSTRACT

Tests were conducted from November 1966 to October 1967 at Aberdeen Proving Ground, Maryland to compare the stability characteristics of the 1/4-ton, M151 and the 3/4-ton, M37B1 trucks and to determine course configurations and procedures suitable for vehicle stability evaluations. Data were also obtained, both statically and dynamically, in an attempt to provide input to mathematical model computations relative to vehicle stability. Instability of both the M151 and the M37 vehicles was attained while negotiating a 40-foot transient steering course; handling of the M151 was superior to that of the M37 while negotiating a 25-foot transient steering course. Neither handling problems nor instability were induced by the constant steering, rectangular bump, or resonance bump courses. Suspension component test data showed wide variations in performance of similar items and nonlinearities which would complicate mathematical model computations. A vehicle stability test procedure was not derived. Recommendations were that the transient steering course be considered essential for stability evaluations and that further efforts be directed toward design of a course which will induce instability at low road speeds.

FOREWORD

Development and Proof Services was responsible for conducting the study and preparing the report.
SECTON 1. INTRODUCTION

1.1 BACKGROUND

Within D&PS, testing of vehicles with respect to handling and stability has been limited to the safety evaluations described in TECP 700-700, Material Test Procedure 2-2-508, and the subjective judgment of experienced drivers. In addition, limited efforts have been made to establish a mathematical model in which known vehicle characteristics could be applied to derive a stability index.

The task described in this report was initiated as a first step toward establishing a vehicle stability test procedure. It includes a stability comparison of the M151 and M37B1 trucks as well as the acquisition of vehicle and component data which could be used in a mathematical model.

1.2 DESCRIPTION OF MATERIEL

Facility fleet M151 and M37B1 vehicles, USA Reg Nos. 2J869 and 3C3063 respectively, were used for this test. Pertinent characteristics are shown in Table 1.2-1.
Table 1.2-I. Characteristic Data

<table>
<thead>
<tr>
<th></th>
<th>M1S1</th>
<th>M37H1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tires</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Size</td>
<td>7.00 x 16</td>
<td>9.00 x 16</td>
</tr>
<tr>
<td>Operating pressures, psi</td>
<td>20 front, 25 rear</td>
<td>40</td>
</tr>
<tr>
<td>Wheelbase, inch</td>
<td>85</td>
<td>112</td>
</tr>
<tr>
<td>Tread width, inch</td>
<td>53</td>
<td>62</td>
</tr>
<tr>
<td><strong>Suspension</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>Individual wheel</td>
<td>Live axle</td>
</tr>
<tr>
<td>Springs</td>
<td>Coil</td>
<td>Leaf</td>
</tr>
<tr>
<td>Shock absorbers</td>
<td>Hydraulic telescopic</td>
<td>Hydraulic, telescopic</td>
</tr>
<tr>
<td>Engine horsepower, max</td>
<td>71 at 4000 rpm</td>
<td>78 at 2300 rpm</td>
</tr>
<tr>
<td>Maximum road speeds (2-wheel drive), mph</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4th gear</td>
<td>66</td>
<td>55</td>
</tr>
<tr>
<td>3rd gear</td>
<td>40</td>
<td>32</td>
</tr>
<tr>
<td>2nd gear</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td>1st gear</td>
<td>11</td>
<td>9</td>
</tr>
</tbody>
</table>

The five basic test course configurations used during this test are as follows:

a. Constant steering courses.
c. Double rectangular bump courses.
d. Resonance (trapezoidal) bump courses.
e. Transient steering courses.

Sketches of these courses are presented in Appendix I.

1.3 TEST OBJECTIVES

To compare the handling and stability of the M1S1 and M37H1 trucks and to develop test procedures for quantitative evaluations of vehicle stability.

1.4 SUMMARY OF RESULTS

The M1S1 truck experienced wheel lift-off and the M37H1 truck lost directional stability while negotiating the transient steering course.
Both vehicles remained stable while negotiating the rectangular bump, constant steering, and resonance bump courses.

Resonant frequencies of each vehicle were obtained during operation over the resonance bump courses and are presented in Table 2.1-1.

Tests of suspension components showed nonlinearities in the performance of both M151 and M37 shock absorbers and front springs of the M37 truck; a wide variation was also indicated in the performance of identical shock absorbers.

1.5 CONCLUSIONS

It is concluded that:

a. A procedure for vehicle stability evaluations was not developed during this test program; the 40-foot transient steering course provides the conditions necessary to cause vehicle instability but the high road speeds required to achieve this instability depend too much on driver ability (ref pars. 2.1.3 and 2.1.4).

b. Safety considerations, driver apprehensions, and economics of destructive testing also inhibit an acceptable vehicle stability evaluation (ref par. 2.1.4).

c. The constant steering, rectangular bump, and resonance bump courses were ineffective in inducing handling problems or instability with either vehicle (ref par. 2.1.3).

d. Test results were inconclusive as to which vehicle was more stable; the handling characteristics of the M151 vehicle, however, were superior to those of the M37 when negotiating the 25-foot-radius transient steering course (ref pars. 2.1.3 and 2.1.4).

e. The nonlinearity of suspension components as well as variations in performance between similar components will complicate mathematical model computations (ref par. 2.3.4).

1.6 RECOMMENDATIONS

It is recommended that:

a. The transient steering test course be considered essential for vehicle stability evaluations.
b. Further efforts be made in the design of a transient steering course which will produce vehicle instability at low road speeds (less than 20 mph).

c. The following be considered for any future instrumented stability tests:

1) Use of matched suspension components.

2) Direct measurement of vehicle body pitch, roll, and yaw angles and velocities.

3) Use of low frequency response accelerometers.
SECTION 2. DETAILS OF TEST

2.1 DYNAMIC TESTING

2.1.1 Objectives

To operate the vehicles over various test course configurations and determine stability and handling characteristics and resonant frequencies.

To develop procedures for quantitative evaluation of vehicle stability and handling.

2.1.2 Method

2.1.2.1 Preparation. Vehicles were equipped with roll bars, outriggers on both sides, driver's seat belts, and instrumentation. Two multichannel, radio-link telemetry transmitters and a telemetry sending antenna were also installed. Figures 2.1-1 and 2.1-2 show the vehicles as tested.

The instrumentation used to determine resonant frequencies consisted of a potentiometer-negator-motor assembly with related circuitry attached to the vehicle body, above each road wheel, with the negator motor drive wires attached to the axles on the M37 truck and control arms on the M151 truck.
A trailing fifth wheel was mounted at the rear of each vehicle. Two generators were attached to the wheel, one for the speed indicator used by the driver and the other for recording.

Four accelerometers and a steering wheel displacement potentiometer were also installed to accumulate data for mathematical model inputs; the data were not used for stability evaluations presented in this report.

2.1.2.2 Testing. The test course layouts listed in paragraph 1.2 were designed to impose conditions inducing vehicular handling problems or instability and to provide inputs for determining resonant frequencies. A detailed description of each course and its desired effects on vehicular characteristics follows:

a. Constant Steering Courses. The vehicles were operated at full steer (minimum turning radii) and in circles of 50- and 100-foot radii to determine handling and stability characteristics resulting from centrifugal forces and the effects of striking vertical obstacles while in this operational mode. Tests were conducted first on a level paved surface without bumps and then with both 2- and 4-inch-high single rectangular bumps (8-inches wide) located at the inside wheel positions (ref page 1-1).

b. Single-Side Rectangular Bump Courses. Stability and handling were evaluated while operating on a paved straightaway and striking vertical bumps with the wheels on one side of each vehicle. Bumps were 2 and 4 inches high and 8 inches wide, spaced as follows (ref page 1-2):

1) Single bump.

2) Two bumps, one-half wheelbase apart.

3) Two bumps, one wheelbase apart.

c. Double Rectangular Bump Course. Stability and handling were evaluated while operating on a paved straightaway and striking vertical bumps with wheels on both sides of each vehicle. Bumps were 2 and 4 inches high and 8 inches wide, spaced as follows (ref page 1-2):

1) Single bump, right and left wheels contact at the same time.

2) Two bumps, one-half wheelbase apart; one on left side, the other on right side of vehicle.
3) Two bump, one wheelbase apart; one on left side, the other on right side of vehicle.

d. Resonance Bump Courses. Trapezoidal bumps were fabricated to determine resonant frequencies dynamically, in lieu of the drop tests requested in the proposed task, and to determine if resonance build-up in negotiating these courses would produce instability or handling problems. Three different layouts were made to provide for vertical, pitch, and roll inputs (ref page 1-3).

e. Transient Steering Courses. A 25-foot and a 40-foot radius sine wave course, on a level paved surface, was negotiated to determine the effects of sudden changes in direction of steering on vehicle handling and stability. The courses required three steering maneuvers in rapid succession. Operations were in both directions on each course except where an initial right steer into the 25-foot-radius turn was required; the approach to that end of the course was too short to permit high speed operation (ref page 1-4).

Testing on each of the courses listed was started at or near minimum vehicle speed. Speeds were then increased at selective increments. All test run data were recorded on magnetic tape which is available in the Engineering and Environmental Test Branch Tape Library.

2.1.3 Results

2.1.3.1 Transient Steering Course. The rear inside wheel of the M151 truck lifted off the ground, with outrigger wheel contact, when negotiating the 25- and 40-foot-radius transient steering courses at road speeds of approximately 18 and 24 mph respectively. In both cases, this condition occurred during the second steering maneuver. The vehicle slid off the course when the wheel lifted but did not lose directional stability; the driver was able to get back on course and complete the test run. A reduction in road speed was experienced, however, after wheel lift-off due to the loss of traction. Handling characteristics of the M37 vehicle were such that the 25-foot-radius transient steering course could not be followed at speeds greater than approximately 19 mph. Two different drivers were unable to follow the course contour after the initial steering maneuver. On the 40-foot-radius transient steering course, directional stability was lost at a road speed of approximately 24 mph during the second steering maneuver. The loss of directional stability was attributed to a combination of slow steering response, the severe body roll from one side to the other as the direction of steer was reversed, and sliding (loss of rear wheel traction).
2.1.3.2 Constant Steering Course. Loss of traction was evidenced on both vehicles traversing the constant steering course both with and without bumps but at no time was wheel lift-off or loss of directional control experienced. Some driver apprehension was apparent during operations on the 100-foot-radius turns which may have reduced vehicle maximum speed potential for this turn. Average maximum speeds obtained and vehicle turning radii are presented in Table 2.1-I.

Table 2.1-I. Constant Steering Course Test Results

<table>
<thead>
<tr>
<th>Turning Radius (Curb-to-Curb), ft</th>
<th>Avg Max Speed, mph</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Truck, M151</strong></td>
<td></td>
</tr>
<tr>
<td>16.7 (min)</td>
<td>13.0</td>
</tr>
<tr>
<td>52.3</td>
<td>21.7</td>
</tr>
<tr>
<td>102.6</td>
<td>28.3</td>
</tr>
<tr>
<td><strong>Truck, M37</strong></td>
<td></td>
</tr>
<tr>
<td>25.6 (left turn) min</td>
<td>14.5</td>
</tr>
<tr>
<td>23.7 (right turn)</td>
<td>22.4</td>
</tr>
<tr>
<td>103.6</td>
<td>29.4</td>
</tr>
</tbody>
</table>

2.1.3.3 Resonance Bump Courses. Resonance build-up in the vertical, pitch, or roll planes was not observed while operating on the resonance bump courses. This was attributed directly to the damping afforded by the vehicle shock absorbers. Examples of this damping effect are shown in page 1-5 and are discussed further in paragraph 2.3.4. The resonant frequencies obtained while operating on these courses are shown in Table 2.1-II.

Table 2.1-II. Resonant Frequencies

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Vert Input</th>
<th>Pitch Input</th>
<th>Roll Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>M151</td>
<td>1.32</td>
<td>1.86</td>
<td>1.42</td>
</tr>
<tr>
<td>M37</td>
<td>1.23</td>
<td>1.72</td>
<td>1.00</td>
</tr>
</tbody>
</table>

2.1.3.4 Rectangular Bump Courses. Neither instability nor handling problems were induced in either vehicle during operations over the single-side and double bump courses.
2.1.4 Analysis

A definition of what constitutes "vehicle instability" could not be found. During this test, the vehicle was considered instable when wheel lift-off occurred in a roll attitude and when sliding (side slipping) could not be controlled by the driver.

The instability which occurred during transient steering course operations was possible because the steering systems are not heavily damped. This is necessary to give the driver maneuverability. As a result, a left turn tilts the body right and stores energy in the suspension system. A sudden right turn tends to throw the body to a left tilt. The resulting roll velocity $\dot{\beta}$ is thus much higher at the turning point than for a single turn. If the angular kinetic energy

$$KE = \frac{1}{2} I_\beta \dot{\beta}^2,$$

Where:

$I_\beta$ = Roll moment of inertia.

$\dot{\beta}$ = Roll velocity

at the "bottoming out" point is great enough to lift the vehicle to the instability point

$$PE = mg \left[ \sqrt{y/2 + \left( \frac{TW}{2} \right)^2} - y \right],$$

Where:

$PE$ = Potential Energy

$m$ = Mass

$g = 32.2$ ft/sec$^2$

$y$ = CG above ground

$TW$ = Tread width

then the vehicle turns over.

The true rocking stability of the vehicles is difficult to evaluate because of the outriggers. Despite the small amount of weight added by the outriggers, the roll moment of inertia, $I_\beta$, was greatly increased; that is,

$$I = \sum_i m_i r_i^2$$

Where:

$m_i$ = outrigger mass

$r_i$ = radius of gyration

and the $r_i$'s are large for each $m_i$ of the outriggers.
Stability was maintained during the constant steering course tests because the static force required to turn the vehicles over was greater than the maximum traction of the rear tires. The suspension plays no role in this test provided the force build-up is slow. Instability occurs when

\[ F_s = \frac{mV^2}{R} \frac{TW}{mg \, 2y} \]

Where:
- \( F \) = Force.
- \( m \) = Mass.
- \( V \) = Constant velocity.
- \( R \) = Radius on which CG moves.
- \( g \) = 32.2 ft/sec².
- \( TW \) = Tread width.
- \( y \) = CG above ground.

\[ \frac{TW}{2y} \]

The expression \( 2y \) is found to be: M151 \( \frac{1.16}{1.10} \)

The tire-road surface coefficient of friction is approximately 0.7; thus, instability at a constant steer with either vehicle is impossible. Directional instability may result, however, from vehicle sliding.

The M151 and M37 vehicles were different in almost every aspect (size, weight, suspension, steering geometry, and horsepower to weight ratio) but test results were inconclusive as to which vehicle is more stable. The M151 truck did experience wheel lift-off on the 40-foot-radius transient steering course and the M37 truck did not, but the loss of directional stability with the M37 on this course constitutes an equally instable condition.

The 40-foot-radius transient steering course appears to be best suited for stability evaluations of those used during this test but it has definite drawbacks. First, test results rely to a great extent on driver ability due to the high road speeds at which instability occurs and the rapid directional steering changes required. There must also be some apprehension on the part of the driver due to the severe vehicle rocking in addition to anticipation of the impending instable condition. A second factor is that the test setup must provide for driver safety and be nondestructive which necessitates some change in vehicle configuration; this can, as discussed previously, influence final test results and would be further complicated should testing with trailers be attempted. Finally, the course would not be suitable for testing larger vehicles which would not have sufficient maneuverability to negotiate the turns.
While limited use was made of the recorded dynamic data in this report, all data were examined and appear satisfactory except for those obtained from the accelerometers which did not have the low frequency response desired. Also, the potentiometer-negator motor drive assemblies were constant problems during the test due to the drive sticking or a high noise to signal ratio from the potentiometer. An unsuccessful effort was made prior to testing to obtain directional gyros for determination of body pitch, roll, and yaw. This instrumentation would provide actual body angles and velocities instead of relative deflections between body and wheels or axles.

2.2 WEIGHT DISTRIBUTION AND CENTER OF GRAVITY LOCATIONS

2.2.1 Objective

To determine the static weight distribution and center of gravity locations of the M151 and M37 vehicles.

2.2.2 Method

Weight distribution of each vehicle was determined using individual wheel load cells.

Center of gravity locations were computed from weight reactions for horizontal and lateral locations and by the suspension method for the vertical location.

Data were obtained with safety fixtures, instrumentation, and telemetry equipment installed with one exception; when the vertical center of gravity was determined by the suspension method, the outriggers had to be removed.

2.2.3 Results

Load distributions are given in Table 2.2-1. Center of gravity locations are shown in Table 2.2-II.
Table 2.2-I. Load Distribution

<table>
<thead>
<tr>
<th>Wheel Location</th>
<th>Weight, lb</th>
<th>( \text{Truck, M151} )</th>
<th>( \text{Truck, M37} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Without Driver and Outriggers} )</td>
<td>( \text{With Driver and Outriggers} )</td>
<td>( \text{Without Driver and Outriggers} )</td>
<td>( \text{With Driver and Outriggers} )</td>
</tr>
<tr>
<td>Left front</td>
<td>670</td>
<td>760</td>
<td>1570</td>
</tr>
<tr>
<td>Right front</td>
<td>720</td>
<td>680</td>
<td>1570</td>
</tr>
<tr>
<td>Left rear</td>
<td>770</td>
<td>890</td>
<td>1960</td>
</tr>
<tr>
<td>Right rear</td>
<td>700</td>
<td>815</td>
<td>1970</td>
</tr>
<tr>
<td>Total</td>
<td>2860</td>
<td>3145</td>
<td>7070</td>
</tr>
</tbody>
</table>

Table 2.2-II. Center of Gravity Location

<table>
<thead>
<tr>
<th>( \text{Truck, M151} )</th>
<th>( \text{Truck, M37} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Driver and Outriggers</td>
<td>With Driver and Outriggers</td>
</tr>
<tr>
<td>Without Driver and Outriggers</td>
<td>With Driver and Outrigers</td>
</tr>
<tr>
<td>Horizontal, forward of rear wheel centerline, in.</td>
<td>40.3</td>
</tr>
<tr>
<td>Lateral, distance from longitudinal centerline, in.</td>
<td>0.2 Left</td>
</tr>
<tr>
<td>Vertical, above ground, in.</td>
<td>22.9</td>
</tr>
</tbody>
</table>

ND = Not determined

2.2.4 Analysis

Not applicable.

2.3 CALIBRATION OF SUSPENSION COMPONENTS

2.3.1 Objective

To determine the following:

a. Shock absorber force-velocity characteristics.

b. Spring forces.

c. Steering characteristics.
2.3.2 Method

2.3.2.1 Shock Absorber Characteristics. The shock absorbers were secured in a dynamic cycling machine as shown in Figure 2.3-1.

![Figure 2.3-1: Shock Absorber Test Setup.](image)

The base of the fixture was secured to a load cell calibrated for both extension and compression loads. Velocities were determined using a potentiometer-negator motor assembly with necessary related circuitry.

The load cell and potentiometer were connected to a recording oscillograph and tests were run at three different speeds and at a stroke length of 3 inches.

2.3.2.2 Spring Forces. After the vehicle bodies had been blocked up and anchored to a bed plate, forces required to vertically displace the vehicle springs were determined using calibrated load cells and a strain indicator. Forces were measured by lifting the M151 truck wheels at the wheel lifting eyes and jacking up the front and rear axles of the M37 vehicle.

Calibrations of the relative body-to-wheel displacement potentiometers (par. 2.1.2) were also accomplished during this test.

2.3.2.3 Steering Characteristics. The front wheels of each vehicle were positioned on portable wheel angle (toe-out) machines and displacement potentiometers were attached to the ends of the steering sector shafts. Cardboard disks were secured to the steering wheels with fixed pointers positioned at their periphery. The following were then determined:
a. Free play (steering wheel movement prior to sector shaft turning).

b. Road wheel angle at various steering wheel positions.

c. Total steering wheel travel.

2.3.3 Results

2.3.3.1 Shock Absorber Characteristics. Results are shown in Table 2.3-1.

Table 2.3-1. Shock Absorber Characteristics

<table>
<thead>
<tr>
<th>Left Front</th>
<th>Right Front</th>
<th>Left Rear</th>
<th>Right Rear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vel, in./sec</td>
<td>Force, lb</td>
<td>Vel, in./sec</td>
<td>Force, lb</td>
</tr>
<tr>
<td>14.4</td>
<td>155</td>
<td>12.5</td>
<td>185</td>
</tr>
<tr>
<td>8.8</td>
<td>95</td>
<td>8.8</td>
<td>125</td>
</tr>
<tr>
<td>5.8</td>
<td>65</td>
<td>6.1</td>
<td>85</td>
</tr>
</tbody>
</table>

Condition: Compression.

<table>
<thead>
<tr>
<th>Truck, M151</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition:</td>
</tr>
<tr>
<td>Rebound</td>
</tr>
<tr>
<td>14.4</td>
</tr>
<tr>
<td>8.8</td>
</tr>
<tr>
<td>5.8</td>
</tr>
</tbody>
</table>

Condition: Compression.

<table>
<thead>
<tr>
<th>Truck, M37a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition:</td>
</tr>
<tr>
<td>Rebound</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>-</td>
</tr>
</tbody>
</table>

Condition: Rebound.

| -           | -            | -         | -          | 13.2       | 780    | 13.2   | 645    |
| -           | -            | -         | -          | 8.9        | 535    | 8.8    | 485    |
| -           | -            | -         | -          | 6.1        | 255    | 6.1    | 285    |

a Front shock absorber data not used (ref par. 2.3.4.1).
2.3.3.2 Spring Calibrations. Results for M151 vehicle are shown in Table 2.3-11.

Table 2.3-II. Average Forces Required to Vertically Displace M151 Road Wheels

<table>
<thead>
<tr>
<th>Wheel Position</th>
<th>Avg Force, lb-in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left front</td>
<td>118</td>
</tr>
<tr>
<td>Right front</td>
<td>125</td>
</tr>
<tr>
<td>Left rear</td>
<td>120</td>
</tr>
<tr>
<td>Right rear</td>
<td>124</td>
</tr>
</tbody>
</table>

Forces required to raise the M37 axles ranged from 730 to 945 lb/in. vertical displacement on the front axle and from 145 to 640 lb-in. on the rear axle. Graphical presentations of these data are given in pages I-9 through I-16.

2.3.3.3 Steering Characteristics. Results are shown in Table 2.3-III.

Table 2.3-III. Steering Characteristics

<table>
<thead>
<tr>
<th>Condition</th>
<th>M151</th>
<th>M37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Steering Wheel Travel, Stop to Stop, No. turns</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Road Wheel Angles at Full</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steering Wheel Travel, deg Left Turn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left wheel</td>
<td>32.0</td>
<td>26.5</td>
</tr>
<tr>
<td>Right wheel</td>
<td>23.5</td>
<td>20.5</td>
</tr>
<tr>
<td>Right Turn</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left wheel</td>
<td>23.0</td>
<td>24.0</td>
</tr>
<tr>
<td>Right wheel</td>
<td>31.5</td>
<td>28.5</td>
</tr>
<tr>
<td>Free Play, steering wheel turns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left turn</td>
<td>0.09</td>
<td>0.20</td>
</tr>
<tr>
<td>Right turn</td>
<td>0.08</td>
<td>0.14</td>
</tr>
<tr>
<td>Total</td>
<td>0.17</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Complete steering characteristics are presented in pages I-17 and I-18.
2.3.4 Analysis

2.3.4.1 Shock Absorber Characteristics. Cycling machine capabilities restricted the test to the 3-inch stroke and a relatively small velocity range.

Test results obtained for the M37 truck front shock absorbers were questionable and therefore are not presented in this report. Two new shock absorbers were obtained to preclude the possibility of the originals being faulty; however, supplementary calibrations could not be scheduled prior to installation on the vehicle due to time and workload considerations.

Ordnance Corps drawing 8359994 shows performance specifications for the M151 front shock absorbers at 320 to 470 pounds and 65 to 155 pounds rebound and compression respectively, with a 3-inch stroke at a velocity of 8.5 inches per second. Actual test data fell within these ranges (325 to 340-pound rebound, 95 to 125-pound compression at 8.8 inches per second velocity). Similar specification requirements were not available for the M151 rear shock absorbers or for the M37 vehicle.

The data for both vehicles shock absorbers (pages I-6 through I-8) indicate that forces are linear in compression but are nonlinear in rebound.

2.3.4.2 Spring Calibrations. Page I-13 shows the total force on the M37 front axle to be relatively linear through the first 4 inches of travel, approximately 780 lb/in. deflection, then increasing to approximately 930 lb/in. This change is attributed to the fact that the spring curvature is reversed after being displaced 4 inches (page I-15).

2.3.4.3 Steering Characteristics. Steering characteristics of the two vehicles are quite different as shown by the comparison presented in Table 2.3-IV.

Table 2.3-IV. Comparison of Steering Characteristics

<table>
<thead>
<tr>
<th></th>
<th>M151</th>
<th>M37</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steering Gear Ratio</td>
<td>16.4:1</td>
<td>23.2:1</td>
</tr>
<tr>
<td>Road Wheel Travel, Stop-to-Stop/ Total Steering Wheel Travel, deg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left turn</td>
<td>16</td>
<td>11.8</td>
</tr>
<tr>
<td>Right turn</td>
<td>15.8</td>
<td>12.7</td>
</tr>
<tr>
<td>Free Play, % full steer</td>
<td>4.35</td>
<td>7.5</td>
</tr>
</tbody>
</table>
Notes: 1. Tests were run w/o bumps and w/2 in. and 4 in. high bumps.
2. Bump width was 8 in. in direction of travel.
3. Vehicles were operated at minimum turning radius and 50 and 100 ft radius turning circles, right and left steers.
VEHICLE STABILITY TEST

SKETCH SHOWING LAYOUT OF RECTANGULAR BUMP COURSES

Single Side Bumps

\[ \begin{array}{c}
A \\
B \\
B \\
C \\
\end{array} \]

\[ \begin{array}{c}
\text{\( \frac{1}{2} \) Wheel Base} \\
\text{Direction of Travel} \\
\text{1 Wheel Base} \\
\end{array} \]

Double Bump Course

\[ \begin{array}{c}
A \\
B \\
C \\
\end{array} \]

\[ \begin{array}{c}
\text{\( \frac{1}{2} \) Wheel Base} \\
\text{1 Wheel Base} \\
\end{array} \]

Notes:
1. Tests were conducted with bumps 2 and \( \frac{1}{2} \) inches high.
2. All bumps were 8 inches wide in direction of travel.
3. Bumps A, B, and C were separated sufficiently to allow for complete damping of suspension.
VEHICLE STABILITY TESTS

TRAPEZOIDAL BUMP COURSE LAYOUTS
M37 Truck Course Configurations

Y Course (vertical Input)

Alpha Course (Pitch Input)

Beta Course (Roll Input)

Note: Dimensions are in inches.
VEHICLE STABILITY TESTS

SKETCH OF TRANSIENT STEERING COURSE

Surface: Level Paved

Dual Lines Painted on Road Surface, 5 Ft Apart.

400

300

200

100

0

46.1 Ft

40 Ft Radius Curve

25 Ft Radius Curve

44.1 Ft

DISTANCE - FEET
VEHICLE STABILITY TESTS

TYPICAL TRACES OF RELATIVE DEFLECTION BETWEEN WHEEL AND BODY WHILE NEGOTIATING RESONANCE COURSE B (ROLL INPUT) AT 5 MPH.

M151

Direction of Travel

M37
VEHICLE STABILITY TESTS

TRUCK, CARGO, 1/4 TON, 4x4, M151, USA REG. NO. 2J8869

FRONT SHOCK ABSORBER PERFORMANCE CHARACTERISTICS

Date of Test: 9 Jan 1967

VELOCITY - IN/SEC

VELOCITY - IN/SEC

REBOUND - LBS

COMPRESSION - LBS

Front-Left

Front-Right

Engr & Environmental Test Br.
Development & Proof Services
Aberdeen Proving Ground, Md.
TCooke/skc/16 January 1968
VEHICLE STABILITY TESTS

TRUCK, CARGO, 1/4 TON, 4x4, M151, USA REG. NO. 2J8864

REAR SHOCK ABSORBER PERFORMANCE CHARACTERISTICS

Date of Test: 9 Jan 1967

Rear-Left
Rear-Right

VELOCITY - IN/SEC

ENGR & ENVIRONMENTAL TEST BR.
DEVELOPMENT & PROOF SERVICES
ABERDEEN PROVING GROUND, MD.

T/C/SC/16 January 1968
VEHICLE STABILITY TESTS

TRUCK: Cargo, 3/4 Ton, 4x4, M37B1, USA REG. NO. 3C3063

REAR SHOCK ABSORBER PERFORMANCE CHARACTERISTICS

Date of Test: 2 Feb 1967

Engr & Environmental Test Br. Development & Proof Services
Aberdeen Proving Ground, Md.
T Cooke/نك/16 January 1966
VEHICLE STABILITY TESTS

STATIC FORCES REQUIRED TO DISPLACE FRONT WHEELS OF TRUCK, UTILITY,
1/4 TON, 4X4, M151, USA REG. NO. 2J8869

Date of Test: 3 Feb & 6 Mar 67

--- W/O Shock Absorbers Installed
×---× W/Shock Absorbers Installed

Tests were started with suspension at full travel. Force was measured at centerline of wheel lifting eye. Tires were removed.

VERTICAL DISPLACEMENT - INCHES

I-9
Tests were started with suspension at full travel and with shock absorbers installed. Force was measured at the centerline of wheel lifting eye. Tires were removed.

VERTICAL DISPLACEMENT - INCHES

Engr & Environmental Test Br.
Development & Proof Services
Aberdeen Proving Ground, Md.
T.Cooke/skc/16 January 1968
VEHICLE STABILITY TESTS

FRONT WHEEL LATERAL AND VERTICAL DISPLACEMENTS OF TRUCK, UTILITY, 1/4 TON, 4x4, M151, USA REG. NO. 2J8869

Dates of Test: 3 Feb & 6 Mar 67

---

Maximum suspension travel with shock absorbers installed. Horizontal distance from lower arm bushings (on frame) centerline to outer diameter of wheel lifting eye assembly = 22-11/16 inches.

---

Engr & Environmental Test Br.
Development & Proof Services
Aberdeen Proving Ground, Md.
TCooke/ekc/16 January 1969
VEHICLE STABILITY TEST

REAR WHEEL LATERAL AND VERTICAL DISPLACEMENTS OF TRUCK, UTILITY, 1/4 TON, 4X4, M151, USA REG. NO. 3C3063

Date of Test: 6 March 1967

Maximum suspension travel with shock absorbers installed. Horizontal distance from suspension arm bushings (on frame) centerline to outer diameter of wheel lifting eye assembly = 28-9/16 inches.
VEHICLE STABILITY TESTS

STATIC FORCES REQUIRED TO DISPLACE FRONT AXLE OF TRUCK, CARGO, 3/4 TON. 4x4, M37B1, USA REG. NO. 3C3063

Date of Test: 9 March 1967

Test was started with axle approximately level. With no load on axle, the right and left sides were lowered by 1 inch & 1/8 inch, respectively. Shock absorbers were removed.

VERTICAL DISPLACEMENT - INCHES

FORCE - POUNDS

TOTAL AXLE

INDIVIDUAL LOAD CELLS

Engr & Environmental Test Br.
Development & Proof Services
Aberdeen Proving Ground, Md.
TCooke/akc/16 January 1968
VEHICLE STABILITY TESTS

STATIC FORCES REQUIRED TO DISPLACE REAR AXLE OF TRUCK, UTILITY, 3/4 TON, 4x4, M37B1, USA REG. NO. 3C3063

Date of Test: 10 March 1967

Test was started with axle approximately level. With no load on axle, the right and left sides were lowered by 1/8 and 1/16 inches, respectively. Shock absorbers were removed.
VEHICLE STABILITY TESTS

FRONT SPRING DEFLECTIONS OF TRUCK, 3/4 TON, 4x4, M37B1, USA REG. NO. 3C3063

Date of Test: 9 March 1967

Spring Length = Right 45.6 In.
Left 45.46 In.

VERTICAL DISPLACEMENT OF AXLE-IN.

Engr & Environmental Test Br
Development & Proof Services
Aberdeen Proving Ground, Md.
TCooke/skc/16 January 1968
VEHICLE STABILITY TESTS

REAR SPRING DEFLECTIONS OF TRUCK, 3/4 TON, 4x4, M37BL, USA REG. NO. 3C3063

Date of Test: 10 March 1967

Note: Shock absorbers were removed.

Spring Length = 51.875 In. Right Side
52.175 In. Left Side

Engr & Environmental Test Br
Development & Proof Services
Aberdeen Proving Ground, Md.
Tcokc/skc/16 January 1968
VEHICLE STABILITY TESTS

STEERING CHARACTERISTICS OF TRUCK, UTILITY, 1/4 TON, 4X4, M151, USA REG. NO. 2J8869

Date of Test: 7 & 8 March 1967

Engr & Environmental Test Br
Development & Proof Services
Aberdeen Proving Ground, Md.
TCooke/ska/16 January 1968
VEHICLE STABILITY TESTS

STEERING CHARACTERISTICS OF TRUCK, CARGO, 3/4 TON, 4x4, M37B1, USA REG. NO. 3C3063

Date of Tests: 10 March 1967

Engr & Environmental Test Br.
Development & Proof Services
Aberdeen Proving Ground, Md.
TCooke/ske/16 January 1968
PROPOSED TASK WITHIN APPROVED PROJECT

Title of Task: Vehicle Stability Tests

Objective: Determine influence of vertical obstacles on vehicle steering, handling, and general stability.

Procedure:
1. Conduct tests to establish dynamic conditions for correlation with computed data on the M151 and M35 trucks:
   a. Determine static tilt angle.
   b. Determine pitch and roll natural frequencies by drop tests.
   c. Operate over rectangular obstacles of increasing severity and speeds, under straightline and minimum turning conditions measuring pitch, roll, and yaw velocities, and overturning moments.
2. References: (Cont'd on Page 2)

Justification: Vehicle handling has been evaluated by the subjective judgment of experienced drivers. This project is an attempt to develop procedures for the quantitative evaluation of vehicle stability and vehicle handling. The end result will be a standard test procedure for evaluating vehicle stability.

Sugg. Distrib.

Est. Cost $ ___________________________ Est. Time to Comp. + 1 months Type Report Lab Report

Appr. ___________________________ Appr. ___________________________ 30 August 1966
DD ET DD SS Tech. Dir. Date

* Heavy SEA oriented workload in Engineering and Environmental Test Branch considered in this estimate.

2 Incl
1. Cy Ref. a
2. Cy Ref. b

TASK ASSIGNMENT TO ET ____________ SS ____________

W.O. # ___________________________ TEAMS # 9-2166-8-45

Sch. Comp. Date ____________ Appr. Tech. Dir. Date

NOTE: If additional space is required use reverse side.

STEAP-DS Form 185, 21 Jul 64   II.I
2. References: (Cont'd)


1. The purpose of the handling test series is to follow through on concepts discussed at a conference held in Colonel Clay's office on 23 June 1966, particularly that portion which involves the influence of road obstacles on steering instability. The field work will attempt to establish dynamic conditions which may be used for correlation with computed data of the M151 and the M37 trucks.

2. The test procedure for each truck will include a phase to:
   a. Determine the static tilt-angle (data available on the M151).
   b. Determine pitch and roll natural-frequency by drop tests.
   c. Operate over three (increasing severity with each run) obstacle heights with a square wave input to each vehicle. Speeds will be stepped up to get pitch, roll, and yaw velocity at which the wheels lose traction: obtain angular roll and pitch velocity with camera or other means.
   d. Pitch and roll velocities will be correlated with computed values and tilt table values.
   e. At limiting speed and with radii found from previous testing, determine influence of step obstacles.

3. From the above, the tilt angle will be correlated with the computed and dynamic steering radii. The tilt angle will also be correlated with angular velocity input by stepped obstacles. Influence of stepped obstacles on computed turns can be evaluated and will have been checked by subparagraph e.

4. Since no study project exists on this subject, kindly supply time and cost estimates to establish a study project. An estimated completion time is also desired commensurate with other EM&A Div. workload.

Copy furnished:
Technical Director, D&PS

W. A. GROSS, JR.
STEAP-DS-EM (26 July 66)  
SUBJECT: Vehicle Handling Tests

TO: Ch, Eng & Env Test Br  
FROM: Ch, Eng Meas & Anal Div  
DATE: 2 Aug 66

Bldg 339  
Bldg 400

Mr. Johnson/wk/4102

Forwarded for preparation of time and cost estimates, as per para 4 of Comment 1. Send reply thru this office.

/s/ R.W. Johnson
/t/ R.W. JOHNSON

STEAP-DS-EE (26 July 66)  
SUBJECT: Vehicle Handling Tests

TO: Ch, Auto Div  
FROM: Ch, Eng Meas & Anal Div  
DATE: 23 Aug 66

Mr. Wiles/cs/3274

1. The estimated cost for the work requested in Par 2 of the basic communication is . This cost does not consider fabrication of vehicle outriggers.

2. It is strongly recommended that if a study task is set up that it be sufficiently inclusive to definitely establish 1) relative stability of the subject vehicles, 2) procedures and criteria for evaluating vehicle stability and 3) requirements for special course conditions for future use. One of the first steps in such a study would be to consider all operating conditions which materially contribute to vehicle instability. Through mathematical analysis and practical reasoning these conditions could be combined or reduced to a workable level. Once this has been accomplished, temporary course conditions could be set up and exploratory testing conducted to establish the minimum overall requirements for vehicle stability evaluations. Maximum utilization would be made of available test data, vehicle characteristics and the mathematical model recently established.

3. Based on present workload it is estimate that the work requested in the basic DF can be completed in approximately sixty (60) days after funds become available. The cost of the program as outlined in Par 2 above is estimated at to and would require at least six months to complete with the present workload.

/s/ Ray L. Wiles
/t/ RAY L. WILES

2

II-4
SUBJECT: Vehicle Stability

1. Reference MFR, 23 Jun 66, subject as above.

2. Discussions were held 24 Aug 66 with Messrs Gross, Montgomery, Liechty, Johnson, Wiles and Noble, following up on items cited in the reference. Mr. Liechty summarized his contacts with Mr. Sorenson (Ford Motor Co) concerning their safety and stability testing. Ford hopes to derive a stability index and expects to have tested procedures for this within about 2 months. They have willingly provided information to us and plan to visit APG and to discuss their procedures when they were formalized.

3. The contact with Ford indicated possible advantage in exchange of information with Chrysler and General Motors in the area of safety tests and possibly on matters of using field maintenance reports. In view of his present success with Ford, Mr. Liechty was requested to follow-up on these items. Following our exchange of information with Ford, Mr. Liechty will suggest an approach to the exchange of information in other areas.

4. ET proposes a dynamic vehicle stability test to consist of:
   a. Impacting rectangular bumps at varying speeds.
   b. Conducting tests under both minimum turning radius and straightline conditions.
   c. Measuring the overturning moments and determining limiting speeds under these conditions.

This approach was proposed as a first step toward dynamic stability testing. Other areas of consideration were discussed, however, no other action is considered appropriate until we determine the value of the initial program. ET is requested to initiate the program proposed as a study project.

/t/ H. A. NOBLE
Technical Director

DISTRIBUTION:
Dep Dir f/Engr Test
Dep Dir F/Supt Svcs
Mr. Gross, Ass'T DD/ET (Actg)
Mr. Montgomery, Actg Chf, Auto Div
Mr. Liechty, Auto Div
Mr. Johnson, Chf, EM&A Div
Mr. Wiles, Chf, EQ&T Br
Incl 2
APPENDIX III - REFERENCES


