U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

Memorandum

**Vehicle Research and Test Center P.O. Box B37
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Subject: FINAL REPORT: VRTC-DCD7110 "Investigation of Liftgate Strut Failure On 2004-2005 Toyota Sienna"

Date: AUG 11 2008

From: W. Riley Garrott WRG
Acting Director, Vehicle Research and Test Center

Reply to Attn. Of: NVS-310

To: Kathleen DeMeter
Director, Office of Defects Investigation

NVS-210

Attached are four (4) copies of the subject report. This completes the requirements for this program.

Attachment:
Final Report

#

VRTC-DCD 7110
EA06-020

Investigation of Liftgate Strut Failure

On 2004-2005 Toyota Sienna

VEHICLE RESEARCH AND TEST CENTER
EAST LIBERTY, OHIO 43319

FINAL REPORT
AUGUST 2008

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National Highway Traffic Safety Administration

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16. Abstract

Claims have been made that the rear liftgate on subject vehicles can drop or close unexpectedly. The objective of the program was to evaluate and compare the performance of the power liftgate system with functional struts to a system with failed struts obtained from subject vehicles. Testing during this program yielded the following results:

- The force required to open the liftgate could not be generated by the liftgate motor drive alone. The required force must be augmented by the liftgate struts. Once the liftgate reached the open position, the liftgate motor disengaged and the struts alone held the liftgate open.
- The force supplied by the liftgate struts varied with temperature. Testing showed a 32% reduction in available force between 110° F and 35° F.
- At room temperature, the maximum combined force that was measured on any one pair of struts was 280 lb.
- The minimum combined strut force that would support the liftgate without letting it drop was greater than 218 lb and less than 231 lb.
- The minimum combined strut force that would prevent the liftgate from dropping quickly and without warning (until the motor drive engaged to control the decent) was greater than greater than 183 lb and less than 197 lb. Impact forces between 145 and 289 lb were measured at a height of 66.5 inches from the floor when degraded struts were tested at 35° F.
- Once the motor drive engaged during closing, maximum force levels varied between approximately 30 and 80 lb and were generated by the motor drive attempting to pull the liftgate closed before the automatic reversing mechanism engaged.
- A liftgate drop rate of 11 deg/sec allowed the liftgate to close without engaging the motor drive while a rate of 12 deg/sec caused the motor drive to engage.
- Activation of the perimeter contact switches that are meant to reverse the closing of the liftgate upon contact with foreign objects required very little force.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 an Engineering Analysis (EA06-020) on 2004 – 2005 Toyota Sienna vehicles equipped with a power liftgate. Claims have been made that the rear liftgate on subject vehicles can drop or close unexpectedly. The objective of the program was to evaluate and compare the performance of the power liftgate system with functional struts to a system with failed struts obtained from subject vehicles.

2.0 Description of Proper Operation

The master switch for the power liftgate is located on the lower instrument panel, in front of the driver's left knee. With the master switch in the "on" position, the liftgate can be opened or closed by a motor drive. Automatic activation of the motor drive is accomplished by depressing the activation button that is located on the overhead center console or the keyless remote-entry device. When either of these buttons is depressed, the motor drive opens the liftgate with no further action required by the operator. Semi-automatic operation of the liftgate is also possible by depressing a button on the liftgate that is located underneath the license plate light. When this button activated, the liftgate latch is released and the liftgate opens slightly. In order to then activate the motor drive, a small amount of opening force must be exerted on the liftgate by the operator. When the motor drive activates, either during opening or closing, the hazard flashers flash twice and a warning horn sounds twice to warn bystanders that the liftgate is moving.

The motor drive can be activated to close the liftgate by using either the button on the overhead console or the keyless remote control, or by pulling down slightly on the open liftgate until the motor drive engages.

The power liftgate system is equipped with two safety devices that will automatically reverse the direction of the liftgate when it is in the automatic-closing mode. A ribbon-type contact switch is located on the lower portion of both sides of the liftgate. These switches activate upon contact with foreign objects. A sensor in the motor drive detects changes of speed of the downward movement of the liftgate caused by blockage of the motion of the liftgate. Additionally, depressing the button on either the overhead console or the keyless remote will reverse the direction of the liftgate.

With the master switch in the "off" position, the liftgate functions as a manual liftgate. Release of the liftgate latch is accomplished by pressing the aforementioned button on the liftgate. With normally functioning struts, the liftgate will then open with minimal effort from the operator. The liftgate can be closed manually by pulling it downward until the latch engages.

The total travel of the liftgate between the fully closed and fully open positions is 80 degrees. When fully open, the distance between the ground and the liftgate latch is 74 in.

3.0 Project Tasks

The following tasks were performed during the course of this program.

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3.1 Procurement of Test Items

Nine struts were acquired for testing. These were labeled A – I.

Strut A: This was a new strut that was purchased from an authorized Toyota dealer.

Struts B – G: ODI provided VRTC with Vehicle Owner Questionnaires (VOQs) in which claims of liftgate failures were made. These VOQs were reviewed to determine which vehicles still had Original Equipment (OE) struts. The owners of three complaint vehicles were identified, contacted, and requested to have a Toyota dealership of their choice replace their liftgate struts at VRTC's expense and to allow VRTC to retain custody of the removed struts for testing. All three owners willingly agreed to this offer. One vehicle (VIN: 5TDZA22C24S) was near enough for a VRTC technician to attend the removal process and take possession of the removed struts. (Struts B & C) Due to the distance from VRTC that was involved for the remaining two vehicles, (VINs 5TDZA22C34S & 5TDZA22C24S) the owners agreed to retain possession of the removed struts and forward them to VRTC. (Struts D – G)

Struts H & I: A 2004 exemplar vehicle (VIN: 5TDZA22C94S) was purchased for testing. The liftgate on this vehicle operated properly and the two struts were added to the test matrix.

3.2 Determination of Force Exerted by Struts

Strut E was completely collapsed when it was received and was unable to exert any force whatsoever. Consequently, strut E was not included in any testing.

The remaining eight struts were tested to determine how much force each exerted through its range of travel. Each was installed, in turn, in a United Tensile Test machine and stroked through the available travel of the strut. Force and displacement measurements were recorded, both as the strut was being compressed and as it was allowed to extend. In order to determine the effect of ambient temperature on the operation of the struts, these force measurements were made after each strut had undergone 3 hour temperature soaks at 72° F, at 110° F, and at 35° F.

The test results showed that with the exception of strut I, the force exerted by each strut was greatest after the 110° soak and least after the 35° soak. The average reduction in force between 110° and 35° was 32%.

In each case, the force that the strut exerted was greatest when the strut was collapsed. The force then decreased as the strut was allowed to extend.

Table 1 lists the maximum force exerted by each strut at each temperature. Figure 1 shows the same information in graphical form.

	Exerted Force (lb)		
Strut ID	110 F	70 F	35 F
A	160	147	140
B	119	113	107
C	89	84	84
D	157	147	139
E	Not Tested		
F	147	133	130
G	55	50	47
H	141	133	125
I	150	129	134

Table 1
Maximum Strut Forces at 110°, 70°, and 35° F

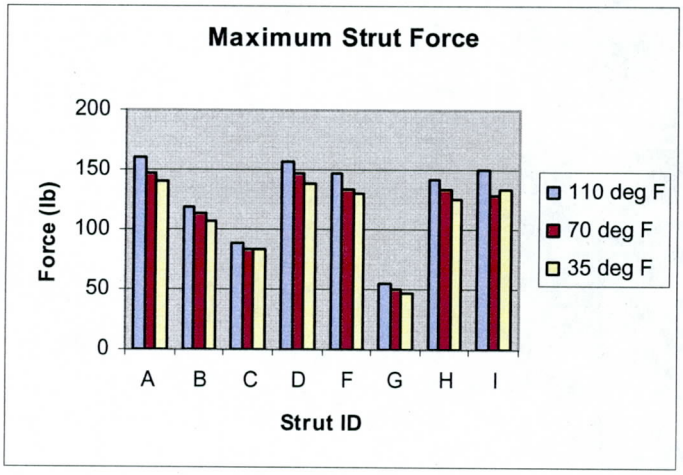


Figure 1
Maximum Strut Forces at 110°, 70°, and 35° F

3.3 Test Instrumentation and Vehicle Preparation

A rotary potentiometer was calibrated and installed on the test vehicle so that the position of the liftgate could be measured and recorded. A 200-lb capacity load cell was calibrated for measuring various forces that were exerted by the liftgate throughout the program.

3.4 Vehicle Testing

The following tests were performed on the subject test vehicle.

3.4.1 Determination of Force Required to Support the Liftgate

The force that was required to support the liftgate was determined by fabricating a series of solid struts that allowed the liftgate to be placed in the open position and at 15°, 30°, and 45° down from fully open. The struts were fabricated in a way that allowed a load cell to be inserted in the strut to measure the compression force in the strut. The distance from the liftgate striker plate to the floor was measured at each of these positions. The forces and distances are listed in Table 2.

Position (deg. down. from open)	Force on strut (lb)	Striker Distance from Floor (in)
Open	200	74
15	206	63
30	210	51
45	218	40

Table 2
Forces Required to Support Liftgate

Logically, if the combined force that the complaint gas struts exerted was less than these measured values, then the gas struts would not support the liftgate and the liftgate would not remain in the open position. The rate of closure would depend on the total force supplied by the two struts that were installed. The more that the force supplied by the gas struts fell below these required forces, the more rapidly the liftgate would drop. Comparison of these measured forces to the forces that were determined Section 3.2 above validated the complaints made by the owners that their struts would not support the weight of the liftgate. The combined force of each pair of complaint struts is shown in Table 3.

Struts	Total Force
B&C	197
D&E	147
F&G	183

Table 3
Combined Force of Pairs of Complaint Struts

3.4.2 Failure Mode Descriptions

The automatic operation of the liftgate was dependent on the two liftgate struts to assist in opening the liftgate and, more importantly, in keeping it open. As struts with less and less combined force were tested, the failure mode progressed through four modes of operation.

3.4.2.1 Condition 1

With struts that were slightly degraded, the motor drive would still fully open the liftgate. Once open, the liftgate would then drift downward slowly until it reached a point approximately 30 degrees from closed, at which point it would drop suddenly to the closed position. The visible and audible warnings did not activate under this scenario because the motor drive did not engage during closing.

3.4.2.2 Condition 2a

With struts that were more degraded, the motor drive would still fully open the liftgate but the liftgate would then rapidly and immediately drop approximately 15°. At that point the motor drive activated and the liftgate began a controlled powered closure.

3.4.2.3 Condition 2b

This condition was similar to Condition 2a but was only discovered late in the program after the vehicle had remained outdoors overnight when the ambient temperature dropped below freezing. Upon activation from a closed position, the liftgate would open fully and immediately reverse direction and close electrically without audible or visual warnings.

3.4.2.4 Condition 3

As the struts degraded to the point that the motor drive was not capable of opening the liftgate, the liftgate would open approximately 30°, the motor drive would reverse, and the liftgate would then close. This condition mimicked Condition 2b but at a much smaller liftgate opening.

3.4.3 Determination of Force Applied by Downward Motion of Unsupported Liftgate

The force that the liftgate exerted as it closed was measured by a load cell that was placed into the path of the lift gate as it closed. The load cell was positioned so that the latch cover on the liftgate always made contact to the load cell. The load cell was mounted to a small, rotatable arm that was attached to the lifting end of an engine hoist. This allowed the load cell to be elevated and rotated, as required, so that it was perpendicular to the movement of the liftgate at the point of contact. A piece of dummy "skin" was placed on the load cell in order to more closely simulate the human body if it was caught in the closing liftgate and to help attenuate any shock loading that the liftgate applied to the load cell. Forces were measured at 10°, 30°, 50°, and 70° down from fully open. These drop angles provided 66½, 51, 36¾, 20¼ inches of clearance, respectively, between the contact point on the liftgate and the floor. Initial testing was performed with the vehicle at room temperature but with strut temperatures of 75° and 35° F. Later testing was performed after the entire vehicle had undergone an overnight cold soak below freezing.

In order to simulate the condition of each complaint vehicle, each pair of complaint struts (B&C, D, F&G) was installed, in turn, on the test vehicle. (Strut D was tested alone because strut E was non-functional.) Strut pair C&G was also tested because this combination provided the lowest combined-force condition that could be produced with the available struts. To begin a test, the motor drive was activated with the liftgate in the closed position. As the liftgate opened, the load cell was inserted into the desired test position before the liftgate began to close. As the liftgate closed, the force that the liftgate exerted on the load cell was measured when the lift gate contacted the load cell. Additionally, the closure rate immediately prior to the point of contact between the liftgate and the load cell was calculated for each test.

When strut pair B&C was tested at room temperature, the liftgate sometimes reacted as described in Condition 1 above (lift to fully open, then drift down slowly without engaging the drive motor). At other times it reacted as described in Condition 2a above (lift to open fully, then immediately drop rapidly ~15°, then close electrically). The differing reactions were consistent with the combined force from the two struts being very close to the force that was required to hold the liftgate open. (197 lb vs. 200 lb) With all other strut combinations except after the entire vehicle experienced an overnight cold soak, the liftgate consistently reacted as described in

Condition 2a above. After an overnight cold soak, several strut pairs sometimes reacted as described in Condition 2a and sometimes reacted as described in Condition 2b. Which of these two reactions would be produced could not be predicted other than the fact that Condition 2b was only found after the entire vehicle experienced a cold soak overnight.

The greatest contact forces were generated when weak struts were installed and the load cell was placed so that the liftgate dropped 10°.

The following trends were noted during testing:

- In tests where the motor drive did not engage, the greatest force was generated during the initial contact of the liftgate. In tests where the motor drive did engage, the greatest force was generated by the motor drive trying to close the liftgate, before the automatic reversing mechanism engaged.
- At both room temperature and at 35°, more force was generated by the motor drive at larger liftgate openings (less drop) than at smaller liftgate openings (greater drop).
- When the motor drive engaged, both the initial impact force and the motor force remained fairly constant at both temperatures for each drop height.
- In free fall (10 deg drop), the liftgate exerted more force at 35° F than at 75° F.
- At the worst condition (10 deg drop), impact forces ranged between 145 and 289 lb for an average of 222 lb.

Table 4 lists the averaged results of these tests in tabular form. Figures 2 and 3 show the same results in graphical form.

	Averages at 75 deg F			Averages at 35 deg F		
Drop Angle (deg)	Impact Force (lb)	Motor Force (lb)	Drop Rate (deg/sec)	Impact Force (lb)	Motor Force (lb)	Drop Rate (deg/sec)
10	127	77	19	222	76	35
30	28	64	12	32	63	12
50	47	57	11	41	57	14
70	27	33	7	27	31	10

Table 4
Average Forces and Drop Rates

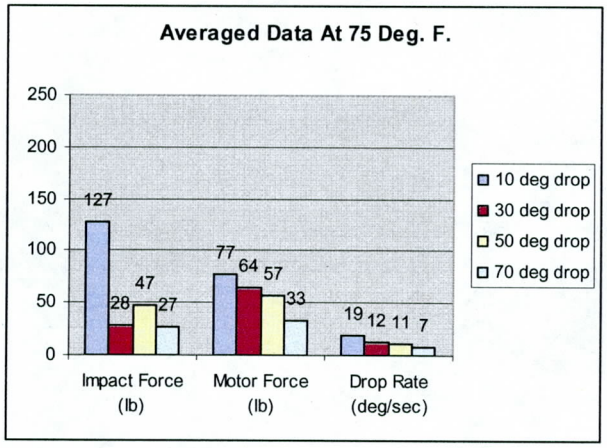


Figure 2
Averaged Forces and Drop Rates
At 75° F

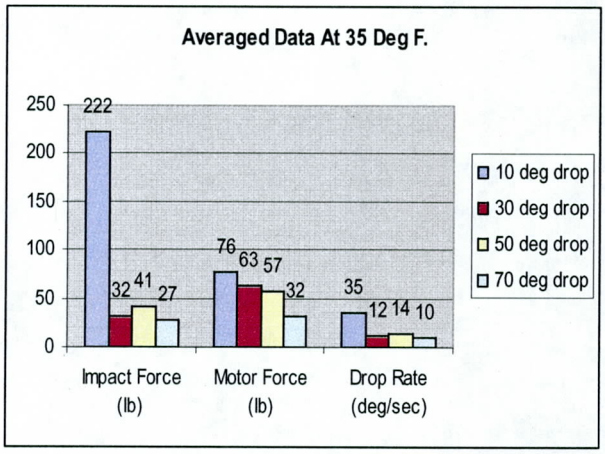


Figure 3
Averaged Forces and Drop Rates
At 35° F

3.4.4 Determination of Strut Force Range When Slow Drop Occurs

Since Condition 1 (lift to fully open, then drift down slowly without engaging the drive motor) caused a rapid closure as the liftgate approached the closed position, and no audible or visual warning was provided when this condition existed, tests were undertaken to determine what range of combined strut forces allowed this condition to exist. The compressed force from each strut, and each combination of struts, was first determined and sorted in descending order. Starting with the greatest available combined force of 280 lb (struts D&F), combinations of struts that produced decreasing force levels were installed and tested in turn. The lowest measured force that would support the liftgate without letting it drop was 231 lb (struts C&D) while the greatest measured force that would allow Condition 1 to exist was 217 lb (struts C&F, C&H). With struts installed that allowed Condition 1, the load cell placed as close as possible to the closed position of the liftgate and the automatic liftgate system was energized. This condition generated an impact force of 153 lb when the liftgate contacted the load cell.

Further reductions of combined strut forces also determined the range of forces that allowed Condition 1 to exist. The lowest measured force that generated Condition 1 was 197 lb (struts D&G) while the greatest measured force that allowed Condition 2a to exist was 183 lb (struts F&G and G&H). Thus, the approximate force limits for Condition 1 are struts with a combined force greater than 183 lb but less than 231 lb when measured at the fully compressed position.

3.4.5 Determination of Drop Rate before Motor Engagement

It appeared that the engagement of the motor to control the closing of the liftgate with degraded struts was dependent on the rate at which the liftgate was closing. In order to determine what this rate of closing was, two struts were installed that would hold the liftgate open and then weight was added that caused the liftgate to begin to close. As additional weight was added, the liftgate closed more rapidly until, at some point, the rate of closing was sufficient to cause the motor drive to engage. The maximum closing rate that was achieved without engagement of the motor was 11 deg/sec. The minimum closing rate that was achieved where the motor did engage was 12 deg/sec.

3.4.6 Determination of Force Required to Activate the Perimeter Reversing Switch

One of the perimeter reversing switches was removed from the vehicle and bench-tested to determine what level of force was required to activate it. After connecting an ohmmeter to the switch contacts, force was gradually applied using a calibrated force gage. The force required to activate the switch was determined to be 2 lb.

3.4.7 Determination of Applied Force Before Speed Sensor Reversing Switch Activation

According to a briefing by Toyota, the Speed Sensor Reversing Switch activates due to a change in the rate of closure of the liftgate, rather than to an increased force encountered by the liftgate as it closes. Testing performed for this program showed that the force that was exerted by the liftgate before the reversing switch activated varied between approximately 30 lb at 70 deg down from fully open and 80 lb at 10 deg down from fully open.

4.0 Conclusions

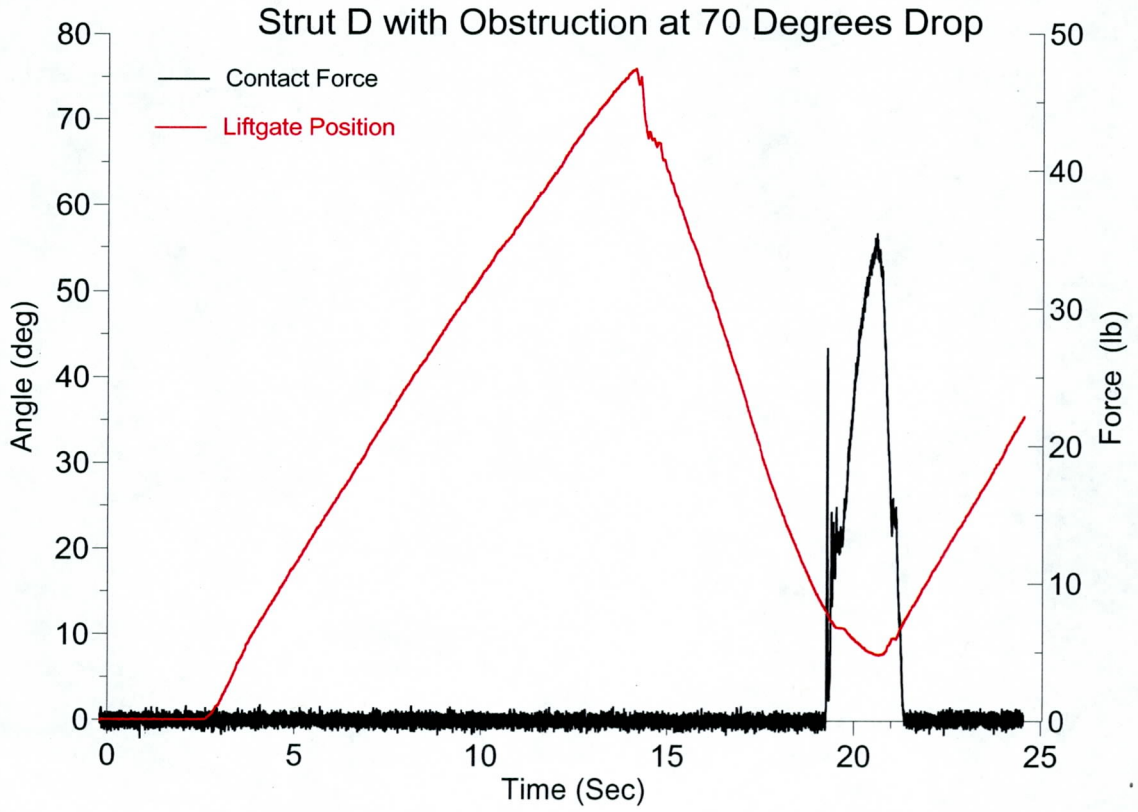
The following conclusions were formed during this testing.

- The force required to open the liftgate could not be generated by the liftgate motor drive alone. The required force must be augmented by the liftgate struts. Once the liftgate reached the open position, the liftgate motor disengaged and the struts alone held the liftgate open.
- The force supplied by the liftgate struts varied with temperature. Testing showed a 32% reduction in available force between 110° F and 35° F.

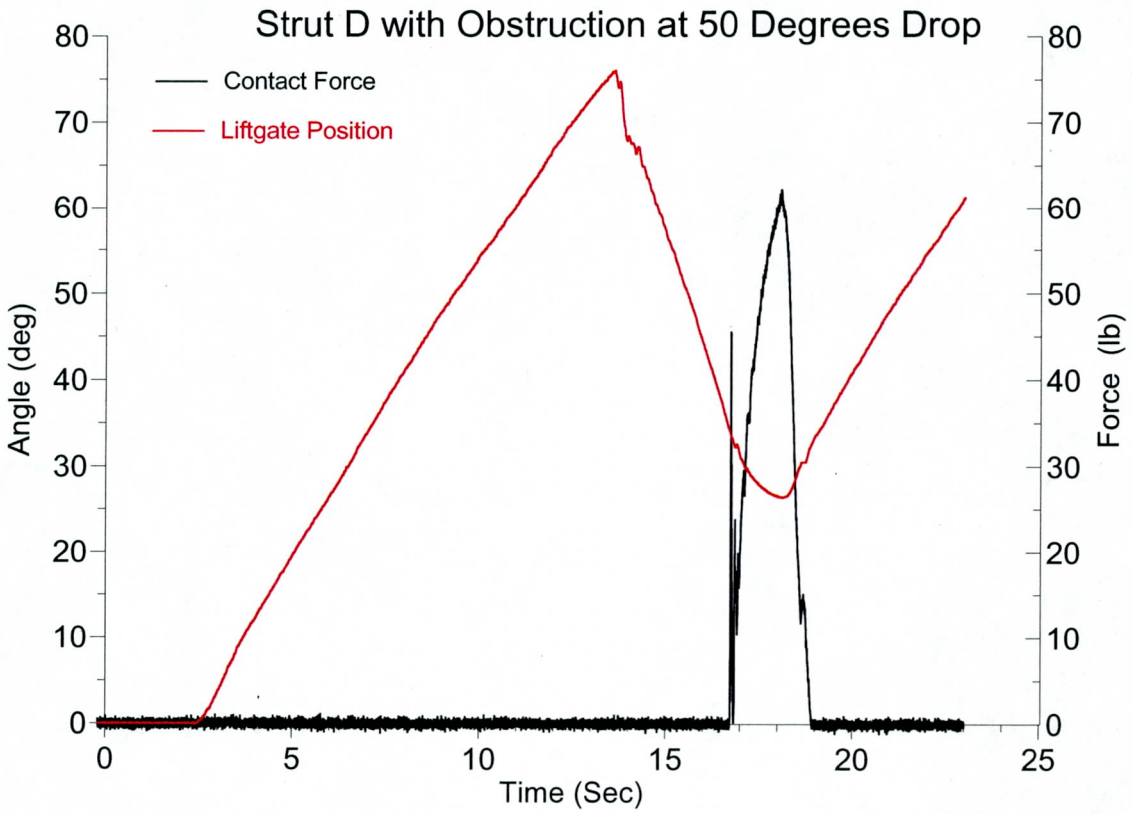
- At room temperature, the maximum combined force that was measured on any one pair of struts was 280 lb (Struts D&F)
- The minimum combined strut force that would support the liftgate without letting it drop was greater than 218 lb and less than 231 lb.
- The minimum combined strut force that would prevent the liftgate from dropping quickly and without warning (until the motor drive engaged to control the decent) was greater than greater than 183 lb and less than 197 lb.
- When measured at a height of 66.5 inches from the floor with the struts at 35° F, impact forces between 145 and 289 lb were measured before the motor drive engaged.
- Once the motor drive engaged during closing, maximum contact force levels varied between approximately 30 and 80 lb and were generated by the motor drive attempting to pull the liftgate closed before the automatic reversing mechanism engaged.
- A liftgate drop rate of 11 deg/sec allowed the liftgate to close without engaging the motor drive while a rate of 12 deg/sec caused the motor drive to engage.
- Activation of the perimeter contact switches that are meant to reverse the closing of the liftgate upon contact with foreign objects required very little force.

Appendix

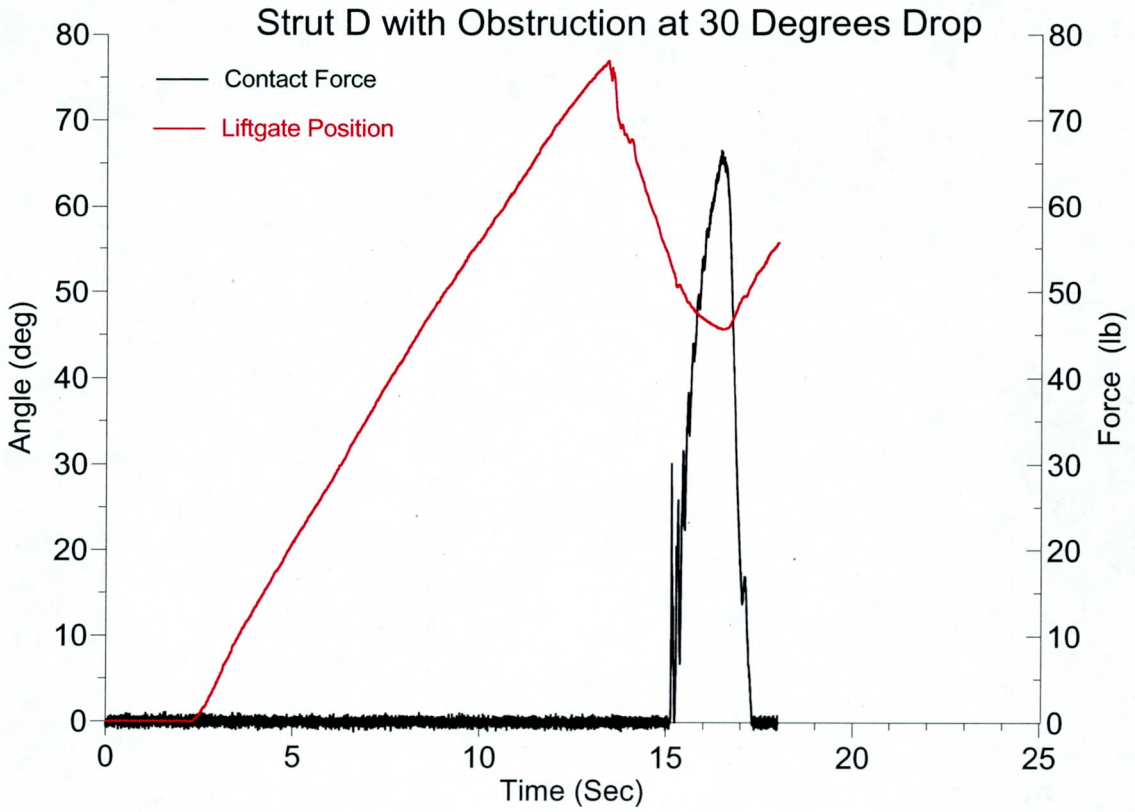
Selected Data from Toyota Sienna Testing



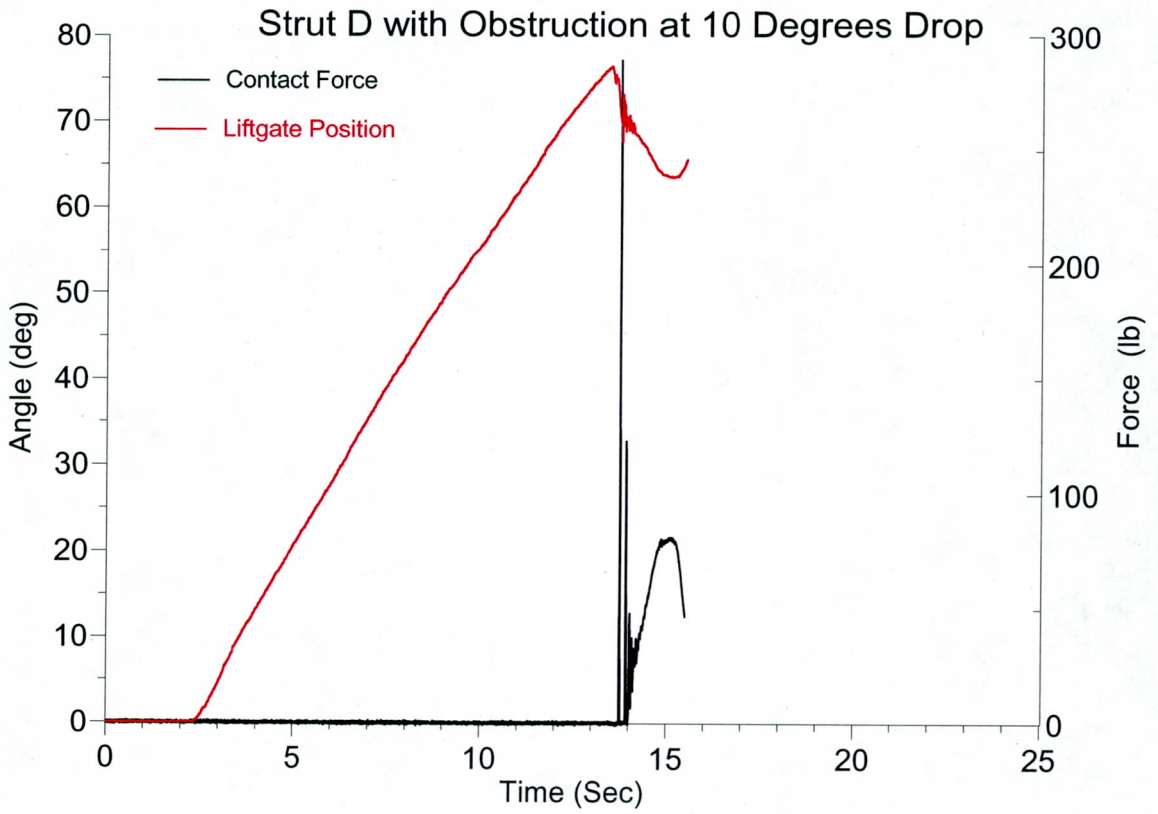
Toyota Sienna Liftgate Performance
Strut D
Obstruction Placed at 70° Drop



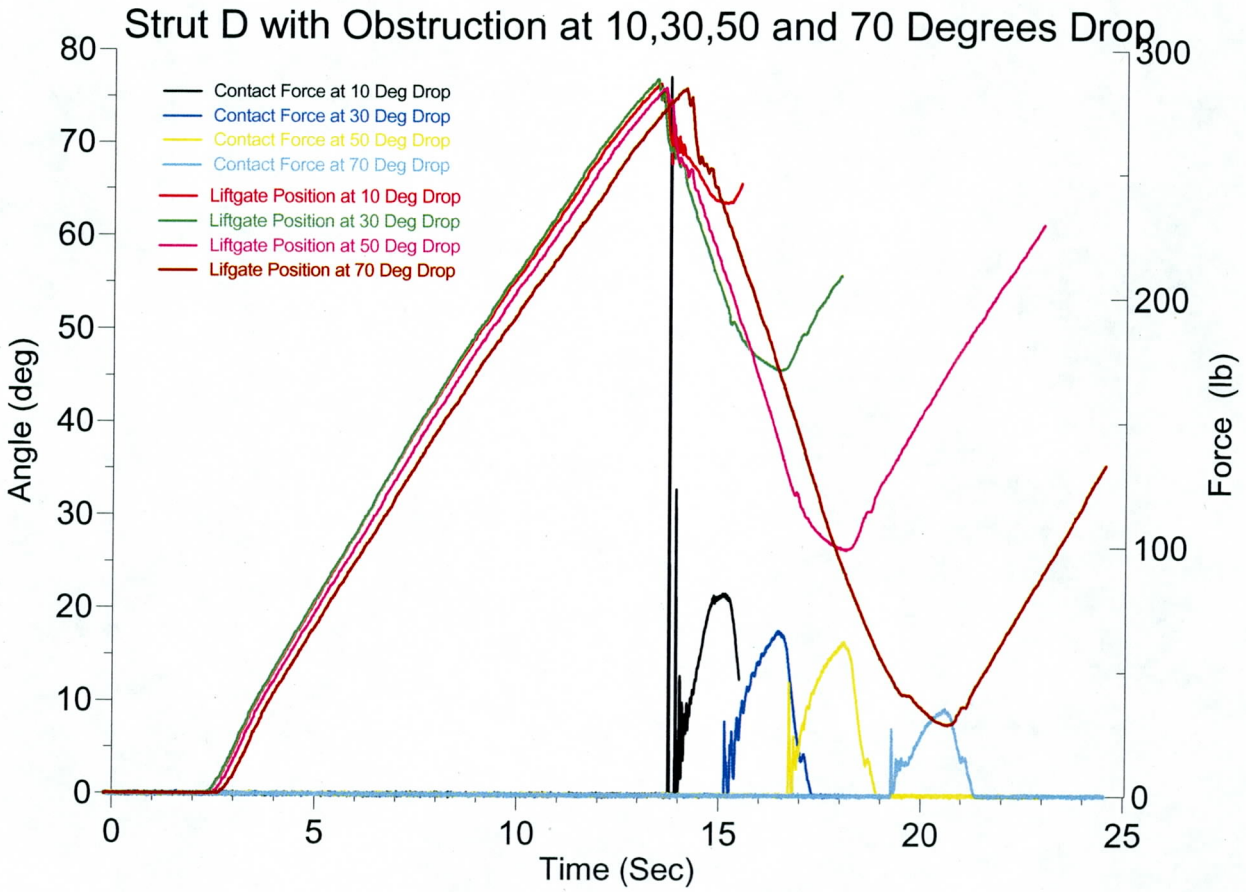
Toyota Sienna Liftgate Performance
Strut D
Obstruction Placed at 50° Drop



Toyota Sienna Liftgate Performance
Strut D
Obstruction Placed at 30° Drop



Toyota Sienna Liftgate Performance
Strut D
Obstruction Placed at 30° Drop



Toyota Sienna Liftgate Performance
Comparison of All Drop Angles
Strut D