DEPARTMENT OF TRANSPORTATION

National Highway Traffic Safety Administration

Denial of Petition for a Defect Investigation

AGENCY: National Highway Traffic Safety Administration (NHTSA), Department of Transportation.

ACTION: Denial of petition for a defect investigation.

SUMMARY: This notice sets forth the reasons for the denial of a petition submitted to NHTSA under 49 U.S.C. 30162, requesting that the agency commence a proceeding to determine the existence of a defect related to motor vehicle safety.

FOR FURTHER INFORMATION CONTACT: Mr. John Hinch, Senior Engineering Advisor, Office of Defects Investigation, NHTSA, 400 Seventh Street, SW, Washington, DC 20590. Telephone: (202) 366-5195.

SUPPLEMENTARY INFORMATION: By letter dated December 23, 1996, David Pittle, of Consumers Union of United States, Inc. (CU), petitioned NHTSA to investigate the alleged propensity of model year (MY) 1995–1996 Isuzu Trooper and 1996 Acura SLX sport utility vehicles (subject vehicles) to roll over during evasive maneuvering and to issue an order concerning the notification and remedy of an alleged safety-related defect in those vehicles.

The petitioner alleges that the subject vehicles have an ‘‘unreasonable risk of rollover associated with emergency maneuvers.’’ In support of this allegation the petitioner argues that: (1) Tests conducted at the petitioner's test facility indicate that the subject vehicles will tip up when driven through the CU ‘‘short course,’’ which is a portion of the testing used by CU to evaluate the vehicle's emergency handling rating; (2) Tests of 3 peer vehicles, conducted at the same time, showed that these vehicles (Toyota 4–Runner, Nissan Pathfinder, and Chevrolet Tahoe) had a distinctively different performance—they did not tip up when driven through the ‘‘short course,’’ (3) Computer simulation, conducted by independent experts retained by CU, indicates that the subject vehicles will tip up while driving through a course like the CU short course; and (4) Additional computer simulation indicates that the rollover propensity of the subject vehicles could be reduced by increasing the front roll stiffness, which could be accomplished by increasing the size of the front stabilizer bar.

CU supplemented its petition with additional information on several occasions. Other relevant information was provided by Isuzu Motors America, Inc., and American Suzuki Motor Corporation.

NHTSA has reviewed all information brought to its attention, conducted tests of the subject vehicles and peer vehicles, and reviewed crash data bases and Office of Defects Investigation's consumer complaint data base. The results of this review and analysis are published in a petition analysis report: ‘‘Petition Analysis DP96–011: Petition for Defect Investigation Concerning the Rollover Propensity of MY 1995–96 Isuzu Trooper and 1996 Acura SLX Vehicles,’’ June 1997. This report is published in its entirety as an appendix to this notice.

For the reasons presented in the petition analysis report, there is no reasonable possibility that an order concerning the notification and remedy of a safety-related defect in the subject vehicles would be issued at the conclusion of an investigation. Therefore, in view of the need to allocate and prioritize NHTSA's limited resources to best accomplish the agency's safety mission, the petition is denied.

Issued on: July 24, 1997.

Kenneth N. Weinstein,

Associate Administrator for Safety Assurance.

Authority: 49 U.S.C. 30162(a); delegations of authority at 49 CFR 1.50 and 501.8

BILLING CODE 4910–59–M

Petition Analysis DP96-011: Petition for Defect Investigation Concerning Rollover Propensity of MY 1995-96 Isuzu Trooper and 1996 Acura SLX Vehicles

June 1997

Office of Defects Investigation
NHTSA
400 7th St., SW
Washington, DC 20590

Table of Contents

1.0 INTRODUCTION 1

2.0 PREVIOUS INQUIRIES AND INVESTIGATIONS BY NHTSA INTO ALLEGED ROLLOVER DEFECTS 1

3.0 ALLEGED DEFECT 2

4.0 VEHICLE INFORMATION 3
4.1 Vehicles Involved 3
4.2 Subject Vehicle Description 3
4.3 Subject Vehicle Parameters 4
4.4 Comparison to Prior Trooper Models 5
4.4.1 1992-1994 Trooper Properties 5
4.4.2 Vehicle Modifications 6
4.4.3 Effect of Vehicle Modifications on Static Stability Metrics 6
4.4.4 CU Rating of MY 1992 Trooper 7

5.0 COMPLAINTS AND LAWSUITS 7
5.1 Complaints to ODI and Manufacturers Regarding the Subject Vehicles 7
5.2 Complaints to ODI Regarding the 1992-94 Trooper 9
5.3 Lawsuits 9
5.4 Analysis of Rollover Complaints Made to ODI Regarding MY 1994-1996 Vehicles 9

6.0 TESTING 11
6.1 Description of the CU Short Course 12
6.1.1 Relationship of CU Short Course Test Maneuver to Likely Real World Crash Avoidance Behavior 12
6.1.2 CU Short Course Testing 16
6.1.2.1 Subject Vehicles and Other Vehicles Tested by CU in the Summer of 1996 17
6.1.2.2 CU Testing of the MY 1992 Isuzu Trooper in 1992 19
6.1.2.3 Historical CU Testing (1988-present) 19
6.1.3 Test Results Submitted by Isuzu 19
6.1.3.1 Isuzu Testing 19
6.1.3.2 Carr Testing 20
6.1.4 NHTSA Testing 20
6.2 Suzuki Testing 24
6.3 Understeer/Oversteer 25
6.3.1 Isuzu Testing 25
6.3.2 NHTSA Testing 26

6.4 Outrigger Effects On Test Outcome 26

7.0 SIMULATION RESULTS 27
7.1 Petitioner's Simulations 28
7.1.1 Jones Simulation 28
7.1.2 Allen Simulation 28
7.2 Isuzu's Simulation 29

8.0 CRASH DATA 30
8.1 NASS Data Analysis 30
8.2 FARS and State Crash Data 31
8.3 Suzuki Data 31

9.0 FINDINGS 32

10.0 CONCLUSIONS 33

List of Tables

Table 1. Sales of Subject Vehicles in U.S. (as of August 31, 1996). 3
Table 2. Basic Subject Vehicle Parameters. 4
Table 3. Subject Vehicle Weight, Inertia, CG Height, and SSF. 5
Table 4. 1994 Trooper Weight, Inertia, CG Height, and SSF. 5
Table 5. Changes in Trooper Design from 1992-1994 Model to 1995-1996 Model. 6
Table 6. Tilt Table Angle, TTR, and SSF for Several Vehicle Configurations. 7
Table 7. Distribution of Complaint by Type of Maneuver. 8
Table 8. Subject Vehicle Complaint Distribution. 8
Table 9. ODI Complaint Distribution by MY for Fault Code = "Rollover," All Vehicles. 10
Table 10. Complaint Distribution by Vehicle Type for Fault Code = "Rollover," ODI Complaints. 10
Table 11. Distribution of Vehicle Action Prior to Rollover for Fault Code = "Rollover," ODI Complaints. 10
Table 12. Steering Inputs and Rates in Crash Avoidance Maneuvers, from Three Studies. 14
Table 13. Comparisons of Selected Non Tip-up and High Tip-Up Runs Conducted by CU. 17
Table 14. Average Steer Angle for CU tests on Short Course by Vehicle Tested. 18
Table 15. Comparison of VRTC Tests, Showing Test Speed, Steer Angles, and Steer Rates for Clean and Intentional Tip-Up Runs - Acura SLX, with VRTC Outriggers. 22
Table 16. Comparison of Subject Vehicle and Peer Vehicle Test Speeds and Steering Inputs for Tests at a Nominal Speed of 38 mph. 24
Table 17. On-Road/Shoulder First-Event Rollovers from NASS, by Crash Type, 1992-1995. 31

List of Figures

Figure 1. Failure Date Analysis, Subject Vehicles. . . . 9
Figure 2. Complaint Date Analysis, Subject Vehicles. . . . 9
Figure 3. CU Short Course (from CU submission). . . . 12
Figure 4. Average Steer Input for CU Tests of Subject Vehicles by Tip-up Result (November 25, 1996 submission). . . . 14
Figure 5. Stopping Distance vs. Vehicle Speed. . . . 16
Figure 6. Clean Run Driving Profile for KS and High Tip-Up Run Driving Profile for EAP. . . 18
Figure 7. Differences between CU Short Course and Initial TRC Course. . . . 21
Figure 8. Steering Wheel Angle vs. Lateral Acceleration, 40 mph, 1996 Acura SLX w/o Outriggers. . . . 26

PETITION ANALYSIS — DP96-011[1]

1.0 INTRODUCTION

Consumers Union of United States, Inc. (CU) (petitioner), 101 Truman Avenue, Yonkers, New York 10703 petitioned the National Highway Traffic Safety Administration (NHTSA) by letter dated August 20, 1996, requesting that an investigation be conducted to determine whether to issue an order concerning the notification and remedy of a defect in model year 1995 and 1996 Isuzu Trooper and 1996 Acura SLX sport utility vehicles (subject vehicles) because of concerns related to their rollover propensity. The petition was supplemented on December 23, 1996, with CU supplying additional information for the agency to consider. The CU petition also requested the agency to commence a rulemaking proceeding related to rollover propensity. That aspect of the CU petition has been addressed in a separate notice.

NHTSA has received submissions in this proceeding from several parties, including CU, Isuzu Motors America, Inc. (Isuzu), and American Suzuki Motor Corporation (Suzuki). Much of the material in these submissions is not directly related to the issue of whether to grant the petition. However, all of the submissions in their entirety have been placed in NHTSA's public file for this petition, DP96-011.

ODI considered all available relevant information in deciding whether to grant or deny the petition. In this case, this included data (including test reports and simulation results) supplied by CU, Isuzu, and Suzuki. In addition, NHTSA conducted a vehicle test program in which the subject vehicles' performance was compared to that of a peer vehicle and analyzed crash data and ODI complaint data. The following sections present a description of the information developed during the petition analysis.

2.0 PREVIOUS INQUIRIES AND INVESTIGATIONS BY NHTSA INTO ALLEGED ROLLOVER DEFECTS

In October 1979 and July 1981, NHTSA's Office of Defects Investigation (ODI) received two petitions for defect investigations concerning the stability of Jeep CJ vehicles. Both these petitions were denied due to the lack of specific information indicating that there was a defect that caused the vehicles to roll over.

In 1988, ODI received two petitions for a defect investigation regarding the alleged rollover propensity of 1986 through 1988 Suzuki Samurai vehicles, including convertible and Suzuki "variants" of the Samurai, the SJ410 and LJ80 models (DP88-011 and DP88-019). NHTSA also denied these petitions, primarily because the available information did not show that the rollovers

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[1] This petition analysis is based on work performed by John Hinch of NHTSA's Office of Defects Investigation (ODI) and Gavin Howe of the Transportation Research Center, Inc., under contract to NHTSA.

were caused by a defect in the vehicle rather than by the driver and/or environmental factors. NHTSA concluded that: 1) The rollover crash involvement of the Samurai was no worse than that of most other light utility vehicles; 2) Occupant ejection is the primary cause of fatal and serious injuries in a rollover; 3) The Samurai had a track width to center of gravity (cg) ratio higher (better) than that of most other light utility vehicles. This ratio has been demonstrated to have a fundamental effect on the rollover propensity of vehicles; 4) The likelihood of a rollover is dependent on a variety of conditions present at any given moment, including vehicle condition, road/ground surface, topography, and vehicle speed; 5) Testing indicated that vehicle control was not a problem when the Suzuki vehicles were driven by experienced drivers. However, the short wheelbase, narrow track width, and low vehicular mass could cause an inexperienced driver to over-react to a given situation and induce rollover; 6) The test procedures for assessing the rollover propensity of vehicles existing during the time period the petition was considered were unsatisfactory identifiers of relative rollover propensity because they did not allow repeatable, reproducible results; and 7) The lack of utility vehicle driving experience exhibited by the Samurai drivers was the most important factor in many of the rollover events reviewed by the agency.

ODI conducted investigation EA89-013 concerning 1984-1989 Ford Bronco II sport utility vehicles. This investigation was opened in response to a defect petition, DP88-020. A peer analysis of rollover rates showed the Bronco II to be similar to other sport utility vehicles, as measured using the metric of first-event rollovers per single vehicle crash. ODI closed this investigation in October 1990, because "there appears no reasonable expectation that further investigation would lead to a determination of the existence of a safety-related defect with respect to any of the allegations regarding the propensity of the Bronco II to roll over."

In 1996 ODI was again petitioned to open a defect investigation into the Suzuki Samurai's rollover propensity. The petitioner alleged that Samurai convertibles have high rollover propensity, as reflected by their low static stability factor, and, when loaded with occupants, the vehicle is even less stable. After reviewing the materials presented in that petition and other available data and information, the agency concluded that it was unlikely that further investigation of alleged Samurai convertible rollover propensity would enable NHTSA to identify a safety-related defect. The petition (DP96-004) was therefore denied.

3.0 ALLEGED DEFECT

CU alleges that the 1995 and 1996 Isuzu Troopers and 1996 Acura SLX have an "unreasonable risk of rollover associated with emergency maneuvers." In support of this allegation, CU argues that:

a. Tests conducted at CU's test facility indicate that the subject vehicles will tip up when driven through the CU "short course," which is a portion of the testing used by CU to evaluate the emergency handling capability of various vehicles. Based on the outcome of these tests, CU rated the subject vehicles as "Not Acceptable;"[2]

b. Three peer vehicles tested at the same time (Toyota 4-Runner, Nissan Pathfinder, and Chevrolet Tahoe) did not tip up when driven through the CU short course;

c. Computer simulation, conducted by independent experts, indicates that the subject vehicles will tip up when driven through a course like the CU short course; and

d. Additional computer simulation indicates that the subject vehicles' rollover propensity could be reduced by increasing the front roll stiffness, such as by increasing the size of the front stabilizer bar.

4.0 VEHICLE INFORMATION

4.1 Vehicles Involved

Table 1 presents the number of subject vehicles sold in the United States, as of August 31, 1996.

Table 1. Sales of Subject Vehicles in U.S. (as of August 31, 1996).

Model Year	Trooper	Acura SLX	Total
1995	22,508	--	22,508
1996	13,810	2,779	16,589
Grand Total			39,097

4.2 Subject Vehicle Description

The Isuzu Trooper underwent a major redesign in MY 1992, in which the size of the vehicle was increased. For MY 1995, Isuzu modified the vehicle slightly. This configuration represents the current generation of the Trooper. The Honda Acura SLX vehicle is the same as the 1996 Trooper, i.e., it has the same, or nearly the same, overall size, weight, engine, tires, etc., with some changes in trim.

The subject vehicles are equipped with four-wheel drive. The front suspension consists of upper and lower control arms, supporting the wheel ends with ball joints. The front suspension incorporates torsion bar springs, a stabilizer bar, and shock absorbers. The rear suspension consists of a solid axle, supported by coil springs. Two trailing links, one on each side, are

[2] CU determines whether a vehicle is considered "Not Acceptable" based on a committee review of a variety of factors, including drivers' impressions, test director oversight, review of movies, whether the tip-up was a repeatable occurrence, etc.

mounted low on the housing. A third trailing center link is mounted high on the rear-end housing. These links control the fore-aft motion and rotation of the axle. A lateral rod is installed to control the lateral motion of the housing. The rear suspension also has a stabilizer bar.

The subject vehicles have disk brakes on the front and rear axles. They are also equipped with a 4 wheel anti-lock brake system. The vehicles have 16-inch wheels with P245/70R16 tires. The tires are supplied by two manufacturers: Goodyear and Bridgestone.

4.3 Subject Vehicle Parameters

The subject vehicles' basic vehicle parameters are presented in Table 2.

Table 2. Basic Subject Vehicle Parameters.

Parameter	Value
Lightly loaded weight	4467 pounds
Wheelbase	108.8 inches
Track Width, front/rear	59.6/59.8 inches
Height	70.5 inches
Center of gravity, from front axle	52.2 inches
Center of gravity, above ground	27.5 inches

Table 3 lists additional vehicle parameters, including inertia parameters, center of gravity (cg) location, and static stability factor (SSF), for several different vehicle configurations. A more complete listing is presented in "Tests Concerning Rollover Propensity of 1995-96 Isuzu Trooper and 1996 Acura SLX," Vehicle Research and Test Center, NHTSA, 1997 (VRTC report), which documents the sources for this data.

Table 3 indicates the following:

1) The effect of vehicle loading: Fully loading a vehicle causes significant increases in the roll and yaw mass moments of inertia (Ixx and Izz). It also increases the cg height and lowers the SSF.

2) The effect of different outrigger designs: The increase in the Izz due to fully loading the vehicle is similar to the increase that occurs when the CU outriggers are used with a driver present, while the increase in the Ixx due to a full load is significantly less. The VRTC outriggers cause a moderate increase (about 10 percent) in the Ixx and a negligible increase (about 2 percent) in the Izz compared to the base vehicle. The CU outriggers cause a very large increase (about 30 percent) in the Ixx and a large increase (about 20 percent) in the Izz compared to the base vehicle.

Since the CU short course requires the vehicle to be steered quickly, and since these quick steering maneuvers generate angular accelerations (both in yaw and roll) that are proportional to the mass moments of inertia, changes in a vehicle's mass moments of inertia could have a significant effect on the vehicle's performance on the course.

Table 3. Subject Vehicle Weight, Inertia, CG Height, and SSF.

Source	Vehicle Configuration	Weight (lb.)	Ixx[a] ($ft.lb.s^2$)	Izz[b] ($ft.lb.s^2$)	CG Height (in.)	SSF[c,d]
VRTC	1996 Acura SLX w/ 1 occ	4467	636	2869	27.5	1.09
	1996 Acura SLX w/ 4 occ + cargo to GVWR	5506	735	3425	27.9	1.07
	1996 Acura SLX	4289	611	2878	27.2	1.10
	1996 Acura SLX w/ VRTC outriggers	4402	675	2935	26.7	1.12
CU	1996 Isuzu Trooper	4448	654	2942	27.5	1.09
	1996 Isuzu Trooper w/ human driver	4614	687	2956	27.7	1.08
	1996 Isuzu Trooper w/ sandbag driver	4614	679	2946	27.7	1.08
	1996 Isuzu Trooper w/ sandbag driver and CU outriggers	4883	894	3460	27.3	1.10
Carr	1996 Isuzu Trooper	4496			27.5	1.10
	1996 Isuzu Trooper w/ instrumentation	4807			27.3	1.10

[a] - Ixx = Roll Mass Moment of Inertia
[b] - Izz = Yaw Mass Moment of Inertia
[c] - SSF = Static Stability Factor = Track Width/(2 x CG Height)
[d] - The measured track widths for subject vehicles were different, hence, vehicles with the same cg height have different SSF values.

4.4 Comparison to Prior Trooper Models

4.4.1 1992-1994 Trooper Properties

Table 4 presents certain measured and calculated values for the 1994 Trooper, which is the same as the 1992 and 1993 Trooper.

Table 4. 1994 Trooper Weight, Inertia, CG Height, and SSF.

Source	Vehicle Configuration	Weight (lb.)	Ixx ($ft.lb.s^2$)	Izz ($ft.lb.s^2$)	CG Height (in.)	SSF
VRTC	1994 Isuzu Trooper w/ 1 occ	4465	617	2918	27.0	1.07
	1994 Isuzu Trooper w/ 4 occ + cargo to GVWR	5513	719	3345	27.7	1.04

4.4.2 Vehicle Modifications

Isuzu stated that it has not made any modifications to the subject vehicles that would affect their rollover susceptibility since the start of the 1995 model year. However, there were differences between the 1995 Troopers and earlier Troopers, including changes to several suspension parameters to make the vehicle's track width 60 mm wider. Increasing the track width tends to make a vehicle less prone to rollover, assuming there are no other changes. Table 5 describes the changes from the 1992-1994 model to the 1995 and 1996 models.

4.4.3 Effect of Vehicle Modifications on Static Stability Metrics

As indicated in Tables 3, 4 and 5, the 1994 Trooper has a lower cg and a narrower track width than the 1996 Trooper/SLX. The SSF of the 1994 Trooper is slightly lower than that of the subject vehicles when calculated with just a driver and in the fully loaded condition. All other things being equal, this would indicate that the subject vehicles have a slightly lower rollover propensity than the 1994 Trooper.

Table 5. Changes in Trooper Design from 1992-1994 Model to 1995-1996 Model.

Component	Change
Track Width, Front	Increased from 1,455 to 1,515 mm
Track Width, Rear	Increased from 1,460 to 1,520 mm
Center of gravity	no change reported
Wheelbase	no change reported
Wheels	no change reported
Tires	Changed tread compound and internal structure
Front Suspension, Upper link	Length increased from 242 to 272 mm
Front Suspension, Upper link bushing	Rubber material was changed
Front Suspension, Lower link end	Length increased from 87 to 117 mm
Front Suspension, Outer track rod	Length increased from 299 to 329 mm
Front Suspension, Drive shaft	Length increased by 30 mm
Front Suspension, Torsion bar	Spring rate increased by increasing bar diameter from 25.0 to 26.6 mm
Front Suspension, Shock absorbers	Damping force @ 0.3 m/s decreased from 183/67 to 148/67 kgf (rebound/compression)
Front Suspension, Stabilizer bar	no change reported
Rear Suspension, Axle case	Length increased 30 mm
Rear Suspension, Axle shaft	Length increased 30 mm
Rear Suspension, Coil springs	Spring rate increased from 2.8 to 3.0 kgf/mm
Rear Suspension, Shock absorbers	Damping force @ 0.3 m/s decreased from 118/33 to 125/52 kgf (rebound/compression)
Rear Suspension, Stabilizer bar	no change reported

VRTC also had SEA, Inc. compute the Tilt Table Ratio (TTR) of the 1996 Acura SLX and the 1994 Isuzu Trooper. The tilt table measures the angle at which both "high side" tires of the vehicle lift off a platform when it is slowly tilted in roll. This angle is then used to compute the TTR. The results are summarized in Table 6, which also summarizes the comparative SSF data.[3] In both the single occupant and fully-loaded condition, the 1996 Acura SLX had a higher TTR than the 1994 Trooper, which, standing alone, would indicate a lower rollover propensity for the 1996 Acura SLX.

Table 6. Tilt Table Angle, TTR, and SSF for Several Vehicle Configurations.

Vehicle Configuration	Tilt Table Angle (deg)	TTR[a]	SSF
1996 Acura SLX w/ 1 occupant	42.6	.92	1.09
1996 Acura SLX w/ 4 occupants + cargo	40.0	.84	1.07
1994 Isuzu Trooper w/ 1 occupant	41.4	.88	1.07
1994 Isuzu Trooper w/ 4 occupants + cargo	38.7	.80	1.04

[a] - TTR = tan(Tilt Table Angle)

4.4.4 CU Rating of MY 1992 Trooper

In its November 1992 issue of Consumer Reports, CU rated the "Emergency Handling" capability of the 1992 Trooper as "Good." This rating was based on several tests, including the vehicle's performance on the CU short course.

5.0 COMPLAINTS AND LAWSUITS

5.1 Complaints to ODI and Manufacturers Regarding the Subject Vehicles

ODI has reviewed owner complaints received by ODI and Isuzu that may be related to the alleged defect in the subject vehicles. Except for a single complaint to Isuzu in April 1996, all complaints were received by Isuzu and ODI after the CU press release (August 21, 1996). This suggests that the relatively high number of complaints regarding the subject vehicles is due to the publicity generated by CU and other media reports. This reduces the reliability of comparisons with the number of complaints submitted to ODI regarding peer vehicles.

A total of 36 complaints have been received. These include 13 to ODI (as of April 18, 1997) and 23 non-duplicate complaints to Isuzu (as of March 21, 1997). Honda did not report any complaints associated with the Acura SLX vehicle, and none have been received by ODI.

[3] A more detailed discussion of this data can be found in the VRTC test report.

Owner complaints vary considerably, with some owners reporting the sensation of tip-up during driving, while others report rollovers. A tip-up sensation is hard to differentiate from a large body lean. (The Trooper leans seven to eight degrees during a hard turn, which feels dramatic, even when the wheels are on the ground.)

Of the 36 complaints, some indicated that there had been a crash prior to rollover, which may have contributed to the rollover event. Others were run-off-the-road rollover crashes, while others were of the crash avoidance type (of which the CU short course maneuver is an example). The events reported in the complaints are presented in Table 7.

Table 7. Distribution of Complaint by Type of Maneuver.

Type of Complaint	Number
Crash Avoidance (without rollover)	14
Crash Avoidance (with rollover)	4
Prior Crash	3
Loss of Control	6
Tip-up While Turning	8
Tip-up While Parked in Lot	1

Table 8 presents the complaints by source and model year.

Table 8. Subject Vehicle Complaint Distribution.

Model Year	ODI	Isuzu	Total
1995	5	17	22
1996	8	5	13
Unknown	0	1	1
Total	13	23	36

The complaints are fairly evenly distributed by failure date (the date of the alleged incident). Failure and complaint date data are presented in Figures 1 and 2.

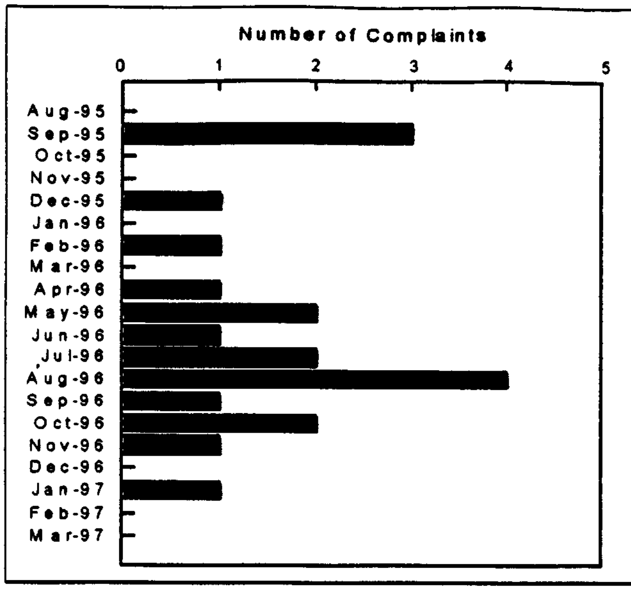

Figure 1. Failure Date Analysis, Subject Vehicles.

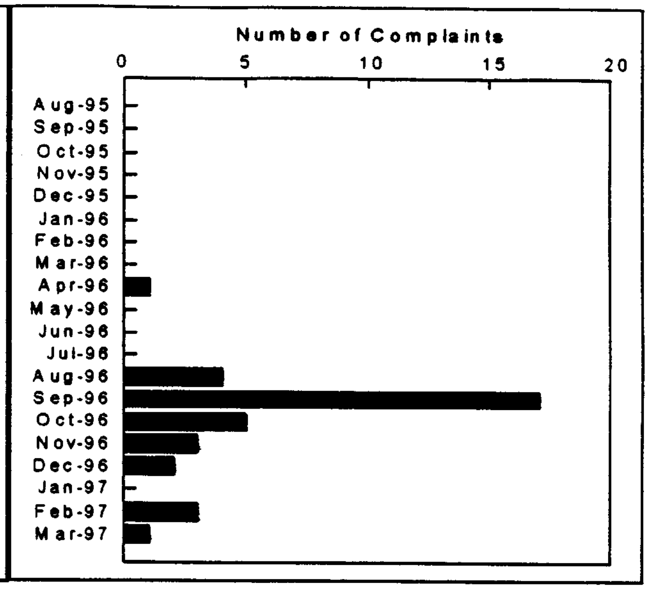

Figure 2. Complaint Date Analysis, Subject Vehicles.

5.2 Complaints to ODI Regarding the 1992-94 Trooper

ODI also received several tip-up complaints involving 1992-94 Troopers following the CU press conference. These consumers claimed that their vehicles were rollover sensitive. Of the five complaints, four involved rollovers.[4]

5.3 Lawsuits

As of March 21, 1997, Isuzu had been named as a defendant in five lawsuits related to the alleged defect. Four of these are class actions.

5.4 Analysis of Rollover Complaints Made to ODI Regarding MY 1994-1996 Vehicles

ODI analyzed its data base for all rollover complaints regarding 1994, 1995, and 1996 model year vehicles. These model years were selected so the vehicles that were being analyzed would be of the same approximate age as the subject vehicles.

Each complaint in the ODI data base is given a "Fault" code for cause and result. Each complaint that had a "cause fault" or "result fault" of "rollover" was individually reviewed to eliminate duplications and non-rollover crashes. 92 such complaints were identified. Table 9 shows the

[4] These complaints were received between August 26, 1996 and March 16, 1997.

distribution of these 92 complaints by model year. Also shown are rates adjusted for exposure years. Annual total vehicle production for these three years was fairly constant, 15.7, 15.2, and 15.3 million vehicles for 1994, 1995, and 1996, respectively, thus no adjustment for number of vehicles produced was made. This table indicates that the distribution of rollover complaints is fairly constant, when normalized by exposure years.

Table 9. ODI Complaint Distribution by MY for Fault Code = "Rollover," All Vehicles.

Model Year	Number of rollover complaints	Exposure Years	Rollover based on exposure (rollovers/year)
1994	51	3	17
1995	24	2	12
1996	17	1	17
Total	92	6	15

The type of vehicle involved in these complaints is presented in Table 10.

Table 10. Complaint Distribution by Vehicle Type for Fault Code = "Rollover," ODI Complaints.

Type of Vehicle	Number of Complaints
Sport Utility Vehicle	42
Car	29
Van	6
Light Truck	15

For each of these complaints, the alleged action of the vehicle just prior to the rollover was ascertained. In many cases, the reported rollover appears to have been caused by a vehicle malfunction, i.e., brake failure, tire failure, steering failure, etc. The distribution of vehicle actions associated with these complaints is shown in Table 11.

Table 11. Distribution of Vehicle Action Prior to Rollover for Fault Code = "Rollover," ODI Complaints.

Cause of event	Number of Complaints
Vehicle Induced	46
Crash Avoidance	3
Crash Prior to Rollover	9
Loss of Control	34

The three complaints for which ODI analysis indicated that the rollover had been preceded by a crash avoidance maneuver involved a 1996 Chevrolet C-1500 full-size pickup, 1995 Dodge Dakota mid-size pickup, and a 1995 Isuzu Trooper.

6.0 TESTING

CU submitted test data to support its petition. In addition, ODI received test data from Isuzu, Carr Engineering, Inc. (Carr) on behalf of Isuzu, and Suzuki. NHTSA conducted additional testing. This section of the petition analysis summarizes the results of this testing. Detailed results of the testing can be found in the public file.

The CU short course test, the results of which constitute the primary basis for this petition, is used as a check test to explore a vehicle's rollover resistance during an extreme maneuver. CU has been using the short course since 1988. CU tests all sport utility vehicles on the short course, as well as selected new entry vehicles such as minivans and compact pickup trucks.

CU performs routine handling, emergency handling, braking, acceleration, and other tests to determine vehicle ratings. For its "Emergency Handling" rating, CU uses a variety of tests, including their short and long crash avoidance courses. If a vehicle tips up substantially in tests on the short course, CU rates it "Not Acceptable," and does not give it an "Emergency Handling" rating. If, on the other hand, the vehicle does not tip up (or tips only slightly), the vehicle rating which was obtained through the series of tests is maintained.

Both Isuzu and Carr tested the subject vehicles using the CU short course. Carr also performed numerous other tests including CU long course, General Motors (GM) avoidance maneuver, man-off-the-street avoidance maneuver, GM - vehicle evasive performance test, System Technologies Inc. (STI) emergency lane change test, Nissan emergency avoidance maneuver, STI unexpected obstacle, Calspan man-off-the-street - surprise intrusion test, Hooker course, International Standards Organization (ISO) lane change, 100 & 200 foot and 18 meter slalom, high speed turn, 75 and 200 foot constant radius turn, 75 and 200 foot tangent turn, step steering, steering return, and panic braking. Carr did not test any peer vehicles, which reduces the value of these tests.

NHTSA conducted tests at the Transportation Research Center (TRC) located in East Liberty, Ohio and at the Uniform Tire Quality Grading (UTQG) facility located on the Goodfellow AFB in San Angelo, Texas. The primary focus of this test program involved driving vehicles through the CU short course. Vehicles tested included a 1996 Acura SLX and a 1996 Isuzu Trooper (supplied by CU). For comparison purposes, a peer vehicle (1994 Isuzu Trooper) was also tested. Additional testing was performed to determine the lateral transient response of the subject vehicles. Outrigger effects on vehicle performance were also analyzed.

6.1 Description of the CU Short Course

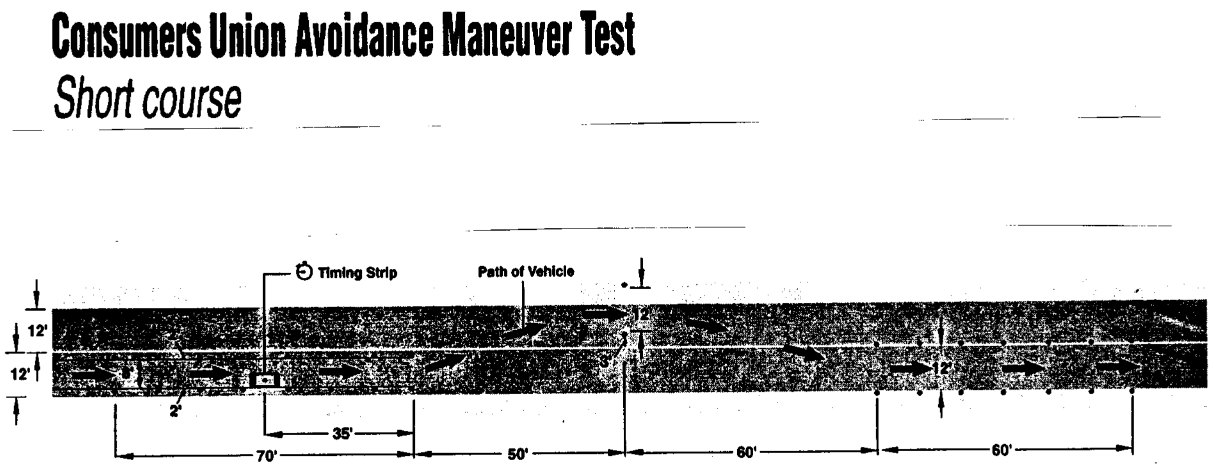

Figure 3. CU Short Course (from CU submission).

The CU short course is depicted in Figure 3. This course requires two lane changes. It consists of a 70-foot-long, 8-foot-wide entrance lane that is centered in the 12-foot-wide first (right) lane, a 50-foot-long area to make the first lane change, a set of gate cones at this 50-foot mark that are 12 feet apart, (with the right cone three feet over into the second (left) lane), a 60-foot-long area to make the second lane change (back to the original (right) lane), and a 12-foot-wide exit lane. CU drivers steer the vehicles through this course at successively higher entry speeds until the vehicle either plows out, slides out, or tips up. The vehicle's brakes are not applied, and the throttle is released as the vehicle passes the timing strip which measures the vehicle speed, located 35 feet before the end of the entrance lane (see Figure 3 for reference).

6.1.1 Relationship of CU Short Course Test Maneuver to Likely Real World Crash Avoidance Behavior

A driver who comes upon an expected obstacle will naturally try to avoid striking that obstacle. Such a driver generally will try to stop and/or turn.

Comparisons of Steering Inputs in CU Short Course Tests and in Real World Driving.
A professional driver going through the CU short course turns the steering wheel hundreds of degrees at a very fast rate, exceeding 1,000 degrees/sec and often exceeding 1,300 degrees/second. CU provided complete steering profiles (prepared by Ian Jones) for only two

tests (See CU's December 23, 1996 submission, Attachment 7, Table 5). In a clean run[5] at 37.5 mph, CU driver KS turned the wheel at about 1,060 degrees/sec. In a high tip-up run, CU driver EAP turned the wheel at 1,020 degrees/sec.

In these same two tests, the steering inputs, as reported by Jones, for driver KS were 172 degrees left and 207 degrees right[6] for a total reverse steer of 379 degrees. The steering inputs employed by driver EAP were greater (179 degrees to the left and 389 degrees to the right, for a total reverse steer of 568 degrees).[7]

In the short course tests conducted by CU in which there was a tip-up, the steering inputs, as reported in CU's November 25, 1996 submission, were generally greater than those in non-tip-up runs. An analysis of the steering inputs on runs conducted by CU is presented in Figure 4. Note the difference in average steering input on the second steer (middle bar in each set) between the non-tip-up runs and the tip-up runs.

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[5] In its November 25, 1996 submission, CU provided a summary of the results of its summer 1996 short course testing. In that summary, CU indicated whether a particular run was "clean," which means that it negotiated the course without knocking down one or more cones. CU also indicated whether there was a "Wheel lift" or "Tip up" based on "Observer Comment:" "Wheel lift means a front wheel lifted, but not a rear wheel. Tip up means two wheels lifted off the pavement."

For each run in which there was a tip-up, CU characterized it as "Low," "Medium," or "High," based on the observer's "judgement:" "Low means off the pavement, but not too obvious (this is best judged from the video). Medium means that it was visually obvious to the observers, usually from several inches to a foot. High means more than one foot, including over onto the outriggers."

In summarizing the results of the VRTC testing, ODI essentially used this CU methodology, except it did not attempt to classify the severity of a tip-up.

[6] Right steer is measured from the initial (straight forward) steering wheel position; i.e., after the steering wheel has been rotated back to zero degrees.

[7] CU reported three different sets of steering inputs for these two runs: 1) supporting data for the petition (October 10, 1996); 2) a November 25, 1996 submission from Arnold and Porter; and 3) an analysis performed for CU by Ian Jones (December 23, 1996 letter from Arnold and Porter). A summary is presented below:

Driver	Speed	Result	October 10, 1996		November 25, 1996		December 23, 1996	
KS	37.5 mph	Clean	180° L	230° R	183° L	216° R	172° L	207° R
EAP	37.5 mph	High Tip-up	190° L	370° R	191° L	388° R	179° L	389° R

The Jones data (December 23, 1996) were used where the complete driving profiles for these two runs were analyzed. The November 25, 1996 steering inputs were used in analyses that address the entire set of CU tests.

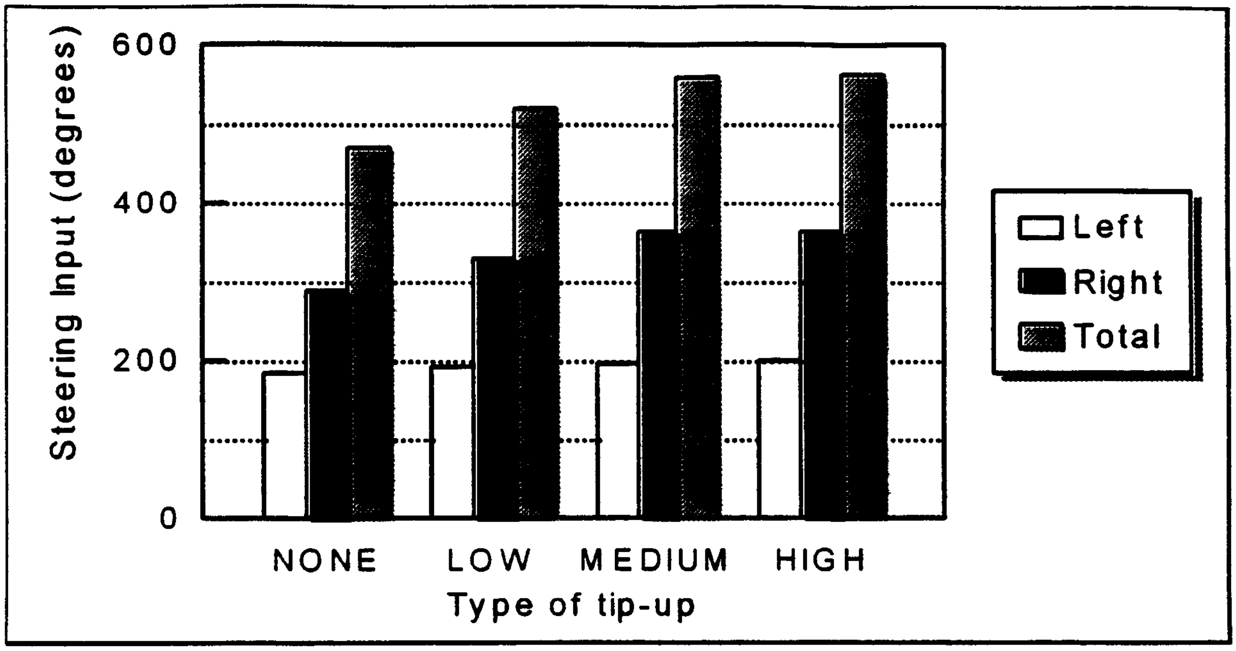

Figure 4. Average Steer Input for CU Tests of Subject Vehicles by Tip-up Result (November 25, 1996 submission).

In NHTSA's tests, in clean runs at 36 mph (Tests 55 & 57), left steers were about 205 degrees and right steers were about 250 degrees. The total reverse steer was about 460 degrees. In Carr's clean run at this speed (Test 34), left/right steers were 175 and 235 degrees respectively, for a total reverse steer of 410 degrees.

Several studies have been done of driver behavior in crash avoidance maneuvers. Average peak steering inputs from three of these studies are presented in Table 12.

Table 12. Steering Inputs and Rates in Crash Avoidance Maneuvers, from Three Studies.

Study	Steering Input (deg)	Steering Rate (deg/sec)
Calspan/GM (SAE-760777)	none reported	520 (all successful drivers) 800 (successful expert drivers) 850-1000 (loss of control)
Nissan (SAE-770130)	200-230 (first steer)	700-900
STI (DOT HS-801 407)	145 (first steer)	none reported

The Calspan/GM report ("Automobile Driver Characteristics and Capabilities—The Man-Off-The-Street," 1976, SAE # 760777) analyzed reaction to an Avoidance Maneuver. Average maximum steering rates for all successful drivers was about 520 degrees/sec. Rates of up to

1,000 degrees/sec were noted, but the higher rates were from drivers who lost control. This study did not report any steering wheel input angles.

The Nissan report ("Performance of Driver-Vehicle System in Emergency Avoidance," 1977, SAE # 770130) described maximum steering wheel angles for the first steer in emergency avoidance maneuvers that were concentrated in the range of 200 and 230 degrees. Maximum angular velocities for the same maneuver were concentrated in the range of 700 to 900 degrees/sec.

The STI report ("Automobile Controllability—Driver/Vehicle Response for Steering Control," February, 1975, DOT HS-801 407) presented data on several drivers' responses to an Unexpected Obstacle Avoidance Maneuver. The report states that the maximum steering inputs were about 145 degrees (it did not report steering rates).

These three studies suggest that the maximum steering input a driver is willing or able to make in response to an unexpected event are within the range of 145 to 230 degrees.[8] As demonstrated in the next section, during the tests conducted by CU drivers on the CU short course in which the subject vehicles tipped up, the initial (left) steering inputs were usually within this range (with one exception), but the second (right) steer was much greater. These studies also indicate that the rate a typical driver turns the wheel is not greater than 1,000 degrees/sec. The CU drivers, based on the two profiles supplied by CU, steered at rates up to 1060 degrees/sec. In tests on the CU short course conducted by NHTSA at speeds above 36 mph, the steering rate was generally in the range of 900 to 1,350 degrees/sec.

CU Short Course Sight and Stopping Distance.

Based on tire marks observed during testing, drivers executing the CU short course begin to turn the vehicle approximately 25 feet prior to reaching the last cone in the entrance gate, which is 50 feet from the obstacle cone. Thus, the CU short course simulates a situation where the driver starts to avoid an obstacle when (s)he is about 75 feet from the obstacle.[9]

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[8] These tests were conducted with MY mid-70's sedans. There are differences between these old sedans and the subject sport utility vehicles in terms of tires, steering gain, cg height, roll gradient, etc. These factors may have an effect on the reported maximum steering input angle and rate.

[9] Real drivers in everyday situations will not react as quickly as professional drivers on the CU short course. A real driver will lose time and distance between the point that (s)he first observe the obstacle and the point at which action is begun. This is due to the fact that the real driver will not be prepared as the test driver is. (S)he must observe the object, decide what to do, and finally take action.

Stopping distance for a typical vehicle with typical brakes on a dry road with coefficient of friction of 0.85 is shown in Figure 5. (These distances will vary with surface conditions.) Vehicles traveling up to 45 mph can stop before they reach an obstacle that is 75 feet away. Vehicles can stop in 60 to 70 feet from speeds typical of the entrance speed used by CU in its short course tests. Thus, a driver who applies the brakes at the point when the CU test drivers began to turn could safely stop before reaching the obstacle, without attempting to turn.

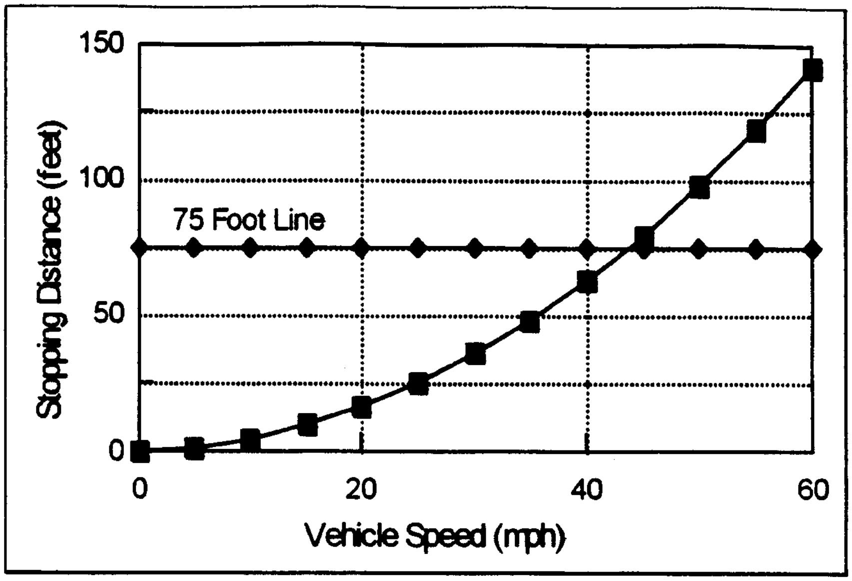

Figure 5. Stopping Distance vs. Vehicle Speed.

In the Surprise Intrusion Maneuver portion of the Calspan/GM study referred to above, about 34 subjects were tested. This test involves throwing a plastic barrel in front of an unsuspecting driver traveling at 55 mph. Of these subjects, 75 percent applied the brakes initially rather than steering. The STI study described the reaction of 17 drivers to an unexpected obstacle, where a silhouette of a vehicle was ejected into the path of a vehicle traveling 30 mph. Of the 17 drivers, seven steered around it, eight hit it, and two stopped in front of it.

Decisions That Involve Both Steering and Braking as Related to the CU Short Course. The subject vehicles are equipped with 4-wheel ABS. Vehicle manufacturers and NHTSA have told consumers with vehicles equipped with ABS to "Stomp and Steer" when they come upon an unexpected obstacle. This combination of braking and steering allows the vehicle to be slowed while turning away from or around the obstacle.

NHTSA conducted a demonstration test of the subject vehicle on the CU short course in which the driver stomped on the brakes at the same time he started to steer to the left to go around the obstacle in the left lane. The vehicle came to a stop near the entry cones on the exit gate, without any tip-up.

6.1.2 CU Short Course Testing

6.1.2.1 Subject Vehicles and Other Vehicles Tested by CU in the Summer of 1996

On the basis of tests conducted in the summer of 1996, CU reported that the 1995-96 Isuzu Trooper/Acura SLX tipped up in short course tests at speeds as low as 33 mph. After the initial series of tests (without outriggers) that resulted in tip-up, CU placed outriggers on the vehicles and made additional test runs. The highest speed reported by CU that resulted in a non-tip-up, clean run was 37.5 mph (driver KS, run 12, 7/10/96, 12:17).[10] CU observed wheel lift on this run.

CU identified many tests in which the subject vehicles tipped up. As stated earlier, CU rated these tip-ups with a severity rating (Low, Medium, and High). Of the tests in which CU videotaped the interior of the vehicle to allow analysis of steering inputs, five produced a high tip-up rating. Data from these tests and the 37.5 mph non-tip-up, clean run are shown in Table 13 (these data are from CU's November 25, 1996 submission).

Table 13. Comparisons of Selected Non Tip-up and High Tip-Up Runs Conducted by CU.

Driver	Date	Time	Speed	Left Steer	Right Steer	Total Reverse Steer	Result
KS	7/10/96	12:17	37.5	183	216	399	Fastest Non-Tip-up Clean Run [a]
EAP	6/26/96	11:15	36.6	190	320	510	High Tip Up
EAP	6/26/96	11:20	40.9	190	370	560	High Tip Up
EAP	7/10/96	13:12	37.5	191	388	579	High Tip Up
EAP	7/10/96	13:14	38.8	236	372	608	High Tip Up
ROS	8/8/96	1:59	37.9	185	365	550	High Tip Up

[a] CU stated that this was a non-tip-up run, with wheel lift.

The lowest magnitude steering inputs reported for a high tip-up run were 190 degrees left and 320 degrees right (36.6mph). This total reverse steer of 510 degrees is 111 degrees greater than the total reverse steer in the non-tip-up, clean run at a higher speed (37.5 mph). This demonstrates the effect of steering inputs on test outcome.

[10] "Short Course Summary," delivered to ODI on November 25, 1996. The steering inputs for this run were reported in the prior section.

CU used three different drivers for these tests: KS, EAP, and ROS. The CU drivers have apparently developed different strategies for driving vehicles through the short course. For example, data from the two tests that CU evaluated in its December 23, 1996 submission, are plotted in Figure 6.[11] KS (marked with squares) steered sooner than EAP (marked with dots), while EAP used more steering input than KS. The KS steering input resulted in an non-tip-up, clean run, while the EAP steering input resulted in a high tip-up, non-clean run.

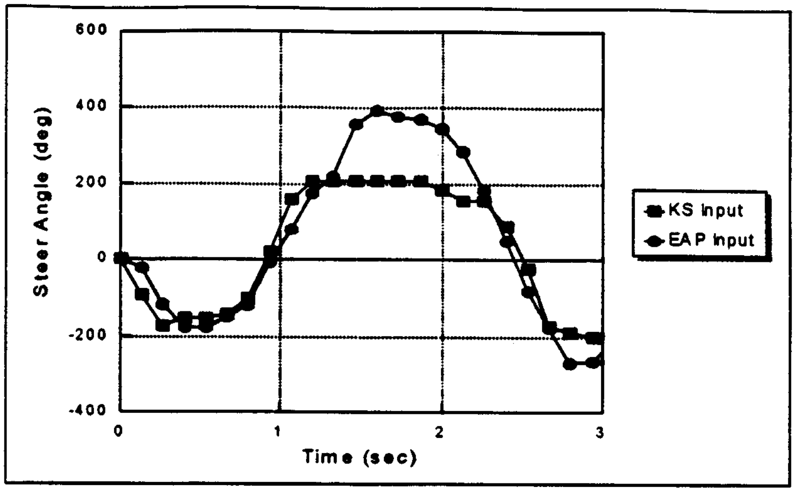

Figure 6. Clean Run Driving Profile for KS and High Tip-Up Run Driving Profile for EAP.

ODI reviewed all the test data supplied by CU for the tests in which steering inputs were reported. Each test has a maximum left and right steer associated with the first and second steering maneuvers. For each vehicle (Tahoe, Pathfinder, 4 Runner, and the subject vehicles[12]), the maximum right and left steer were averaged; i.e., for the Tahoe, the 16 tests resulted in an average left steer of 185 degrees and average right steer of 225 degrees. Table 14 presents these data.

Table 14. Average Steer Angle for CU tests on Short Course by Vehicle Tested.

Vehicle	Test Speed	Left Steer	Right Steer	Total Reverse Steer	Number of Tests
1996 Tahoe	35.2	185	225	410	16
1996 4 Runner	37.8	175	225	400	15
1996 Pathfinder	37.3	171	228	399	13
Subject Vehicles	36.6	188	312	500	124

In general, the steering inputs for the subject vehicles were greater than those for the Tahoe, Pathfinder, and 4 Runner. The three peer vehicles were driven in a very similar pattern - with the left and right inputs for each vehicle being very similar. The subject vehicles had only slightly

[11] As described in Footnote 7, because of differences in the submissions by CU, the maximum steering inputs depicted in Figure 6 are different from those included in Table 13.

[12] The subject vehicle tests included tests of three different vehicles: 1996 Trooper, 1996 SLX, and 1995 Trooper.

more left steer than the other three vehicles, but substantially more right steer – about 90 degrees more than the other vehicles.

6.1.2.2 CU Testing of the MY 1992 Isuzu Trooper in 1992

In 1992, CU conducted a series of tests to evaluate the MY 1992 Isuzu Trooper. (A new version of the Trooper had been introduced in 1992. This version continued with no relevant changes through MY 1994.) The testing included runs on the CU short course. This testing was performed by one driver, ROS, on October 28, 1992. A total of 10 runs were made; five of them were clean runs. The highest speed of the clean runs was 37.1 mph. The fastest run, conducted at a speed between 38 and 39 mph, resulted in a two-wheel lift. CU also recorded several clean runs in which one wheel lifted.

CU rated this vehicle as "Good" for "Emergency Handling."

6.1.2.3 Historical CU Testing (1988-present)

CU started using the short course in mid-1988 while evaluating the 1988 Suzuki Samurai. Since that time, CU has used it to evaluate rollover performance of 44 models (as described in issues of Consumer Reports from July 1988 through October 1996), including all SUV's and many other light vehicles, such as new entry minivans and small pickups. During that time period, CU has rated two vehicles as "Not Acceptable" in terms of rollover: the Suzuki Samurai and the subject vehicles.[13]

6.1.3 Test Results Submitted by Isuzu

6.1.3.1 Isuzu Testing

Testing in Japan
Isuzu tested the subject vehicles and the 1994 Trooper in Japan. While no documentation was submitted as to the exact course layout, it appears that the course was similar to the CU short course. The tests were documented on videotape recordings. The test vehicles were not equipped with outriggers.

This testing showed that the subject vehicles could be cleanly driven through the Isuzu version of the CU short course at speeds up to 36.6 mph, which is several mph faster than the speed at which CU reported its first two-wheel tip-up (without outriggers).

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[13] Three of the vehicles that CU did not find to be "Not Acceptable" had tip-ups in CU tests on the short course: the 1989 Ford Bronco II, the 1992 Mitsubishi Montero, and the 1992 Isuzu Trooper.

Isuzu's testing of the 1994 Trooper indicated that its performance on the Isuzu version of the CU short course was similar to that of the subject vehicles. Isuzu conducted several clean runs with this vehicle, at speeds up to 36.5 mph.

Other Isuzu Test Information
Isuzu also submitted a compilation of historical testing (conducted by several organizations) which purported to show that many vehicles could be made to tip up on dry roadway surfaces. Several maneuvers were used, including crash avoidance and J-turns.[14]

6.1.3.2 Carr Testing

Isuzu also submitted tests of a 1996 Trooper conducted by Carr Engineering using the CU short course, without outriggers. Typical test speeds ranged between 30 and 37 mph. The vehicle was instrumented to collect steering inputs, as well as an assortment of vehicle dynamic data, including lateral acceleration. The fastest clean run by Carr was at 36 mph (Carr Test 34). The steering inputs on this run were 175 degrees to the left and 235 degrees to the right; thus, the total reverse steer was 410 degrees. These steering inputs were similar to those on the clean run that CU driver KS had at 37.5 mph.

6.1.4 NHTSA Testing

Tests were conducted by NHTSA in two locations: the Vehicle Dynamics Area (VDA) at TRC, which is a 50-acre asphalt pad, and an asphalt runway at the UTQG test facility.

Initial testing conducted at TRC was based on an improperly labeled drawing of the CU short course.[15] The centers of the entrance lane cones were nine feet apart, while the inside bases of the left and right side cones should have been eight feet apart. In addition, the right gate cone was centered three feet into the second lane, while the inside base of that cone should have been three feet into the lane. A comparison of the CU short course and the course originally used at TRC is

[14] The steering inputs made by the drivers in these tests were not reported.

[15] In its October 10, 1996 submission, CU supplied a drawing that reflected the layout of the CU short course. This drawing did not give the exact cone placement to mark the lane widths or offset gate placement. At Isuzu's press conference (September 12, 1996), Isuzu presented an analysis conducted by Carr Engineering that purported to depict the CU short course in detail. NHTSA used the Carr drawing of the course during its initial round of testing at TRC. In its December 23, 1996 submission, CU submitted a higher quality drawing of the CU short course, shown earlier in this section. At this point NHTSA realized the original course was not precisely identical to the CU short course and changed the course accordingly. All tests conducted in Texas and those conducted in Ohio after the Texas testing (except for the evaluation tests to compare the two courses and to ascertain the effect of outriggers) were on a course identical to that used by CU.

given in Figure 7. Since the original TRC course was set up on cone centers, the diameter of the cones affect the inside base distances. The cone size used in this TRC testing resulted in an inside base distance of eight feet six inches, as compared to the CU short course distance of eight feet, and an inside base gate cone distance of three feet three inches, as compared to the CU short course distance of three feet.[16] All short course testing at the UTQG facility was on a course identical to the CU short course.

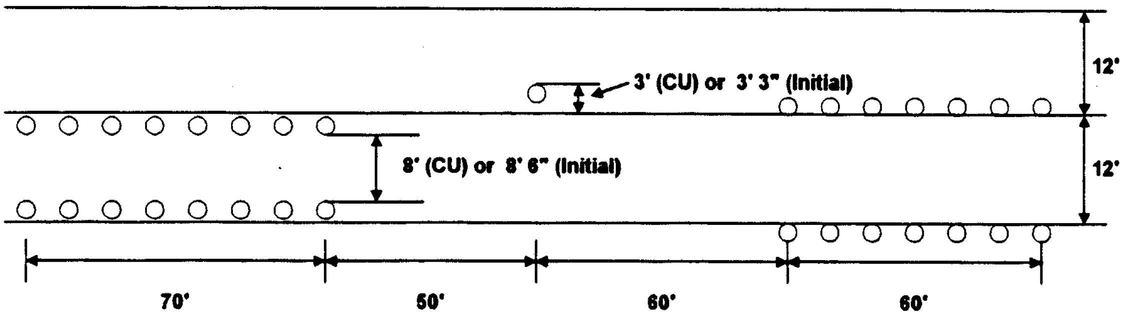

Figure 7. Differences between CU Short Course and Initial TRC Course.

Phase 1 Testing in Ohio

The following vehicle configurations were tested at TRC on the initial course layout, using Bridgestone Dueler tires.

1996 Acura SLX without outriggers
1996 Acura SLX with VRTC outriggers

Testing was first performed without outriggers at speeds from 26 to 32 mph. There was no sign of wheel lift. VRTC outriggers were then added to the vehicle, and the vehicle was tested at nominal[17] speeds ranging from 30 to 40 mph. In general, the tests up to a nominal speed of 38 mph produced very little or no front wheel lift. The highest actual test speed that produced a clean run was 37.6 mph.

[16] NHTSA has compared the results of the tests conducted on the initial TRC layout with those conducted at TRC using the precise CU course layout. These results indicate that the slight differences in the cone placement did not produce significantly different results. For example, the maximum clean run speeds for both courses were very similar (37.6 mph in Test 76 and 37.3 mph for Test 559). See Appendix E of the VRTC report for more details.

[17] The term "nominal speed" indicates the target speed for a set of runs. Typically, tests were conducted with a target speed in two mph increments; i.e., 30, 32, 34 mph, etc. The actual test speed was collected with on-board instrumentation.

At 40 mph, front wheel lift was more noticeable, and there was one test that produced significant tip-up; the outrigger hit the ground. Another test produced significant front wheel lift, but the vehicle did not approach a rollover.

These results did not coincide with the lower tip-up speeds reported by CU, so several tests were run to try to produce a tip-up at lower speeds using an Acura SLX with VRTC outriggers. The methodology used to intentionally tip the vehicle (characterized by the test driver as "whipping" the steering wheel) was to increase the steer angle and steer rate, especially for the reverse steer. The initial steer was also slightly delayed.

Intentional tip-ups were produced at speeds as low as 35.2 mph. Attempts to tip the vehicle up at 34 mph were unsuccessful. The left and right maximum steer angles and total reverse steer angles for two clean runs and two intentional tip-up runs at nominal speeds of 36 mph are given in Table 15.

Table 15. Comparison of VRTC Tests, Showing Test Speed, Steer Angles, and Steer Rates for Clean and Intentional Tip-Up Runs - Acura SLX, with VRTC Outriggers.

Test Outcome	Speed (mph)	Left Steer (deg)	Left Steer Rate (deg/sec)	Right Steer (deg)	Right Steer Rate (deg/sec)	Total Steer (deg)	VRTC Test Reference Number
Clean Run [a]	36.5	202	891	236	1053	438	55
Clean Run [a]	36.0	210	1030	258	1007	468	57
Tip-Up Run [b]	36.6	225	832	332	1389	557	106
Tip-Up Run [b]	35.2	228	875	395	1383	623	109

[a] These runs did not have a tip-up.
[b] These runs were not clean.

These data indicate that while testing at the same nominal speed, dramatic differences in the outcome can be generated by the test driver. A slight increase in the left steer with similar steering rates, followed by a substantial increase in the right steer at a much higher rate produced tip-up, while the vehicle could go through the course successfully with less severe steering inputs.

Testing in Texas

Due to inclement weather in Ohio, NHTSA's testing was continued at the UTQG facility in San Angelo, Texas. The following vehicle configurations were tested at this site:

1996 Isuzu Trooper (CU) with CU outriggers and Goodyear Wrangler Tires
1996 Isuzu Trooper (CU) with CU outriggers and Bridgestone Dueler Tires
1996 Acura SLX with VRTC outriggers and Bridgestone Dueler Tires
1994 Isuzu Trooper with VRTC outriggers and Bridgestone Dueler Tires

The primary purpose of these tests was to compare the performance of the subject vehicles with that of the 1994 Trooper.

Subject Vehicle Testing in Texas

At no time did tip-up occur at nominal speeds less than 38 mph, so this summary will concentrate on the tests at 38 mph. Out of 49 tests with the subject vehicles (33 with the 1996 Trooper and 16 with the 1996 SLX) at this speed, there were two significant tip-ups, each with the 1996 Trooper equipped with the CU outriggers and Bridgestone Dueler tires.

These results suggest that the Bridgestone Dueler tires were slightly more aggressive (as reflected by their ability to produce a tip-up for the 1996 Trooper) than the Goodyear Wranglers. However, these data cannot be the basis for definitive findings about tire aggressivity due to possible variations in the test surface and the lack of repeatability of the driver inputs.

The 1996 Acura SLX with VRTC outriggers produced no tip-ups at 38 mph.

Peer Vehicle (1994 Trooper) Testing in Texas

Prior to beginning NHTSA's tests of the 1994 Trooper, it was observed that the test surface had become heavily covered with black marks, most likely from tire wear, but possibly from tar coming out of the test surface. Because of a concern that the surface might have changed, a second, "new" surface was set up. To accomplish this, the course direction was reversed; i.e., the twelve-foot wide exit lane became an eight-foot wide entrance lane and vice versa. This reversal had the effect of placing the area in which the vehicle was turned on relatively clean pavement. The "new" course was first used with the 1996 Trooper with the Bridgestone tires.

Out of 24 tests conducted with the 1994 Trooper at a nominal speed of 38 mph, 19 were run on the "old" course and five were run on the "new" course. There were two tip-ups on the "new" course and no tip-ups on the "old" course. Since no tip-ups occurred when the 1994 Trooper was tested on the "old" course, even though there were greater steering inputs on some test runs, it was theorized that previous testing on the "old" course had affected the friction properties of the test surface. It was later confirmed that the original course had a significantly lower skid number[18] than the new course, even after a few tests had been conducted.[19]

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[18] Skid Number refers to the frictional resistance of the pavement measured in accordance with ASTM E-274. Higher skid numbers mean that the pavement has a higher frictional resistance. As the skid number of a surface decreases, a vehicle's ability to generate lateral traction diminishes. This would generally lower the maximum speed at which a vehicle could be driven through the course cleanly. A lower skid number surface would also diminish the likelihood of rollover, since the lower pavement resistance would be insufficient to generate the needed forces at the tire/road interface to cause rollover. This principle is demonstrated by the fact that it is very difficult to roll a vehicle on an icy road surface.

[19] See VRTC test report; Appendix F for more details.

The peer vehicle testing was compared to the subject vehicle testing to ascertain whether the tests were conducted in a similar manner. Table 16 presents the average speed and left and right steering inputs for these tests. As these data indicate, the tests were conducted in a similar manner.

Table 16. Comparison of Subject Vehicle and Peer Vehicle Test Speeds and Steering Inputs for Tests at a Nominal Speed of 38 mph.

Vehicle	Number of Tests	Average Speed (mph)	Average Left Steer Input (deg)	Average Left Steer Rate (deg/sec)	Average Right Steer Input (deg)	Average Right Steer Rate (deg/sec)	Total Reverse Steer (deg)
Subject Vehicles	49	38.4	215	852	265	1113	480
Peer Vehicles	24	38.6	225	921	258	1144	483

Phase 2 Testing in Ohio

NHTSA conducted a second phase of tests at TRC after completion of the testing in Texas. These included 122 tests to investigate two issues: 1) the effects of outriggers on a vehicle's performance on the CU short course; and 2) whether differences between the initial TRC course (used during the beginning of NHTSA's test program) and the course used in Texas (a course setup precisely like the CU course) resulted in differences in vehicle performance.

The results of the outrigger-effect testing will be discussed in Section 6.4, while the effect of the differences in the two courses was discussed at the beginning of this section.

6.2 Suzuki Testing

Suzuki submitted test results for many vehicles which it had tested on a course similar to the CU short course. This testing demonstrated that many vehicles could be tipped onto two wheels. Suzuki did not test the subject vehicles.

6.3 Understeer/Oversteer [20]

Based on analysis using a simulation model (discussed in Section 7, below), CU claimed that the subject vehicle will oversteer at high lateral acceleration levels.[21] CU's analysis was based on computer simulation of a vehicle's behavior while slowly increasing its speed around a constant radius turn, rather than using the CU short course. Both Isuzu and NHTSA conducted tests to ascertain whether this actually occurred at high lateral acceleration levels (in the 0.65 to 0.75 g range).[22] A vehicle which changes from understeer to oversteer at high lateral acceleration levels would generate higher sideslip angles. These high sideslip angles could generate more lateral force acting through the vehicle's center of gravity, which would make the vehicle more likely to tip over.

6.3.1 Isuzu Testing

Isuzu's April 8, 1997 submission presented a series of tests to determine the subject vehicles' propensity to understeer or oversteer under certain circumstances. Data were derived from a series of tests around a constant-radius path, at an ever-increasing speed. The faster speeds require more steering wheel angle to maintain a constant-radius path, which in turn generates higher lateral accelerations. Isuzu used the relationship between the steering wheel angle and the measured lateral g's to determine understeer/oversteer. Isuzu claims that "... one can see that the vehicle is definitely understeering and that it tends to plow out at the limit."

[20] A vehicle is said to understeer when, as lateral acceleration increases, the slip angle at the front axle increases more than it does at the rear axle. The opposite applies for a vehicle which oversteers. In layman's terms, an understeer vehicle "plows out" – that is, tends to go straighter than expected -- while an oversteer vehicle "spins out" – that is, the rear end tends to swing around. A vehicle that oversteers has more sideslip and yaw angle during a turning maneuver, which generates more lateral force. Increased lateral force will develop additional roll (lean) in the vehicle and could generate sufficient forces to roll the vehicle over.

[21] Lateral accelerations are generated while driving a vehicle through different maneuvers. Suzuki submitted data that indicates that typical driving on freeways generate lateral accelerations of up to about 0.16 g's; surface streets generate up to about 0.25 g's; emergency turns generate up to about 0.45 g's; and the ISO lane change maneuver generates up to about 0.48 g's. Reference: Suzuki letter dated March 19, 1997, Attachment A, Figure 4.1.

[22] NHTSA considered possible methods to measure vehicle understeer/oversteer during the transient maneuver associated with the steering reversal (right turn) in the CU short course. However, the agency was unable to identify any practicable methods to obtain such measurements. Based on the facts that NHTSA could not identify a practicable method to measure oversteer in the reverse steer maneuver and since CU used a standard industry approach to determine understeer/oversteer, NHTSA used an approach similar to CU's; that is, it measured the vehicle's response to a series of increasing steering inputs in a single direction.

6.3.2 NHTSA Testing

NHTSA conducted a series of step- steer tests using a committee draft of International Standards Organization (ISO) 7401 procedure "Road Vehicles - Lateral Transient Response Test Methods Part 1: Fixed Steer Control."[23] NHTSA used the 1996 Acura SLX without outriggers. During step-steer testing, the steering wheel is set up in a way that it can be turned to a preset steer angle, which is referred to as a "step." The step is increased on each run until all desired steer angles are tested. On each run, the driver turns the steering wheel as fast as possible to the steering stop and holds it there until the vehicle reaches a steady-state condition, holding the throttle constant and without applying the brakes.

Testing was conducted at 40 mph to steer angles of 230 degrees, which resulted in lateral acceleration levels of nearly 0.8 g, a very high lateral acceleration. The results of these tests are plotted in Figure 8. These data indicate that the vehicle exhibits understeer throughout the range of testing; that is, for each percentage increase in the steering wheel angle, there is an even smaller percentage increase in lateral acceleration.

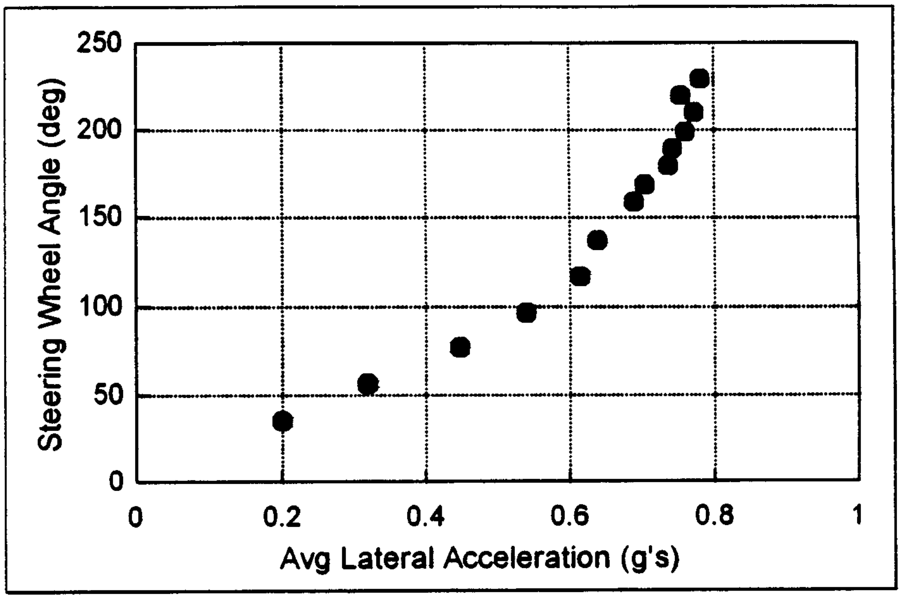

Figure 8. Steering Wheel Angle vs. Lateral Acceleration, 40 mph, 1996 Acura SLX w/o Outriggers.

6.4 Outrigger Effects On Test Outcome

Since Isuzu's tests of the subject vehicles without outriggers did not lead to tip-ups, and since the 1996 Isuzu Trooper with CU outriggers seemed to more readily tip up than the 1996 Acura SLX

[23] There are two primary methods for determining the relationship between steer angle and lateral acceleration. One is to drive around a constant radius curve at an increasingly faster speed. Each speed increment will require additional steering angle to maintain the path. (This is the method used by Isuzu that was described in the prior section.) Another method, which can only be used with a large test area, is to conduct all the tests at the same speed. Using this method, the steer angle is increased in steps, and the resultant lateral acceleration is measured. Since the CU tests were conducted at speeds around 40 mph, NHTSA used the step-steer test to measure the steer angle-lateral acceleration relationship at that speed.

with VRTC outriggers at similar test speeds, NHTSA attempted to ascertain the effects of the outriggers on tip-up propensity. Tests were run on the CU short course with the 1996 Acura SLX with no outriggers, VRTC outriggers, and CU outriggers.[24] The no-outrigger tests were run at a nominal speed of 34 mph, while those with the outriggers were run at nominal speeds of 34, 36 and 38 mph.

The vehicle was driven by a test driver, so the steering inputs for each test configuration could not be repeated exactly, but enough tests were run to allow a comparison of vehicle responses. For the lower levels of initial steer (200-210 degree range), the driver needed to put in significantly more second steer for the VRTC-outrigger configuration than for the no-outrigger configuration. At higher levels of initial steer (210-230 degree range), the second steer for the VRTC-outrigger configuration was only slightly greater. The first and the second steer inputs were significantly greater for the CU-outrigger configuration than for both the no-outrigger and the VRTC-outrigger configurations. The details of this testing are discussed in the VRTC report.

7.0 SIMULATION RESULTS

Computer simulation is a tool used by many researchers to investigate the dynamic performance of vehicles. In the mid 1980's, NHTSA entered into a contract with STI to develop a vehicle handling computer simulation program. The result of that effort was the computer simulation Vehicle Dynamics Analysis, Non-Linear (VDANL). VDANL has been upgraded over the years to expand and improve its capabilities. This simulation program has been utilized by CU and Isuzu to analyze the subject vehicle's performance in certain crash avoidance maneuvers.

Simulations are generally validated through actual field testing by comparing the field observations to those predicted by the simulation. When agreement is achieved for a particular test or maneuver (based on a comparison of various attributes from the model and test, such as path position, angular and linear rates and accelerations, etc.), the model is considered validated with respect to that test or maneuver. The zone of agreement between the actual test results and the computer simulation is referred to as the range of validation.

Often the simulation's predictions are good for some period, but degrade as the simulation continues. For example, a simulation may predict well during the beginning of the modeled event, but degrade with time.

A simulation may also be validated for maneuvers that regularly occur in normal driving, but not give predictive results for maneuvers that are near or at the limit of a vehicle's performance envelope. In these extreme cases, the accuracy of the input data that describe the vehicle's

[24] The VRTC outriggers, which are installed near the vehicle's fore-aft cg, are made of steel and aluminum, use small casters for wheels, and weigh about 115 lbs. The CU outriggers, which are installed at the vehicle's front and rear, are made of steel pipe, use trailer wheels, and add about 270 lbs to the vehicle's weight (the bumper is removed for installation).

attributes becomes particularly important. Typically, these attributes, such as spring rates, tire factors, inertial factors, etc., need to be measured with extreme precision to obtain the best results. However, as a practical matter, it may not be possible to obtain exact measurements, and estimates are often used. When these estimates are not precisely accurate, there may not be agreement between the computer simulation prediction and actual vehicle performance, especially during severe maneuvers. When this occurs, the simulation is considered to be not validated under these circumstances and cannot legitimately be used to predict vehicle performance during those maneuvers.

7.1 Petitioner's Simulations

CU submitted two experts' reports with its December 23, 1996 submission. These reports were authored by Ian Jones of Ian S. Jones & Associates and Wade Allen of STI. Both Jones and Allen used parametric data for the subject vehicles obtained from S.E.A., Inc. and Calspan.

7.1.1 Jones Simulation

Jones reported that using the VDANL simulation program, he was able to independently confirm that the subject vehicles will tip up during the CU short course maneuver. Jones cited an independent evaluation of VDANL by the Iowa State University, which concluded that VDANL most closely modeled vehicles at their limit of performance.

Jones also analyzed several potential improvements to the subject vehicles, including increasing the front roll stiffness, lowering the cg, and changing the track width. Jones asserted that increasing the front roll stiffness would improve the vehicles' ability to proceed through the CU short course without tip-up.

7.1.2 Allen Simulation

Allen conducted VDANL simulations using two maneuvers: steady state and steering reversal. Parametric inputs for the simulations were the same as those used by Jones.

Allen computed understeer/oversteer for the subject vehicles. For lateral acceleration levels up to about 0.65 g's, Allen's analysis showed the vehicle would understeer. For higher lateral acceleration levels (above 0.65 g's), the simulation indicated the vehicle would oversteer. Allen concluded that the vehicle needs additional roll stiffness in the front axle to avoid oversteering at high lateral accelerations.

Allen also reported that the simulation predicted that the vehicle would roll over in a steering-reversal maneuver.[25] Simulation results were presented to support this finding.

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[25] The steering wheel input simulated by Allen was trapezoidal in nature, consisting of a right steer to 3.0 radians (172 degrees) in 0.25 seconds, which is held for 0.25 seconds (0.5

Allen suggested that increasing the size of the front anti-roll bar would make the subject vehicle more stable and less prone to roll over during a reverse-steer maneuver. Using the VDANL program, Allen presented simulation data to demonstrate improved rollover performance with the proposed "remedy."

7.2 Isuzu's Simulation

Isuzu contracted with S.E.A., Inc., the same company that had measured the subject vehicle's parameters for the petitioner, to assess the validity of VDANL for use in limit maneuvers, such as a rollover event. This work was performed by Gary Heydinger.

Heydinger found several problems with the VDANL simulation program in the context of the issues raised by this petition. He concluded that VDANL did not accurately model the performance of the subject vehicles at a limit condition, primarily due to a shortcoming in its suspension sub-program. The suspension sub-program is a portion of the simulation program that simulates what will occur when the forces acting on the vehicle's sprung mass are transmitted through the load paths to the axles, wheels, tires, and finally to the road.

The suspension of the subject vehicles is comprised of several components, including the springs and dampers. The spring system consists of the main springs (torsion bars in the front and coil in the rear), stabilizer bars (front and rear), and bump stops (front and rear). The dampers consist of friction in the suspension joints and the shock absorbers (front and rear).

Heydinger concluded that the vehicle's bump stops, the portion of the suspension which is contacted when the springs reach either their maximum or minimum extension,[26] were not modeled correctly in the VDANL simulations performed by Jones and Allen. These devices are often contacted when the vehicle leans while making a very hard turn, and they control the amount of lean during some limit maneuvers, such as a severe steering reversal. As the vehicle leans, one side of the suspension compresses and the other side extends, both front and rear. In a severe turn, this can continue until the vehicle's suspension reaches bump stop engagement.

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seconds of accumulated time), followed by a left steer to -3.0 radians (-172 degrees) in the next 0.5 seconds (1.0 seconds of accumulated time). This steering wheel angle is held for the remainder of the simulation. This input is somewhat like the CU short course, except the timing is fixed and the steering wheel is not returned to center after the second steer.

[26] For example, minimum extension bump stops are the devices that are hit when a driver "bottoms out" a car's suspension, such as when going over a deep pot hole. Maximum stops are the devices which limit the extension travel of the vehicle's springs, and are often incorporated into the vehicle's shock absorbers as a limiting device that is engaged when the shock absorber reaches its full extension.

The VDANL program does not include data reflecting the actual bump stops in the subject vehicles. Rather, the simulation uses a generic bump stop model. According to Heydinger, the shortcomings of this bump stop model include: 1) single value stiffness in bounce and rebound, 2) same value of stiffness front and rear, 3) suspension travel to engagement is the same in bounce and rebound, and 4) suspension travel to engagement is the same front and rear. Heydinger concluded that "the modeling of the bump stops and lack of modeling nonlinear suspension characteristics is inadequate for correctly modeling suspension behavior ... at high lateral acceleration levels." Heydinger presented simulation runs where the bump stop forces were graphically shown. It could be seen that the bump stop forces were significant. This suggests that the correct modeling of these items could be important in predicting the performance of the subject vehicles during maneuvers in which the bump stops are engaged, such as severe crash avoidance maneuvers. In the subject vehicles, the bump stops are engaged at about five to six degrees of roll angle, considerably less than the roll angle experienced by the subject vehicle in the CU short course.

8.0 CRASH DATA

The National Automotive Sampling System (NASS) data were analyzed to determine the type of vehicle maneuver that is associated with an on-road or on-shoulder rollover crash. FARS data were also reviewed. Suzuki submitted an analysis of crash data. Isuzu and CU did not supply any crash data.

8.1 NASS Data Analysis

ODI reviewed the 1992-1995 NASS data files. During this four-year period, weighted[27] estimates from NASS data indicate that there were 11,244,450 tow-away crashes. Of these, 779,502 were rollover crashes. Of these rollovers, 337,307 were first-event, single-vehicle rollovers.

ODI conducted a more detailed (hard copy) analysis of first-event, single-vehicle rollovers in the NASS files that occurred on the roadway or shoulder. Crashes that were coded as having been caused by a vehicle problem, e.g., tire, engine, etc., were excluded, although rollovers that were related to the vehicle's operation, such as overloaded vehicle, high cg of truck-mounted equipment, wheel shimmy, and brake grab causing loss of control, were kept in the analysis. Also, crashes in which the vehicle that rolled over was towing another unit were excluded. Using these criteria, 60 individual cases were identified, which represent 23,247 single-vehicle rollover crashes occurring on the road or shoulder. The 60 cases can be grouped into several general categories, as shown in Table 17.

[27] Weighted values in NASS are determined through statistical sampling techniques. They allow the use of the NASS sample of about 5,000 to 6,000 annual cases to produce estimates representative of the annual total of tow-away crashes on our nation's highways.

Table 17. On-Road/Shoulder First-Event Rollovers from NASS, by Crash Type, 1992-1995.

Category	Number of Rollover Cases	Weighted Value of Rollover Cases [28]	Standard Error [a] (crashes)
Operational Related	6	3,919	± 3,416
Run off the road	24	2,866	± 1,181
Crash Avoidance	12	12,053	± 6,849
Road Conditions	8	2,620	± 1,968
Excessive Speed	4	842	± 757
Lost Control	6	947	± 527
Totals	60	23,247	± 8,839

[a] - Standard Errors were determined using SUDAAN.

Using NASS weighted values for these four years, there were 12,053 rollovers that occurred on the road or shoulder that involved a crash avoidance maneuver. This represents, during the time period, 0.11 ± 0.06 percent of all crashes, 1.55 ± 0.88 percent of all rollover crashes, and 3.56 ± 2.04 percent of all first-event, single-vehicle rollover crashes.

8.2 FARS and State Crash Data

Since the subject vehicles are very new, MY 1995-96, and since crash data tends to be delayed one to two years, there were insufficient crash data to allow ODI to compare the real-world rollover performance of the subject vehicles with that of their peers. Review of the FARS data indicate that there have been no rollover crashes with the subject vehicles, and therefore no evidence from FARS that indicate the subject vehicles are worse that their peers. An analysis of crash data from five states found very minimal crash exposure for the subject vehicles, hence no statistically valid comparative analyses could be performed.

8.3 Suzuki Data

Suzuki submitted several crash data analyses. One analysis used FARS data to estimate the frequency of first-event rollovers on the roadway in single-vehicle crashes involving an avoidance maneuver, defined as a crash in which the vehicle overturned without first leaving the roadway. Suzuki claims that this analysis assesses the representativeness of the CU's procedure in testing the rollover propensity of light trucks in crash avoidance maneuvers. The analysis finds that only 0.4 percent of the 58,366 light trucks in fatal single-vehicle crashes in FARS between 1982 and

[28] These figures have been adjusted to account for cases in the NASS data file where the selection variables were coded as "unknown" (about 1,750 crashes).

1995 fit the above criteria. Using the variable "Crash Avoidance Maneuver" introduced in FARS in 1991, the authors present a similar calculation for crash-involved sport utility vehicles with an occupant fatality. They find that between 1991 and 1995, out of 4,494 such cases in FARS, only 0.1 percent were single-vehicle, first-event rollovers on the roadway taking place while maneuvering to avoid a vehicle, pedestrian, or other object on two-lane undivided road with a speed limit of 45 mph or less and involving steering-only maneuvers.

Suzuki also presented an analysis of North Carolina state data for 1979-1995, which indicates that out of 169,441 light trucks in single-vehicle crashes, only 0.6 percent were first-event, single vehicle rollovers without leaving the roadway with an avoidance maneuver. Using the North Carolina data for 1982-1995, the authors also found that out of 66,584 crashes involving sport utility vehicles, only 0.005 percent were first-event, single-vehicle rollovers taking place while maneuvering to avoid a vehicle, pedestrian, or other object on a two-lane undivided road with a speed limit of 45 mph or lower.

The statistical validity of Suzuki's analyses is questionable because they do not address the problem of missing data (which affects a large portion of the data elements used), and the interpretation of the variables "Vehicle Maneuver," and "Crash Avoidance Maneuver" is not clear (they seem to be interpreted as overlapping). Also, the criteria chosen to classify crashes as relevant to the CU test are too narrow. The additional requirement that the road be a two-lane highway with speed limit of 45 mph or less is even more restrictive. For these reasons, ODI did not rely upon these Suzuki analyses in deciding whether to grant or deny the petition.

Suzuki also presented a multi-state analysis, comparing the rollover rates (rollovers per single-vehicle crash and rollovers per registered vehicle) for many 4x4 SUV's with the vehicles' CU "Emergency Handling" rating; i.e., Poor through Excellent. However, CU did not claim that its "Emergency Handling" rating would correlate with rollover propensity. Rather, CU's determination as to whether a vehicle's rollover performance is "Not Acceptable" is based solely on its performance on the short course, and the short course tests are not utilized by CU in developing its "Emergency Handling" rating. Hence, Suzuki's effort to demonstrate that there is no correlation between CU's "Emergency Handling" ratings and the vehicles' rollover rate is not relevant to this petition analysis.

9.0 FINDINGS

① A comparison of the vehicle parameters of the subject vehicles with those of the 1992-1994 Trooper does not provide any basis on which to conclude that the subject vehicles have a greater rollover propensity. In fact, the subject vehicles have a wider wheel base, higher static stability factor, and higher tilt table ratio, which, if all other things were equal, would suggest that they are less likely to roll over.

② Analyses of rollover complaints in the ODI consumer data base data do not suggest that the subject vehicles have an abnormally high rollover propensity. Analysis of FARS and state data bases indicate that there are insufficient data to conduct a statistically valid comparative analysis.

③ Although the VDANL simulation program provides valid predictions of vehicle behavior during most vehicle operations, a shortcoming in its suspension sub-program undermines its ability to predict the precise performance of the subject vehicles at certain limit conditions, such as those experienced during the CU short course maneuver and other severe driving maneuvers that cause the vehicles' bump stops to be engaged.

④ Although the computer simulation submitted by CU indicated that the subject vehicles would switch from understeer to oversteer at high lateral acceleration levels, testing of the subject vehicles by NHTSA and Isuzu indicates that the vehicles understeer throughout a range of lateral accelerations up to nearly 0.8 g's.

⑤ ODI's review of tests performed by CU drivers on the CU short course demonstrates that the test can be and has been conducted with a variety of strategies, including timing of turns, severity of steering inputs, and rate of steering inputs, which can lead to different results under similar initial conditions.

⑥ In testing conducted by NHTSA on the CU short course, the results of tests of a peer vehicle (the 1994 Trooper) were similar to those of the subject vehicles.

⑦ Equipping a vehicle with outriggers has an effect on the vehicle's performance on the CU short course. These effects are more noticeable with the CU outriggers than with the lighter VRTC outriggers.

⑧ Data developed during ODI's testing and its review of the CU tests, demonstrates that the CU short course test, as conducted by CU, does not provide a sufficient scientific basis on which to determine the existence of a safety-related defect.

10.0 CONCLUSIONS

Because of deficiencies in the CU short course testing and since none of the other information reviewed by ODI indicates that a safety-related defect exists, there is no reasonable possibility that an order concerning the notification and remedy of a safety-related defect in the subject vehicles would be issued at the conclusion of an investigation.

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