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Automatic Emergency Braking System (AEB) Research Report

An Update of the June 2012 Research Report Titled, "Forward-Looking Advanced Braking Technologies Research Report"

August 2014

This report is free of charge at http://www.regulations.gov

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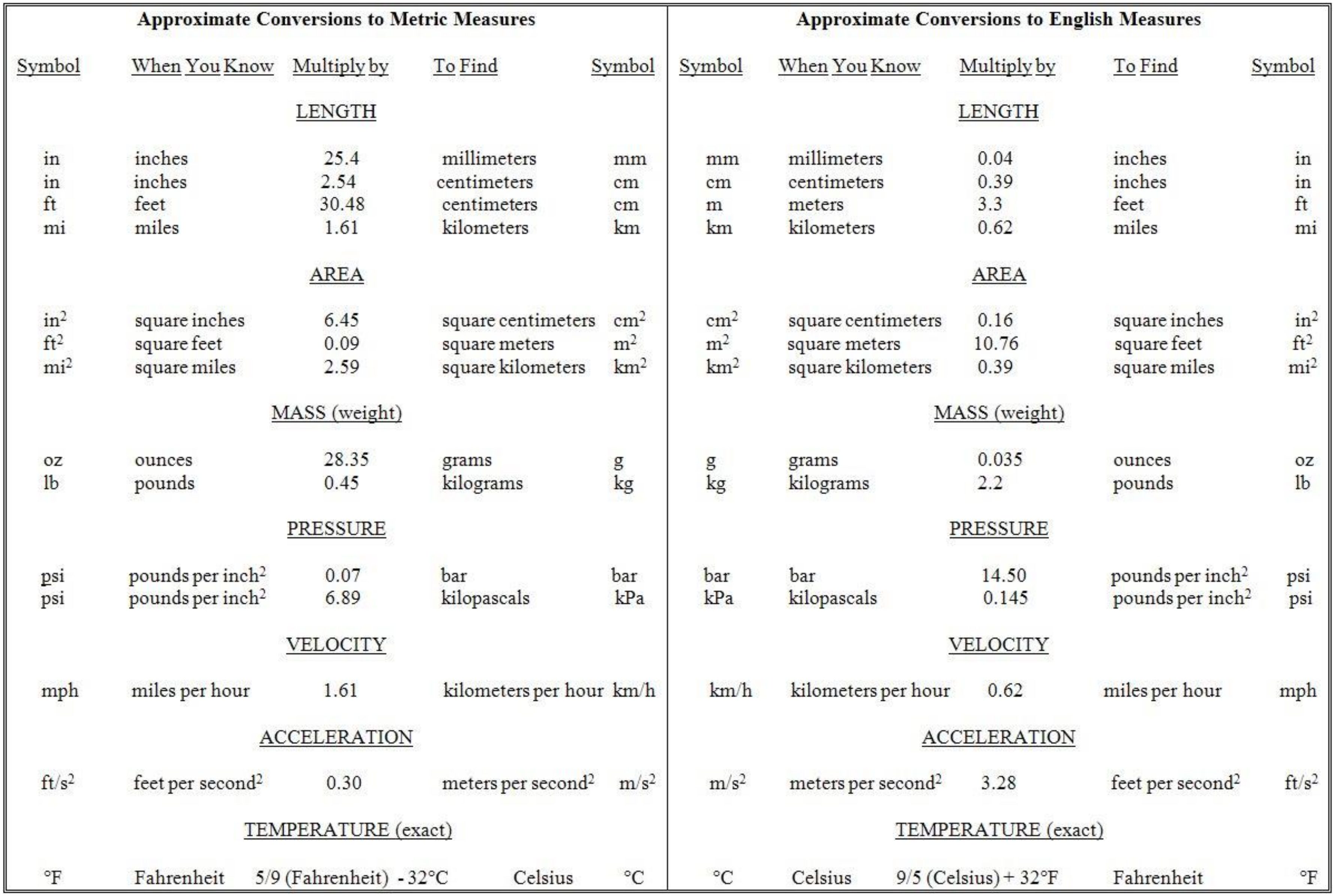
CONVERSION FACTORS



Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
in	inches	2.54	centimeters	cm
ft	feet	30.48	centimeters	cm
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	6.45	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
mi^2	square miles	2.59	square kilometers	km^2
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.45	kilograms	kg
		PRESSURE		
psi	pounds per inch^2	0.07	bar	bar
psi	pounds per inch^2	6.89	kilopascals	kPa
		VELOCITY		
mph	miles per hour	1.61	kilometers per hour	km/h
		ACCELERATION		
ft/s^2	feet per second^2	0.30	meters per second^2	m/s^2
		TEMPERATURE (exact)		
°F	Fahrenheit	5/9 (Fahrenheit) - 32°C	Celsius	°C

Approximate Conversions to English Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.39	inches	in
m	meters	3.3	feet	ft
km	kilometers	0.62	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	10.76	square feet	ft^2
km^2	square kilometers	0.39	square miles	mi^2
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
		PRESSURE		
bar	bar	14.50	pounds per inch^2	psi
kPa	kilopascals	0.145	pounds per inch^2	psi
		VELOCITY		
km/h	kilometers per hour	0.62	miles per hour	mph
		ACCELERATION		
m/s^2	meters per second^2	3.28	feet per second^2	ft/s^2
		TEMPERATURE (exact)		
°C	Celsius	9/5 (Celsius) + 32°F	Fahrenheit	°F

LIST OF ACRONYNMS

ADAC	Allgemeiner Deutscher Automobil-Club
AEB	Automatic Emergency Brake
AIS	Abbreviated Injury Scale
ARV	Assessment Reference Value
BA	Brake Assist
BC	Brake Controller
CA	Crash Avoidance
CIB	Crash Imminent Braking
COTR	Contracting Officer’s Technical Representative
DAS	Data Acquisition System
DBS	Dynamic Brake Support
EDR	Event Data Recorder
FCAM	Forward Collision Avoidance and Mitigation
FCW	Forward Collision Warning
GAWR	Gross Axle Weight Rating
GVWR	Gross Vehicle Weight Rating
IIHS	Insurance Institute for Highway Safety
LVS	Lead Vehicle Stopped
LVM	Lead Vehicle Moving
LVD	Lead Vehicle Decelerating (general case)
LVD1	Lead Vehicle Decelerating (throughout duration of maneuver)
LVD2	Lead Vehicle Decelerating to a Stop
MAIS	Maximum Abbreviated Injury Scale
MTRI	Michigan Transportation Research Institute
NASS-CDS	National Automotive Sampling System: Crashworthiness Data System
NASS-GES	National Automotive Sampling System: General Estimates System
NCAP	New Car Assessment Program
NHTSA	National Highway Traffic Safety Administration
NMVCCS	National Motor Vehicle Crash Causation Study
POV	Principal Other Vehicle

RCS	Radar Cross Section
RFC	Request for Comment
SSV	Strikeable Surrogate Vehicle
SV	Subject Vehicle
STP	Steel Trench Plate
TPS	Throttle Position Sensor (data reported as a percentage of wide open throttle)
TTC	Time to Collision
UMTRI	University of Michigan Transportation Research Institute
UVW	Unloaded Vehicle Weight

EXECUTIVE SUMMARY

This document describes recent progress made by National Highway Traffic Safety Administration (NHTSA) to better understand the safety potential of Automatic Emergency Brake (AEB) system technologies and discusses advances in the agency's objective measures used to quantify their test track performance. AEB systems are a subset of what the agency refers to as Forward Crash Avoidance and Mitigation (FCAM) systems. Whereas the FCAM designation includes systems that provide Forward Collision Warning (FCW) only, AEB systems such as Crash Imminent Braking (CIB) and Dynamic Brake Support (DBS) are specifically designed to help drivers avoid, or mitigate the severity of, rear-end crashes. CIB systems provide automatic braking when forward-looking sensors indicate that a crash is imminent and the driver has not braked, whereas DBS systems provide supplemental braking when sensors determine that driver-applied braking is insufficient to avoid an imminent crash.

To better understand the potential benefits of CIB and DBS, NHTSA in late 2010 began an examination of the current state of the development, functionality, and deployment of these technologies. The agency performed a literature review, met with vehicle manufacturers and FCAM system suppliers, and conducted a series of vehicle tests to quantify the capabilities of then-current CIB and DBS systems. This work culminated in a June 2012 report titled, "Forward-Looking Advanced Braking Technologies Research Report," and publication of a Request for Comment (RFC) in July 2012.

Twenty-four (24) organizations responded to the July 2012 RFC. Most agreed that FCAM technologies will provide positive safety benefits. Automobile manufacturers and suppliers provided detailed feedback on NHTSA's draft test procedures referenced in the RFC, and several recommended specific changes. Additionally, most commenters acknowledged the importance of preventing false activations, but did not believe all potential false-positive scenarios could be evaluated on a test track.

According to data from NHTSA's Traffic Safety Facts 2011, a total of 1,721,000 rear-end crashes occurred in 2011, of which the agency determined 897,000 could have been favorably affected by CIB/DBS. This target population is essentially the same size as that noted in the June 2012 research report.

The preliminary benefit estimates provided in this document were calculated by assuming that all light vehicles would be equipped with a Forward Collision Warning (FCW), CIB and DBS, and that CIB and DBS systems would provide speed reductions at levels that would satisfy the draft Assessment Reference Values (ARVs), metrics developed by NHTSA researchers and given in this report. The agency estimates that the combined effect of FCW, CIB, and DBS on all light vehicles would prevent approximately 200,000 minor injuries (Abbreviated Injury Scale (AIS) 1 - 2), 4,000 serious injuries (AIS 3 – 5), and save approximately 100 lives annually.

In addition to updating preliminary estimates of benefits associated with FCAM technologies, this document also summarizes refinements made to the draft test procedures since their concurrent publication with the June 2012 research report. Revisions include:

- Addition of two lead vehicle decelerating maneuvers
- Addition of a false-positive test that utilizes a steel trench plate similar to those used as temporary roadway covers during construction.
- Updates to the brake application methods used for DBS testing,

With these revisions, the CIB and DBS draft test procedures are now comprised of the following test scenarios:

- **Lead Vehicle Stopped (LVS):** The Subject Vehicle (SV) approaches a stopped principal other vehicle (POV) at 25 mph (40.2 km/h).
- **Lead Vehicle Moving (LVM):** Two SV/POV speed combinations are used. In the first, the SV is driven at 45 mph (72.4 km/h) toward a POV traveling at 20 mph (32.2 km/h). In the second, the SV is driven at 25 mph (40.2 km/h) toward a POV traveling at 10 mph (16.1 km/h).
- **Lead Vehicle Decelerating (LVD1)**: The SV and POV are both driven at 35 mph (56.3 km/h) with an initial headway of 45.3 ft (13.8 m), and then the POV decelerates at 0.3g.
- **Lead Vehicle Decelerating to a Stop (LVD2)**: The SV and POV are both driven at 25 mph (40.2 km/h) with an initial headway of 328.1 ft (100 m), and then the POV decelerates to a stop at 0.3g.
- **Steel Trench Plate (STP) False Positive Tests**: Two test speeds are used. The SV is driven over a 8 ft x 12 ft x 1 in (2.4 m x 3.7 m x 25 mm) steel trench plate at 45 mph (72.4 km/h) or 25 mph (40.2 km/h).

To address concerns that the agency has observed with other surrogate vehicles used to evaluate CIB/DBS on the test track, NHTSA developed the Strikeable Surrogate Vehicle (SSV), a surrogate vehicle modeled after a small hatchback and fabricated from light-weight composite materials such as carbon fiber and Kevlar. The SSV appears as a “real” vehicle to the sensors used by contemporary CIB/DBS systems, and retains its shape during test conduct.

NHTSA tested seven late-model light vehicles equipped with a variety of production CIB and DBS systems during 2013 using the revised draft test procedures. For the LVS, LVM, and LVD maneuvers, the draft ARVs used to assess system performance were either speed reduction (i.e., crash mitigation), or crash avoidance, depending on the specific maneuver, test speed, and technology being evaluated (i.e., CIB or DBS). For the STP false positive tests, the performance metric was “no activation.” LVS tests were performed with NHTSA’s SSV and the German Allgemeiner Deutscher Automobil-Club’s (ADAC) inflatable surrogate vehicle to provide a basis for comparing results from different surrogate vehicles.

The 2013 FCAM tests focused on performability (whether it was possible to perform the test conditions repeatably and accurately within the tolerances provided in the draft test procedures) and system performance (whether it was possible to satisfy the draft ARVs). Some of the key observations from these tests include:

Performability: Some test scenarios require complex choreography, but the agency has demonstrated that each is performable. Careful attention to SV and POV speeds, SV throttle release timing, and SV brake application range was found to be particularly important during test conduct, as these were the most common sources of validity violations overall. Based on these research findings, the agency expects that the number of validity violations realized during testing could be reduced by providing test drivers with better test-to-test feedback about whether a given trial had been acceptably performed, and by improving brake controller programming to correctly initiate brake applications at the desired range.

System Performance: Several vehicles were able to satisfy the overall draft ARVs; however, CIB performance was not always indicative of that realized with DBS:

- CIB speed reduction draft ARV: 3 of 7 vehicles met criteria
- DBS speed reduction draft ARV: 3 of 7 vehicles met criteria
- CIB false positive suppression: all 7 vehicles met criteria
- DBS false positive suppression: 6 of 7 vehicles met criteria

Brake Application: For some vehicles, DBS activation can cause the brake pedal to move beyond a commanded position (i.e., toward the floor without additional force from the driver's foot or programmable brake controller). When combined with a brake application designed to maintain a constant pedal position throughout a test (known as "displacement feedback"), the vehicle's DBS system can be adversely affected. To address this, the DBS draft test procedure now includes a "hybrid-feedback" control option that uses a combination of position and force control logic.

During the 2013 FCAM tests, hybrid feedback helped certain vehicles realize better performance than that observed by using displacement feedback. However, the limited data collected indicate use of hybrid-based braking will <u>not</u> benefit most vehicles. With few exceptions, vehicles achieved better DBS performance with displacement-feedback-based brake applications as opposed to hybrid brake applications.

False Positives: No CIB false-positive events were recorded during the 2013 tests. However, DBS false positives occurred during evaluations of two vehicles.

Surrogate Vehicle: No consistent differences in SV response were observed between tests performed with the SSV versus the ADAC surrogate vehicle in the LVS scenario.

1.0 INTRODUCTION

1.1. Purpose of this Report

Automatic Emergency Brake (AEB) systems are a subset of what the agency refers to as Forward Crash Avoidance and Mitigation (FCAM) systems. Whereas the FCAM designation includes systems that provide Forward Collision Warning (FCW) only, AEB systems such as Crash Imminent Braking (CIB) and Dynamic Brake Support (DBS) are specifically designed to help drivers avoid, or mitigate the severity of, rear-end crashes. CIB systems provide automatic braking when forward-looking sensors indicate that a crash is imminent and the driver has not braked, whereas DBS systems provide supplemental braking when sensors determine that driver-applied braking is insufficient to avoid an imminent crash.

The purpose of this report is to summarize recent research conducted by the National Highway Traffic Safety Administration (NHTSA) on AEB system technologies and to update a June 2012 NHTSA report titled, "*Forward-Looking Advanced Braking Technologies Research Report*" [1]. The agency published the June 2012 Report[1] to:

- Provide a technical development and market status of CIB and DBS technologies.
- Present a preliminary estimate of the target crash population that could be addressed by these technologies.
- Present preliminary estimates of system effectiveness and resulting safety benefits.
- Discuss draft test procedures and maneuvers used to evaluate CIB- and DBS-equipped vehicles.
- Present preliminary performance measures for CIB and DBS systems, as well as early test results from production vehicles.

Simultaneous with the release of the June 2012 research report, the agency also released CIB and DBS performance-based draft test procedures and issued a Request for Comment (RFC)[2] in the Federal Register [2,3,4].

In late 2012, the agency began a further study of FCAM technologies, specifically CIB and DBS systems. This report contains the results of these research efforts, which focused primarily on NHTSA's testing of production systems, the refinement of the target population analysis, as well as changes to the draft test procedures. Changes to the draft test procedures were based on industry feedback received in response to the July 2012 RFC, as well as on continuing analysis and research of FCAM technologies.

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[1] Subsequently referred to as the "June 2012 research report" for the remainder of this document.

[2] Subsequently referred to as the "July 2012 RFC" for the remainder of this document.

1.2. July 2012 RFC Summary

In the July 2012 RFC, the agency posed 27 questions to seek comments on a variety of areas related to testing, performance, and benefits of advanced crash avoidance braking technology, specifically:

- Minimum performance requirements for such systems
- Various aspects of the DBS test protocol, particularly brake application methods
- Design elements of a surrogate vehicle or vehicles that could be used for CIB and DBS testing, and improvements to the surrogate vehicle towing systems used thus far by NHTSA
- How to accommodate system suppression features (included in some manufacturers' systems) in executing the proposed test procedures
- General feedback in other areas of research included in the June 2012 research report (benefits, crash population, international research, etc.)

Twenty-four (24) organizations provided comments in response to the July 2012 RFC.[3] Most commenters agreed with the agency's belief that FCAM technologies will provide positive safety benefits. Automobile manufacturers and suppliers of these advanced crash avoidance technologies provided detailed technical feedback on the draft test procedures. Several commenters recommended changes to the draft test procedures, such as replacing the lead vehicle stopped (LVS) scenario with a lead vehicle decelerating to-a-stop scenario, allowing a passing rate of less than 100 percent, and modifying the DBS brake-pedal-application method and rate. Commenters were split on whether or not false-positive tests should be included. While most commenters acknowledged the importance of preventing false activations, they did not believe that all potential false-positive scenarios could be evaluated on a test track.

The July 2012 RFC and all comments received can be accessed at www.regulations.gov in Docket NHTSA-2012-0057. The agency reviewed the target population and test protocols in response to July 2012 RFC feedback. Changes made by the agency after the FCAM research report and June 2012 draft test procedures are explained in the relevant sections of Sections 3, 4, and 5 of this document.

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[3] Those who submitted comments in response to the RFC are: Advocates for Highway and Auto Safety (Advocates), American Motorcyclist Association, Automotive Safety Council, Autoliv North America (Autoliv), BMW of North America (BMW), Continental Automotive Systems, Inc. (Continental), Delphi Automotive (Delphi), Denso Corporation (Denso), Dynamic Research, Inc. (DRI), Ford Motor Company (Ford), Global Automakers, Inc. (Global), General Motors LLC (GM), Insurance Institute for Highway Safety (IIHS), Magna Electronics (Magna), Mercedes-Benz USA (Mercedes), Mitsubishi Motors R&D of America, Inc. (Mitsubishi), Motorcycle Safety Foundation, National Transportation Safety Board (NTSB), Robert Bosch LLC (Bosch), TK Holdings, Inc. (Takata), Toyota Motor Corporation (Toyota), Truck and Engine Manufacturers Association (EMA), Volvo Car Corporation (Volvo), Volkswagen Group of America (VW/Audi).

1.3. Forward Collision Avoidance and Mitigation (FCAM) Technologies

FCAM refers to crash avoidance technologies that help reduce the likelihood of a forward-moving vehicle being involved in a rear-end crash with another vehicle traveling in the same direction directly in front of it. Depending on the implementation and driving situation, FCAM systems are capable of automatically applying a vehicle's foundation brakes or supplementing the driver's brake input in a way that prevents or mitigates the rear-end crash. NHTSA's recent FCAM research has focused on three technologies currently in the marketplace, which were defined in the FCAM research report. They are defined again here, in slightly more detail, for the convenience of the reader.

1.3.1. Forward Collision Warning (FCW)

FCW utilizes forward-looking sensors[4] designed to monitor the distance between a forward moving vehicle and another vehicle in its lane. If the system determines that the relative speed of the vehicles and headway distance between the vehicles is such that a collision is likely, the system alerts the driver by means of auditory, visual (e.g., on the dash board, heads up display (HUD), and/or haptic (e.g., vibrations or movement in the seat, pedals, or steering wheel) alerts. The timing of an FCW alert relative to an imminent rear-end collision is intended to provide the driver with enough time to assess the potential hazard and respond with the appropriate combination of braking or steering needed to avoid the crash.

1.3.2. Dynamic Brake Support (DBS)

DBS applies supplemental braking in situations in which the system has determined that the braking applied by the driver is insufficient to avoid a collision. Typically, DBS relies on information provided by forward-looking sensor(s) to determine when supplemental braking should be applied. FCW most often works in concert with DBS by first warning the driver of the situation and thereby providing the opportunity for the driver to initiate the necessary braking. If the driver's brake application is insufficient, DBS provides the additional braking needed to avoid or mitigate the crash.

1.3.3. Crash Imminent Braking (CIB)

CIB systems also use forward-looking sensors to provide the information needed to determine when automatic braking is necessary to avoid or mitigate the effects of a crash in those situations in which the driver fails to apply any braking or steering in response to an FCW warning. In such a situation, a CIB system will automatically apply braking (between partial and full braking depending on system design and circumstances) in an attempt to avoid or mitigate the crash.

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[4] FCAM system sensors presently include radar, lidar (laser-based), camera(s), or combinations thereof. Future sensing technologies may include infrared and dedicated short-range communication (DSRC) radios.

2.0 SAFETY CHALLENGES, TECHNOLOGY, AND MARKET OVERVIEW

This chapter reviews NHTSA's preliminary estimate of the target crash population which may be addressed by FCAM technologies, provides an overview of marketplace availability, briefly discusses FCAM field data studies, and presents high-level summaries for preliminary estimated FCAM system cost and preliminary safety benefits.

2.1. Target Population

Approximately 1.7 million rear-end crashes occur each year. Not all of these would be expected to benefit from FCAM technologies. The target population is the subset of crashes that could potentially be avoided or mitigated by FCAM technologies.

The agency developed a detailed target population in the in the June 2012 research report, finding that 910,000 crashes per year could potentially be avoided or mitigated. These crashes involve an estimated 2,700,000 persons per year, and a total annual cost of $47 billion. More than 400,000 people are injured and over 200 people are killed in these crashes each year.

This target population was arrived at through the following process:

- First, the agency identified through known limitations of the technology that the target population should be limited to crashes in which the front of a passenger vehicle (the subject vehicle, or SV), which was going straight in a travel lane in a controlled fashion at a speed of 9 mph or higher, strikes a motor vehicle (the lead vehicle, also referred to as the principal other vehicle, or POV) that was stopped or going straight in the same lane and direction as the SV, and the SV driver did not steer to try to avoid the crash.
- Next, the agency conducted an in-depth review of a sample of rear end crashes from the agency's National Automotive Sampling System - Crashworthiness Data System (NASS-CDS) and National Motor Vehicle Crash Causation Study (NMVCCS). Through this review, the agency determined that crashes involving the following situations should not be considered part of the target population of crashes expected to potentially have a favorable effect by CIB and/or DBS:
    - Crashes with a relative impact speed greater than 80 km/h (50 mph) in which a fatality or fatalities occurred in the lead vehicle.
    - Crashes in which a fatality or fatalities occurred in the following vehicle after an impact with a large truck or trailer.
    - Crashes involving the lead vehicle cutting into the lane of the following vehicle in which the system would not have had time to detect and react to the crash threat.

  The review of NASS-CDS and NMVCCS cases found that crashes involving these three situations were so severe that current FCAM technology performance would not be able to prevent, or favorably affect the outcomes, of these crashes.

As the number of rear end crashes is fairly constant at about 1.7 million per year, we have not updated the target population estimation for this report.

2.2. Target Population by Crash Type

Rear-end crashes are coded within NASS-GES into the following major categories that denote the kinematic relationship between the striking and struck vehicle:

- Lead Vehicle Moving (LVM) - struck vehicle was moving at a constant but slower speed, compared to the striking vehicle.
- Lead Vehicle Decelerating (LVD) - struck vehicle was decelerating at the time of impact.
- Lead Vehicle Stopped (LVS) - struck vehicle was stopped at the time of impact.

NHTSA's analysis of the crash data in support of the June 2012 research report on CIB and DBS technologies showed that the target population of rear-end crashes by the above-listed categories was approximately as follows:

- LVM: 12%
- LVD: 24%
- LVS: 64%

In part because of the large percentage of rear-end crashes involving stopped lead vehicles, NHTSA included such a scenario in its testing protocols for CIB and DBS technologies. In response to the July 2012 RFC, several commenters noted that in real-world situations, many lead vehicles that are coded in NASS-GES as "stopped" at the time of the collision were in fact moving just prior to the collision. These commenters suggested that in many of those crashes the lead vehicle would have been decelerating at the time it first came into the SV's sensor tracking range (i.e., its radar and/or camera range) and therefore would have been classified as a moving or decelerating lead vehicle by the SV's crash avoidance system. In other words, commenters suggested there were fewer "true" LVS crashes (in which the struck vehicle was in fact stationary before it was in the range of the SV's tracking ability) than NHTSA had originally estimated.

To better understand the rear-end crash population, and to respond to the above industry feedback, the agency reviewed a sample of the NMVCCS crash cases coded as "lead vehicle stopped" to determine whether they may in fact have been "lead vehicle decelerating to a stop." The review included examinations of case files containing scene descriptions; interviews with drivers, passengers, or witnesses (if available); and the accompanying police accident reports.

This review revealed that in many of the crashes coded "lead vehicle stopped," while the lead vehicle was in fact stopped at the moment of impact, it had been decelerating while within the tracking capability of the SV's sensors. Based on the sample selection characteristics, NHTSA was able to leverage crash descriptors in the NASS-GES database to estimate the percentage of crashes coded as lead vehicle stopped (LVS) that were actually *lead vehicle decelerating to a stop* crashes (subsequently referred to as the LVD2 scenario in this document) versus those for which the lead vehicle had been stopped well before the SV sensors would have been able to detect it (subsequently referred to as the LVD1 scenario in this document). In this preliminary analysis, the agency showed that approximately half of the LVS-coded crashes were likely LVD2 crashes, as shown in Figure 2-1.

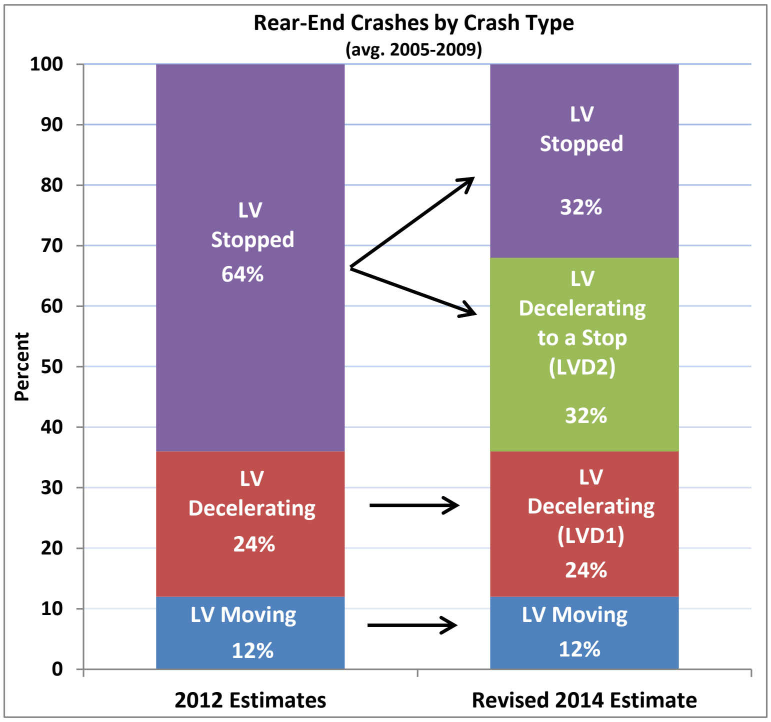

Figure 2-1. Rear-end crashes by crash type

2.3. FCAM Market and Technology Overview

In 2011, NHTSA added FCW to its list of Recommended Advanced Technology Features in the New Car Assessment Program (NCAP). Since the 2011 model year, NHTSA has asked manufacturers to voluntarily indicate in an annual submission of vehicle-safety-related information whether or not the vehicles they manufacture are equipped with certain advanced crash avoidance technologies and, if so, whether or not those technologies meet the agency's applicable NCAP performance criteria for those technologies. Table 2-1 indicates the number of vehicle models from model years 2011-2014 reported by manufacturers as offering FCW and which of those models met NHTSA's performance criteria (typically offered as optional equipment, but in some instances included as a standard feature). Note that the actual number of vehicle models in the marketplace offering FCW may be higher since it is possible some manufacturers elect not to inform NHTSA of the availability of these systems on the vehicles they manufacture. Also indicated in the chart is the total number of different vehicle models[5]

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[5] Vehicle models on www.safercar.gov are listed according to what is generally referred to as "trim lines." So, for example, 4x2 and 4x4 versions of a vehicle from a manufacturer marketed under a particular name are listed as separate vehicles, but are the same "vehicle model". As another example, four door, two door, and convertible versions are listed as separate vehicles, but all are the same "vehicle model."

listed on www.safercar.gov for the model year involved. Advanced crash avoidance technologies, such as FCAM technologies, are typically first available commercially in a relatively small number of new luxury vehicles. However, as shown in Table 2-1, the percent of models offering FCW has increased substantially over the last four years.

Table 2-1. Number of MY 2011-2014 Vehicle Models Offering FCW

Model Year	Vehicle Models Listed on Safercar.gov	Vehicle Models Offering FCW	Vehicle Models Meeting NCAP FCW Criteria
2011	704	82 (12%)	37 (5%)
2012	760	83 (11%)	79 (10%)
2013	772	183 (24%)	166 (22%)
2014	713	314 (44%)	229 (32%)

Table 2-2 summarizes information received from vehicle manufacturers indicating whether CIB, DBS, or both was available on vehicles they manufacture. The information shows a steady increase in the number of vehicle models offering active braking technologies from 2012-2014.

Table 2-2. Number of MY 2012-2014 Vehicles Offering CIB, DBS, or Both[6]

Technology	Model Year		
	2012	2013	2014
Both DBS and CIB Optional	90	131	173
Both DBS and CIB Standard	1	9	10
DBS Optional (and CIB not available)	39	12	18
DBS Standard (and CIB not available)	8	5	1
CIB Optional (and DBS not available)	-	5	-
DBS Standard and CIB Optional	-	-	16
Total Vehicle Offering CIB, DBS, or Both	**138**	**157**	**225**
Total Vehicles	**760**	**772**	**713**
Percent of Models Offering CIB, DBS, or Both	**18%**	**20%**	**32%**

2.4. FCAM Field Experience

The evaluation of FCAM technology in real-world operational settings (i.e. field testing) is an important complement to test track, laboratory, simulation, and other analytical research, and may provide the most realistic measure of performance, reliability, and customer acceptance.

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[6] The numbers in this chart reflect only that the manufacturer indicated that CIB, DBS, or both was available on a vehicle, not whether the particular system performs up to any given set of performance criteria.

FCAM technology is, however, comparatively new to the marketplace and only limited field testing has been completed by NHTSA. NHTSA is increasing its real-world assessment activities with two new studies: a long-term exposure study involving 20 vehicles equipped with FCW, CIB, and DBS; and a field test of over 2,000 vehicles equipped with FCW. Also, while vehicle manufacturers engage in substantial real-world testing in the course of product development, limited information on field testing of FCAM systems can be found in published technical articles in the public domain.

2.4.1. NHTSA FCAM Field Studies

NHTSA is conducting field studies of FCAM technologies to better understand driver adaptation issues and operational/performance characteristics. A summary of the on-going research is discussed in the following sections.

2.4.1.1. Long-Term Exposure Study

In February 2013, NHTSA initiated a field-operational study that includes FCAM systems with CIB and DBS capability. The key objective of the study is to determine driver adaptation to FCAM systems and to better understand their impact on driver behavior. The study will result in capturing driver-vehicle performance data over various time periods (from 3 months to 12 months) to determine driver-behavior adaptation and risk compensation.

The study includes a total of 20 model year 2013 vehicles equipped with FCW, CIB, and DBS technologies operated by a total of 36 drivers. Each vehicle is instrumented with an on-board data collection system that is linked to the vehicle’s CAN bus. Four video cameras are also installed in each vehicle to capture the forward, side, and cockpit views. A variety of vehicle data elements are recorded for pre-defined events (including system alerts and brake activations). Such data include brake, steering, throttle and turn signal inputs, as well as vehicle speed, acceleration, yaw rate and other kinematic data. Goals of the study include:

- Identify the conditions that result in safety benefits to drivers using FCAM systems
- Identify unintended consequences (e.g., driver distraction or risk compensation)
- Understand role of user acceptance and its effect on system use and driving behavior

The study is also expected to help identify instances of false positives, false negatives, nuisance alarms, as well driver usage and operational patterns. A final report is expected in 2015.

2.4.1.2. NHTSA Crash Avoidance Technology Field Data Collection Study

NHTSA is currently working with a vehicle manufacturer to collect field-operational data on approximately 2,000 model year 2013 vehicles equipped with a camera-based (single-sensor) crash avoidance system that includes FCW and lane departure warning (LDW) functionality. The vehicles included in the study are production models purchased by customers from dealerships across the country. Study participants were volunteers and provided written consent for all data collection efforts. Vehicle kinematic and driver response data are collected for crash avoidance system warning events through the production telematics system included on the vehicles. Data are collected for approximately three seconds before and three seconds after each predefined event (e.g., system warnings) and include information such as vehicle speed, acceleration, as well as driver response to warnings (such as steering, brake, and throttle inputs). Other "normal driving" data are also collected including on/off status and user-selected sensitivity setting for the FCAM system. Analysis of the data will help NHTSA to better understand how drivers utilize the crash avoidance system functionality, relative to traffic and speed conditions, trip length, environmental factors, time of day, and other parameters. Information on drivers' reactions to warnings and if/how such reactions change over time will also be collected.

2.4.2. Summary of Industry FCAM Field Studies

The field test data that have been documented by OEMs and others (and available in the public domain) show that FCAM technologies reduce rear-end crashes, deaths and injuries. More specifically:

- A large study of insurance claims by the Highway Loss Data Institute indicates a significant reduction in claim frequency for vehicles equipped with FCAM technology, including vehicles equipped with FCW-only as well as those equipped with FCW together with automatic braking features [7].
- A multi-year, seven-million kilometer field study by Mercedes-Benz suggests that over one-half of all rear-end crashes could be mitigated to some degree by FCAM technologies [8].
- A study of a low-speed automatic braking system indicates a reduction of 23 percent in insurance claims related to rear-end crashes [9].
- A study by the University of Adelaide in Australia predicted that FCAM systems (having FCW together with automatic braking features) would reduce fatal crashes by 20 to 25 percent and injury crashes by 25 to 35 percent [10].

While continued collection of real-world performance data is needed to better understand benefits and long-term driver-behavioral changes associated with FCAM systems, these early studies provide insight into the safety potential of forward collision warning and automatic braking systems.

2.5. Costs

NHTSA contracted with Ricardo, Inc. to complete a cost tear-down study of FCW and related automatic crash avoidance braking systems for light vehicles. The final report of this study was published on May 16, 2012 and is titled, *"Cost & Weight Analysis of Forward Collision Warning System (FCWS) and Related Braking Systems for Light Vehicles"* [11].

In the five vehicles analyzed by Ricardo, the retail costs[7] for FCW, CIB, and DBS systems varied widely, depending on the sensing technology implemented. Systems using a combination of vision and radar sensing technologies were estimated to cost up to $459 while single-sensor radar or camera (vision) systems were estimated at $115.

Trade journals and NHTSA's own observations and experience with camera, radar, and combined sensor systems indicate that these technologies will not only continue to improve (mature), but also become more integrated within the vehicle. As such, the agency believes there is a potential for cost change over time as manufacturers learn more about producing these units and economies of scale develop with wider application. As the Ricardo research was completed on model year 2011/12 vehicles, NHTSA will consider updating its cost tear-down study in the future.

2.6. Preliminary Safety Benefits

2.6.1. Approach

The agency developed preliminary benefit estimates for FCW, CIB, and DBS systems. These preliminary estimates used the forward collision target population from the June 2012 research report in combination with system performance assumptions implied by CIB/DBS draft assessment reference values (ARV). The draft ARVs are performance metrics (i.e., speed reductions or crash avoidance goals) associated with each of the various forward collision test scenarios established for purposes of characterizing overall system performance (see Section 4.7 for additional details related to the draft ARVs). The preliminary estimates were also based on assumptions that included the following:

- All light vehicles will be equipped with FCW[8], CIB, and DBS. These CIB and DBS systems will perform at levels equivalent to the minimum assessment reference values listed in Section 4.7.
- FCW will prevent 15 percent [12] of all injuries in the target population [13].
- CIB and DBS target populations are mutually exclusive, that is, they include crashes in which the driver braked (DBS), or did not brake (CIB).
- No passenger vehicles currently in use are equipped with FCW, CIB, and/or DBS.[9]

2.6.2. Estimated Injuries/Lives Saved

Crash severity is often characterized by the "delta-v" measurement associated with the collision. It is a measure of the change in velocity of the striking and struck vehicles just before and just after the impact occurs. Delta-v reductions[10] from the FCAM technologies were calculated based on speed reductions associated with the CIB/DBS system draft ARVs presented in Section 4.7.

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[7] See docket NHTSA-2011-0066-0011 for details related to cost definitions and analyses.

[8] The agency believes that manufacturers will not install CIB and DBS without FCW and for the purpose of estimating benefits will assume FCW will provide a warning prior to any automatic brake intervention.

The corresponding reduction in injuries[11,12] was estimated using injury risk versus delta-v curves that have been previously used by the agency for its light vehicle tire pressure monitoring system rulemaking.[13] NASS-CDS [14] police-reported estimates of tow-away crashes were adjusted to reflect all police-reported rear-end crashes.[14]

Using these assumptions and applying them to the target population, the agency tentatively found that if CIB functionality alone were on all light vehicles, it could potentially prevent approximately 40,000 minor/moderate injuries (Abbreviated Injury Scale (AIS) levels 1 and 2), 640 serious-to-critical injuries (AIS 3 – 5) and save approximately 40 lives, annually. DBS alone on all light vehicles on the road could potentially prevent approximately 107,000 minor/moderate injuries (AIS 1 – 2), 2,100 serious-to-critical injuries (AIS 3 – 5), and save approximately 25 lives, annually. These safety benefits from CIB and DBS would be incremental to the benefits from an FCW alert.

FCW, CIB, and DBS combined on all light vehicles could potentially prevent approximately 200,000 minor injuries (AIS 1 - 2), 4,000 (AIS 3 – 5) serious injuries, and save approximately 100 lives annually, as shown in Table 2-3.

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[9] We assumed that no passenger vehicles currently in use are equipped with these technologies since the current market penetration remains low at approximately 1 to 2 percent.

[10] For the delta-v reduction estimate, the effective deceleration was derived from the initial system activation time-to-collision (TTC) and the reduction in striking speed of the SV. The effective deceleration was assumed to be constant during the CIB and DBS applications. In addition, we assumed that the initial TTC remains constant regardless of the initial braking speed.

[11] We assume that all rear-end collisions are perfectly plastic and the vehicles in them have the same mass, so that their (shared) velocity after impact can be calculated by the conservation of momentum.

[12] Delta-v is defined as a change in velocity of a vehicle in a front to rear-end crash. The reduction in delta-v was calculated from the delta-v's with and without the technologies. Due to limited NHTSA test data for each vehicle tested, for the analysis, we used a regression line/curve to calculate the percent reduction in delta-v at a given delta-v without the technologies.

[13] For the safety benefit estimate, the delta-v with the technology (either CIB or DBS) at a given delta-v was calculated with the percent reduction delta-v curve. For example, if we assume that a vehicle experiences a delta-v of 20 mph without the technology and that CIB decreases the delta-v by 30 percent, the delta-v with the technology would be 14 mph. According to the injury-risk curve, the risk of having an MAIS 2+ injury (a moderate injury level based on the Maximum Abbreviated Injury Scale) would be 16 percent at a delta-v of 20 mph and 6 percent with at a delta-v of 14 mph. Therefore, the percent reduction in MAIS 2+ injury would be 63 percent (1 - 6/16 = 63%). In addition, if we assume there are 30 MAIS 2+ injured occupants at a delta-v of 20 mph, the technology would prevent 19 MAIS 2+ injuries (30 x 63% = 19 MAIS 2+).

[14] According to the NASS-CDS, there were a total of 160,000 injuries in towed rear-end crashes. The NASS-GES [15] showed that a total of 367,000 injuries in towed and non-towed rear-end crashes. Among the 367,000 NASS-GES injuries, 204,000 were in towed crashes and the remaining 163,000 were non-towed crashes.

Table 2-3. Preliminary Benefit Estimates for FCAM Systems That Satisfy NHTSA's Draft ARVs[15]

Injuries and Lives Saved, FCW+CIB+DBS		
Minor Injuries	**Serious Injuries**	**Fatal**
200,000	4,000	100

NHTSA plans to complete additional research projects that could help the agency improve its benefits assessment of AEB technology. These research projects include additional studies with drivers using production vehicles equipped with the technology, studies of available crash data for vehicles with and without the technology, and, additional studies that the agency has underway with respect to crash warning systems. For example, NHTSA plans to gather operational and performance information on several hundred production vehicles equipped with optional AEB technology. The data from this study will provide information related to how drivers respond to warnings in various conditions, the prevalence of false positives, overall reliability and availability of the systems, and customer acceptance and usage data. NHTSA is also planning a study to build off of previous work performed by the Insurance Institute for Highway Safety. This study will use real world crash data to gain insight into system performance, and will be completed with the cooperation of OEMs to determine the crash avoidance technology content on specific vehicles using vehicle identification coding. Finally, the injury risk curves used for the preliminary estimates in this report were based on older vehicles. The agency is working to determine whether additional refinement of the risk curves used to calculate injury reduction for this technology is required.

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[15] See Section 4 for details pertaining to CIB/DBS draft ARVs.

3.0 RECENT REFINEMENTS OF NHTSA'S CIB AND DBS DRAFT TEST PROCEDURES

3.1. History

In the June 2012 research report, the agency explained its understanding of the current state of forward-looking advanced braking technologies and described various key areas in which additional information or refinements were needed. Section 3.2 of this document discusses the agency's work relating to the technical aspects of understanding and evaluating forward-looking advanced braking technologies, specifically:

- Test Protocols:
  - ➢ Reasonableness, Repeatability and Reproducibility
  - ➢ Brake Application Methodology
  - ➢ Vehicles and Tow Apparatus
  - ➢ False Positives/Non-activations
- Evaluation Criteria Test Protocols
  - ➢ Speed Reduction
- System Suppression

3.2. Developments since Publication of the July 2012 RFC and June 2012 Research Report

Between publication of the July 2012 RFC and the beginning of the agency's 2013 FCAM test track evaluations described in Section 4, advances in how NHTSA evaluated CIB/DBS systems were made. Sections 3.2.1 through 3.2.3 describe the agency's Strikeable Surrogate Vehicle (SSV), changes to the CIB/DBS test methodologies, and briefly describes a series of CIB evaluations performed in non-ideal environmental conditions, respectively.

3.2.1. Strikeable Surrogate Vehicle (SSV)

3.2.1.1.Overview

NHTSA uses surrogate vehicles (also known as strikeable artificial vehicles or test targets) to safely, accurately, and objectively perform CIB and DBS performance evaluations on the test track. The agency believes that a surrogate vehicle should ideally:

- Be "realistic" (i.e., be interpreted the same as an actual vehicle) to systems using radar, lidar, cameras, and/or infrared sensors to assess the potential threat of a rear-end crash;
- Be robust (able to withstand repeated impacts with little to no change in shape over time);

- Not impose harm to the test driver(s) or damage to the test vehicle under evaluation; and
- Be capable of being accurately and repeatably constructed.

The agency has evaluated several surrogate vehicle designs in recent years (e.g., inflatable and foam-based cars) and believes each possesses some potentially undesirable attributes. Of particular concern are two elements capable of confounding track-based performance assessments:

- Non-realistic radar return and/or visual characteristics (i.e., the surrogate does not present as an actual vehicle); and
- A propensity for the surrogate's shape to physically change throughout the testing timeline (e.g., due to panel buffeting while in motion, sensitivity to changes in ambient temperature, or due to damage sustained from repeated impacts). The shape of an actual vehicle does not vary in the real-world; it remains dimensionally stable.

In 2012, NHTSA designed and manufactured the SSV, a carbon fiber-based surrogate vehicle intended to address the design concerns described above. The extensive use of carbon fiber provides a rigid structure that is stable under dynamic maneuvers and provides a consistent presence for the following test vehicle to identify, classify, and respond appropriately to. The body structure of the SSV simulates the rear end of a 2011 Ford Fiesta, so its physical appearance is representative of a high-volume passenger car sold worldwide. The SSV preliminary design specifications have been documented in a NHTSA report, "*NHTSA's Strikeable Surrogate Vehicle Preliminary Design Overview*" [5].

The following paragraphs discuss in more detail some of the important design attributes of the SSV. Additional details about how the SSV is used during the conduct of CIB and DBS test track evaluations are available within (1) the respective draft test procedures, and (2) the design specifications available in the docket.

3.2.1.2. Design Attributes

a. Appearance

The SSV provides visual and dimensional characteristics representative of an actual vehicle when approached from the rear to promote accurate identification and classification by the CIB/DBS system of the vehicle being evaluated. Since the SSV body was based on a dimensional scan of a 2011 Ford Fiesta, its height and width dimensions are inherently realistic. To maximize visual realism, the SSV shell is wrapped with commercially available vinyl material to simulate paint on the body panels and rear bumper, and a tinted glass rear window. The SSV is equipped with a simulated United States specification rear license plate. The taillights, rear bumper reflectors, and third brake light installed on the SSV are original equipment from the production vehicle (see Figure 3-1). The SSV is rigid so it maintains the same shape (i.e., visually, dimensionally, and from a radar-sensing perspective) over time.

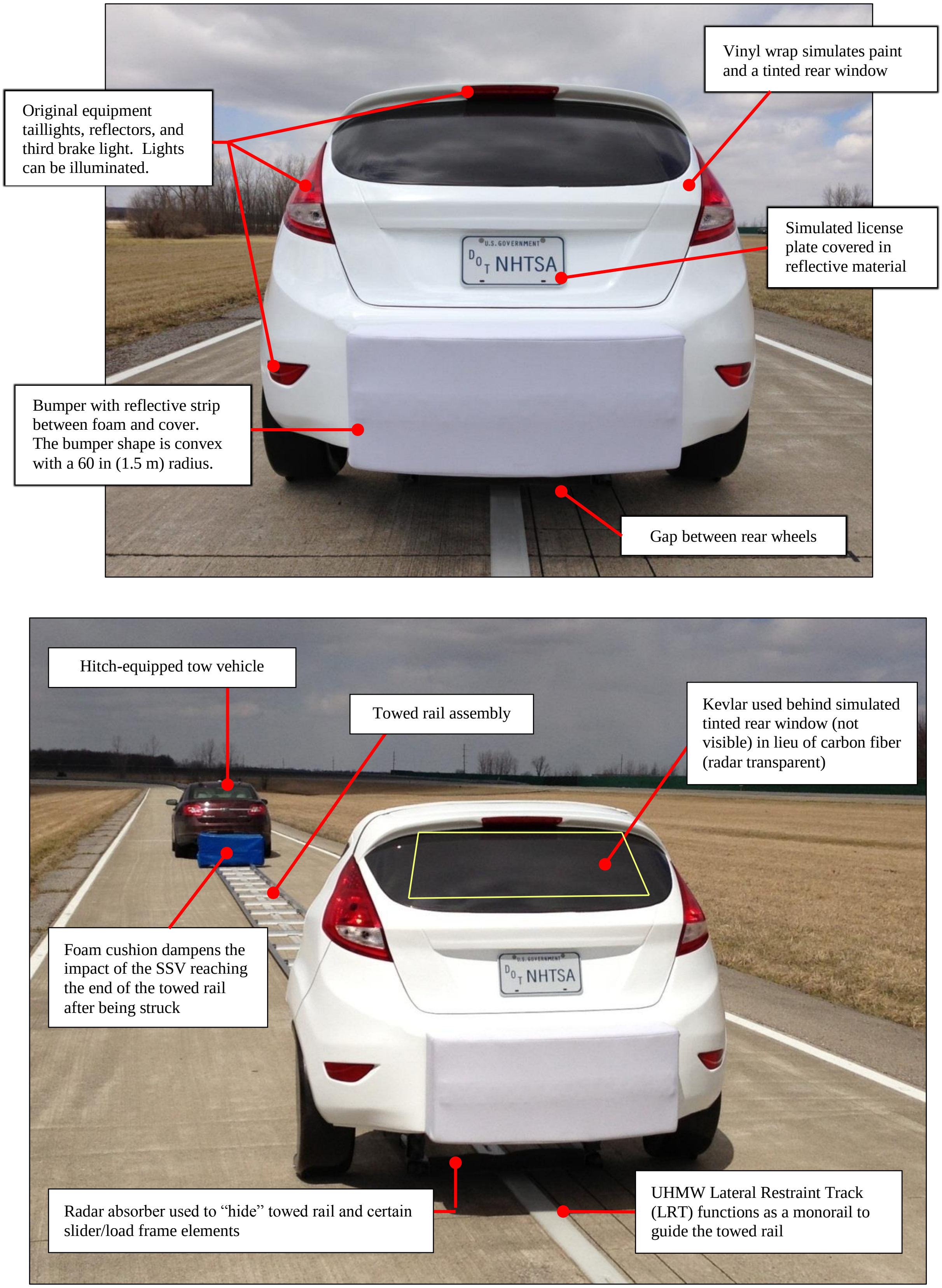

Figure 3-1. Important design elements of NHTSA's SSV

b. Robustness

To reduce the potential of damage to the striking vehicle during an impact, the SSV is constructed from carbon fiber, Kevlar, and Nomex honeycomb, lightweight composite materials with favorable strength-to-weight characteristics. A foam bumper is attached to the rear of the SSV to reduce the peak forces realized shortly after an impact occurs.

c. Radar Characteristics

The contour of the SSV rear bumper has been designed with a flat face to accommodate impacts from vehicles with a wide range front bumper heights. However, the vertical orientation of this face increased the radar cross section (RCS) of the rear aspect beyond that representative of most light vehicles. Additionally, the radar-reflective carbon fiber shell of the SSV did not accurately simulate a vehicle’s rear window when evaluated at certain frequency bands (for some bands the window glass is radar-transparent). Therefore, tuning (attenuation) was performed to make the SSV’s characteristics more representative of most light vehicles:

- Bumper corners were rounded
- The simulated rear window was made from Kevlar (a radar-transparent material) rather than carbon fiber (highly radar-reflective)
- A radar-absorbing mat was secured to the inside of the SSV’s rear bulkhead behind the simulated rear window

Using highly accurate test equipment and scans performed at frequency bands representative of those presently used by the automotive industry (i.e., 24 GHz and 77GHz), the Michigan Transportation Research Institute (MTRI) and the University of Michigan Transportation Research Institute (UMTRI) assessed the radar-return characteristics for the SSV, other surrogate vehicles, and actual vehicles at different elevation aspects and azimuths. Results from this evaluation were documented in a report titled, *“Radar Measurements of NHTSA’s Surrogate Vehicle SSV*” [16]. This report indicates that the SSV exhibits automobile-like radar-scattering characteristics at tail-aspect for both radar bands of interest, and that it is suitable for evaluating radar-based detection systems.

3.2.1.3. Design Revisions

Since the public release of the preliminary SSV design specifications, the design has remained largely unchanged. However, some adjustments have been made to improve durability and to address concerns expressed by some vehicle manufacturers regarding how the SSV’s towed rail presents to radar-based systems.

a. Durability Improvements

With regards to durability, three elements were changed during the 2013 testing season:

- The brackets used to support load frame movement along the towed rail assembly have been redesigned. The new brackets are stronger, lighter, and now connected longitudinally.
- Shock absorbers were added between the load frame and the energy-absorbing nylon straps connecting the load frame to the slider assembly
- Reinforcements were made to the SSV shell in front of the simulated wheels

The design intent of the SSV is to withstand repeated impacts at relative speeds of up to 25 mph (40.2 km/h). With the provisions listed above, the SSV has successfully withstood repeated impacts of approximately 20 mph (32.2 km/h) without damage, 4.8 mph (7.7 km/h) greater than the highest nominal impact speed the SSV would be expected to sustain during a test in which the SV satisfies the minimum CIB performance defined by the draft ARVs described in Section 4.7. While NHTSA believes higher-speed impacts can be supported and that the SSV provides the agency with most of the attributes needed to objectively evaluate FCAM technologies, concerns remain about the durability of the unit should repeated impacts at the maximum relative speed be imposed in the LVS scenario. For this reason, the SSV appears to be most appropriately used at this time for providing the test track data in evaluation programs for vehicles whose CIB systems are expected to provide speed reductions of at least 5 mph (8.0 km/h). Research programs requiring a surrogate vehicle with higher impact speed capability, but with potentially less absolute realism, may be better suited to consider use of an SSV alternative.

Note: None of the components added to improve SSV durability, shown in Figure 3-2, are expected to alter the SSV radar-return characteristics (e.g., RCS), as they are concealed by its carbon fiber shell or behind radar-absorbing material.

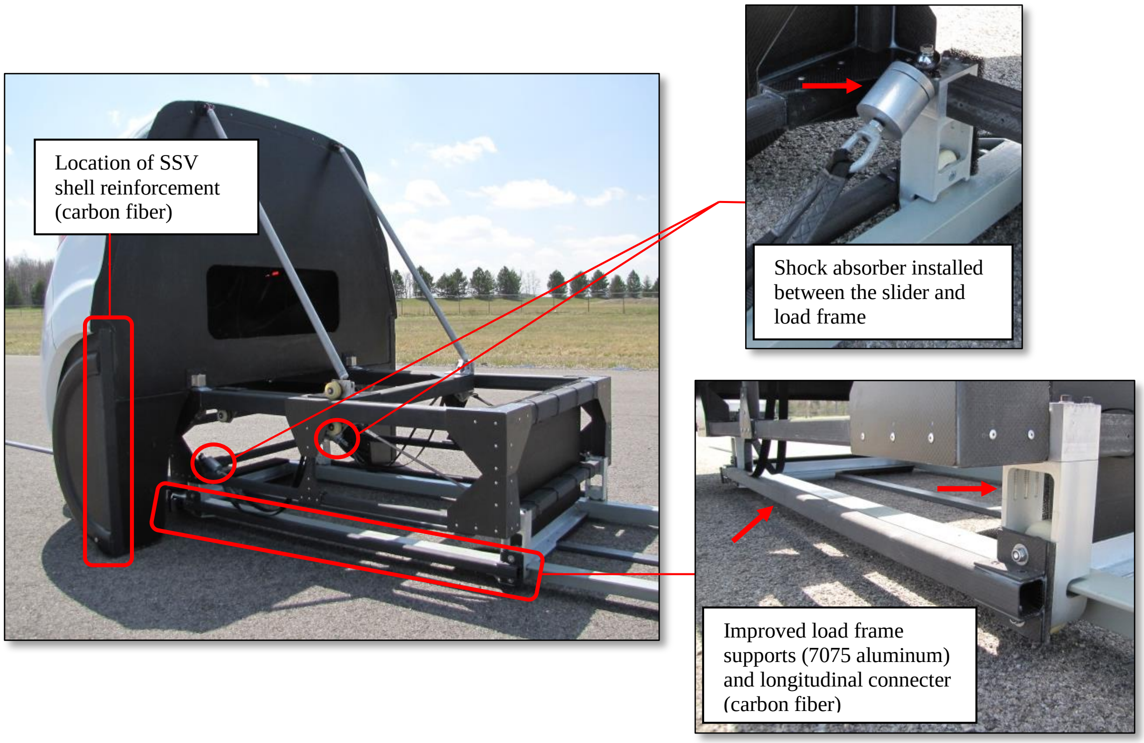

Figure 3-2. Components installed to improve SSV durability

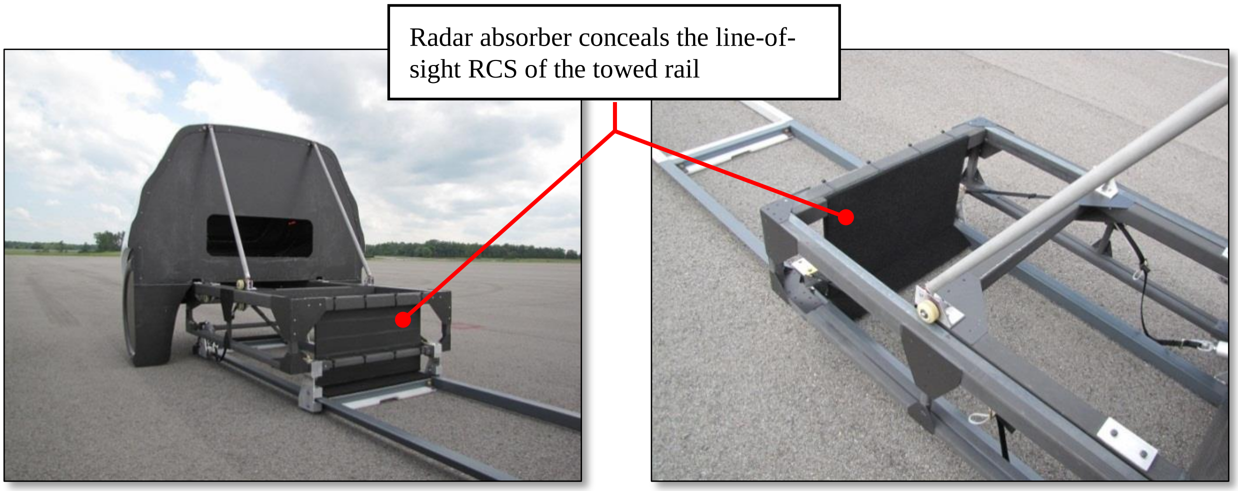

Figure 3-3. Wideband radar-absorbing material installed on first section of the SSV towed rail

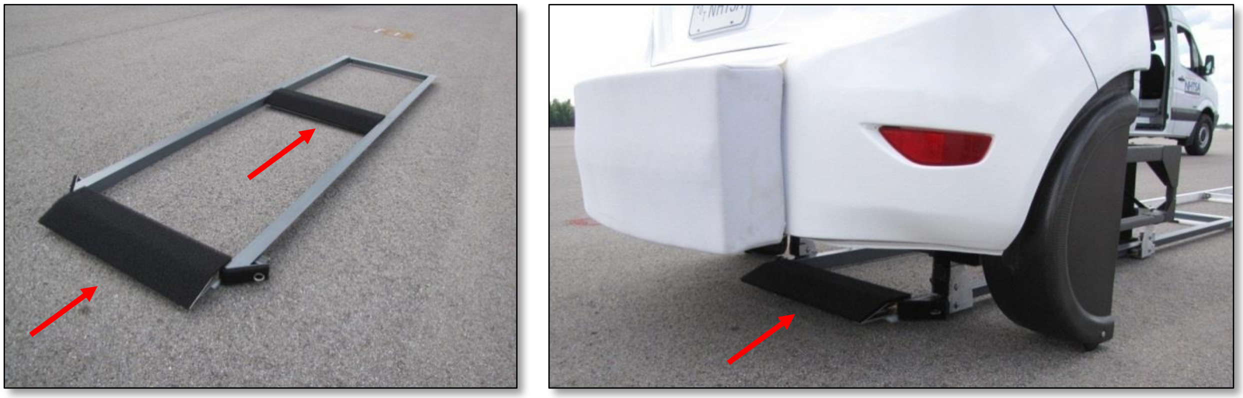

Figure 3-4. Wideband radar-absorbing material installed on the SSV load frame

b. More Appropriate Radar Reflectivity

Multiple vehicle manufacturers, suppliers, and testing organizations have performed short, collaborative SSV evaluations with NHTSA. The intent of this work was not to provide the agency with insight into proprietary CIB/DBS algorithms or design, but rather to understand how contemporary systems perceive the SSV and its peripherals. To do this, a series of scans were performed, with a focus on answering three questions:

1. At what longitudinal distance was the SSV first detected?
2. At what longitudinal distance was the SSV first classified as a vehicle?
3. Did the SSV classification remain stable (i.e., continuously identified as a vehicle throughout the pre-crash timeline)?

The vehicles used to perform the scans were equipped with automotive-grade radar and camera-based sensors, most of which were part of commercially available FCW/CIB/DBS systems. However, unlike the standard production implementation, these systems were configured in a way that allowed sensor data and system measurements to be monitored and recorded for later review. Under confidentiality agreements, system performance summaries were then submitted to the agency for analysis. This provided valuable information the agency would not have otherwise been able to obtain.

Generally speaking, the feedback provided by the participants in the collaborative research effort was favorable. With few exceptions, the SSV was detected and classified as if it was an actual vehicle. However, one participant indicated that the towed rail assembly that the SSV rides on was detected by their vehicle's radar system due to the gap present between the simulated tires of the SSV. As explained by the participant, the rail assembly, which visually looks like a long ladder set flat on the ground, has the potential of being misclassified as a guardrail at the entrance of a curved road. Should such misclassification occur, inconsistent and/or sub-optimal performance may be realized, including the suppression of automatic/supplementary braking. In the real world, such control logic is intended to reduce the incidence of false positives. However, such suppression would likely prevent the vehicle from achieving satisfactory speed reductions during the agency's test-track evaluations.

To address this issue, NHTSA has installed a combination of shallow ramps and wideband radar-absorbing material to the first section of the towed rail assembly (Figure 3-3) and additional radar-absorbing material to the rear of the SSV load frame (Figure 3-4). Although these countermeasures were not validated prior to performing the 2013 FCAM tests, the intent was to prevent radar waves from traveling under the SSV (i.e., between the simulated tires), thereby preventing the sensor from detecting the RCS of the towed rail's horizontal members.

3.2.2. Changes to the CIB/DBS Test Methodologies

With regard to improved test methodology, the agency has focused on two areas: the inclusion of two new test scenarios to further evaluate CIB/DBS system robustness, and brake application revisions intended to better allow DBS systems to demonstrate their speed reduction capabilities.

3.2.2.1. Inclusion of New Test Scenarios

a. Lead Vehicle Decelerating (LVD)

The rear-end crash problem is dominated by three pre-crash scenarios: the SV encounters either a stationary lead vehicle (LVS); the SV encounters a slower moving lead vehicle (LVM); and SV encounters a decelerating lead vehicle (LVD). In early 2013, the agency developed LVD maneuvers to complement the LVS and LVM maneuvers already used to objectively evaluate CIB/DBS system performance on the test track. Prior to this time, NHTSA had not used LVD maneuvers for this purpose for three reasons: (1) it was not possible to perform LVD maneuvers with sufficient accuracy and repeatability with the tow apparatus associated with the balloon and foam-based surrogate vehicles previously used by NHTSA during its CIB/DBS test track evaluations; (2) the agency believed the LVD target population was relatively small (due to an over-estimation of the LVS target population, as discussed in Section 2.3); and (3) the agency believed that the test track performance observed during conduct of the LVM maneuvers provided a reasonable indication of a vehicle's capability in the LVD scenario. However, results from a 2012 ADAC report documenting their CIB and DBS performance evaluations contradicted this belief [17]. Using ten late-model European-specification vehicles and a series of LVS, LVM and LVD test scenarios, the ADAC found that vehicles with the best LVM speed reductions did not always have the best (or even comparable) speed reductions during their respective LVD evaluations. Based on the ADAC data, and the fact that NHTSA's recent advances in surrogate vehicle and tow apparatus design now enable accurate and repeatable LVD test conduct, the agency decided to include LVD scenarios in 2013 FCAM test matrix.

In developing its LVD maneuvers, the agency considered the pre-crash circumstances of real-world lead vehicle decelerating scenarios. The first maneuver (LVD1) simulates the scenario where a lead vehicle decelerates to a slower speed in front of the SV and a crash between the two vehicles occurs while the lead vehicle is still decelerating. The second maneuver (LVD2) simulates the scenario where a lead vehicle decelerates to a stop before being struck by the SV. Each NHTSA LVD maneuver specifies that the lead vehicle decelerate at 0.3g, the same deceleration magnitude used in the agency's FCW NCAP program. To maximize the accuracy and consistency by which the POV deceleration was achieved, a second brake controller was installed in the SSV tow vehicle.

Subject Vehicle (SV) and Principal Other Vehicle (POV) Speed Considerations

Multiple combinations of SV and POV speeds and headways were evaluated before selecting the initial conditions ultimately used for NHTSA's LVD test maneuvers (see Table 3-1). During each test condition, the nominal POV deceleration of 0.3g was achieved 1.5 seconds after its brakes were applied.

Table 3-1. LVD Development Test Matrix

SV and POV Speed		Initial Headway		Nominal POV Decel (g)	Nominal Impact Speed*		Comment
(mph)	(km/h)	(ft)	(m)		(mph)	(km/h)	
35	56.3	26.0	7.9	0.3g	15	24.1	LVD1_35_26.0
		45.3	13.8		20	32.2	LVD1_35_45.3
		70.5	21.5		25	40.2	LVD1_35_70.5
25	40.2	26.0	7.9		15	24.1	LVD1_25_26.0
		45.3	13.8		20	32.2	LVD1_25_45.3
25	40.2	147.3	44.9	0.3g	25	40.2	LVD2_25_147.3; intended to have the POV be stopped for 2.1 s before impact
		98.4	30.0		25	40.2	LVD2_25_98.4; NCAP FCW LVD headway

*Nominal impact speed is relative and assumes no SV brake application or CIB/DBS speed reductions.

As with the agency's LVM maneuvers, NHTSA wanted to include multiple vehicle speeds to evaluate CIB/DBS system robustness over a range of vehicle speeds, as well as the use of the LVM maneuver's 25 and 45 mph (40.2 and 72.4 km/h) test speeds. However, because the initial conditions of the LVD maneuver specify that both the SV and the surrogate POV travel at the same speed prior to the POV brake application, the agency had to consider the maximum speed the surrogate vehicle could be safety accelerated to and towed at. These factors are related not only to the design of the SSV itself, but also the length of the SSV monorail[16] and available testing area.

In the scenario where the SV's CIB/DBS system needs to respond to a decelerating lead vehicle that is still moving (LVD1), the SV and POV initial travel speeds tested were 25 and 35 mph (40.2 and 56.3 km/h), respectively. With the correct headway, use of these scenario/speed combinations imposed a nominal impact speed no higher than 25 mph (40.2 km/h), which was the upper impact design threshold of the agency's SSV. It was not possible to conduct the LVD1 scenario with a SV and POV initial travel speed of 45 mph (72.4 km/h), due to test equipment and test track length limitations.

For the scenario where the lead vehicle decelerates to a stop (LVD2), the only SV and POV initial travel speed tested was 25 mph (40.2 km/h). The reason for this was twofold: it was the maximum relative speed supported by the design of SSV[17], and it was the same SV speed used in the slower LVM scenario. Due to the lower speeds, these tests were safe to perform and imposed acceptable facility length requirements.

SV-to-POV Headway Considerations

The headway specified for a given LVD maneuver determines maneuver severity, quantified by the nominal impact speed. During the development of the LVD maneuvers, multiple headways shown in Table 3-1 were selected to include a wide range of operating conditions (i.e., very close to far away) while still ensuring that the maximum nominal relative impact speed was less than 25 mph (40.2 km/h).

Test Vehicles

Two production vehicles equipped with commercially available CIB systems were used for the LVD test development: a 2012 Volvo S60 (equipped with a mono camera, a 77 GHz radar, and lidar) and a 2013 Subaru Outback (equipped with a stereo camera system).

LVD Speed and Headway Selection

The CIB speed reductions associated with each LVD1 and LVD2 variant shown in Table 3-1 are shown in Table 3-2. Nominally, these speed reductions could be achieved by a vehicle that instantly achieves a deceleration of 0.6g at a time-to-collision (TTC) of 0.6s. Note that the name

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[16] A long plastic guide used to prevent nearly all lateral lane deviation when the SSV is in motion.

[17] Recall that if the SV brakes are not applied in the LVD2 scenario (e.g., CIB does not operate), it will nominally impact the POV at same speed used at the beginning of the test.

convention used for each scenario listed in Tables 3-2, 3-3, and 3-4 describes the speed and headway used (e.g., LVD1 35_26.0 refers to a LVD1 test maneuver performed with the SV and POV both initially moving at 35 mph (56.3 mph) with a headway of 26.0 ft (7.9 m)).

Table 3-2. LVD Draft Assessment Reference Values (ARVs) – SV CIB Speed Reductions

LVD1 35_26.0	**LVD1 35_45.3**	**LVD1 35_70.5**	**LVD1 25_26.0**	**LVD1 25_45.3**	**LVD2 25_147.3**	**LVD2 25_98.4**
13.2 mph (21.2 km/h)	10.5 mph (16.9 km/h)	9.7 mph (15.6 km/h)	13.2 mph (21.2 km/h)	10.5 mph (16.9 km/h)	9.8 mph (15.8 km/h)	9.8 mph (15.8 km/h)

Tables 3-3 and 3-4 summarize the LVD development tests performed with each combination of vehicle, maneuver, speed, and headway. Table 3-3 provides a summary of how many individual trials performed per scenario were able to satisfy the respective draft ARVs, whereas Table 3-4 summarizes crash avoidance capability to further quantify system performance.

Table 3-3. Number of Trials with Speed Reductions Greater Than or Equal to the Draft ARV

Vehicle	**LVD1 35_26.0**	**LVD1 35_45.3**	**LVD1 35_70.5**	**LVD1 25_26.0**	**LVD1 25_45.3**	**LVD2 25_147.3**	**LVD2 25_98.4**
Volvo S60	Not Performed	3/3	1/2[1]	5/5	5/5	5/5	6/6
Subaru Outback	0/4	3/3	3/3	0/8	4/4	5/5	5/5

[1] CIB did not engage during one of four tests performed, however only two of these tests produced data due to a data acquisition problem.

Table 3-4. Number of Trials with Crash Avoidance

Vehicle	**LVD1 35_26.0**	**LVD1 35_45.3**	**LVD1 35_70.5**	**LVD1 25_26.0**	**LVD1 25_45.3**	**LVD2 25_147.3**	**LVD2 25_98.4**
Volvo S60	Not Performed	0/3	0/2[1]	5/5	5/5	0/5	3/6
Subaru Outback	0/4	1/3	2/3	0/8	4/4	5/5	5/5

[1] CIB did not engage during one of four tests performed, however only two of these tests produced data due to a data acquisition problem.

With the exception of the LVD1 scenario performed from 35 mph with the longest headway (70.5 ft (21.5 m)), the Volvo S60 was able to achieve the desired speed reductions for each scenario tested. In the case of the Subaru Outback, the vehicle was able to achieve the desired speed reductions for each scenario except the two LVD1 tests performed with the shortest headway (26 ft (7.9 m)).

Ultimately, the final LVD1 and LVD2 maneuvers were selected on the basis of the following four evaluation factors:

- The LVD development test results shown in Tables 3-3 and 3-4
- Acknowledging that it may be difficult for CIB/DBS systems to effectively respond to a scenario performed with a 26 ft (7.9 m) headway at the near limit of the 8 ft tolerance specified in the FCW NCAP test procedure. This would be unreasonably close, as the SV-to-POV headway would be only 14 ft (4.3 m) when the POV initiated braking
- A desire to be reasonable with the test burden imposed by incorporation of the LVD tests into the CIB/DBS draft test procedures
- A desire to differentiate the LVD1 and LVD2 maneuvers to the greatest extent possible.

With respect to the LVD1 maneuver, the combination of a 35 mph (56.3 km/h) SV and POV initial speed and 45.3 ft (13.8 m) initial headway was selected. This combination uses the highest speed at which NHTSA is able to safely perform LVD evaluations in conjunction with a headway that results in (1) a relatively tight SV-to-POV proximity, and (2) a nominal impact speed of 20 mph (32.2 km/h) should the SV CIB system not provide any braking prior to impact.

For the LVD2 maneuver, the combination of a 25 mph (40.2 km/h) SV and POV initial speed and 328 ft (100.0 m) initial headway was selected. The test speed used in this scenario was the maximum supported by the SSV (i.e., the maximum collision design speed of 25 mph (30.2 km/h) if the test vehicle's CIB system did not activate) at the time the tests were performed. At 328 ft (100.0 m), the selected LVD2 headway is much longer than even the longest evaluated experimentally (98.4 ft (30.0 m)). However, it ensures the POV has come to a complete stop prior to any SV brake application. Even with this long headway, the sensor ranges associated with all contemporary production CIB and DBS systems known to NHTSA are sufficiently high that they would be expected to detect the POV deceleration well ahead of it being braked to a complete stop.

b. Inclusion of a False Positive Assessment Using a Steel Trench Plate

NHTSA has been concerned about the safety implications associated with automatic emergency braking systems that could activate under conditions when no immediate threat exists. The agency defines this condition as a "false positive" condition because the system could falsely activate braking when it is unnecessary. Potentially, in a worst-case scenario, a false positive event could be the cause of a crash. Furthermore, if false activations were to occur in real world conditions, vehicle operators might decide to turn the systems off.

In 2011, the agency completed a research program intended to evaluate whether CIB false positives could be consistently induced on the test track using simulated real-world driving scenarios. The agency also wanted to assess the practicality of these scenarios being executed accurately and repeatedly. The report, "*An Evaluation of CIB System Susceptibility to Non-Threatening Driving Scenarios on the Test Track*" [18] documented this work.

The false positive test matrix included eight scenarios and five vehicles. The scenarios were chosen after review of work performed by other research, testing, and international organizations such as the Crash Avoidance Metric Partnership (CAMP), the International Organization for Standardization (ISO), and Euro NCAP [19,20,21], and included the following:

- Objects in the roadway (Botts' dots[18] and steel trench plate)
- Decelerating vehicles in adjacent lanes on straight and curved roads
- Roadside vehicle placement on straightaway and curved roads
- Driving under overhead structures

The test vehicles were contemporary passenger cars and sport utility vehicles (model years 2008-2011) equipped with a variety of single- and multiple-sensor combinations. Of the eight scenarios tested, only one was found to elicit CIB false positive events. That scenario, driving over the 8 ft x 12 ft x 1 in (2.4 m x 3.7 m x 25 mm) ASTM A36 steel trench plate shown in Figure 3-5, was the single false positive test condition included in the agency's follow-on 2013 FCAM test program described in Section 4 of this document, and in the August 2014 CIB and DBS draft test procedures.

Figure 3-5. Steel plate used to evaluate unintended CIB/DBS activations

NHTSA recognizes that each sensing technology used by a particular CIB/DBS system (e.g., radar, lidar, cameras, etc.), is likely to have a unique vulnerability. Although the agency has identified the steel trench plate as a real-world scenario capable of challenging radar-based systems, it has not defined comparable scenarios relevant for other technologies, namely camera-

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[18] Round raised pavement markers common on California freeways and highways.

based systems or those based on combinations of multiple sensing technologies. For these systems, poor visibility and/or environment conditions (e.g., sun angle, glare, color contrast, shadows), odd roadway geometries, and/or pavement markings (e.g., curvature, grade, lane markings, etc.) are challenging factors capable of negatively affecting system performance. However, recreating these conditions precisely and repeatably on the test track is difficult. Therefore, NHTSA has only included the steel trench plate in the agency's current CIB/DBS draft test procedures.

3.2.2.2. Revision of Brake Application Methods Used for DBS Evaluation

NHTSA uses a programmable brake controller (robot) for all brake inputs applied during DBS testing. This required the agency to first define what constitutes a "realistic and appropriate" crash avoidance brake application so that the input conditions specified in the DBS draft test procedures would relate to those used by real-world drivers. However, this realism also had to be balanced with the DBS activation criteria used by production algorithms and what applications are technically achievable with commercially available brake controllers. Ultimately, NHTSA believes the best brake application is one that offers the best combination of:

- Ability to activate DBS
- Input definability (via use of characterization data)
- Ability to show improvements over a baseline brake condition
- Accuracy
- Repeatability

In response to the July 2012 RFC, NHTSA received comments about the brake application methods specified in the June 2012 DBS draft test procedure. Based on this feedback and on the agency's own observations during previous DBS test track evaluations, the agency made revisions to the brake pedal application speed and control logic used to command the applications.

a. Increased Brake Pedal Application Rate

The brake pedal application speed specified in the DBS draft test procedure must be sufficiently high that it satisfies the thresholds required by production DBS systems, yet low enough that the vehicle's conventional brake assist (BA)[19] is not activated.

Early drafts of NHTSA's DBS test procedures specified a nominal brake application rate of 12.6 in/s (320 mm/s), a value within a range of pedal rates associated with panic inputs, but near the end of the distribution associated with "normal" driving, as shown in Figure 3-6[20] [22]. However, after review of NHTSA's subsequent track-based test data and consultation with braking experts from the automakers and FCAM system suppliers, this rate was believed to be

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[19] Conventional BA is a technology that initiates supplemental braking based on brake pedal application rate without the use of any forward-sensing information.

too high. For at least one vehicle tested by NHTSA[21], an application rate of 12.6 in/s (320 mm/s) appeared to be sufficient to activate its conventional brake assist. For this vehicle, tests performed with and without a surrogate vehicle in the SV's forward path (i.e., DBS vs. baseline test trials) both produced high decelerations and nearly identical speed reductions. As a result, although the braking performance observed without the test target could be attributed to conventional BA alone; it was not possible to distinguish the contribution of DBS from conventional BA when the target was used.

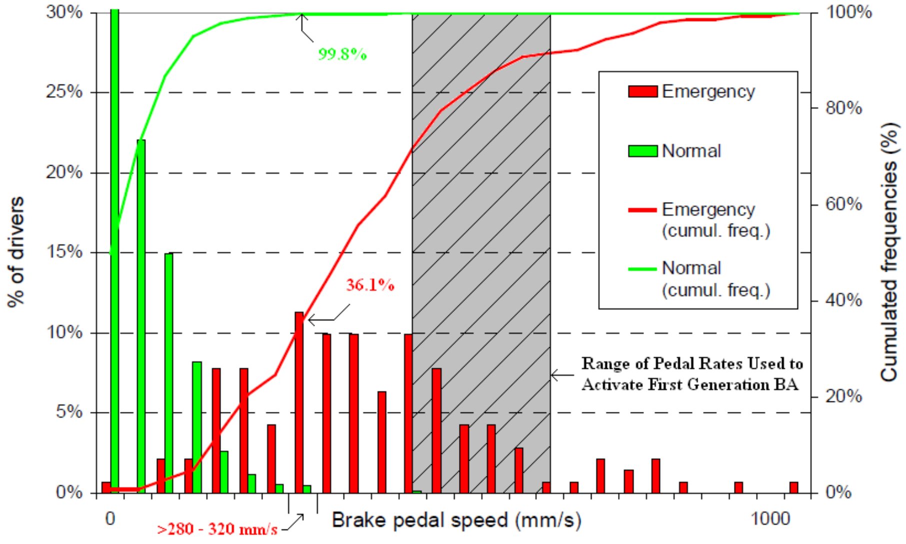

Figure 3-6. Brake applications used by drivers in emergency and non-emergency situations

In response to this concern, NHTSA lowered the nominal application rate by approximately one-half to 6 in/s (152 mm/s), with a tolerance of ± 1 in/s (25.4 mm/s), and incorporated the revision into the agency's publically-available June 2012 DBS draft test procedure. However, numerous RFC commenters indicated this reduction was too extreme since tuning a DBS system to respond to such a low application rate could result in DBS activations in real-world driving situations where they are not needed. To address these concerns, the latest DBS draft test procedure specifies a nominal pedal application speed of 10 in/s (254 mm/s) with a tolerance of ± 1 in/s

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[20] This study examined real-world responses of common drivers in both emergency and non-emergency situations, with the goal of optimizing proper vehicle responses to critical situations and minimizing inappropriate ones during normal driving. Figure 3-6 replicates a graph from that study, showing the different distributions of emergency and non-emergency brake pedal speed. By dividing the x-axis into 25 equal parts and interpolating the cumulative frequency, it is possible to estimate that approximately 99.8 percent of non-emergency brake pedal speeds were 320 mm/s or slower for this particular vehicle and study. Using the same process, it is estimated that 36.1 percent of emergency brake pedal speeds were 320 mm/s or slower.

A shaded region is superimposed atop the graph which depicts the range of brake pedal rates used to activate conventional BA [23], using a displacement feedback-based application. These pedal rates ranged from 472.4 – 683.3 mm/s (18.6 – 26.9 in/s). Based on the data presented in [22], selecting a brake pedal speed of 320 mm/s (12.6 in/s) implies that approximately 63.9 percent of drivers could attain this application rate in emergency situations and still be unlikely to activate conventional BA, as it is only 68 percent of the slowest application rate observed in [23].

[21] Results discussed in the 2012 FCAM research report.

(25 mm/s). This produces an allowable range of 9 to 11 in/s (229 to 280 mm/s), and NHTSA believes this sufficiently addresses industry's concern of slow brake pedal inputs contributing to DBS false positives (from an activation speed perspective), while still being much less than what is required for conventional BA.

b. Hybrid Feedback Control

Historically, NHTSA has used a programmable brake controller and two brake applications ("displacement feedback" and "force feedback") to evaluate DBS performance on the test track. With force feedback, the controller modulates actuator displacement to maintain constant brake pedal force for the duration of the braking event. Conversely, displacement-feedback control modulates actuator force to achieve the desired constant brake pedal position.

As explained in Section 3.2.2.2, brake pedal application rate is an important consideration for DBS evaluations, and for this reason it must be accurately controlled. Displacement feedback-based applications allow the desired application rate to be directly and accurately specified as position achieved per unit of time (e.g., mm/s), and it is not affected by brake pedal free play (mechanical slack present until just after force has been applied to the brake pedal). This is not necessarily the case when force feedback applications are used since the amount of force required to overcome free play is typically much less than that needed to produce deceleration. Therefore, for force feedback to apply a constant force per unit of time during a single application, brake pedal displacement speed can vary from slow (while the brake pedal is accelerated from rest) to fast (achieving the desired force gradient requires the pedal to move more rapidly). This is an important difference when comparing the implications of using a particular feedback algorithm. Since NHTSA has seen discontinuities of pedal velocity result in inconsistent DBS activation, the agency has generally favored use of displacement-based brake applications.

Unfortunately, test track evaluations performed by NHTSA and some vehicle manufacturers indicate the interaction between displacement-based brake pedal control and the DBS control algorithms used by certain vehicles may adversely affect system performance. For some vehicles, DBS activation can cause the brake pedal to physically move towards the floor without additional force applied from the driver's foot. However, since the brake pedal is held at a fixed position during tests performed with displacement feedback control, this motion is not possible and the constraint can confound the test outcome. For affected vehicles, holding the brake pedal position constant while DBS is active can induce a pressure gradient within the system hydraulics similar to that caused by the driver releasing force from the brake pedal. If the system relies on these pressure data (and not brake pedal position, which would indicate the driver has not released their application) to determine the driver's requested brake output, it may decide the supplemental braking provided by DBS is no longer needed. As a result, DBS is disengaged and normal unassisted braking resumed.

To evaluate whether alternative brake application methods could be used to accommodate vehicles with these operational characteristics, NHTSA performed a series of tests to assess the viability of incorporating "hybrid feedback" brake applications into the agency's DBS draft test procedure. These applications use a combination of displacement and force control strategies rather than displacement feedback alone. To begin a hybrid application, the same application rate and position used for displacement-feedback tests were commanded. However, once at the desired position, the application force was reduced at a rate of 56.2 lbf/s (250 N/s) to a force magnitude equal to 50 percent of that capable of achieving an average deceleration of 0.3g during the vehicle's brake system characterization. The intent of this strategy is to ensure some force remains present at the brake pedal for the duration of the test trial, but at a low enough level that the pedal displacement is not increased substantially[22]. Figure 3-7 presents a conceptual comparison of the displacement and hybrid feedback-based brake applications for a vehicle whose brake pedal falls towards the floor during DBS activation. Note how the hybrid application uses displacement feedback to establish the initial pedal position, and then switches to force-based control.

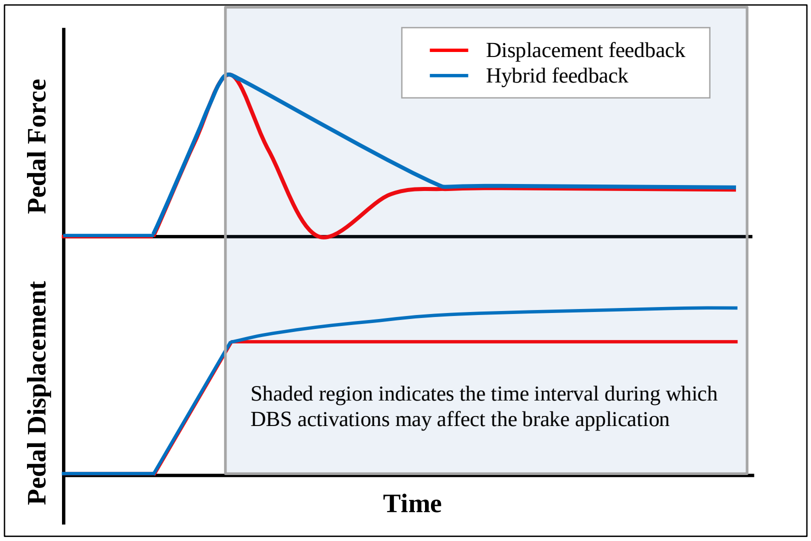

Figure 3-7. Conceptual comparison of displacement versus hybrid feedback brake applications

Prior to performing the 2013 FCAM tests described in Section 4, NHTSA had very little experience with the use of hybrid feedback-based brake applications. The brake controllers previously used by NHTSA were not equipped with the necessary functionality. To address this shortcoming, a brake controller with greater capability was purchased (a "C-Bar" from Anthony Best Dynamics) and a late-model vehicle with DBS performance affected by use of displacement feedback was obtained (a 2014 Mercedes ML320).

Since use of displacement feedback to command the initial brake application *rate* has not been problematic or criticized by industry, all hybrid feedback development at NHTSA focused on what happens after the displacement-feedback target magnitude was achieved, when the controller's logic changes from displacement to force-based control. From that point, identification of two specifications was required: (1) the application force target magnitude and (2) the manner in which force should be applied from the transition point to the force target.

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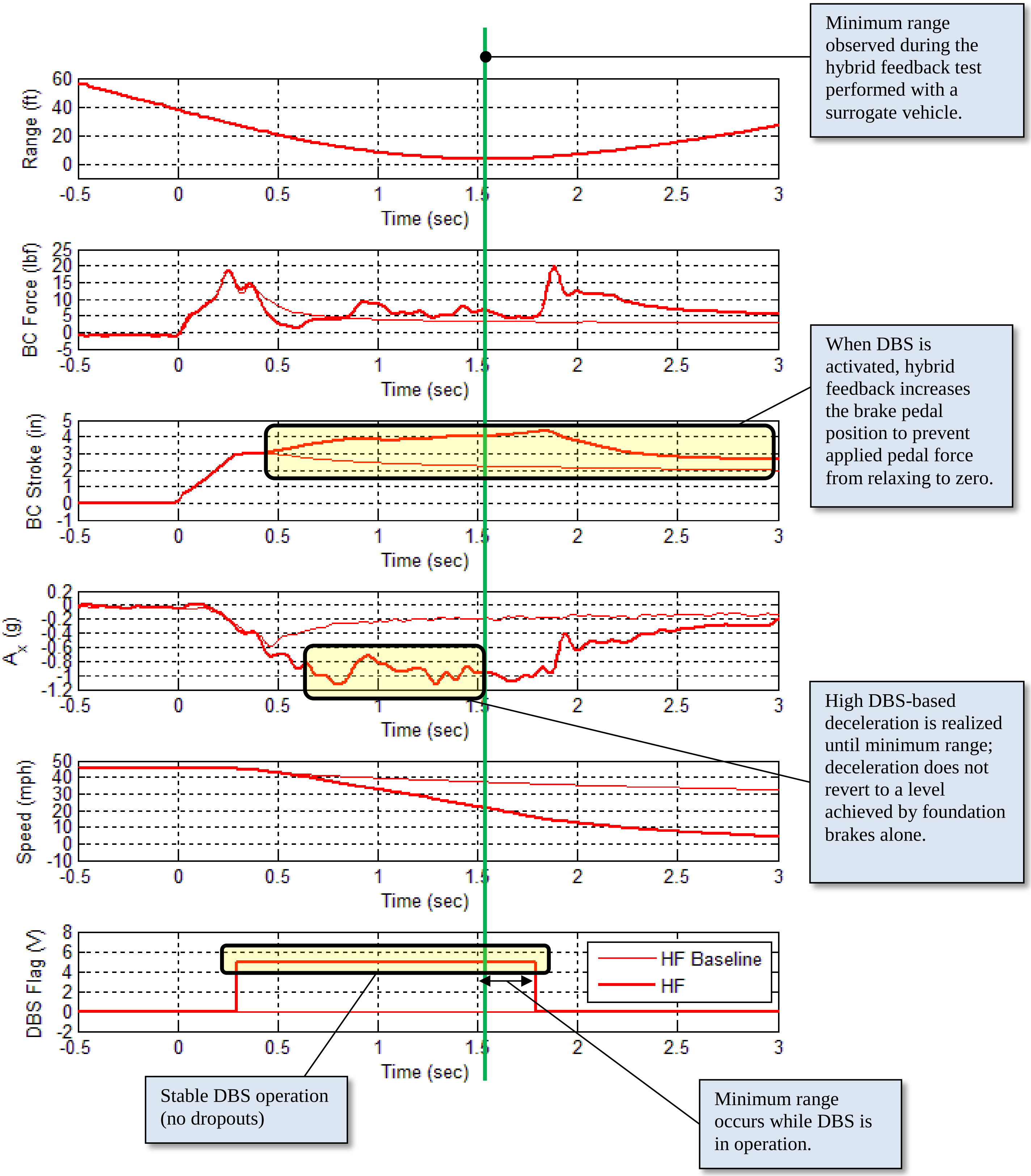
[22] Increasing brake pedal displacement generally increases a vehicle's deceleration. If it is allowed to increase too much beyond the magnitude used for displacement feedback, there is concern a vehicle could satisfy the DBS draft ARVs (i.e., speed reductions) by virtue of the increased brake pedal travel, not necessary because of the DBS intervention.

Although testing was limited, multiple combinations of these factors were evaluated with the Mercedes ML320. Ultimately, the hybrid-based applications best able to prevent the brake pedal force from reaching zero while maintaining strong deceleration and no DBS dropouts (i.e., instances where the supplemental braking provided by DBS becomes unavailable) were identified. Specifically, the applications included the following elements:

- Displacement feedback used to achieve the desired brake pedal position (i.e., the position needed to achieve a deceleration of 0.3g during brake system characterization) at a rate of 10 in/s (254 mm/s)
- Control logic changed to force feedback
- Application force reduced at 56.2 lbf/s (250 N/s) to the desired pedal force (i.e., 50 percent of the force needed to achieve a deceleration of 0.3g during brake system characterization)

Figure 3-8 compares two trials from Mercedes ML320 tests performed with hybrid-based applications: with (bold line) and without (thin line) DBS activation. Note that although the pedal force did not cleanly follow the requested 56.2 lbf/s (250 N/s) force fallback rate during the test with DBS or rigidly maintain the requested 6.1 lbf (27.2 N) fallback force thereafter, brake pedal displacement was increased to prevent a zero-force condition, and minimum range was achieved before deceleration reverted to the foundation brake system level. In this figure, no surrogate vehicle was used during the baseline tests to prevent DBS from being activated. A surrogate was used for the other test, however, and DBS was activated. Note that in this figure, as well as in Figures 3-9 and 3-10, “BC” is defined as “brake controller.”



Minimum range observed during the hybrid feedback test performed with a surrogate vehicle.

When DBS is activated, hybrid feedback increases the brake pedal position to prevent applied pedal force from relaxing to zero.

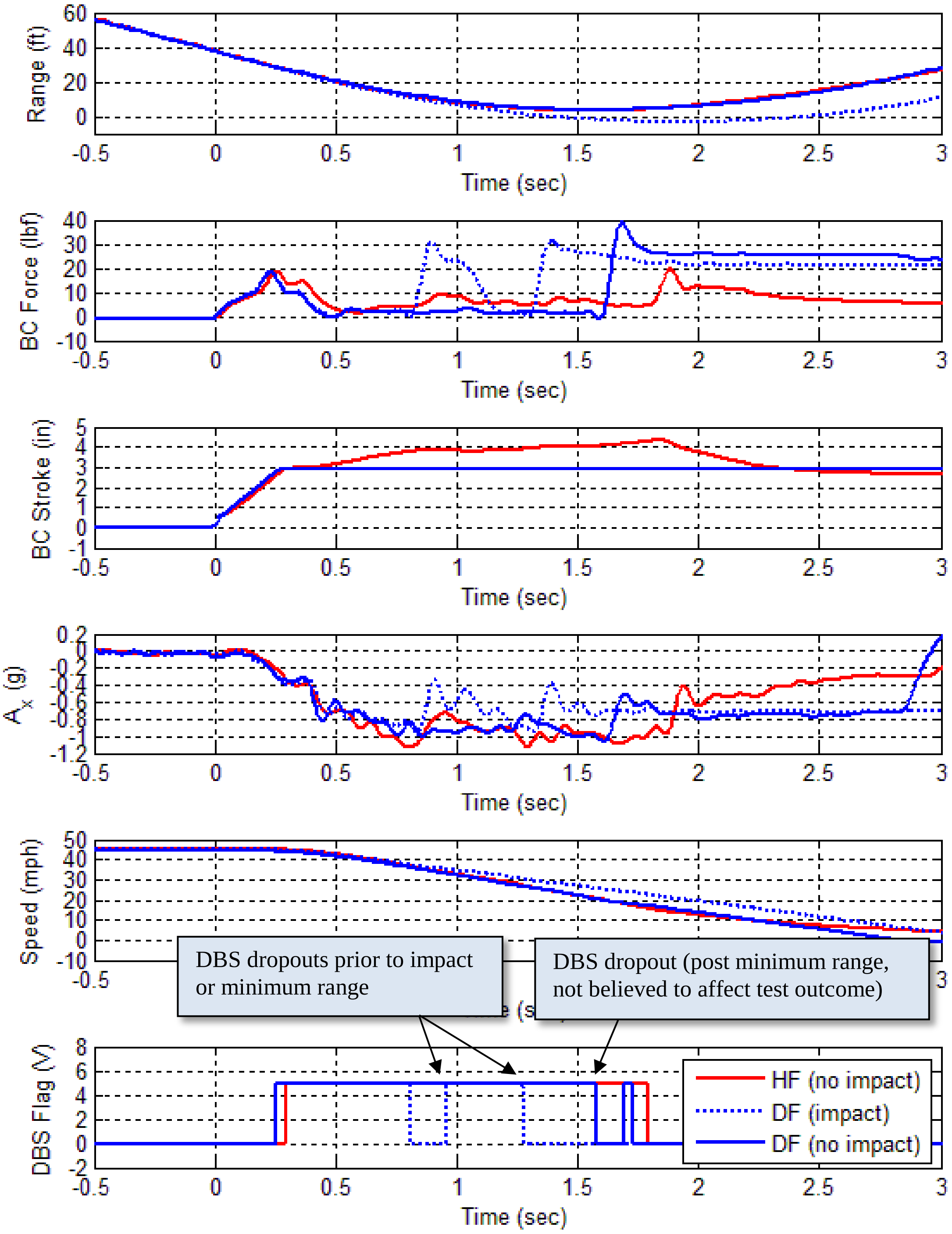
High DBS-based deceleration is realized until minimum range; deceleration does not revert to a level achieved by foundation brakes alone.

Stable DBS operation (no dropouts)

Minimum range occurs while DBS is in operation.

Figure 3-8. Hybrid feedback brake applications performed with the Mercedes ML320

Figure 3-9 compares Mercedes ML320 three trials performed with displacement and hybrid-based applications. Although DBS was activated during each trial, note that system dropouts were present during both displacement feedback trials (indicated with blue and blue dotted data traces), one of which concluded with an impact. No DBS dropout occurred during the hybrid test (red data trace).

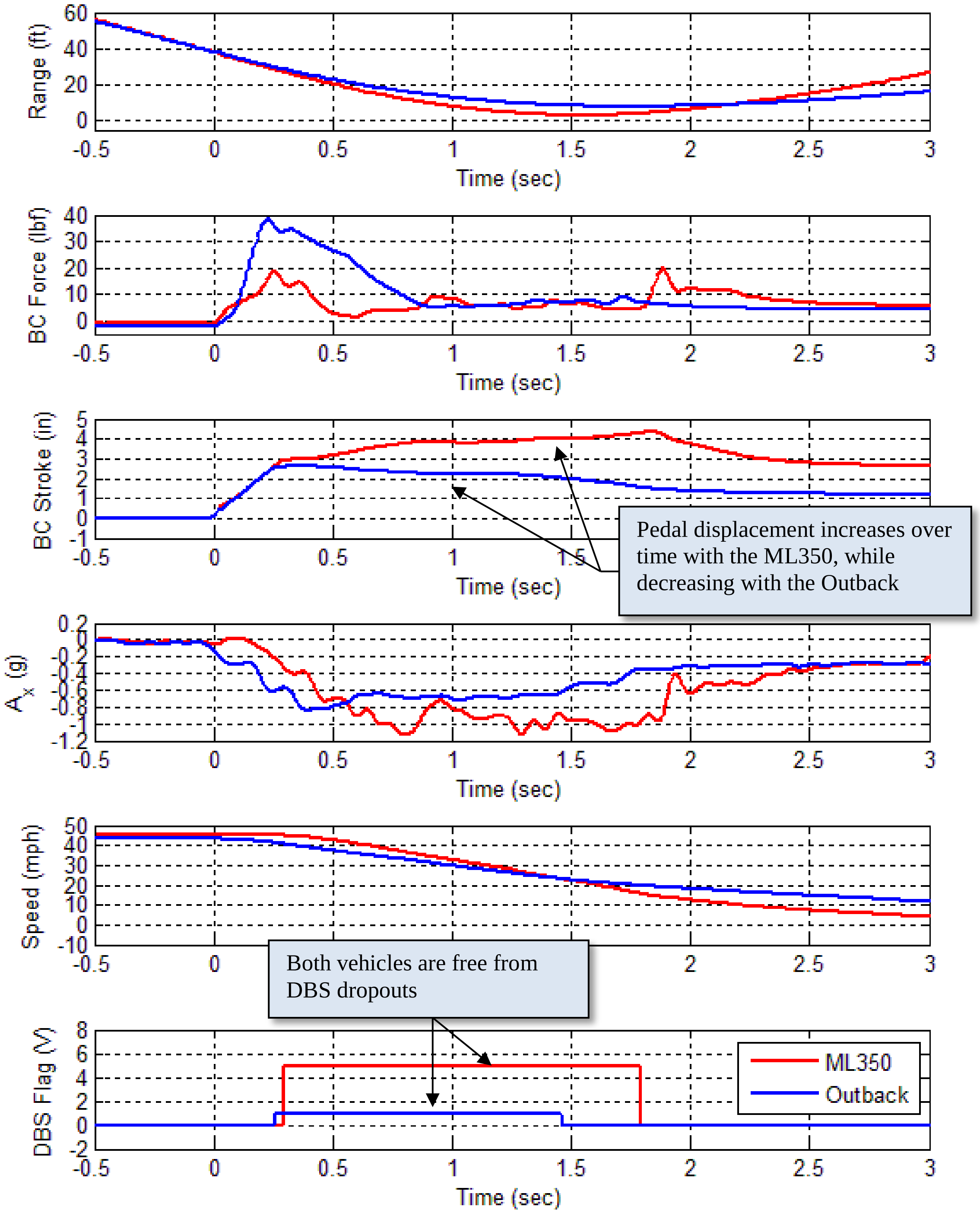


DBS dropouts prior to impact or minimum range

DBS dropout (post minimum range, not believed to affect test outcome)

Figure 3-9. Displacement and hybrid feedback brake applications performed with the Mercedes ML320

Figure 3-10 compares the Mercedes ML320 hybrid-based application shown in Figure 3-9 with that observed during a similar test performed with a Subaru Outback. The comparison is important for three reasons: (1) like the Mercedes ML320, tests performed with the Subaru Outback and displacement feedback can result in applied force falling to zero; (2) unlike the Mercedes ML320, the reduced application force does not appear to adversely affect test



Pedal displacement increases over time with the ML350, while decreasing with the Outback

Both vehicles are free from DBS dropouts

Figure 3-10. Hybrid feedback brake applications performed with the Mercedes ML320 and Subaru Outback outcome; and (3) even though they are not required to promote proper system operation, use of hybrid-based applications do not appear to adversely affect the Subaru Outback DBS performance (i.e., the applications "did no harm"). In other words, when compared to the Mercedes ML320, the DBS performance observed with the Subaru Outback appeared to be less sensitive to the manner in which the vehicle's brakes were applied.

After considering the results of these two vehicles, NHTSA determined that using hybrid feedback caused one vehicle's DBS system to operate in a manner consistent with that expected by its manufacturer, and appeared to have no adverse effect on the other vehicle's DBS system functionality. For this reason, hybrid-based brake applications were deemed suitable for inclusion into the 2013 FCAM test matrix described in Section 4.

3.2.3. Non-Ideal Environmental Condition Tests

In April 2013, the agency evaluated how the two CIB-equipped vehicles used for the LVD development work previously described in Section 3.2.2.1.a would perform in three non-ideal environmental conditions. The vehicles were selected because of their different sensor sets (the Volvo S60 was equipped with a mono camera, lidar, and a 77 GHz radar, whereas the Subaru Outback was equipped with stereo cameras) and availability (NHTSA-owned vehicles instrumented for other FCAM-related testing). The test conditions – moderate rain, darkness, and high-glare – were selected because they frequently occur in the real world and can compromise the detection capability of the vehicle's sensors. All evaluations used the LVS scenario only, and were generally performed at low speed, nominally 15 mph (24.1 km/h).[23] On a dry, high friction paved surface, both of these vehicles are capable of providing crash avoidance braking through their CIB systems from 15 mph in the LVS scenario.

3.2.3.1. Moderate Rain

The rain tests were performed on April 11, 2013. The rain was moderate and steady for each evaluation, and the test surface was wet, as shown in Figure 3-11. The nominal SV speed for the rain tests was 15 mph (24.1 km/h); however, single trials were also performed at SV speeds of 10, 20, and 25 mph (16.1, 32.2, and 40.2 km/h).

Figure 3-11. Subaru Outback CIB test performed in moderate rain

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[23] At the time these tests were performed, the durability of NHTSA's SSV had not yet been assessed. Since it was unknown whether and to what extent speeds would be reduced due to the non-ideal test conditions, the test speeds and number of test trials used for these evaluations were conservative.

No notable performance degradation was observed for either vehicle for SV speeds up to 20 mph (32.2 km/h). One collision with the SSV was observed during a 25 mph (40.2 km/h) trial performed with the Volvo S60. However, it is unclear whether this was due to test variability or the weather conditions, since only a single trial was performed at this speed and no baseline trial was performed on dry pavement. A crash avoidance summary for the rain tests is provided in Table 3-5.

Table 3-5. Crash Avoidance Summary from Tests Performed in Moderate Rain

SV Test Speed	Subaru Outback	Volvo S60
10 mph (16.1 km/h)	1/1	1/1
15 mph (24.1 km/h)	8/8	8/8
20 mph (32.2 km/h)	1/1	1/1
25 mph (40.2 km/h)	1/1	0/1[1]

[1] 14.1-mph speed reduction produced during the test concluding with an impact

3.2.3.2. Darkness

The darkness tests were performed during early morning, prior to sunrise, as shown in Figure 3-12. For the Subaru Outback they occurred from 6:20 a.m. to 6:24 a.m. EST on April 15, 2013 (sunrise was at 6:54 a.m.). The Volvo S60 tests were performed on April 22, 2013 from 5:42 a.m. to 6:04 a.m. EST (sunrise was at 6:44 am). Other than the light originated from the SV's headlights, the road surface was not illuminated during the darkness tests. The taillights of the SSF were not illuminated.

Figure 3-12. Volvo S60 CIB test performed in the dark

While operating in darkness, the Volvo S60 exhibited some CIB performance degradation (crash avoidance was not achieved during every trial), despite being equipped with multiple sensors. The Subaru Outback exhibited no performance degradation (see Table 3-6).

Table 3-6. Crash Avoidance Summary From Tests Performed In Darkness.

SV Test Speed	Subaru Outback	Volvo S60
15 mph (24.1 km/h) (low beam tests[1])	5/5	1/8[2]
15 mph (24.1 km/h) (high beam tests)	Not Performed[3]	3/5[4]

[1] Headlight switch set to “auto” for the low beam tests performed with both vehicles.

[2] 7.1 – 12.0 mph speed reductions produced during tests concluding with an impact

[3] Subaru Outback tests occurred before those performed with the Volvo S60, and were only performed with the low beams. The Volvo S60 high-beam tests were not originally defined in the test matrix, but were performed to see if the additional light would affect test outcome.

[4] 7.7 – 8.1 mph speed reductions produced during tests concluding with an impact

3.2.3.3. High Glare

For each vehicle, the high glare tests were performed after the darkness tests described in Section 3.2.3.2 from just prior to sunrise to late morning. For the Subaru Outback they occurred from 6:41 a.m. to 10:29 a.m. EST. The Volvo S60 tests were performed from 6:16 a.m. to 10:31 a.m. EST; an example of the conditions is shown in Figure 3-13. To maximize the amount of data available to identify as accurately as possible how each system was affected by the sun, groups of five trials were initiated approximately 30 minutes apart. To ensure a worst-case approach was used for each trial (i.e., the vehicles were always driven directly into the sun), the orientation of the SSV, the towed rail, and the tow vehicle was changed prior to performing each group of tests. Each trial was initiated from 15 mph (24.1 km/h), and the headlight switch set to “auto” for both vehicles. Neither the road surface nor the SSF taillights were illuminated during the high-glare tests.

Figure 3-13. Volvo S60 CIB test performed with high glare

As shown in Table 3-7, both vehicles exhibited CIB performance degradation when being driven directly into the sun at low angles in the horizon. The Subaru Outback provided a message to the driver just before each test during the time of sensor washout indicating "Eyesight Inactive," where Eyesight refers to the name of Subaru's CIB system. After each trial, as the vehicle was driven away from the sun, the system automatically restored its operational state to active.

Table 3-7. Crash Avoidance Summary from Tests Performed in High Glare.

Ambient Condition	Subaru Outback		Volvo S60	
	Time of Day (EST)	Crash Avoidance	Time of Day (EST)	Crash Avoidance
Pre-sensor washout	6:41 - 6:58 a.m.	6/6	6:16 - 6:46 a.m.	8/9[1]
During sensor washout	7:16 - 7:48 a.m.	0/6 (no speed reductions)	6:53 - 7:46 a.m.	6/21[2]
Post-sensor washout	7:49 - 10:29 a.m.	36/36	7:48 – 10:31 a.m.	36/36

[1] 8.8 mph speed reduction produced during the test ending with an impact

[2] 6.6 – 9.8 mph speed reductions produced during tests concluding with an impact

The Volvo S60 CIB system never appeared to fully disable itself, and no notification was provided to the driver that the system was in an inactive or compromised state. However, after completion of a given trial, one of two messages was presented on the instrument cluster, indicating either "Auto braking by City Safety" or "Auto braking was activated," where City Safety refers to the name of Volvo's CIB system designed to operate at speeds ≤19 mph (30 km/h). Although it is beyond the scope of this document to determine why different CIB modes were activated within a common group of trials, the test track data shown in Figure 3-14 clearly indicate intervention timing differences between the modes exist and help to explain the crash avoidance variability shown in Table 3-7.

3.2.3.4. Non-Ideal Environmental Condition Test Observations

The objective of this work was to provide NHTSA with CIB performance data beyond that typically recorded in more idealized testing environments. Since the scope of this work was very limited (one test scenario performed at low speed, two vehicles, etc.), the test results may, or may not, be representative of that achieved with other vehicles. In summary:

- No apparent performance degradation was observed in the rain
- Some performance degradation was present during Volvo S60 tests in the dark
- Each system was affected/suppressed during periods of high glare shortly after sunrise
    - Subaru Outback: for 32 minutes
    - Volvo S60: for 53 minutes

There are an unlimited number of non-ideal environmental conditions present in the real world, and it is impossible to precisely and repeatably reproduce most of them within practical

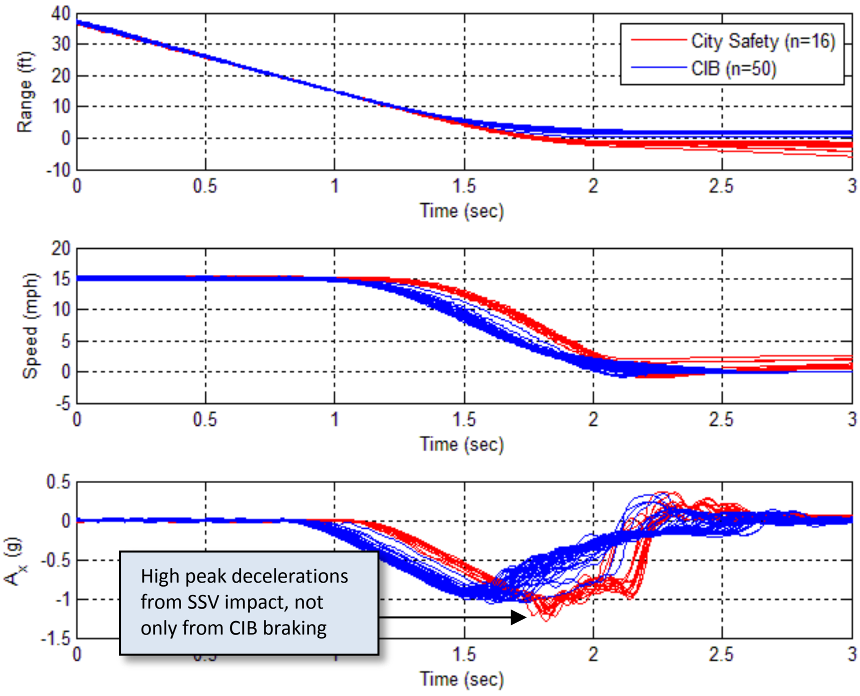

Figure 3-14. Vehicle responses observed during high-glare CIB tests performed with the Volvo S60

constraints on a test track. For these reasons, the current draft test procedures suggest that testing be conducted under near-ideal conditions. Specifically, the following language is used, with emphasis added:

> *"Tests shall not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, and/or ash.*
>
> *The tests shall be conducted during daylight hours with good atmospheric visibility, defined as an absence of fog and the ability to see clearly for more than 3.1 mile (5.0 km).* ***The tests shall not be conducted with the SV and POV oriented into the sun during very low sun angle conditions (where the sun is oriented 15 degrees or less from horizontal) as camera "washout" or system inoperability may result.***

4.0 2013 FCAM TESTS

4.1. Introduction

NHTSA's latest series of CIB and DBS test track evaluations, the 2013 FCAM tests, were performed from July 15 through November 19, 2013. The objective of this work was to validate the refinements made to the agency's methods of objectively evaluating CIB and DBS test track performance. Specific areas of interest included:

- Draft test procedure performability
- Effect of different brake application strategies (for DBS tests)
- Effect of test targets
- Ability to satisfy the assessment reference values

4.2. Test Matrix

The 2013 FCAM test matrix was designed to provide as many test configurations as possible, while still maintaining a reasonable test burden for NHTSA researchers. To accomplish this, the matrix included the following components:

- Seven test maneuvers for each technology (CIB and DBS)
- Two brake application techniques for DBS tests
- Seven light vehicles (subject vehicles)
- Two test targets (surrogates used as principal other vehicles)

4.3. Test Maneuvers

The test maneuvers used to evaluate CIB and DBS are summarized in Tables 4-1 and 4-2, respectively. Each technology was evaluated using LVS, LVM, LVD1[24], LVD2[25], and false positive (FP) tests performed with identical combinations of initial SV and POV speeds and headways.

With regards to Tables 4-1 and 4-2,

- "Initial Headway" describes the SV-to-POV distance (also referred to as "range") at the beginning of the maneuver, when the vehicles are to be at the desired speeds, etc., and can differ depending on whether a CIB or DBS evaluation is specified.
- "Nominal Impact Speed" values provided in Table 4-1 provide the relative speed the SV would be expected to strike the POV if no CIB-based automatic braking occurred.
- "Brake Apply Headway" describes the SV-to-POV distance at the onset of the SV brake application. To ensure accuracy and repeatability, the brake robot initiated these applications based on GPS triggers during DBS evaluations.

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[24] As indicated in Section 2.2, the kinematic conditions of an LVD1 scenario are such that the POV will still be decelerating (moving) at the time of SV CIB/DBS activation.

[25] The kinematic conditions of an LVD2 scenario are such that the POV will have decelerated to a stop ahead of SV CIB/DBS activation.

Table 4-1. 2013 FCAM CIB Test Matrix

Maneuver	Speed				Initial Headway		Nominal Impact Speed	
	SV		POV					
	(mph)	(km/h)	(mph)	(km/h)	(ft)	(m)	(mph)	(km/h)
LVS_25_0	25	40.2	0	0	>187	>57	25	40.2
LVM_45_20	45	72.4	20	32.2	>183	>56	25	40.2
LVM_25_10	25	40.2	10	16.1	>110	>34	15	24.1
LVD1_35_35	35	56.3	35	56.3	45.3	13.8	20	32.2
LVD2_25_25	25	40.2	25	40.2	328.1	100	25	40.2
STP_45 (CIB FP)	45	72.4	--	--	>337	>106	45	72.4
STP_25 (CIB FP)	25	40.2	--	--	>187	>57	25	40.2

Table 4-2. 2013 FCAM DBS Test Matrix

Maneuver	Speed				Initial Headway		Brake Apply Headway	
	SV		POV					
	(mph)	(km/h)	(mph)	(km/h)	(ft)	(m)	(ft)	(m)
LVS_25_0	25	40.2	0	0	>150	>46	40	12
LVM_45_20	45	72.4	20	32.2	>147	>45	37	11
LVM_25_10	25	40.2	10	16.1	>88	>27	22	7
LVD1_35_35	35	56.3	35	56.3	45.3	13.8	31.5	9.6
LVD2_25_25	25	40.2	25	40.2	328.1	100	40	12
STP_45 (DBS FP)	45	72.4	--	--	>271	>83	73	22
STP_25 (DBS FP)	25	40.2	--	--	>150	>46	40	12

4.3.1. LVS and LVM Tests

The LVS and LVM maneuvers presented in Tables 4-1 and 4-2 have been used by NHTSA to evaluate FCAM technologies for years, and variants of the scenarios have been incorporated into the agency's FCW NCAP. They are straight-forward to perform, and provide a reasonable way to quantify system performance. The SV and POV speeds specified for these maneuvers are intended to balance the speeds at which these crash types commonly occur in the real-world with the 25 mph (40.2 km/h) maximum relative impact speed supported by NHTSA's test equipment (i.e., the impact speed realized if no CIB activation were to occur due to a system fault, suppression, etc.). With few exceptions, the LVS and LVM scenarios used during the 2013 FCAM tests followed the protocols specified in the June 2012 draft test procedures. Note, however, that the nominal brake application rate used during the 2013 FCAM tests was 10 in/s (254 mm/s), not 7 in/s (178 mm/s) as stated in the June 2012 DBS procedure draft. As indicated in Tables 4-1 and 4-2, the 2013 FCAM tests matrix included one LVS and two LVM scenarios.

The LVS maneuver was performed with an SV speed of 25 mph (40.2 km/h). If the SV CIB does not activate in response to this scenario, it will impact the POV with a relative speed of 25 mph (40.2 km/h).

The LVM_45_20 tests were performed with the SV and POV traveling at 45 and 20 mph (72.4 and 32.2 km/h), respectively. If the SV CIB does not activate in response to the slower moving POV in this scenario, an impact with a relative speed of approximately 25 mph will occur. The LVM_45_20 test scenario is also used by the agency's NCAP to evaluate Forward Collision Warning (FCW) alert timing.

The LVM_25_10 tests were performed with the SV and POV traveling at 25 and 10 mph (40.2 and 16.1 km/h), respectively. If the SV CIB does not activate in response to the slower moving POV in this scenario, an impact with a relative speed of approximately 15 mph (24.1 km/h) will occur. The LVM_25_10 test scenario complements the LVM_45_20 tests by evaluating a similar driving scenario performed with lower speeds (a provision intended to help quantify CIB/DBS system robustness).

4.3.2. LVD Tests

The LVD maneuvers were developed just prior to the 2013 FCAM tests, and were included to provide a better overall quantification of FCAM system performance than possible with LVS and LVM testing alone. Although these maneuvers were more difficult to accurately perform than the LVS or LVM tests, they were included in the test matrix because they represent a large population of real-world rear-end crashes. The POV deceleration used during the 2013 FCAM tests was nominally 0.3g, which is equivalent to that specified in the FCW NCAP procedure, and consistent with decelerations seen in the crash data. As indicated in Tables 4-1 and 4-2, the 2013 FCAM test matrix included two LVD scenarios.

The LVD1_35_35 test was performed with the SV and POV traveling closely together (45.3-ft (13.8 m) initial headway) at 35 mph (56.3 km/h). If the SV CIB does not activate in response to the decelerating POV in this scenario, it will impact the POV with a relative speed of approximately 20 mph (32.2 km/h). This test was referred to as the LVD1_35_45.3 variant in Section 3.2.2.1.a of this document.

The LVD2_25_25 test begins with the SV and POV travelling at a lower speed (25 mph (40.2 km/h)) and a much larger headway of 328 ft (100.0 m). In this case, the POV decelerates to a stop well before any SV CIB intervention would be expected to occur. If the SV CIB does not activate in response to this scenario, it will impact the POV with a relative speed of 25 mph (40.2 km/h). This test was referred to as the LVD2 variant in Section 3.2.2.1.a of this document.

4.3.3. False Positive Tests

Steel trench plates (STP) are often used in road construction to temporarily cover sections of pavement that are unsafe to drive over directly (typically during repair). Although the STP is large and metallic, it is designed to be driven over without risk of injury to the driver or damage to the SV. Therefore, in this scenario the automatic braking available from CIB, or supplementary braking provided by DBS, is not necessary and should not occur.

The STP false positive tests were performed by driving over an 8 ft x 12 ft x 1 in (2.4 m x 3.7 m x 25.4 mm) ASTM A36 steel trench plate at two SV speeds: 25 and 45 mph (40.2 and 72.4 km/h). Conduct of these tests simply required the SV driver to approach the STP at a constant speed while respecting the tolerances used to assess maneuver validity.

4.4. Brake Applications (for DBS Evaluation)

The brake applications used during the 2013 FCAM DBS tests consisted of two parts: characterization and performance evaluation. All brake applications were performed using programmable brake robot using displacement- or hybrid-control feedback algorithms. Use of force feedback alone (i.e., controlling SV brake applications on the basis of applied pedal force only) was not included in the 2013 FCAM test matrix.

4.4.1. Foundation Brake Characterization

To objectively determine the commanded brake application magnitude to be used for DBS performance evaluations, a characterization process was used. To begin, the SV was driven in a straight line at 45 mph. The driver fully released the throttle pedal and, using displacement feedback, a brake application capable of achieving a deceleration of 0.7g was applied at a rate of 1 in/s (25.4 mm/s). A total of eight characterization trials were performed per vehicle. For each trial, a first-order regression was applied to the brake pedal position versus SV deceleration data from 0.25g to 0.55g to determine the pedal displacement needed to produce a deceleration of 0.3g. The 0.3g deceleration rate value is consistent with real-world crash data as identified by the agency in its review of electronic data recorder (EDR) data, summarized in Table 4-3. Results from the individual trials were then averaged and used for the tests described in Section 4.4.2.

Table 4-3. Results from NHTSA's EDR Analysis Of Rear-End Crashes

Description	Cases	Avg. Deceleration
# of rear end EDR cases, on dry pavement applying brake (<1g)	73	0.383g
# of rear end EDR cases, on dry pavement applying brake (<1g, weighted*)	48,331	0.316g
# of rear end EDR cases, on dry pavement applying partial brake (<0.75g)	65	0.324g
# of rear end EDR cases, on dry pavement applying partial brake (<0.75g, weighted*)	44,975	0.275g

* NASS-CDS case weights were applied to the EDR-based sample to estimate values for the total crash population. See DOT Report HS 811 807 for NASS-CDS case weight methodology.

4.4.2. DBS Performance Evaluation

Regardless of the control feedback algorithm used, displacement or hybrid-based, the applications each share the following attributes:

- The SV brake pedal began at rest. The brake controller was not used to preload the SV brake pedal or to remove free play.
- Each application was triggered by a GPS-based headway signal. Since the DBS draft test procedure indicates that the onset of SV braking occurs when brake pedal force is 2.5 lbf (11.1 N), some iterative tuning was needed to ensure this force was realized at the correct headway; the command to activate the brake controller was sent prior to reaching the desired trigger point to account for signal latency and mechanical delays.
- The application rate was 10 in/s (254 mm/s) until the brake pedal reached the position capable of achieving 0.3g during brake system characterization.

4.4.2.1. Displacement Feedback Control

With "displacement feedback," the brake controller was used to modulate applied force to achieve the desired brake pedal position. Use of this algorithm allowed the application ramp rate from zero (i.e., at rest) to the desired magnitude to be directly programmed into, and accurately realized by, the controller. Once at the position capable of achieving 0.3g during brake system characterization, the brake pedal position was held constant until the end of the test trial.

4.4.2.2. Hybrid Feedback Control

As previously mentioned in Section 3.2.2.2.b, hybrid-feedback control logic includes a combination of position- and force-control strategies. For the hybrid applications used during the 2013 FCAM tests, the same application rate and position used for displacement-feedback tests were commanded. However, once at the desired position, application force was reduced at a rate of 56.2 lbf/s (250 N/s) to a force magnitude equal to 50 percent of that capable of achieving an average deceleration of 0.3g during the vehicle's brake system characterization. The intent of this strategy was to ensure that some force remains present at the brake pedal for the duration of the test trial, but at a low enough level that the pedal displacement was not increased significantly.

4.5. Test Vehicles

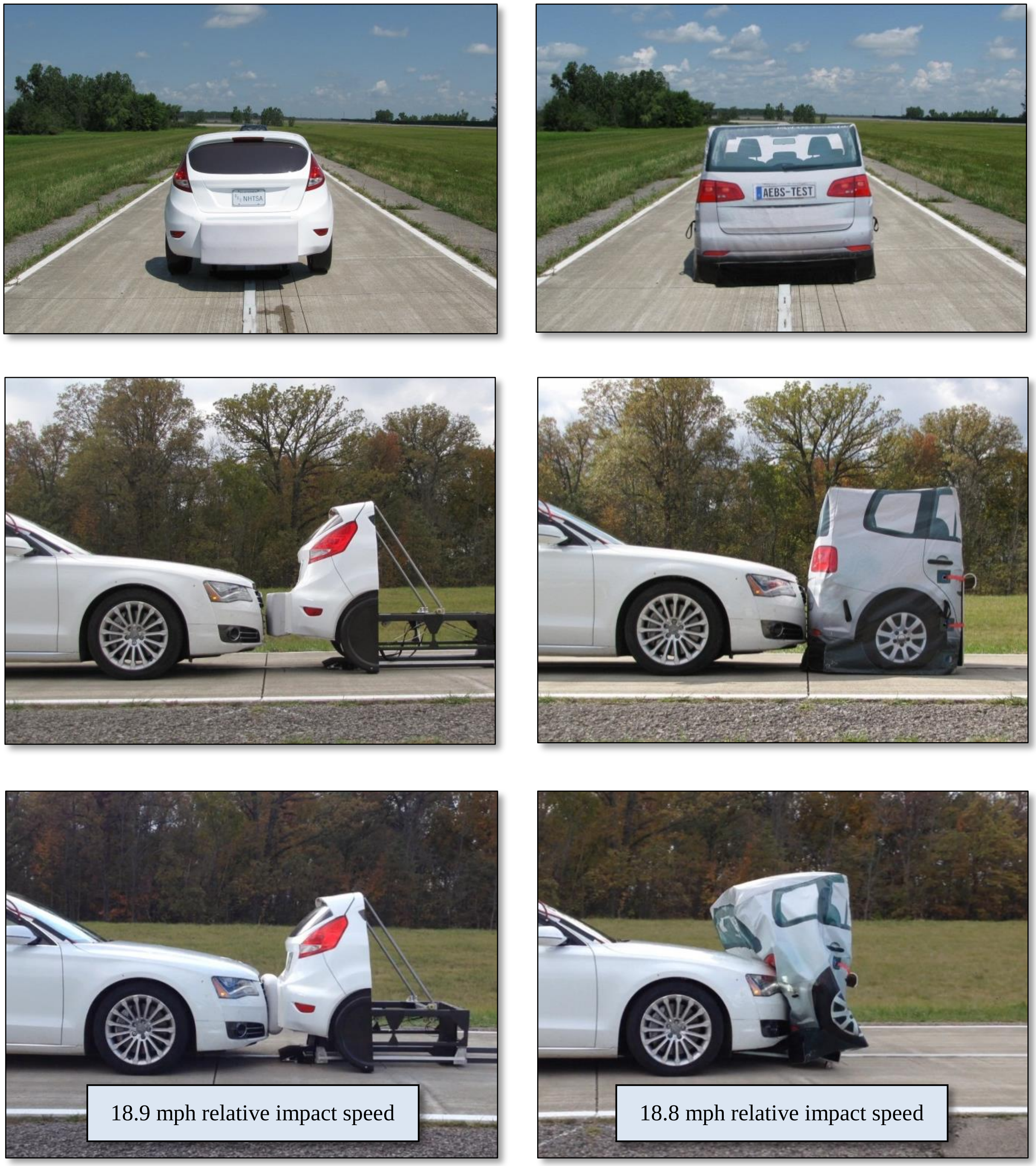
The vehicles selected for the 2013 FCAM tests, shown in Table 4-4, are representative of contemporary offerings in the United States (U.S.), and were generally equipped with different sensor combinations. Only the Infiniti Q50 and Mitsubishi Outlander were equipped with the same type of sensing package (a single long-range radar). Time and funding allowed for only a limited number of vehicles to be evaluated with the 2013 FCAM tests. There was an interest in including vehicles from manufacturers that the agency had not included in previous test efforts. Many of these systems were not available for sale in the U.S. until the 2014 model year. As a result, samples from other manufacturers that produce vehicles equipped with CIB/DBS were not included (e.g., Honda/Acura and Volvo).

Table 4-4. 2013 FCAM Test Vehicle List

Vehicle	Sensing Technology			
	Radar		Cameras	
	SRR (24 GHz)	LRR (77 GHz)	Mono	Stereo
2014 Audi A8L		2	✓	
2014 Cadillac ATS	2	1	✓	
2014 Infiniti Q50		1		
2014 Mercedes E350	2	1		✓
2014 Mitsubishi Outlander		1		
2013 Lexus LS460		1		✓
2013 Subaru Outback				✓

4.6. Surrogate Vehicles

The NHTSA SSV and ADAC inflatable surrogate, shown in Figure 4-1, were the most highly developed surrogate vehicles available to NHTSA for the 2013 FCAM tests. At the time the 2013 FCAM test matrix was conceived, a comparison of each vehicle's CIB/DBS performance as a function of test target was desired. Unfortunately, the number of such comparisons was limited. Although NHTSA owns the SSV, the ADAC target had to be leased from the Insurance Institute for Highway Safety (IIHS). When IIHS procured their ADAC target, they did not purchase the tow apparatus needed to support slower-moving or decelerating lead vehicle tests. For this reason, only the LVS scenario was used to evaluate the effect of surrogate vehicle on test outcome.



18.9 mph relative impact speed

18.8 mph relative impact speed

Figure 4-1. NHTSA SSV (left) and ADAC (right) test targets

4.7. Draft Assessment Reference Values (ARVs)

Table 4-5 presents the draft ARVs used to evaluate the 2013 FCAM test results. In the case of the LVS, LVM, and LVD maneuvers, the performance metric was speed reduction. For the false positive tests, no autonomous (CIB) or supplementary (DBS) braking was allowed.

Table 4-5. CIB and DBS Draft Assessment Reference Values (ARVs)

FCAM Technology	**SV Speed Reduction or Crash Avoidance**						
	LVS 25_0	**LVM 45_20**	**LVM 25_10**	**LVD1 35_35**	**LVD2 25_25**	**STP_45 (FP)**	**STP_25 (FP)**
CIB	≥ 9.8 mph (15.8 km/h)	≥ 9.8 mph (15.8 km/h)	Crash Avoidance	≥ 10.5 mph (16.9 km/h)	≥ 9.8 mph (15.8 km/h)	No Activation[1]	
DBS	Crash Avoidance					No Activation[2]	

[1] CIB activation is said to occur if SV deceleration ≥ 0.25g within the validity period

[2] DBS activation is said to occur if SV deceleration ≥ 125% of a baseline average

The LVS and LVM draft ARVs were provided within the June 2012 CIB and DBS draft test procedures, were described in the June 2012 research report, and were mentioned in the July 2012 RFC. The LVD and false positive tests are recent additions to the draft test procedures, and their respective evaluation criteria are included in the August 2014 CIB and DBS draft test procedures. The speed reductions specified for the LVD tests are based on the same performance levels applied to the LVS and LVM maneuvers.

For CIB, the speed reductions criteria with the draft ARVs presented in the Table 4-5 correspond to an effective deceleration of 0.6g from a TTC of 0.6 s. These criteria were developed using NHTSA test data collected during 2011, and were intended to promote safety-beneficial and attainable performance.

For DBS, the draft ARVs are full crash avoidance for the LVS, LVM, and LVD maneuvers. Although the absolute speed reductions needed to meet these criteria are higher than those of CIB, the effective deceleration is slightly lower since braking is initiated at an earlier TTC.

The June 2012 CIB and DBS draft test procedures specified that the LVS and LVM draft ARVs presented in Table 4-5 were to be satisfied during 100 percent of the tests performed (i.e., during each of the eight trials performed per scenario). In response to the RFC, many commenters cited the difficulty in meeting the performance criteria during every trial performed. At the time this feedback was provided, the CIB draft test procedure included only one LVS and two LVM conditions, or 24 individual test trials. Since that time, the test burden of the 2013 FCAM test matrix increased 133 percent to 56 trials per technology.

The ARVs described in Table 4-5 represent meeting at least 7 of 8 trials for each scenario, as 7 of 8 was considered a useful performance benchmark for the purposes of this research.

4.8. Test Results

With regards to the 2013 FCAM test results, NHTSA determined two factors were the most important:

- **Performability.** Can each test scenario be repeatably and accurately performed within the tolerances provided in the draft test procedures?
- **System Performance.** Can the draft ARVs be achieved by current production vehicles?

With respect to performability, the test tolerances associated with the seven (CIB) to eight (DBS) parameters shown in Table 4-6 were compared to the actual deviations from the specified parameters observed in testing. The validity violations (i.e., instances where a parameter exceeded its allowable tolerance) for each vehicle were combined across test condition and summarized. System performance was quantified by comparing the ability of each 2013 FCAM test vehicle to achieve the performance previously specified in Table 4-5.

Table 4-6. CIB and DBS Test Tolerance Overview

Parameter	Tolerance
SV speed	±1 mph (1.6 km/h)
POV speed	±1 mph (1.6 km/h)
SV lateral position from road center	±2 ft (0.6 m)
SV-to-POV lateral orientation relative to each other	±2 ft (0.6 m)
SV-to-POV headway (applicable to LVD tests only)	±8 ft (2.4 m)
SV yaw rate	±2 deg/s
SV brake application range to POV (DBS)	±2 ft (0.6 m)
SV throttle release timing (CIB)	Fully released after SV deceleration ≥ 0.1g permitted
SV throttle release timing (DBS)	>1 s prior to brake application

4.8.1. CIB Maneuver Performability

The ability to successfully perform each CIB test scenario is summarized in the pie charts presented in Figure 4-2. For each scenario, the expression “n = x of y” is defined as follows:

- x = total number of trials performed with a validity violation, collapsed across test scenario
- y = total number of trials performed, collapsed across test scenario

Of the “n” trials, the cause of the violation is presented in the Figure 4-2 pie charts.

4.8.1.1. CIB LVS Scenario

No LVS validity violations were observed during the 2013 FCAM CIB tests.

4.8.1.2. CIB LVM Scenario

For the LVM maneuvers, the only validity violations were for SV and POV speed. In both cases, POV speed exceeding the ±1 mph (1.6 km/h) tolerance specified in Table 4-6 was the most common violation. Interestingly, there were only three non-valid CIB trials of the 59 performed in the LVM_45_20 condition (5.1 percent), far fewer than the 14 recorded for the slower LVM_25_10 tests (22.2 percent).

4.8.1.3. CIB LVD Scenario

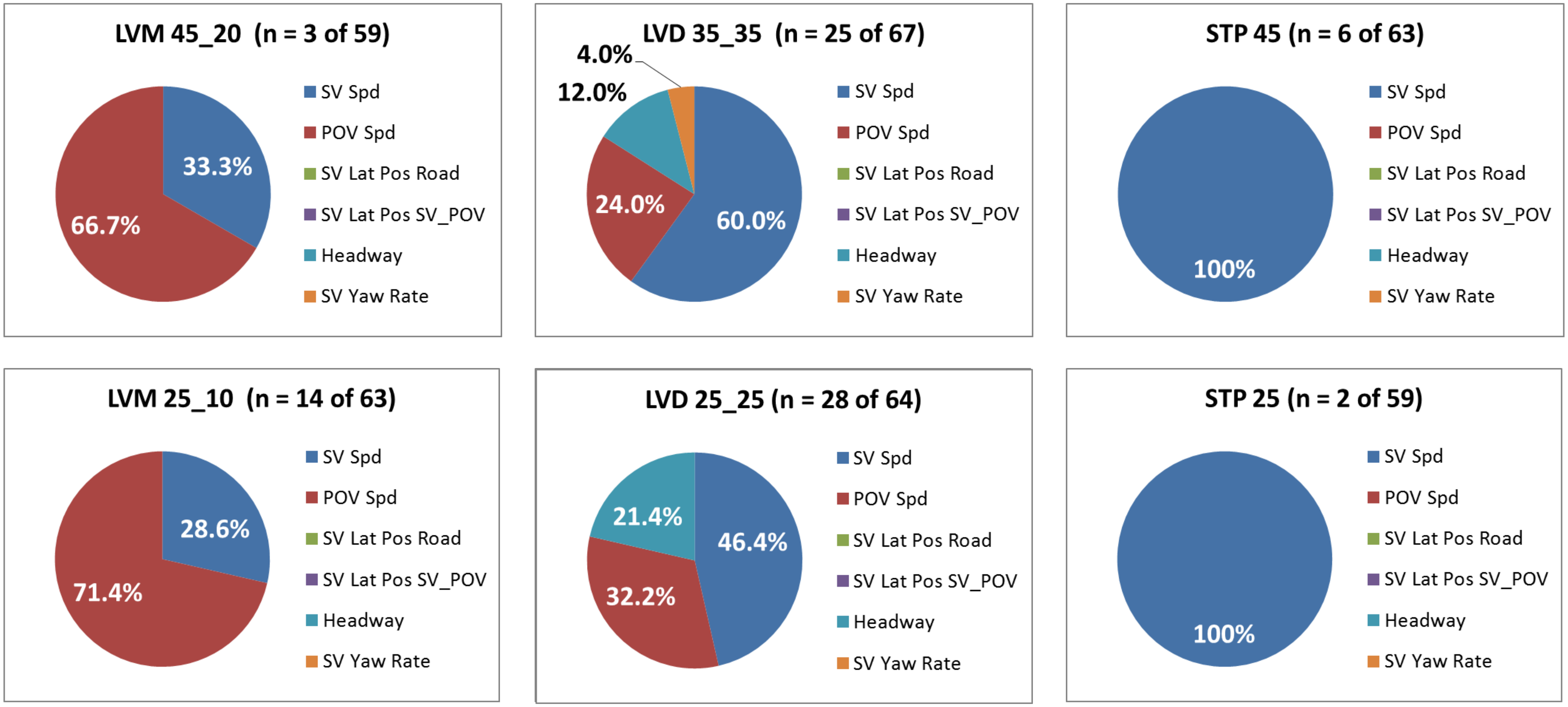
The LVD maneuvers were the most difficult to execute during the 2013 FCAM tests. This was largely because the SV and POV speeds and headway need to be quickly established and maintained within the confines of the relatively short test surface. As a result, 37.3 percent of the LVD1_35_35 trials had at least one validity violation. In the case of the LVD2_25_25 tests, this increased to 43.8 percent.

Like the LVM maneuvers, the most common LVD validity violations were due to speed violations. Unlike the LVM tests, most were due to SV speed problems associated with the SV driver trying to "catch up" to the POV when the headway was outside of the ±8 ft (2.4 m) tolerance specified on Table 4-6. This issue is believed to be an isolated problem attributed to a specific driver since most of these violations occurred during the Subaru Outback LVD trials, which were all performed by the same test driver. SV speed infractions occurred during fifteen LVD1_35_35 tests overall, and eight (53.3 percent) involved the Subaru Outback. For the LVD2_25_25 scenario, nine of the thirteen overall SV speed violations (69.2 percent) involved the Subaru Outback, where eight of the fifteen (53.3 percent) SV speed infractions occurred during the LVD1_35_35 tests, and during nine of the thirteen (69.2 percent) LVD2_25_25 tests. When they occurred for this vehicle, the SV speed violations ranged from 0.2 to 1.6 mph (0.3 to 2.8 km/h) greater than the ±1 mph (±1.6 km/h) allowable tolerance.

Since the LVD maneuver imposes a tolerance on SV-to-POV headway, it was not surprising that headway violations occurred during some trials. However, since the tolerance is not particularly strict at 8 ft (2.4 m), the number of violations for this parameter was lower than the number of SV or POV speed tolerance violations for each maneuver: 12.0 and 21.4 percent of all 35 and 25 mph (56.3 and 40.2 km/h) LVD test violations, respectively.

4.8.1.4. CIB False Positive Scenario

From an ease of conduct perspective, the STP tests were expected to be equivalent to the LVS maneuver. Although no validity violations occurred during the CIB LVS evaluations, a small number of SV speed violations were observed during the STP tests (9.5 and 3.4 percent of the STP_45 and STP_25 tests, respectively).



n = number of all trials performed with a validity violation, per maneuver. Of the "n" trials, the cause of the violation is presented.

Figure 4-2. CIB maneuver performability; validity violations by test scenario.

4.8.2. CIB Test Track Performance

Tables 4-7 and 4-8 present overall summaries of how well the 2013 FCAM test vehicles were able to satisfy the CIB draft ARVs. The data shown in Table 4-7 are inclusive of non-valid trials, whereas those in Table 4-8 only contain valid results: i.e., those performed within the tolerances specified in Table 4-6 and in the August 2014 CIB draft test procedures [24].

Some of the tolerances used to screen the tests for validity were established after data collection of the 2013 FCAM tests (i.e., after the vehicles had been de-instrumented and/or were no longer available), some trials initially considered to be acceptable were later deemed non-valid during the final post-processing of the test data. In some cases, the later validity screen reduced the number of valid tests per vehicle and condition to be less than eight. For this reason, the assessments described within Section 4.8.2 are based on valid trials where possible, but with consideration of non-valid trials where necessary. When data from non-valid trials were considered, their contribution is noted.

Inclusion of results from non-valid test trials, when needed to achieve eight trials per scenario, provided a way to increase the amount of data available to describe how a given vehicle performed. For a test trial to be deemed non-valid, it is important to recognize that only one test tolerance (e.g., as previously specified in Table 4-6) for one data channel must be violated. Often, these violations were very small, and affected a single data channel. If data from a non-valid trial were used to quantify a vehicle's performance, the cause of the violation was first screened to ensure it would not be expected to affect the ability of the vehicle to satisfy an ARV.

NHTSA believes there is value to the data produced by non-valid test trials provided the validity infraction would not be expected to affect test outcome. In the context of this research report, an appropriate consideration of non-valid trials improves the ability of the agency to present a representative overall account of a vehicle's test track performance.

If a test trial was performed so poorly that the corresponding data did not accurately represent the scenario being performed (e.g., a wind gust caused the SSV to move out of position during a LVS test), it was classified as egregious, not just non-valid. Egregious trials were not included in the Tables 4-7 or 4-8 and were not used to discuss vehicle performance.

Summarizing the results in Table 4-7 and 4-8:

- Three vehicles were able to satisfy all CIB draft ARVs (the Mercedes E350, Lexus LS460[26] and Subaru Outback[27]). These vehicles also achieved full crash avoidance during the LVS, LVM, and LVD2_25_25 tests.

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[26] An assessment of the Lexus LS460 required consideration of non-valid trials for the LVM and LVD maneuvers, and for the STP_25 tests. However, all Lexus LS460 trials performed, regardless of test validity, were able to satisfy the respective draft ARVs.

[27] An assessment of the Subaru Outback required consideration of non-valid trials for the LVM and LVD maneuvers. However, all Subaru Outback trials performed, regardless of test validity, were able to satisfy the respective draft ARVs.

- Two vehicles were able to satisfy all but one of the CIB draft ARVs. The Mitsubishi Outlander did not satisfy the LVS draft ARV, whereas the Infiniti Q50 did not satisfy the LVD1_35_35 draft ARV.
- No CIB false positive events were recorded.
- The ability of the vehicles to satisfy the LVS CIB draft ARV was not affected by the surrogate vehicle used.
- The vehicles equipped with the largest number of sensors did not necessarily perform better than those equipped with a single sensing technology.
- Three vehicles were not evaluated in the LVS condition, as these vehicles were not designed to respond to stationary objects at the speed specified in the draft test procedure (Audi A8L, Cadillac ATS, and Mitsubishi Outlander).

Table 4-7. Number of Trials Able to Satisfy CIB Draft ARVs
(Data not screened for test validity; bright yellow indicates an inability to satisfy the draft ARVs.)

Vehicle	**Number of Tests Satisfying the CIB Performance Assessment Reference Values**							
	LVS 25_0		**LVM 45_20**	**LVM 25_10**	**LVD1 35_35**	**LVD2 25_25**	**STP_45 (FP)**	**STP_25 (FP)**
	SSV	**ADAC**						
2014 Audi A8L	--	--	8/8	0/9	12/12	7/8	8/8	9/9
2014 Cadillac ATS	--	--	8/8 8/8[2]	6/13[1] 7/9[2]	0/10[2]	8/8[2]	11/11	9/9
2014 Infiniti Q50[2]	9/9[4]	8/8[4]	9/9[4]	5/10[3] 8/9[4]	3/8[4]	9/9[4]	9/9	8/8
2014 Mercedes E350	9/9	8/8	8/8	9/9	8/8	8/8	8/8	8/8
2014 Mitsubishi Outlander	--	--	10/10	10/10	9/9	8/8	9/9	8/8
2013 Lexus LS460	8/8	8/8	8/8	8/8	9/9	9/9	13/13	10/10
2013 Subaru Outback	8/8	8/8	8/8	8/8	10/10	14/14	8/8	9/9

-- = test not performed because the vehicle's CIB system was not designed to respond to stationary objects at the 25-mph test speed

[1] Minimum range was less than 1 ft for all tests where no impact occurred

[2] Result achieved with full FMVSS No. 135 burnish

[3] Driver attempted to maintain constant throttle position before and after FCW-based throttle pedal pushback

[4] Result achieved with throttle release after FCW-based throttle pedal pushback

Table 4-8. Number of Trials Able to Satisfy CIB Draft ARVs
(Valid* tests shown; bright yellow indicates an inability to satisfy the draft ARVs.)

Vehicle	Number of Tests Satisfying the CIB Performance Assessment Reference Values							
	LVS 25_0		LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP_45 (FP)	STP_25 (FP)
	SSV	ADAC						
2014 Audi A8L	--	--	8/8	0/7	8/8	6/7	8/8	7/7
2014 Cadillac ATS	--	--	6/6 8/8[1]	6/8[1]	0/7[1]	7/7	8/8	8/8
2014 Infiniti Q50[1]	8/8[3]	8/8[3]	8/8[3]	4/8[2] 7/8[3]	3/8[3]	8/8[3]	8/8	7/7
2014 Mercedes E350	8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8
2014 Mitsubishi Outlander	--	--	8/8	8/8	8/8	7/7	8/8	8/8
2013 Lexus LS460	8/8	8/8	7/7	6/6	6/6	5/5	8/8	7/7
2013 Subaru Outback	8/8	8/8	7/7	3/3	2/2	4/4	8/8	8/8

*Validity assessment does not consider POV deceleration

-- = test not performed because the vehicle's CIB system was not designed to respond to stationary objects at the 25-mph test speed

[1] Result achieved with full FMVSS No. 135 burnish

[2] Driver attempted to maintain constant throttle position before and after FCW-based throttle pedal pushback

[3] Result achieved with throttle release after FCW-based throttle pedal pushback

Note that the June 2012 draft test procedures specified that performance criteria for a given test condition were to be satisfied during 100 percent of the tests performed. Some respondents to the July 2012 RFC indicated that this was not reasonable and that the criteria should be relaxed. To investigate the effect of test stringency, two performance benchmarks were compared: meeting ARV criteria during eight out of eight trials (i.e., 100 percent of the trials) and meeting ARV criteria during seven out of eight trials (i.e., up to one trial per scenario not meeting the ARV criteria).

By allowing up to one test per scenario to not satisfy the CIB draft ARVs, the following effects were observed:

- Audi A8L: now able to satisfy the LVD2_25_25 draft ARV[28] (but was still unable to satisfy the LVM_25_10 draft ARV)
- Cadillac ATS: no change
- Infiniti Q50: now able to satisfy the LVM_25_10 draft ARV (but was still unable to satisfy the LVD1_35_35 draft ARV)
- Mercedes E350: no change
- Mitsubishi Outlander: no change
- Lexus LS460: no change
- Subaru Outback: no change

4.8.2.1. Effect of Performing a Complete FMVSS No. 135 Brake Burnish

To ensure the SV brake pads, linings, rotors, and/or drums have been adequately conditioned, one July 2012 RFC commenter indicated the NHTSA CIB/DBS draft test procedures should include the brake burnish and temperature maintenance schedules defined in the current light vehicle brake standard, FMVSS No. 135, and not those adopted from the light vehicle standard on electronic stability control systems, FMVSS No. 126. The burnish procedure in FMVSS No. 135 specifies 200 stops with a deceleration of 9.8 ft/s^2 (3.0 m/s^2) from a speed of 49.7 mph (80.0 km/h), whereas the burnish procedure in FMVSS No. 126 specifies 10 stops with a deceleration of 16.1 ft/s^2 (4.0 m/s^2) from a speed of 35 mph (56.3 km/h) in addition to three stops from 45 mph (72.4 km/h). The commenter's rationale was that CIB and DBS effectiveness rely more heavily on the state of the SV's foundation brake system than does electronic stability control (ESC) since the duration of the brake application (automatic or otherwise) during a particular test trial is much longer.

The CIB evaluations of two vehicles, the Cadillac ATS and Infiniti Q50, occurred after a FMVSS No. 135 brake burnish had been performed. However, while all Infiniti Q50 tests were performed after this more rigorous burnish, only the LVM and LVD maneuvers were with the Cadillac ATS. Furthermore, two series of LVM evaluations were performed with the Cadillac ATS: first after a FMVSS No. 126 burnish, then after a FMVSS No. 135 burnish. Both of these series used the same brake pads, rotors, and tires.

For the LVM_45_20 tests, the speed reductions realized by the vehicle satisfied the draft ARV evaluation criteria during each test trial regardless of which burnish was performed. Differences in the speed reductions achieved with each burnish (13.5 to 19.8 mph after the FMVSS No 126 burnish, versus 16.7 to 24.6 mph after the FMVSS No 135 burnish) were not statistically significant. Analysis of the LVM_25_10 tests is confounded by the lack of any valid tests being

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[28] An assessment of the Audi A8L required consideration of a non-valid LVD_25_25 trial. However, although the non-valid test was performed with an SV speed 0.2 mph greater than the allowable tolerance, it was still able to satisfy the speed reduction defined by the LVD_25_25 draft ARV.

performed (POV speed was 0.1 to 0.6 mph too high for each trial performed in this series), however the data are still useful and are presented in Table 4-9.

Table 4-9. Cadillac ATS LVM_25_10 mph Tests Performed After Two Different FMVSS Brake Burnishes

FMVSS Burnish	Number of Trials		Number of Impacts (a draft ARV violation)	SV-to-POV Impact Speeds (mph)	Number of Collisions Avoided	SV-to-POV Avoidance Distance (ft)
	Valid	Non-Valid				
No. 126	0	13	7	0.6 – 2.7	6	0.2 – 0.9
No. 135	8	0	2	0.9 – 5.5	6	0.2 – 1.2

Even if the effects of the minor validity infractions observed during the tests performed after the FMVSS No. 126 burnish are discounted (which would have the effect of making the maneuver less severe since the SV closing velocity was nominally less), identifying whether the additional burnishing of the FMVSS No. 135 procedure improved the foundation brake system effectiveness was not possible.

- Although a higher percentage of the 13 trials performed after the FMVSS No. 126 burnish resulted in a collision (a test failure condition), the range of impact speed magnitudes overlaps that realized during the test series performed after the FMVSS No. 135 burnish.
- For the tests that concluded with the SV avoiding the POV, the avoidance magnitude (the minimum range observed during each trial associated with each burnish) overlapped.
- The maximum overall impact speed and maximum avoidance range were both realized during the test series performed after the FMVSS No. 135 burnish.

In summary, the FMVSS No. 135 burnish may potentially affect a vehicle's braking performance beyond that achieved by the FMVSS No. 126 procedure, as indicated by a 2012 RFC commenter. However, in the case of the Cadillac ATS, the effect was not pronounced and does not appear to affect the vehicle's ability to satisfy the draft ARVs discussed in this section.

4.8.2.2. Comments Regarding the Infiniti Q50 Forward Collision Warning

Generally speaking, the results shown in Tables 4-7 and 4-8 were achieved by simply performing the various tests in the manner described in the June 2012 draft test procedures. However, a notable exception was the Infiniti Q50. As part of its FCW, this vehicle includes a haptic throttle pedal that pushes back against the driver's foot[29].

When performing the 2013 FCAM CIB tests, the driver was instructed to gently modulate the throttle pedal to maintain constant speed from a TTC ≈ 5 to 3 seconds. From a TTC ≈ 3 seconds

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[29] This occurs coincident with an auditory alert and a message on the instrument cluster.

to the onset of CIB (or impact), the draft test procedure required the driver to maintain constant throttle pedal position, a specification designed to reduce the potential for throttle pedal movement confounding how or when CIB activation was initiated by the SV. However, when the driver attempted to maintain constant throttle pedal position in the Infiniti Q50, despite the haptic FCW alert, it appeared that the vehicle's CIB performance was affected or suppressed. As shown by the LVM_25_10 condition results in Table 4-7, this can have a significant effect on the ability of the vehicle to satisfy a draft ARV.

The draft ARV for the CIB LVM_25_10 test was crash avoidance. When the driver attempted to recover throttle pedal position after receiving the haptic FCW alert, the vehicle did not satisfy the performance criteria during 4 of 8 otherwise valid tests[30], although speed reductions of 4.2 to 11.8 mph were observed. However, if the driver fully released the throttle pedal after the haptic FCW alert, and allowed it to remain at its zero position until the end of the test, the vehicle was able to satisfy the test's draft ARV during 7 of 8 valid tests. Figure 4-3 compares examples of each throttle application method. In short, it was not possible for the driver to respond to the Infiniti Q50 haptic FCW alert while following the maneuver's test protocol. Not responding to this alert directly affected the ability of the vehicle to satisfy the CIB draft ARVs. Furthermore, by failing to meet the LVM_25_10 condition draft ARV, the vehicle also failed to satisfy the overall CIB series criteria.

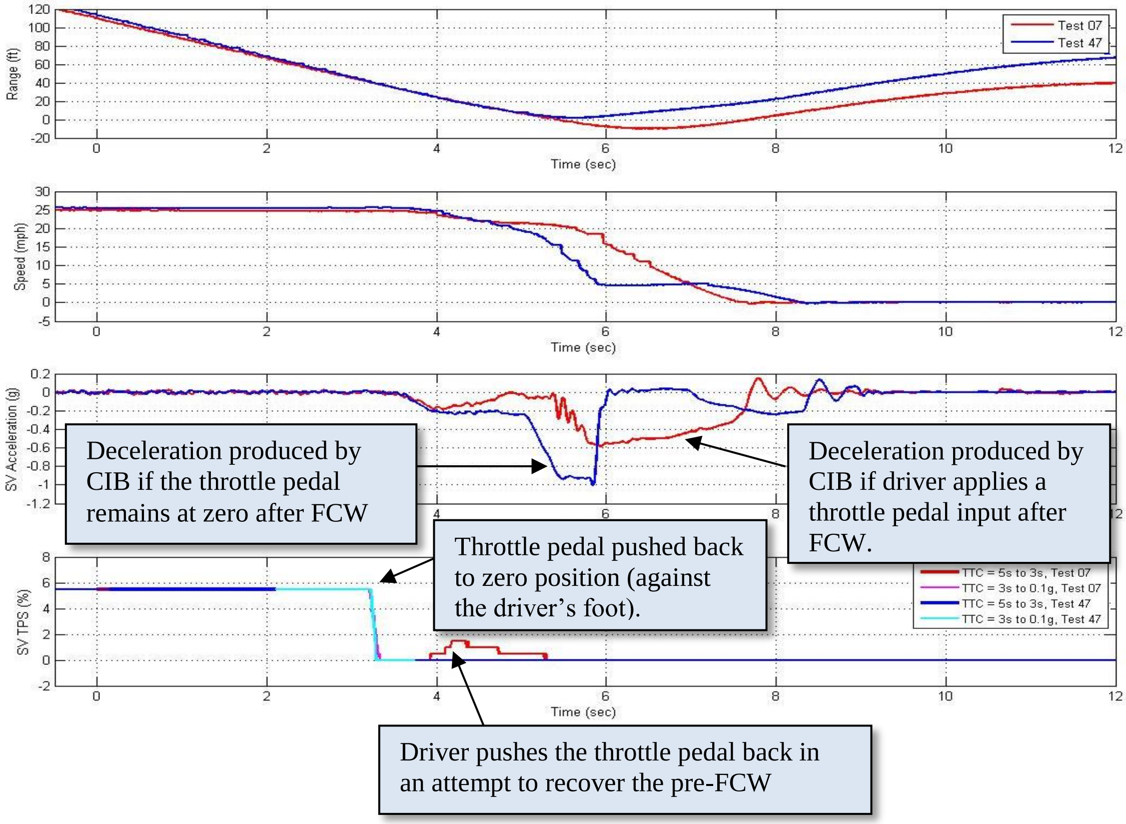

Figure 4-3. Infiniti Q50 CIB tests performed with two throttle release methods

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[30] For the four Infiniti Q50 tests that did not satisfy the LVM_25_10 draft ARV, relative impact speeds from 3.2 to 10.8 mph were observed.

As a result of the challenges described above, researchers subsequently decided to perform all remaining Infiniti Q50 CIB tests using a throttle pedal application method that would allow the vehicle to realize the maximum potential of its CIB. This method was incorporated into the revised CIB draft test procedures to accommodate the demands of vehicles such as the Infiniti Q50, and is described in Section 5.2.1.

4.8.3. DBS Maneuver Performability

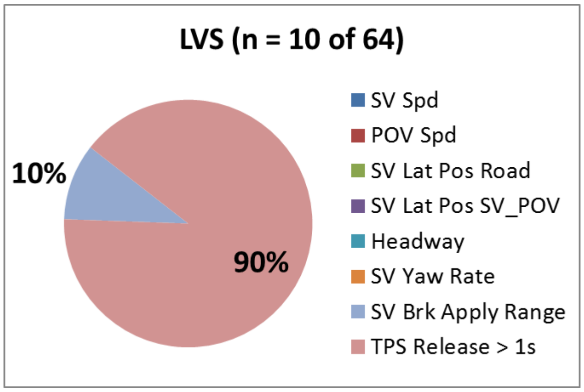
The ability to successfully perform each DBS test scenario is summarized with the pie charts presented in Figures 4-4 and 4-5. For each scenario, the expression “n = x of y” is defined as follows:

- x = total number of trials performed with a validity violation, collapsed across test scenario
- y = total number of trials performed, collapsed across test scenario

Of the “n” trials, the cause of the violation is presented in the pie charts of Figures 4-4 and 4-5. Note that in addition to the parameters used to assess CIB performability, the DBS analysis adds a consideration of SV brake application range and SV throttle release timing. Due to the limited number of tests performed with hybrid-based brake applications, only results from the displacement-feedback-based trials are discussed.

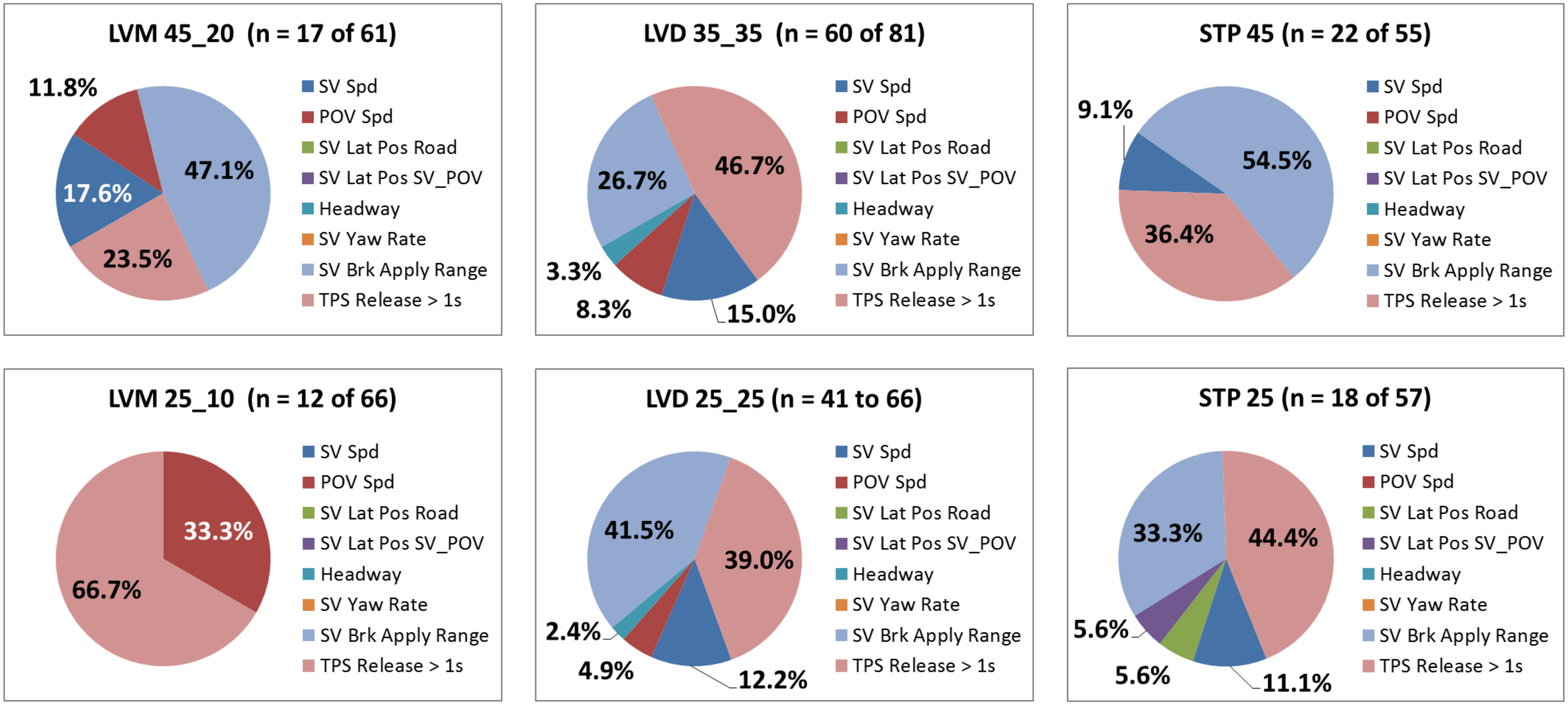
4.8.3.1. DBS LVS Scenario

15.6 percent of all LVS DBS tests performed with displacement feedback had at least one tolerance violation. As shown in Figure 4-4, 90 percent of those involved the SV throttle pedal not being fully released for a full one second prior to the SV brakes being applied. 10 percent of the LVS tests included trials during which the SV brakes were applied outside of the ±2-ft (0.6-m) tolerance.



n = number of all trials performed with a validity violation, per maneuver.
Of the “n” trials, the cause of the violation is presented.

Figure 4-4. DBS LVS maneuver performability



n = number of all trials performed with a validity violation, per maneuver. Of the "n" trials, the cause of the violation is presented.

Figure 4-5. DBS maneuver performability; validity violations by test scenario

4.8.3.2. DBS LVM Scenario

At least one validity violation was present during 27.9 and 18.2 percent of the LVM_45_20 and LVM_25_10 tests, respectively (see Figure 4-5). Although some SV and/or POV speed violations were present during the LVM DBS evaluations, most LVM validity problems were due to throttle release timing and the SV brakes being applied outside of the allowable tolerance.

4.8.3.3. DBS LVD Scenario

Of all the evaluations performed during the 2013 FCAM tests, the DBS LVD trials were the most challenging to perform. At least one validity violation occurred during 74.1 percent of the trials performed at 35 mph, and during 62.1 percent of the trials initiated from 25 mph (40.2 km/h) (see Figure 4-5). To further evaluate the high number of violations per test condition, a more detailed breakdown of the infractions is presented in Tables 4-10 and 4-11.

A majority of the LVD validity violations occurred because of throttle release timing, and in the case of the LVD1_35_35 tests, at least one such infraction occurred for each vehicle. In agreement with the other LVD test conditions, SV-to-POV brake application range was the second most common source of validity violations. SV and POV speed tolerances were exceeded during both LVD maneuvers performed during the DBS evaluations, but were often isolated to a particular vehicle or only occurred once. For example, of the nine SV speed violations that occurred in the LVD1_35_35 condition, six (66.7 percent) occurred during tests performed with the Infiniti Q50.

Table 4-10. LVD1_35_35 Validity Violation Count and Magnitudes

Parameter (Nominal ±Tolerance)	Vehicle						
	Audi A8L	**Cadillac ATS**	**Infiniti Q50**	**Mercedes E350**	**Mitsubishi Outlander**	**Lexus LS460**	**Subaru Outback**
SV speed (35 mph ±1 mph)	--	--	6; 0.02-0.7 mph	--	--	2; 0.2-0.7 mph	1; 0.2 mph
POV speed (35 mph ±1 mph)	--	--	--	1; 0.2 mph	1; 1.7 mph	3; 0.07-0.6 mph	--
SV-to-POV brake apply range (31.5 ±2 ft)	--	--	--	--	3; 1.3-2.1 in	12; 0.4-9.5 in	1; 4.3 in
SV throttle release timing (>1 s before brake application)	2; 70-225 ms	1; 170 ms	5; 71-442 ms	1; 90 ms	6; 390-1095 ms	8; 710-1765 ms	5; 80-845 ms
SV-to-POV headway (45.3 ± 8 ft)	--	--	--	--	--	2; 0.7-3.3 ft	--

Table 4-11. LVD2_25_25 Validity Violation Count and Magnitudes

Parameter (Nominal ±Tolerance)	Vehicle						
	Audi A8L	Cadillac ATS	Infiniti Q50	Mercedes E350	Mitsubishi Outlander	Lexus LS460	Subaru Outback
SV speed (25 mph ±1 mph)	--	1; 0.2 mph	--	--	1; 0.1 mph	1; 0.1 mph	2; 0.2-1.7 mph
POV speed (25 mph ±1 mph)	--	--	--	--	--	1; 2.1 mph	1; 0.1 mph
SV-to-POV brake apply range (40 ±2 ft)	--	--	--	--	9; 0.6-5.4 in	8; 1.9-9.5 in	--
SV throttle release timing (>1 s before brake application)	--	--	3; 191-335 ms	--	7; 120-1295 ms	6; 70-675 ms	--
SV-to-POV headway (328.1 ± 8 ft)	--	--	--	--	--	--	1; 1.1 ft

Generally speaking, the magnitudes of the validity infractions shown in Tables 4-10 and 4-11 were small. It may be possible to reduce the incidence of SV and POV speed violations, as well as those associated with SV-to-POV headway, by providing the drivers with better test-to-test feedback about whether a given trial had been performed acceptably (e.g., by using a data processing script to evaluate each test immediately after it had been performed or by further automating the actual test conduct). Similarly, driver feedback could assist the driver with achieving more consistent throttle pedal release timing; however, validity violations associated with this parameter are expected to be less problematic after the new FCW-based release strategy described in Section 5 of this document is implemented. Improving the ability of the brake controller to correctly initiate its applications at the desired range is also possible, albeit at the expense of the additional time and resources needed to support iterative tuning prior to actual test conduct.

4.8.3.4. DBS False Positive Scenario

In a manner consistent with the other DBS test conditions, at least one of the SV-to-POV brake application ranges, throttle release timing, and SV speed tolerances was exceeded during 40 percent of the STP_45 tests. Twelve brake application range violations occurred during conduct of this maneuver overall (55 percent of all STP_45 violations), seven of which occurred with the Audi A8L due to a brake controller configuration error. For this vehicle, the brake application range infractions occurred 2.7 to 12.0 in (69 to 304 mm) outside of the allowable 2-ft (0.6-m) tolerance. With regards to throttle release timing, four of the eight violations occurred during tests performed with the Lexus LS460, where the SV driver released the throttle pedal between 70 to 310 ms too late.

The STP_25 validity violations were generally consistent with those seen during conduct of the other DBS maneuvers, and they occurred during 31.6 percent of the tests performed. In this condition, the most common violation was throttle release timing. Four of the eight violations occurred during tests performed with the Lexus LS460, where the SV driver released the throttle pedal between 140 to 300 ms too late. For this maneuver, the SV lateral position from road center (SV Lat Pos Road) and SV-to-POV lateral orientation relative to each other (SV Lat Pos SV_POV) violations occurred during the same (i.e., single) test trial. Here, the POV is actually the STP, which does not move during the evaluations. Since the plate is located in the center of the test lane, any SV lateral deviation from the center of the STP is the same as that observed relative to the STP.

4.8.4. DBS Test Track Performance

Tables 4-12 and 4-13 present overall summaries of how well the 2013 FCAM test vehicles were able to satisfy the DBS draft ARVs using displacement-feedback-based brake applications. Similarly, Tables 4-14 and 4-15 present the hybrid-feedback-based brake application summaries. The data shown in Tables 4-12 and 4-14 are inclusive of non-valid trials, whereas those in Tables 4-13 and 4-15 contain only valid results (those performed within the tolerances specified in the August 2014 DBS draft test procedures [25]).

In agreement with the CIB draft ARVs, acceptable speed reductions for the LVS, LVM, and LVD scenarios, and false-positive suppression for the STP-based tests, were to be achieved during at least seven of eight individual trials performed within the respective test group. However, because some of the tolerances used to screen the tests for validity were established well after data collection of the 2013 FCAM tests (i.e., after the vehicles had been de-instrumented and/or became unavailable), some trials initially considered to be acceptable were later deemed non-valid during the final post-processing of the test data.

As previously explained in Section 4.8.2, the later validity screen reduced the number of valid tests per vehicle and condition to be less than eight in some cases. For this reason, the assessments described within this section (i.e., Section 4.8.4) are based on valid trials where possible, but with consideration of non-valid trials where appropriate. When data from non-valid trials are considered, their contribution is noted. Egregious trials were not included in the Tables 4-12 through 4-15 and were not used to discuss vehicle performance.

4.8.4.1. Overall and Displacement Feedback Results Summary

Based on the results specified in 4-13 (and 4-12 where appropriate), the following observations were made:

- Where directly comparable data were available, the vehicles were better able to achieve the DBS draft ARVs with displacement-feedback-based brake applications.

- The Mitsubishi Outlander[31], Subaru Outback[32], and Infiniti Q50[33] appear to be capable of satisfying all DBS draft ARVs, provided displacement feedback was used in the LVS scenario.
- Two of the three vehicles unable to respond to the LVS condition with CIB did so during their respective DBS evaluations. Using displacement-feedback-based brake applications, the Mitsubishi Outlander and Cadillac ATS not only responded to the LVS scenario, but were able to satisfy the DBS assessment reference values. Although the Audi A8L responded to the LVS scenario during its DBS evaluation, it did not satisfy the draft ARVs.
- Despite satisfying all the CIB draft ARVs (regardless of surrogate vehicle used), the Lexus LS460[34] was unable to achieve the DBS draft ARVs (1) during the LVD1_35_35 evaluation or (2) in the LVS condition when evaluated with the ADAC target.
- DBS false positives occurred during Infiniti Q50 and Mercedes E350 evaluations.
    - ➢ One DBS false positive event was observed during STP_25 tests series performed with the Infiniti Q50. During this valid trial, the vehicle achieved a peak deceleration of 0.62g (versus a mean of 0.42g during comparable baseline trials) and avoided the steel trench plate.
    - ➢ 63 percent of the valid STP_45 trials performed with the Mercedes E350 induced DBS false positives. These tests produced decelerations of 1.12g to 1.26g versus a mean of 0.52g during comparable baseline trials. When evaluated at 25 mph (40.2 km/h), DBS false positives were induced during 71 percent of the valid trials. While these events did not produce the decelerations seen during the STP tests performed at the higher speed, they too were enough to stop the vehicle before reaching the steel trench plate (0.73 to 0.84 g versus a mean of 0.56g during comparable baseline trials).
- With one exception, the ability of the vehicles to satisfy the LVS DBS draft ARV was not affected by the surrogate vehicle used. During Lexus LS460[35] LVS tests performed with displacement feedback, 50 percent of all trials performed with the ADAC surrogate were

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[31] An assessment of the Mitsubishi Outlander required consideration of non-valid trials for each LVM, LVD, and STP test condition. However, all trials performed with the vehicle, regardless of test validity, were able to satisfy the respective draft ARVs.

[32] An assessment of the Subaru Outback required consideration of non-valid trials for the LVM_45_20 and STP_45 test conditions. However, all LVM, STP, and 25 mph LVD trials performed with the vehicle, regardless of test validity, were able to satisfy the respective draft ARVs.

[33] Of the thirteen overall Infiniti Q50 trials performed in the 35 mph LVD condition with displacement feedback, eleven satisfied the evaluation criteria. After screening for validity, all five trials produced acceptable speed reductions.

[34] An assessment of the Lexus LS460 required consideration of non-valid trials for each test condition. However, all LVM, STP, and 25 mph LVD trials performed with the vehicle, regardless of test validity, were able to satisfy the respective draft ARVs. In the case of the 35 mph LVD evaluation, 83 percent of the tests performed (valid and non-valid) were unable to achieve the necessary speed reduction.

[35] An assessment of the Lexus LS460 required consideration of non-valid trials for each LVS test condition.

able to achieve the draft ARV speed reductions, compared with 89 percent of the LVS tests performed with the SSV.

- Consistent with the trend established by the CIB test results, the vehicles equipped with the largest number of sensors did not necessarily perform better in the DBS tests than those equipped with a single sensing technology.

4.8.4.2. Hybrid Feedback Results Summary

Based on the results specified in 4-15 (and 4-14 where appropriate), the following observations were made:

- Despite being able to satisfy the DBS draft ARV during 100 percent of the LVS test trials performed with displacement feedback (regardless of surrogate vehicle), the Mitsubishi Outlander[36] was unable to do so in any of the tests performed with hybrid feedback.

- With one exception, the ability of the vehicles to satisfy the LVS DBS draft ARV was not affected by the surrogate vehicle used. None of the Subaru Outback LVS trials performed with hybrid feedback were able to satisfy the DBS draft ARV with the SSV, despite doing so during each of the five comparable trials performed with the ADAC surrogate. This finding was particularly surprising given the vehicle's performance during (1) comparable DBS tests performed with displacement feedback and (2) CIB evaluations. During these tests, the Subaru Outback's ability to satisfy the respective draft ARVs was not affected by the surrogate vehicle used.

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[36] An assessment of the Mitsubishi Outlander required consideration of non-valid trials for the LVS tests performed with hybrid feedback and the SSV. However, all trials performed with the vehicle, regardless of test validity, were unable to satisfy the respective draft ARVs.

Table 4-12. Number of Trials Able to Satisfy DBS Draft ARVs with Displacement Feedback (Data not screened for test validity; bright yellow indicates an inability to satisfy the draft ARVs.)

Vehicle	Number of Tests Satisfying the DBS Performance Assessment Reference Values							
	LVS 25_0		LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP_45 (FP)	STP_25 (FP)
	SSV	ADAC						
2014 Audi A8L	0/8	2/12	8/9	0/8	5/9	8/8	8/8	8/8
2014 Cadillac ATS[2]	11/11	7/8	8/8	9/9	1/12	7/8	8/8	8/8
2014 Infiniti Q50[2]	8/8	8/8	9/9	9/9	11/13	9/9	9/9	8/9
2014 Mercedes E350	9/9	10/10	8/8	10/10	10/10	8/8	3/10	2/8
2014 Mitsubishi Outlander	10/10	8/8	9/9	9/9	11/11	10/10	3/3[1]	8/8
2013 Lexus LS460	8/9	4/8	9/9	10/10	2/12	8/8	9/9	9/9
2013 Subaru Outback	8/8	11/11	9/9	9/9	14/14	15/16	9/9	9/9

[1] Only three tests performed

[2] Result achieved with full FMVSS No. 135 burnish

Table 4-13. Number of Trials Able to Satisfy DBS Draft ARVs with Displacement Feedback (Valid* tests shown; bright yellow indicates an inability to satisfy the draft ARVs.)

Vehicle	Number of Tests Satisfying the DBS Performance Assessment Reference Values							
	LVS 25_0		LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP_45 (FP)	STP_25 (FP)
	SSV	ADAC						
2014 Audi A8L	0/8	1/8	7/8	0/7	4/7	8/8	1/1	8/8
2014 Cadillac ATS[1]	8/8	7/8	8/8	8/8	1/8	6/7	6/6	8/8
2014 Infiniti Q50[1]	8/8	8/8	8/8	8/8	5/5	6/6	7/7	4/5
2014 Mercedes E350	8/8	8/8	8/8	8/8	8/8	8/8	3/8	2/7
2014 Mitsubishi Outlander	8/8	8/8	6/6	6/6	4/4	no valid tests	no valid tests*	7/7
2013 Lexus LS460	1/2	4/5	5/5	6/6	no valid tests	no valid tests	3/3	2/2
2013 Subaru Outback	8/8	8/8	2/2	8/8	8/8	7/8	7/7	8/8

*Only three tests performed

[1] Result achieved with full FMVSS No. 135 burnish

Table 4-14. Number of Trials Able to Satisfy DBS Draft ARVs with Hybrid Feedback (Data not screened for test validity; bright yellow indicates an inability to satisfy the draft ARVs.)

Vehicle	Number of Tests Satisfying the DBS Performance Assessment Reference Values							
	LVS 25_0		LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP_45 (FP)	STP_25 (FP)
	SSV	ADAC						
2014 Audi A8L	--	--	--	--	--	--	--	--
2014 Cadillac ATS[1]	10/11	7/8	8/8	9/9	--	8/8	--	--
2014 Infiniti Q50[1]	9/9	8/8	8/8	9/9	--	--	--	--
2014 Mercedes E350	10/10	8/8	8/8	8/8	--	--	--	--
2014 Mitsubishi Outlander	0/9	0/9	9/9	8/8	--	--	--	--
2013 Lexus LS460	7/9	7/8	9/9	11/12	--	--	10/10	9/9
2013 Subaru Outback	1/11	5/5[2]	8/8	9/9	--	--	--	--

-- = test not performed

[1] Result achieved with full FMVSS No. 135 burnish

[2] Only five tests performed due to instrumentation issues

Table 4-15. Number of Trials Able to Satisfy DBS Draft ARVs with Hybrid Feedback (Valid* tests shown; bright yellow indicates an inability to satisfy the draft ARVs.)

Vehicle	Number of Tests Satisfying the DBS Performance Assessment Reference Values							
	LVS 25_0		LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP_45 (FP)	STP_25 (FP)
	SSV	ADAC						
2014 Audi A8L	--	--	--	--	--	--	--	--
2014 Cadillac ATS[1]	7/8	7/8	8/8	8/8	--	6/6	--	--
2014 Infiniti Q50[1]	8/8	8/8	8/8	8/8	--	--	--	--
2014 Mercedes E350	8/8	8/8	8/8	8/8	--	--	--	--
2014 Mitsubishi Outlander	0/4	0/8	8/8	8/8	--	--	--	--
2013 Lexus LS460	3/3	4/5	8/8	6/7	--	--	2/2	4/4
2013 Subaru Outback	0/8	5/5[2]	2/2	8/8	--	--	--	--

*Validity assessment does not consider POV deceleration

-- = test not performed

[1] Result achieved with full FMVSS No. 135 burnish

[2] Only five tests performed due to instrumentation issues

Note that the June 2012 draft test procedures specified that performance criteria for a given test condition were to be satisfied during 100 percent of the tests performed. Some respondents to the July 2012 RFC indicated that this was not reasonable and that the criteria should be relaxed. To investigate the effect of test stringency, two performance benchmarks were compared: meeting ARV criteria during eight out of eight trials (i.e., 100 percent of the trials) and meeting ARV criteria during seven out of eight trials (i.e., up to one trial per scenario not meeting the ARV criteria).

By allowing up to one test per scenario to not satisfy the respective draft ARV, the following effects were observed for tests performed with displacement feedback-based brake applications:

- Audi A8L: now satisfies the LVM_45_20 draft ARV[37] (but still failed to satisfy the LVS, LVM_25_10, and LVD1_35_35 criteria).

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[37] An assessment of the Audi A8L required consideration of non-valid trials for the STP_45 test condition.

- Cadillac ATS: now satisfies the LVS draft ARV, and became more likely to satisfy LVD2_25_25 draft ARV[38] (but still failed to satisfy the LVD1_35_35 criteria).
- Infiniti Q50: became more likely to satisfy the LVD1_35_35 and STP_25 conditions[39].
- Mercedes E350: no change.
- Mitsubishi Outlander: no change.
- Lexus LS460: the effect cannot be accurately ascertained because of the lack of valid trials. Even if the least invalid tests were considered (i.e., two trials where the SV brakes were applied 8.7 to 9.5 inches (221 to 241 mm) beyond the allowable tolerance), the impact speeds were still 4.9 to 6.0 mph (7.9 to 9.7 km/h). Conclusively determining the effect of allowing one trial unable to satisfy the LVD1_35_35 ARV on the vehicle's ability to satisfy the overall LVD1_35_35 ARV requires data from more valid trials.
- Subaru Outback no longer failed to satisfy the LVD2_25_25 draft ARV, therefore satisfying the draft ARVs for each DBS test scenario.

4.8.4.3. Effect of Hybrid-Feedback Brake Applications on the 2013 FCAM Test Vehicles

For most 2013 FCAM test vehicles, hybrid feedback was used for LVS and LVM evaluations[40]. Generally speaking, its use did not improve DBS performance beyond that realized with displacement feedback, and in some cases the performance was much worse. One possible reason for this is explained in the Mitsubishi Outlander comparison shown in Figure 4-6. However, it appears most of the vehicles tested simply did not respond to hybrid-based applications the way the 2014 Mercedes ML350 used in the agency's development research did.[41]

In Figure 4-6, note that pedal forces realized during tests with DBS activations (labeled "HF" and "DF" for hybrid and displacement feedback brake applications, respectively) are greater than their respective baseline trials, and that the application force realized during the displacement feedback test with DBS (DF) does not fall to zero; it remains high until the vehicle stops (at which point pedal force falls to the foundation brake system level approximately two seconds

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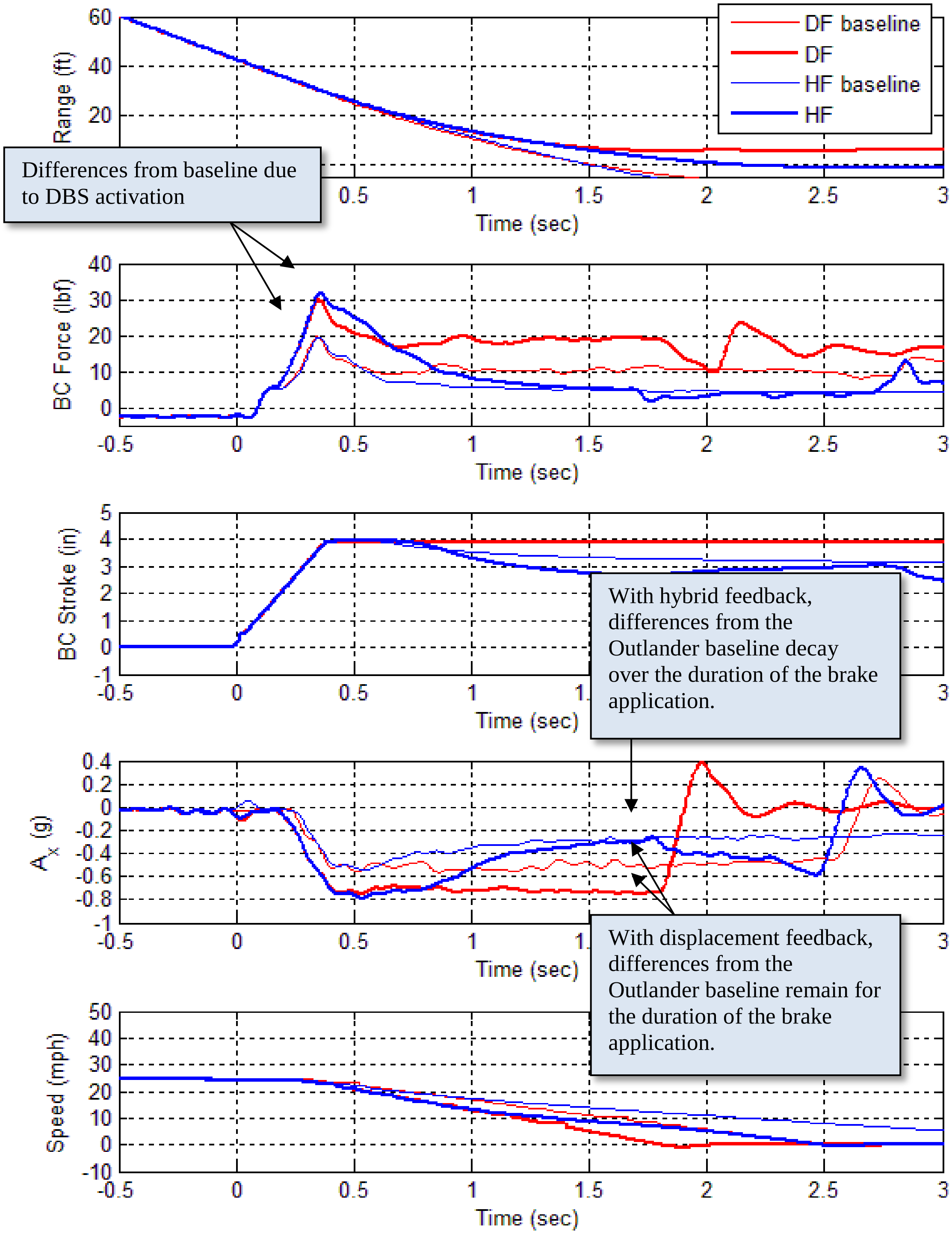
[38] Of the eight overall Cadillac ATS trials performed in the LVD2_25_25 condition with displacement feedback, seven satisfied the performance criteria. After screening for validity, six of the seven trials produced acceptable speed reductions.

[39] Of the thirteen overall Infiniti Q50 trials performed in the LVD1_35_35 condition with displacement feedback, eleven satisfied the performance criteria. After screening for validity, five valid trials were found to be valid and all five trials produced acceptable speed reductions. Of the nine overall STP_25 trials performed, one produced a DBS false positive (11 percent). Since this trial was deemed valid (i.e., one of five valid trials produced a false positive), the likelihood of realizing such an event increased to 20 percent. However, the fact one mistrial is allowed per test condition increases the likelihood the vehicle performance will be deemed acceptable.

[40] In an attempt to keep the 2013 FCAM test burden reasonable, LVD evaluations included only very limited use of hybrid-based brake applications.

[41] As previously explained in S2.2.2.2, a 2014 Mercedes ML350 was used to develop NHTSA's hybrid brake application strategy.

after braking was initiated). Together, these elements indicate that the vehicle's brake pedal attempts to push up against the driver's foot when DBS is activated, not fall towards the floor. Since hybrid feedback is designed to gradually *reduce* applied force from the instant commanded pedal position is reached to a small nominal value, the only way the brake controller can realize the commanded fallback force and rate is to also reduce brake pedal displacement, as seen in



Differences from baseline due to DBS activation

With hybrid feedback, differences from the Outlander baseline decay over the duration of the brake application.

With displacement feedback, differences from the Outlander baseline remain for the duration of the brake application.

Figure 4-6. Displacement versus hybrid feedback brake applications performed with the Mitsubishi Outlander

Figure 4-6. NHTSA believes that the vehicle's DBS system interprets this reduction of applied force and position as the driver requesting less braking torque, not requiring the supplemental braking available by DBS. This is supported by the brake force and vehicle deceleration realized by the time of impact at $t \approx 1.5$ s, as by this time they had fallen to the magnitudes associated with baseline levels (i.e., indicating DBS was no longer active).

4.8.4.4. Hybrid-Feedback-Based Brake Application Observations

Hybrid feedback has been shown to help certain vehicles reach their DBS-enhanced braking levels by preventing applied brake force from falling to zero. However, the limited data collected by NHTSA ($n = 8$) indicate use of hybrid-feedback-based braking will not benefit most vehicles. Although a provision for hybrid braking has been added to the latest DBS draft test procedures, it is unclear whether it will necessarily improve braking performance beyond that achieved via use of displacement feedback.

4.9. 2013 FCAM Research Observations

NHTSA's 2013 FCAM tests were performed to validate refinements made to the agency's CIB and DBS draft test procedures and the corresponding evaluation criteria. In summary:

- Some test scenarios require complex choreography, but the agency believes that each should be performable. Careful attention to SV and POV speeds, SV throttle release timing, and SV brake application range are particularly important factors to monitor during test conduct, as they were the most common sources of validity violations overall.
- The ARVs specified in the August 2014 CIB and DBS draft test procedures are achievable, although this assessment sometimes required consideration of non-valid trials (in which minor infractions were not believed to affect test outcome).
- Multiple 2013 FCAM test vehicles appear to be capable of satisfying the evaluation factors described in the respective draft procedures.
    - CIB speed reduction criteria: 3 of 7 vehicles met criteria
    - DBS speed reduction criteria: 3 of 7 vehicles met criteria
    - CIB false positive suppression: all 7 vehicles met criteria
    - DBS false positive suppressions: 6 of 7 vehicles met criteria
- CIB performance was not always indicative of that realized with DBS.
- With few exceptions, the vehicles achieved better DBS performance with displacement-feedback-based, as opposed to hybrid-feedback-based brake applications.
- No consistent SV response differences were observed as a function of surrogate vehicle for the LVS scenario tested.

5.0 SUMMARY OF CIB AND DBS DRAFT TEST PROCEDURE REFINEMENTS

Although the scenarios performed during the 2013 FCAM testing were each found to be performable, further refinement to test tolerances and evaluation processes are expected to provide better clarification and to improve efficient test conduct. Section 5 describes the key changes made to the CIB and DBS draft test procedures after completion of the 2013 FCAM tests in the areas of:

- Use of the SV FCW alert
- Revised throttle management specification
- Brake application specifications (for DBS evaluations)
- SV load specification
- Test tolerance revision

NHTSA will use the refined draft test procedures to assess additional vehicles for research purposes during calendar year 2014.

5.1. Use of the FCW Alert

Based on its review of the 2013 FCAM test results, the agency believes that performability could be improved if the throttle release schedules defined in the CIB/DBS procedures were based on when the FCW alert occurred (further discussed in Section 5.2) rather than headway (used in the past). This is because NHTSA expects the FCW alert to be more apparent, and more simply interpreted, than a monitor numerically displaying a decaying headway to the test driver. To describe how the SV FCW will be quantified, the August 2014 CIB and DBS draft test procedures now include language indicating:

> *"The Forward Collision Warning (FCW) activation flag shall indicate when the system has issued an alert to the SV driver. The FCW modality shall be either the auditory alert, or the alert indicated to the test conductor by a NHTSA representative. The FCW activation flag shall be recorded from a discrete signal and/or other methods that clearly indicate when the alert has been issued provided there is no damage to the SV."*

5.2. Throttle Management Specification

5.2.1. Throttle Management During CIB Evaluations

The validity screen used by NHTSA for its 2013 FCAM tests required that each maneuver include (1) a period of constant SV speed, followed by (2) a period of constant SV throttle position. Specifically, constant SV throttle position was to remain between ±3 percent of the average throttle position calculated between the end of the constant SV speed interval to the instant CIB automatically braked the SV with a deceleration ≥0.1g. Specifying a period of constant throttle position prior to CIB activation (included in prior draft procedures) was implemented in an attempt to reduce test variability observed from two sources: suppression algorithms triggered by throttle pedal movement and throttle pedal-based brake system precharge.

NHTSA has been told by both vehicle manufacturers and suppliers that the manner in which the SV driver modulates the throttle pedal is very important. For some vehicles, this movement can cause the CIB system to infer the driver is "active and attentive" and therefore not in need of automatically-applied crash mitigation or avoidance braking. From a testing perspective, this is undesirable since such suppressions confound, or even prevent, the ability to objectively and repeatably assess CIB system performance.

Brake system precharge is designed to reduce the response time needed to apply brake torque in emergency braking situations, regardless of whether the request is initiated by the driver or a safety system such as CIB or DBS. Precharging is designed to reduce brake system response time by allowing system pressure to build much faster than commanded by the driver's brake pedal movement alone, and for some vehicles it can be initiated by rapidly releasing the throttle pedal. In the past, NHTSA has been concerned that modulating the throttle to maintain SV speed has the potential to activate precharge. Of particular concern was that it may not be realized in the same way during each trial performed within a given test series. Therefore, to minimize the potential for throttle pedal-based precharge to confound the test outcome, previous draft test procedures specified a period of constant throttle pedal position prior to CIB activation, as demonstrated in Figure 5-1.

Although the intent of specifying periods of constant throttle position was to minimize test-to-test variability, NHTSA ultimately concluded that the action was too difficult for the SV driver to perform consistently. One of the most common reasons for this was that the deceleration produced by CIB activation was great enough to move the driver's leg/foot into the throttle pedal prior to them being able to initiate a release, as shown in Figure 5-2.

To address this problem, the August 2014 draft test procedures no longer specify periods of constant SV throttle position for any scenario. The revised procedure now states that the SV shall maintain constant speed up to the onset of either the FCW auditory alert, or to the FCW alert modality indicated to the test conductor by the NHTSA representative[42]. From that instant, the SV driver has up to 500 ms to fully release the throttle pedal. Any speed reduction that occurs from the release of the throttle pedal to the onset of CIB activation is acceptable.

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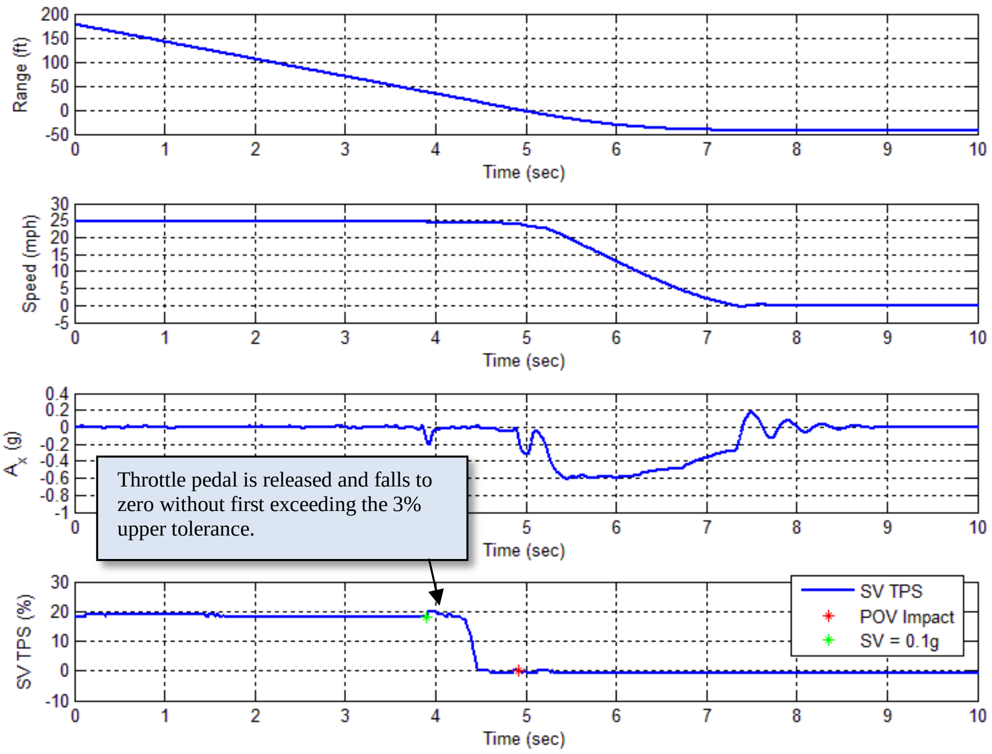
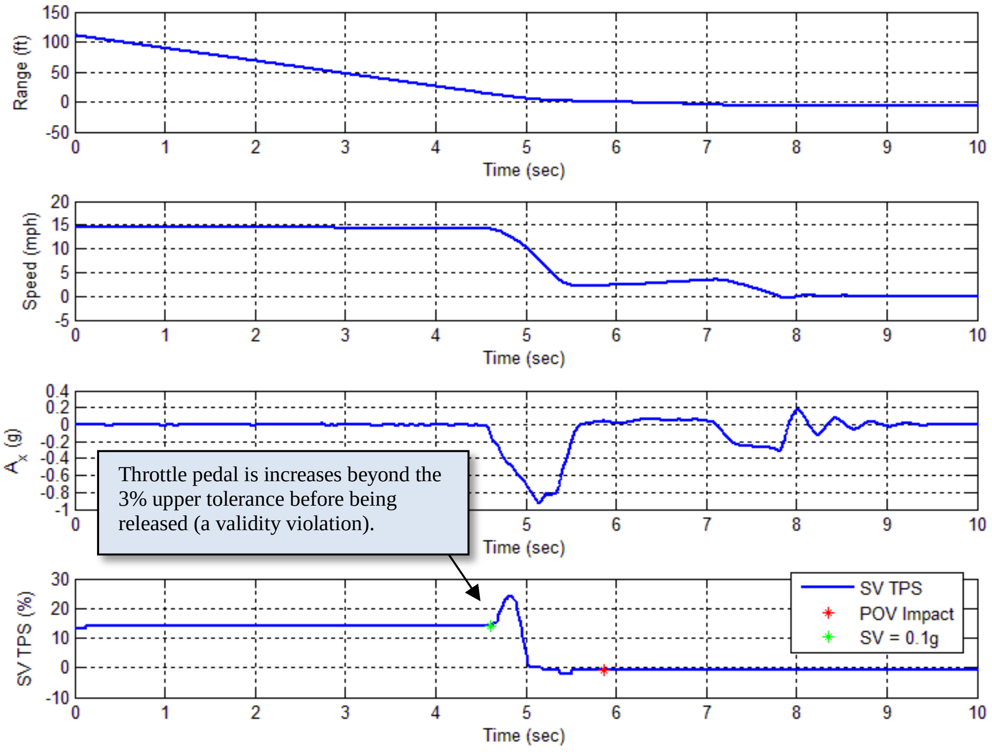
[42] At the time when the June 2014 CIB/DBS draft test procedures were written, the FCW systems known to the agency each had an auditory component, and NHTSA believes the determination of their respective onsets to be straight-forward. This is not always the case for haptic cues such as throttle pedal pushback (confounded by driver modulation) or brake application pulses (requires measurement of brake line pressures).



Throttle pedal is released and falls to zero without first exceeding the 3% upper tolerance.

Figure 5-1. Release from constant throttle after SV deceleration reaches 0.1g (due to a haptic FCW alert in this example)



Throttle pedal is increases beyond the 3% upper tolerance before being released (a validity violation).

Figure 5-2. Throttle position violation after SV deceleration reaches 0.1g (due to CIB activation in this example)

5.2.2. Throttle Management During DBS Evaluations

To be consistent with the CIB procedures, the SV will now be specified to maintain speed up to the onset of either the FCW auditory alert, or to the FCW alert modality indicated to the test conductor by a NHTSA representative during DBS evaluations. At that point, throttle is released and a short while later the brake controller applies the brakes. Applicable sections now state:

> *"Within 500 ms after t_{FCW}, but prior to the onset of the SV brake applications…the SV throttle pedal shall be fully released. The throttle pedal release rate is not restricted."*

Note: The brake application timing/headway in the DBS procedure is still based on fixed TTC values (which originate from the TTCs specified in the FCW NCAP), so the timing between throttle release and brake application is expected to vary depending on what vehicle is evaluated. This is different from the Euro NCAP procedure, which specifies the SV brakes are to be applied 1 second after the FCW is presented. Conceptually, the Euro NCAP method provides a way to normalize the SV brake application timing. However, the headway at which the application occurs (and therefore the subsequent speed reduction) is directly affected by FCW variability. NHTSA has not evaluated the extent to which this variability may affect DBS performance.

Note: If FCW-based throttle release timing is used and a late FCW alert occurs, it is possible the throttle (human input) and brake (robot input) could be applied at the same time. This could suppress DBS and is the reason that the "*Within 500 ms after t_{FCW}, but prior to the onset of the SV brake applications …"* language was specified in the above draft test procedure excerpt.

5.3. Brake Application Specifications

5.3.1. Hybrid Feedback Magnitude Adjustment

For the hybrid brake applications used during 2013 FCAM tests, the same application rate and position used for displacement feedback tests were commanded. However, once at the desired position, application force was reduced at a rate of 56.2 lbf/s (250 N/s) to a force fallback magnitude equal to 50 percent of the brake force required to achieve an average deceleration of 0.3g during the vehicle's brake system characterization. This fallback magnitude has been increased to 100 percent of that capable of achieving an average deceleration of 0.3g during the vehicle's brake system characterization in the August 2014 DBS draft test procedures. The reasons for this are two-fold:

- Earlier versions of NHTSA's DBS draft test procedures included an option to use displacement or force feedback to evaluate system performance. Regardless of which feedback control was specified, the magnitude of the commanded input was based on that required to produce average deceleration of 0.3g during the vehicle's brake system characterization. By basing the applications on a common deceleration, maneuver severity was intended to be equal, regardless of the application method selected.

- Applications based only on force (i.e., force feedback applications) are no longer present in the DBS draft test procedures; they have been superseded by hybrid-based applications. During the 2013 FCAM tests, the fallback force magnitude associated with hybrid applications was only one-half of that which would have been used with force feedback. Therefore, to better align the magnitude of displacement and hybrid-based applications, the hybrid force fallback will be equal to that which would have been used for force feedback-based evaluations.

5.3.2. Brake Application Feedback Mode Selection

The August 2014 DBS draft test procedure includes the provision to evaluate an SV using displacement- or hybrid-feedback-based brake applications. However, since DBS performance evaluations are time-consuming, it is not practical for the agency to utilize both application strategies per vehicle tested. For this reason, the August 2014 DBS draft test procedure includes language stating that:

> *"…a NHTSA representative may specify to the Contractor which programmable brake controller mode shall be used for a vehicle's respective evaluation."*

To determine the most appropriate brake application strategy for a given vehicle, NHTSA may need to consult with the respective vehicle manufacturer prior to test conduct. The August 2014 DBS draft test procedure states that the SV must satisfy all draft ARVs using one brake application method. Applicable language states:

> *"[DBS test procedure] Tables 11 and 12 provide a summary of acceptable SV performance for each test scenario. The performance requirements specified in [DBS test procedure] Table 11 and the non-activation requirements specified in [DBS test procedure] Table 12 must be satisfied using the same NHTSA-specified brake application method (i.e., displacement or hybrid feedback)."*

5.4. SV Load Specification

The June 2012 draft test procedures described the SV loading condition as:

> *"The SV shall be loaded with one driver and all required equipment during the testing. Where possible, the equipment shall be placed on the front passenger seat of the SV."*

Some RFC commenters requested that this description be more explicitly defined, and one suggested the loading condition provided in FMVSS No. 135 be adopted[43]. Based on the amount of instrumentation required to perform the tests, NHTSA expects the lightly loaded condition specified in FMVSS No. 135will be exceeded if an in-vehicle experimenter is used to support the test driver (allowed in the August 2014 draft test procedures). However, to better define the load condition NHTSA expects to use in its evaluations, the previous language has been changed. The new language provided in the August 2014 CIB and DBS draft test procedures explicitly allows an in-vehicle experimenter in the SV and states the vehicle's loading should not exceed

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[43] NHTSA assumes this commenter intended to recommend the "Lightly Loaded" condition defined in FMVSS No. 135 (the vehicle's unloaded weight plus the weight of a mass of 396 lbs (180 kg) including driver and instruments).

the front or rear Gross Axle Weight Ratings (GAWRs) or the vehicle's Gross Vehicle Weight Rating (GVWR):

> *"Inclusion of an in-vehicle experimenter to assist the SV driver with test conduct (e.g., data acquisition, completion of logs, etc.) is permitted. Where possible, the in-vehicle experimenter shall be seated in the first seating position behind the front passenger's seat.*
>
> *Vehicle load shall include the unloaded vehicle weight (UVW) plus driver, experimenter (if required), and instrumentation without exceeding vehicle Gross Vehicle Weight Rating (GVWR) and all Gross Axle Weight Ratings (GAWR)."*

5.5. Test Tolerance Revision

Table 5-1 provides a comparison of the three major CIB and DBS draft test procedure tolerance specifications. Each change present in this table has been made in response to a request for clarification by 2012 RFC commenters and/or to improve test performability based on NHTSA's experience with test track evaluations to date.

Table 5-1. CIB and DBS Test Tolerance Overview and Change History
(Changes from a previous version are indicated in red.)

Parameter	Draft Test Procedure Version		
	June 2012	2013 FCAM testing (not publicly released, only used internally by NHTSA for CIB/DBS testing in 2013)	August 2014
SV and POV speed	±1 mph (1.6 km/h)	No change	No change
Constant SV speed range (CIB)	LVS: TTC = 5.1 ⇨ 3.1s LVM: TTC = 5.0 ⇨ 3.0s	LVS: TTC = 5.1 ⇨ 3.1s LVM: TTC = 5.0 ⇨ 3.0s **LVD_35_35: Validity onset ⇨ POV brake** **LVD_25_25: Validity onset ⇨ POV brake** **STP: TTC = 5.1 ⇨ 3.1 s**	LVS: TTC = 5.1 ⇨ t_{FCW} LVM: TTC = 5.0 ⇨ t_{FCW} LVD1_35_35: Validity onset ⇨ t_{FCW} LVD2_25_25: Validity onset ⇨ t_{FCW} STP: 5.1 ⇨ t_{FCW} **(or to end-of-test if the SV FCW is not presented)**
Constant SV speed range (DBS)	LVS: TTC = 4.1 ⇨ 2.1s LVM: TTC = 4.0 ⇨ 2.0s	LVS: TTC = 4.1 ⇨ 2.1s LVM: TTC = 4.0 ⇨ 2.0s **LVD1_35_35: Validity onset ⇨ POV brake** **LVD2_25_25: Validity onset ⇨ POV brake** **STP: TTC = 4.1 ⇨ 2.1 s**	LVS: TTC = **5.1** ⇨ t_{FCW} LVM: TTC = **5.0** ⇨ t_{FCW} LVD1_35_35: Validity onset ⇨ t_{FCW} LVD2_25_25: Validity onset ⇨ t_{FCW} STP: **TTC = 5.1 ⇨** t_{FCW} **(or TTC = 5.1 ⇨ 2.1 s if TTC = 2.1s occurs before** t_{FCW}**)**
SV and POV lateral position from road center	Not specified	Not specified	**±2 ft (0.6 m)**
SV-to-POV lateral orientation relative to each other	±1 ft (0.3 m)	No change	**±2 ft (0.6 m)**
SV-to-POV headway (applicable to LVD tests only)	n/a	± 8 ft (2.4 m)	No change
SV yaw rate	±1 deg/s	No change	**±2 deg/s up to the instant SV deceleration exceeds 0.25g**
Constant SV throttle position (CIB)	Within +/- 2% from applicable[1] TTC to end of test	**Within +/- 3% of an average position from applicable[2] TTC to end of test or SV deceleration ≥ 0.1g**	**No longer required**

t_{FCW} = Onset of the SV FCW alert

POV Brake = onset of the POV brake application, defined as the instant when POV deceleration ≥ 0.05g

[2] For LVS, TTC = 3.1 s; for LVM, TTC = 3.0 s

[3] For LVS, TTC = 3.1 s; for LVM, TTC = 3.0 s; for LVD, TTC = 3.4 s

Table 5-1. CIB and DBS Test Tolerance Overview And Change History (continued)
(Changes from a previous version are indicated in red.)

Parameter	**Draft Test Procedure Version**		
	June 2012	**2013 FCAM Testing (not publicly released, only used internally by NHTSA for CIB/DBS testing in 2013)**	**August 2014**
SV throttle release timing (CIB)	Not permitted	**Permitted to be fully released after SV deceleration ≥ 0.1g**	**LVS, LVM, LVD: Fully released within 500 ms of t_{FCW}** **STP: Fully released within 500 ms of t_{FCW}. If the SV FCW is not presented, SV throttle pedal is not released until end-of-test.**
SV throttle release timing (DBS)	>1 s prior to brake application	No change	**LVS, LVM, LVD: Fully released within 500 ms of t_{FCW} but prior to the onset of the SV brake application.** **STP: Fully released within 500 ms of t_{FCW} or TTC = 2.1s (whichever occurs first) but prior to the onset of the SV brake application.**
SV brake application range to POV (DBS)	Not specified	Not specified	**±2 ft (±0.6 m)**
SV brake application rate (DBS)	7 ± 1 in/s (178 ± 25.4 mm/s)	No change	10 ± 1in/s (254 ± 25.4 mm/s)
POV deceleration (applicable to LVD tests only)	Not specified	**FCW NCAP criteria; minimum and maximum values must remain within 0.3g ±0.03g overall; an initial overshoot up to 0.375g allowed for 50 ms**	**Mean must fall within 0.3g ± 0.03g**
Ambient temperature range	32° F (0° C) to 100° F (38° C)	No change	**45° F (7° C) to 104° F (40° C)**

6.0 REFERENCES

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[2] "*Crash Imminent Brake System Performance Evaluation, June 2012 Working Draft*," Docket NHTSA-2012-0057-0001

[3] "*Dynamic Brake Support Performance Evaluation, June 2012 Working Draft*," Docket NHTSA-2012-0057-0001

[4] Request for Comment in the Federal Register seeking responses to the public release of its CIB/DBS research efforts (77 FR 39561, July 3, 2012); Docket NHTSA-2012-0057-0002

[5] "*NHTSA's Strikeable Surrogate Vehicle Preliminary Design Overview*," Docket NHTSA-2012-0057-0032

[6] National Highway Traffic Safety Administration. (2013). "*Traffic Safety Facts 2011.*" Washington DC: U.S. Department of Transportation, DOT HS 811 754

[7] IIHS/HLDI ESV paper number 13-0126, 2013 ESV Conference

[8] "*Advanced Brake Assist – Real World effectiveness of current implementations and next generation enlargements*," presented by Mercedes-Benz at the 2013 ESV Conference. (Paper Number 13-0194).

[9] Irene Isaksson-Hellman (IF Insurance Company P&C Ltd.) and Magdalena Lindman (Volvo Car Corporation) in connection with the Association for the Advancement of Automotive Medicine (AAAM) conference in Seattle, Washington, 2012.

[10] Centre for Automotive Safety Research, The University of Adelaide, AUSTRALIA; Paper Number 13-0152 presented at the 2013 ESV Conference in Seoul Korea.

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7.0 APPENDICES

APPENDIX A-1: 2013 FCAM CIB and DBS Test Summaries – Draft ARV Performance

APPENDIX A-2: 2013 FCAM CIB and DBS Test Summaries – SV Speed Reduction

APPENDIX A-3: 2013 FCAM CIB and DBS Test Summaries – SV Crash Avoidance

APPENDIX A-1a: 2013 FCAM CIB Test Summary – Draft ARV Performance (Valid Trials)

Vehicle	**Tech**	**Maneuver (speeds in mph)**							
		LVS 25_SSV	**LVS 25_ADAC**	**LVM 45_20**	**LVM 25_10**	**LVD1 35_35**	**LVD2 25_25**	**STP 45**	**STP 25**
2014 Audi A8L	CIB	Not performed	Not performed	8/8	0/7	8/8	6/7	8/8	7/7
2014 Cadillac ATS		Not performed	Not performed	8/8	6/8	0/7	7/7	8/8	8/8
2014 Infiniti Q50		8/8	8/8	8/8	7/8	3/8	8/8	8/8	7/7
2014 Mercedes E350		8/8	8/8	8/8	8/8	8/8	8/8	8/8	8/8
2014 Mitsubishi Outlander		Not performed	Not performed	8/8	8/8	8/8	7/7	8/8	8/8
2013 Lexus LS460		8/8	8/8	7/7	6/6	6/6	5/5	8/8	7/7
2013 Subaru Outback		8/8	8/8	7/7	3/3	2/2	4/4	8/8	8/8

Note: Infiniti Q50 CIB results obtained during tests where the SV driver released the throttle after the FCW haptic throttle pedal pushback occurred.

Note: No throttle position sensor (TPS) data for Cadillac ATS CIB STP tests; throttle release validity could not be assessed.

Note: POV decelerations recorded during the LVD evaluations were not screened for validity.

APPENDIX A-1b: 2013 FCAM DBS Test Summary – Draft ARV Performance (Valid Trials)

Vehicle	Tech	Maneuver (speeds in mph)							
		LVS 25_SSV	LVS 25_ADAC	LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP 45	STP 25
2014 Audi A8L	DBS (DF)	0/8	1/8	7/8	0/7	4/7	8/8	1/1	8/8
2014 Cadillac ATS		8/8	7/8	8/8	8/8	1/8	6/7	6/6	8/8
2014 Infiniti Q50		8/8	8/8	8/8	8/8	5/5	6/6	7/7	4/5
2014 Mercedes E350		8/8	8/8	8/8	8/8	8/8	8/8	5/8	2/7
2014 Mitsubishi Outlander		8/8	8/8	6/6	6/6	4/4	No valid tests	No valid tests	7/7
2013 Lexus LS460		1/2	4/5	5/5	6/6	No valid tests	No valid tests	3/3	2/2
2013 Subaru Outback		8/8	8/8	2/2	8/8	8/8	7/8	7/7	8/8
2014 Audi A8L	DBS (HF)	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed
2014 Cadillac ATS		7/8	7/8	8/8	8/8	Not performed	6/6	Not performed	Not performed
2014 Infiniti Q50		8/8	8/8	8/8	8/8	Not performed	Not performed	Not performed	Not performed
2014 Mercedes E350		8/8	8/8	8/8	8/8	Not performed	Not performed	Not performed	Not performed
2014 Mitsubishi Outlander		0/4	0/8	8/8	8/8	Not performed	Not performed	Not performed	Not performed
2013 Lexus LS460		3/3	4/5	8/8	6/7	Not performed	Not performed	2/2	4/4
2013 Subaru Outback		0/8	5/5	2/2	8/8	Not performed	Not performed	Not performed	Not performed

Note: Only three STP_45 DBS tests were performed with the Mitsubishi Outlander, and none had the correct brake application timing.

Note: POV decelerations recorded during the LVD evaluations were not screened for validity.

APPENDIX A-2a: 2013 FCAM CIB Test Summary – SV Speed Reduction (Valid Trials)

Vehicle	**Tech**	**Maneuver (speeds in mph)**							
		LVS 25_SSV	**LVS 25_ADAC**	**LVM 45_20**	**LVM 25_10**	**LVD1 35_35**	**LVD2 25_25**	**STP 45**	**STP 25**
2014 Audi A8L	CIB	Not performed	Not performed	12.3 - 17.5	4.3 - 5.7	14.7 - 21.7	9.3 - 11.8	n/a	n/a
2014 Cadillac ATS		Not performed	Not performed	16.7 - 24.6	8.6 - 14.9	1.9 - 7.6	10.6 - 12.4	n/a	n/a
2014 Infiniti Q50		11.2 - 25.6	15.1 - 25.5	11.4 - 25.4	12.0 - 14.9	4.5 - 12.2	24.3 -25.6	n/a	n/a
2014 Mercedes E350		10.5 - 25.1	24.3 - 25.4	23.9 - 25.5	13.6 - 15.9	21.1 - 29.3	24.6 - 25.7	n/a	n/a
2014 Mitsubishi Outlander		Not performed	Not performed	17.3 - 20.1	14.1 - 15.7	17.8 - 22.3	14.6 - 16.6	n/a	n/a
2013 Lexus LS460		24.5 - 25.2	24.2 - 25.5	23.6 - 25.1	13.8 - 15.6	16.2 - 24.4	24.7 - 25.6	n/a	n/a
2013 Subaru Outback		24.6 - 25.7	24.6 - 25.4	23.8 - 25.8	13.9 - 15.6	20.6 - 21.1	25.0 - 25.4	n/a	n/a

Note: Infiniti Q50 CIB results obtained during tests where the SV driver released the throttle after the FCW haptic throttle pedal pushback occurred.

Note: No throttle position sensor (TPS) data for Cadillac ATS CIB STP tests; throttle release validity could not be assessed.

Note: POV decelerations recorded during the LVD evaluations were not screened for validity.

APPENDIX A-2b: 2013 FCAM DBS Test Summary – SV Speed Reduction (Valid Trials)

Vehicle	Tech	Maneuver (speeds in mph)							
		LVS 25_SSV	LVS 25_ADAC	LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP 45	STP 25
2014 Audi A8L	DBS (DF)	8.8 - 14.7	11.8 - 25.4	18.4 - 25.2	6.7 - 10.7	16.5 - 29.3	24.2 - 25.3	6.1	6.8 - 9.3
2014 Cadillac ATS		24.5 - 25.3	21.7 - 25.4	23.7 - 25.4	13.4 - 15.2	13.1 - 30.8	24.2 - 25.9	8.7 - 10.1	10.2 - 11.8
2014 Infiniti Q50		23.5 - 25.0	23.9 - 25.1	22.3 - 24.8	13.1 - 14.9	24.6 - 31.9	24.3 - 25.3	9.1 - 10.6	10.3 - 24.3
2014 Mercedes E350		24.6 -25.6	24.6 - 25.8	24.2 - 25.6	14.0 - 14.7	26.4 - 31.6	24.2 - 25.4	11.2 - 28.7	13.4 - 24.6
2014 Mitsubishi Outlander		24.3 - 25.3	23.7 - 25.7	23.7 - 25.2	13.7 - 15.0	24.3 - 27.3	No valid tests	No valid tests	15.0 - 21.0
2013 Lexus LS460		21.3 - 24.5	16.5 - 25.5	23.6 - 24.6	14.2 - 15.8	No valid tests	No valid tests	9.8 - 10.6	9.9 - 10.2
2013 Subaru Outback		24.1 - 25.2	24.2 - 25.3	25.0 - 25.4	14.5 - 16.6	26.6 - 35.4	14.6 - 25.3	8.9 - 10.3	8.3 - 9.5
2014 Audi A8L	DBS (HF)	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed
2014 Cadillac ATS		21.7 - 25.4	19.8 - 25.1	23.8 - 25.2	14.0 - 15.1	Not performed	24.1 - 25.2	Not performed	Not performed
2014 Infiniti Q50		24.2 - 25.1	23.4 - 25.0	23.6 - 25.4	13.8 - 15.9	Not performed	Not performed	Not performed	Not performed
2014 Mercedes E350		23.9 - 25.6	24.6 - 25.6	23.0 - 25.0	13.8 - 14.9	Not performed	Not performed	Not performed	Not performed
2014 Mitsubishi Outlander		15.4 - 19.4	19.1 - 22.5	24.5 - 25.5	14.0 - 15.1	Not performed	Not performed	Not performed	Not performed
2013 Lexus LS460		24.8 - 25.9	17.4 - 25.5	23.8 - 25.3	13.0 - 15.2	Not performed	Not performed	7.5 - 8.6	7.6 - 8.2
2013 Subaru Outback		19.6 - 25.0	24.5 - 25.4	25.4 - 25.5	15.1 - 15.9	Not performed	Not performed	Not performed	Not performed

Note: Only three STP_45 DBS tests were performed with the Mitsubishi Outlander, and none had the correct brake application timing.

Note: POV decelerations recorded during the LVD evaluations were not screened for validity.

APPENDIX A-3a: 2013 FCAM CIB Test Summary – SV Crash Avoidance (Valid Trials)

Vehicle	Tech	Maneuver							
		LVS 25_SSV	LVS 25_ADAC	LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP 45	STP 25
2014 Audi A8L	CIB	Not performed	Not performed	0/8	0/7	0/8	0/7	0/8	0/7
2014 Cadillac ATS		Not performed	Not performed	8/8	6/8	0/7	0/7	0/8	0/8
2014 Infiniti Q50		7/8	7/8	4/8	7/8	0/8	8/8	0/8	0/7
2014 Mercedes E350		6/8	8/8	8/8	8/8	0/8	8/8	0/8	0/8
2014 Mitsubishi Outlander		Not performed	Not performed	0/8	8/8	0/8	0/8	0/8	0/8
2013 Lexus LS460		8/8	8/8	7/7	6/6	5/6	5/5	0/8	0/7
2013 Subaru Outback		8/8	8/8	7/7	3/3	0/2	4/4	0/8	0/8

Note: Infiniti Q50 CIB results obtained during tests where the SV driver released the throttle after the FCW haptic throttle pedal pushback occurred.

Note: No throttle position sensor (TPS) data for Cadillac ATS CIB STP tests; throttle release validity could not be assessed.

Note: POV decelerations recorded during the LVD evaluations were not screened for validity.

APPENDIX A-3b: 2013 FCAM DBS Test Summary – SV Crash Avoidance (Valid Trials)

Vehicle	Tech	Maneuver							
		LVS 25_SSV	LVS 25_ADAC	LVM 45_20	LVM 25_10	LVD1 35_35	LVD2 25_25	STP 45	STP 25
2014 Audi A8L	DBS (DF)	0/8	1/8	7/8	0/7	4/7	8/8	0/1	0/8
2014 Cadillac ATS		8/8	7/8	8/8	8/8	1/8	6/7	0/6	0/8
2014 Infiniti Q50		8/8	8/8	8/8	8/8	5/5	6/6	0/7	1/5
2014 Mercedes E350		8/8	8/8	8/9	8/8	8/8	8/8	0/8	5/7
2014 Mitsubishi Outlander		8/8	8/8	6/6	6/6	4/4	No valid tests	No valid tests	0/7
2013 Lexus LS460		1/2	4/5	5/5	6/6	No valid tests	No valid tests	0/3	0/2
2013 Subaru Outback		8/8	8/8	2/2	8/8	8/8	7/8	0/7	0/8
2014 Audi A8L	DBS (HF)	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed	Not performed
2014 Cadillac ATS		7/8	7/8	8/8	8/8	Not performed	6/6	Not performed	Not performed
2014 Infiniti Q50		8/8	8/8	8/8	8/8	Not performed	Not performed	Not performed	Not performed
2014 Mercedes E350		8/8	8/8	8/9	8/8	Not performed	Not performed	Not performed	Not performed
2014 Mitsubishi Outlander		0/4	0/8	8/8	8/8	Not performed	Not performed	Not performed	Not performed
2013 Lexus LS460		3/3	4/5	8/8	6/7	Not performed	Not performed	0/2	0/4
2013 Subaru Outback		0/8	5/5	2/2	8/8	Not performed	Not performed	Not performed	Not performed

Note: Only three STP_45 DBS tests were performed with the Mitsubishi Outlander, and none had the correct brake application timing.

Note: POV decelerations recorded during the LVD evaluations were not screened for validity.