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16. Abstract
The portion of the research project included in this report focuses on 23 Federal Motor Vehicle Safety Standards. It provides research findings, including the performance requirements and test procedures, in terms of options regarding technical translations, based on potential regulatory barriers identified for compliance verification of innovative new vehicle designs that may appear in vehicles equipped with Automated Driving Systems that lack manually operated driving controls. This report continues to use the foundational work from the Volume 1 report (Blanco et al., 2020) and Volume 2 report (Chaka et al., 2021) and builds on the findings from the Volume 3 report (Chaka et al., 2025). The current report focuses on the braking and electronic stability control test methods for FMVSS Nos. 135 and 126; the heavy braking and ESC requirements associated with FMVSS Nos. 105, 121, and 136; the technical translations of FMVSS Nos. 122, 122a, 123, 131, 223, 224, 403, 404, and C.F.R. Part 571 Subpart A; and potential unconventional seating barriers associated with FMVSS Nos. 201, 202a, 207, 209, 210, 214, 216a, 219, and 226.

17. Key Words
ADS, ADS-DV, Automated Driving System, Federal Motor Vehicle Safety Standards, FMVSS, safety, standards, test procedures

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Executive Summary

This project presents research findings in terms of options regarding technical translations of select Federal Motor Vehicle Safety Standards (FMVSS), including performance requirements and test procedures. The newly created technical translation options take into account potential unnecessary/unintended regulatory barriers[1] to innovative new vehicle designs equipped with Automated Driving Systems (ADSs).

This report uses the framework presented in three previous reports *FMVSS Considerations for Vehicles With Automated Driving Systems: Volumes 1* (Blanco et al., 2020) and *FMVSS Considerations for Vehicles With Automated Driving Systems: Volume 2* (Chaka et al., 2021), and *FMVSS Considerations for Vehicles With Automated Driving Systems: Volume 3* (Chaka et al., 2025) to evaluate regulatory text and test procedures. A technical translation is a language adaptation which identifies potential regulatory barriers with the intent to result in the same basic engineering performance and rigor without manual control-specific restrictions or references.

The goal of this framework is to identify possible options to remove regulatory barriers for the compliance verification of ADS-dedicated vehicles (ADS-DVs) that lack manually operated driving controls. This report, along with the previous research efforts, incorporates feedback obtained from research team experts, stakeholders, and subject matter experts (SMEs). Figure ES-1 summarizes the research areas covered in Volumes 1, 2, and 3.

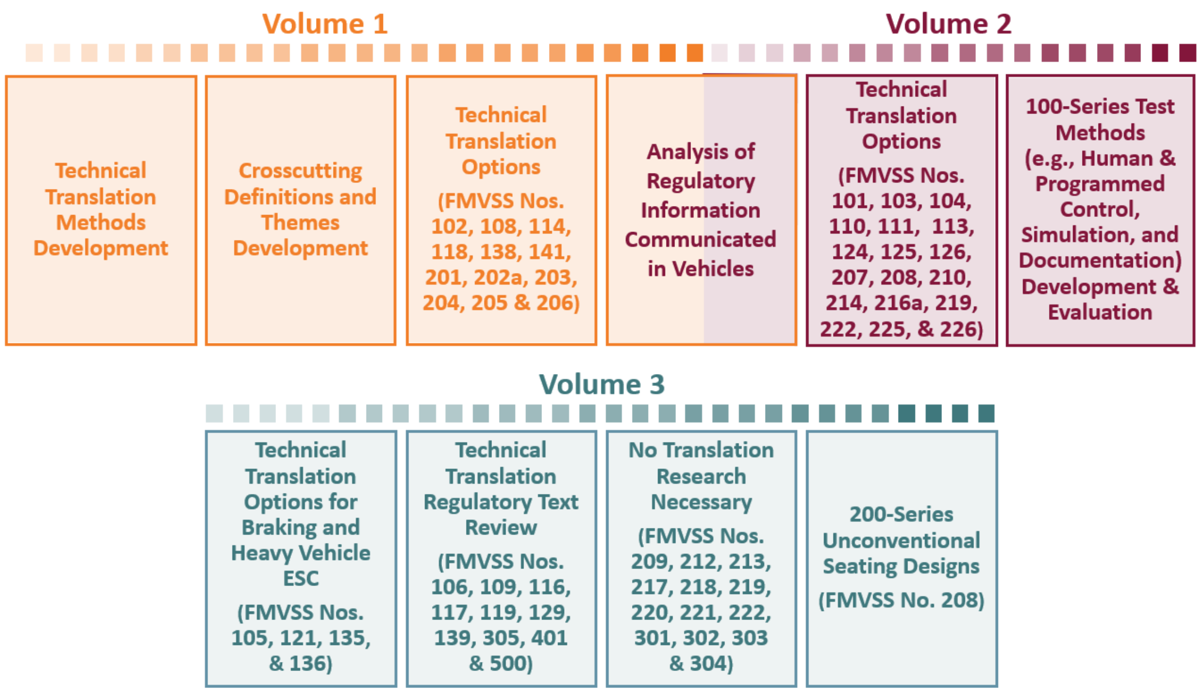

Figure ES-1. Volume 1, 2, and 3 research areas

[1] The use of the term "regulatory barrier" in this volume report always refers to "an unintended and unnecessary regulatory barrier."

This report (Volume 4) documents the framework and testing process carried out to develop technical translations and testing procedure options for the remaining FMVSS standards. The research included 23 standards: 49 C.F.R. Part 571 Subpart A-General; 8 crash avoidance standards (with a focus on braking and electronic stability control [ESC] test methods), 4 crashworthiness standards (focus on rear impact and platform lift systems), and 9 crashworthiness standards exploring the considerations for unconventional seating. The technical translation analysis varied depending on the complexity of the potential regulatory barriers and proposed findings from NHTSA's other activities. The research areas are shown in Figure ES-2 below.

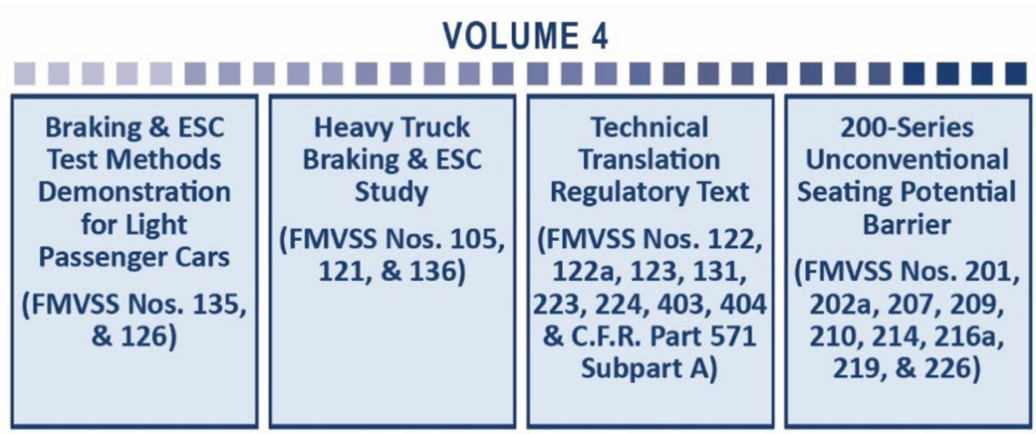

Figure ES-2. Volume 4 research areas

It is important to disclose the limitations in legality of the potential translation options that have been discussed in this report. First, the potential options in this report have yet to be fully verified in terms of legality and scope. The potential options that are included are limited only to the suggestions and discussions of the authors of the report and subsequent stakeholder involvement. These potential options are only discussed as being potentially feasible at the time the research was performed. Thus, this is not an exhaustive analysis, and other applicable options may not have been included in this report. Third, it should be noted that the majority of stakeholders involved in this project were representatives of industry, not public interest groups, or others that NHTSA would deem "stakeholders" in NHTSA's rulemaking processes. Please see Appendix B for a complete listing of the stakeholder organizations involved in the development of this report and in the technical translations of each of the FMVSS included throughout this report.

Scope

The focus of all volumes of the FMVSS technical translations effort centers on ADS-DVs, as defined to be operated exclusively by an SAE International driving automation Level 4 or Level 5 ADS for all trips within its given ODD limitations (if any), which may not be equipped with manually operated driving controls (SAE International, 2018). In other words, these technical translations do not expand applicability to automation levels below Level 4, such as a Level 3 vehicle with advanced driver assistance features and manually operated driving controls. The focuses of these technical translations were developed with provisions for Level 4 or Level 5 ADS-equipped vehicles with the physical characteristics necessary to perform the analyzed test procedures in this report. When NHTSA uses test procedures for compliance verification, NHTSA's Office of Vehicle Safety Compliance (OVSC) test procedures are derived from the FMVSS regulatory language. When a potential regulatory barrier is present or causes a potential challenge to NHTSA's compliance verification (e.g., a required feature as a reference point not being present in a vehicle), a technical translation option was presented. The scope of this effort attempted to provide a systematic approach in identifying alternative options for situations where a portion of an OVSC test procedure could not be implemented as prescribed (e.g., steering wheel angle) and might present a barrier for self-certification and compliance verification.

Crash Avoidance Standards

For this report, the 100-series crash avoidance work builds on the focus of Volume 3 on light- and heavy-vehicle (LV and HV) braking, and HV ESC standards. The cross-cutting themes that were repeated between the research of Volumes 1 to 3 appeared again in the analysis here. These terms, found throughout 49 C.F.R. Part 571, relate to the driver (operator), service brake application, shift position, controls, and indicators that represent the inherent assumption a human is operating the vehicle equipped with manually operated driving controls. As was the case in the Volume 1 and 2 reports, the research team determined that most of the current 100-series FMVSS covered in this report could be addressed with straightforward clarification of the regulatory language.

As determined in Volume 3, test method procedure analysis for FMVSS No. 135, *Light vehicle brake systems* showed the need for evidence of adequate lateral control during an emergency braking maneuver. In this report a braking test method execution study was performed to further (1) develop test procedure technical translation options for FMVSS No. 135, and (2) further refine test methods development and evaluate methods for use in compliance verification for braking standards. This required further examination of the braking system and performance requirements for an ADS based on stopping distance when a failure has been introduced during a normal operating mode under both human control (surrogate controls) and program control (scripted procedures).

The analysis of FMVSS No. 126, *Electronic stability control systems for light vehicles,* builds upon the findings in Volume 2 regarding procedures that may cause a challenge in compliance verification (and the related functionalities) of ADS-DVs. Using steering input locations and differences in measurements, this research will include (1) more complete identification of options for test procedure technical translations for FMVSS No. 126, and (2) further refined test methods development and evaluation for use in compliance verification of ESC standards.

This report also discusses the outcomes of the test method study that identifies potential suitable options for steering input locations and various measurement variables that were assessed in the context of HV test method development. These were considered for use in compliance verification of ESC standards. This assessment further identifies the suitability of cross-application between both HV and LV categories.

Test Procedures

The approaches from Volumes 1 and 2 that are replicated in the test procedure development for Volumes 3 and 4 seek to confirm a test method's capacity for ADS-DV testing by replicating driving and nondriving functionalities required by a particular standard. The Volume 3 research continued to apply the approach developed in Volume 1 and Volume 2 when addressing test procedures—to confirm a given test method's capacity to replicate the driving and non-driving functionalities required in the respective standard and associated test procedures. Both testing procedures occurred on the Virginia Tech Transportation Institute test platform and subsequently with three different Industry Test Partners for both standards.

In the case of FMVSS No. 135, this research further refines the emergency driving functionality testing from Volume 2. Fault conditions as defined in the standard (e.g., S7.5, S7.7, S7.8) were used as the foundation to test a variety of condition variables for ADS-DVs. This testing sought to meet the objectives of identifying potential challenges for ADS-DVs in fault conditions, investigate options for injecting fault conditions, and determine potential alternative control inputs that would demonstrate the functionalities needed for compliance verification through unique braking requirements and sequences. Data captured included longitudinal and lateral control variables, acceleration, angulator velocity, and a range of state and reference information. All test procedure translations were reviewed by industry stakeholders for further testing and refinement.

Assessment of LV Braking and ESC ADS Test Implementation for HVs

A systems and test procedure text comparison analysis was also completed between HV braking and ESC standards—FMVSS No. 105, *Hydraulic and electric brake systems*, FMVSS No. 121, *Air brake systems*, and FMVSS No. 136, *Electronic stability control systems for heavy vehicles*—and braking and LV ESC standards —FMVSS Nos. 126 and 135. Compressible air and non-compressible hydraulic braking systems were examined between Class 7 and Class 8 HVs and LVs to identify differences that may affect stopping distance procedures. Steering, propulsion, and braking systems as well as static and dynamic functionalities were examined and compared. The objective was to ultimately determine how the evaluation of programmed and manual control modes that were tested previously for LV ADS-DVs could be applied to HV test procedures. All test procedure translations were reviewed by industry stakeholders for consideration and refinement. Considerations are provided, but no significant barriers were identified for the systems and functionalities of the HV braking and ESC test procedures.

Crashworthiness and Remaining Standards

Section 571.3, Definitions, is the only section in Subpart A with potential barriers that may require technical translations. Several of the definitions contained in section 571.3 were addressed in Volume 1 and included by NHTSA in the *Occupant Protection for Vehicles With Automated Driving Systems* Final Rule (87 F.R. 61, 18560, 2022). The definition of "Forward Control" was newly identified as a potential barrier and is discussed below. Additional research may be needed to confirm that the translation from this research for the forwardmost designated seating position maintains the original intent of the forward control definition. The remaining crashworthiness standards—FMVSS No. 223, *Rear impact guards*, FMVSS No. 224, *Rear impact protection*, FMVSS No. 403, *Platform lift systems for motor vehicles*, and FMVSS No. 404, *Platform lift installations in motor vehicles*—were reviewed to identify any potential barriers. Requirements for specific audible notifications to the human lift operator when the lift is in use and the "direct, unobstructed view" requirement are specific audio or visual requirements provided to a human operator. Translations were proposed to support the potential option of the ADS operating the platform lift under the supervision of a human. In this particular case, additional research may be required to focus on the human-centered nature of the audio and visual specifications.

Several 200-series standards were also reviewed for potential regulatory barriers for ADS-DVs with unconventional seating designs. Many of the cross-cutting themes previously identified in Volume 3 analysis of FMVSS No. 208, *Occupant crash protection for unconventional seating,* established the baseline for analysis of the remaining crashworthiness standards. If a potential regulatory barrier was identified that did not correspond to one of these six identified cross-cutting themes previously identified, the theme was listed as "Other," with a potential new theme included in parentheses. Out of the standards reviewed for unconventional seating (i.e., fixed rear facing front row), most were found to have no or minimal regulatory barriers. The exceptions were FMVSS No. 201, *Occupant protection in interior impact*, and FMVSS No. 214, *Side impact protection*. New themes identified by these standards which may pose potential regulatory barriers or require additional research were related to dummy positioning, directionality of the seats, and non-applicability of test reference locations identified in the standard or the test setup itself.

Stakeholders and Subject Matter Experts

For all volumes of this research, the technical translation process incorporates feedback from stakeholders and SME reviewers. Consistent with the research of other volumes in this project, those invited to provide feedback included companies, organizations, and advocacy groups based on their experience with FMVSS and ADS-equipped vehicles. For Volume 4 activities, several industry test partners agreed to perform the same or similar research tests at their own facilities with their own ADS platforms to further refine feedback on test procedure development for crash avoidance standards. HV stakeholders and SME reviewers were also asked to provide input on the systems and test procedure text comparison analysis.

Report Contents

This report includes the following information:

Appendices –Information on definitions, technical translations, analysis of information communicated to occupants, lists of standards incorporated by reference for the FMVSS covered in Volume 4 research, and stakeholder information.

Summary Conclusion

Testing demonstrated that the test methods developed were able to perform a representative sample from the OVSC test procedures used for compliance verification. However, due to the nature of the braking and stability control testing, the ADS may prevent the vehicle from executing the defined test procedures without modification to the ADS and/or test procedures. The fault conditions defined in FMVSS No. 135 present a unique scenario in which the ADS safety systems would likely not allow the vehicle to operate or make it impossible to execute the test procedures as defined. In addition, implementation of either the program or human control test methods would at least in the near term likely require manufacturer involvement to be able to implement the test method so that the ADS could execute the test procedures. While no testing was performed with HVs, the functionalities required to execute the HV test procedures were demonstrated during LV testing. Taking into account the difference between hydraulic and air brake systems, the analysis did not identify any barriers introduced with HVs.

Of the remaining standards requiring translation for vehicles with conventional seating, only Section 571.3, Definitions, FMVSS No. 403, *Platform lift systems for motor vehicles*, and FMVSS No. 404, *Platform lift installations in motor vehicles*, presented any potential barriers that required proposed technical translations. In addition, the remaining 200 series standards were assessed against the recurring themes identified as potential regulatory barriers in the Volume 3 review of FMVSS No. 208 with unconventional seating (i.e., fixed rear-facing front row). This assessment verified the existence of the same themes and identified additional themes which may represent potential regulatory barriers unique to these standards. The themes applicable to each standard and potential considerations are provided to identify sections that may require translation or additional research to accommodate unconventional seating.

Chapter 1. Introduction

Project Approach and Scope

This report integrates the same basic approaches and processes for developing FMVSS technical translation options as the guiding practices of the standard analyses performed in Volumes 1, 2, and 3 (Figure 1). Different sections in this report detail the expansion of scope on previously analyzed standards through new test method studies, (e.g., FMVSS Nos. 126, *Electronic stability control systems for light vehicles,* and 135, *Light vehicle brake systems*) newly identified potential considerations, and changes in focus from conventional to unconventional seating for certain crashworthiness standards. New technical translation options were developed for the standards identified in Figure 2. The set of definitions used throughout Volumes 1 to 3 have been repeated for reference in Appendix A (a detailed definition approach can be found in Volume 1).

Technical translation options and their potential considerations identified in Volume 2 revealed a potential research gap in which further refinement of the test methodology may help to better inform future potential technical translation options, refine options from previous volumes, or enable a means to pass NHTSA compliance verification. For example, FMVSS No. 135's focus on the driving sequence of a shift from neutral, to coasting, to the final application of the brakes needed further test method development to build on the technical translation options identified for regulatory text in previous Volumes. This new assessment for Volume 4 (Figure 3) applies findings from the ADS-DV testing of LVs to further test the potential of translation options related to HV braking and ESC test procedures. This analysis examined comparison functionality similarities and differences between both types of vehicles for individual test method navigation.

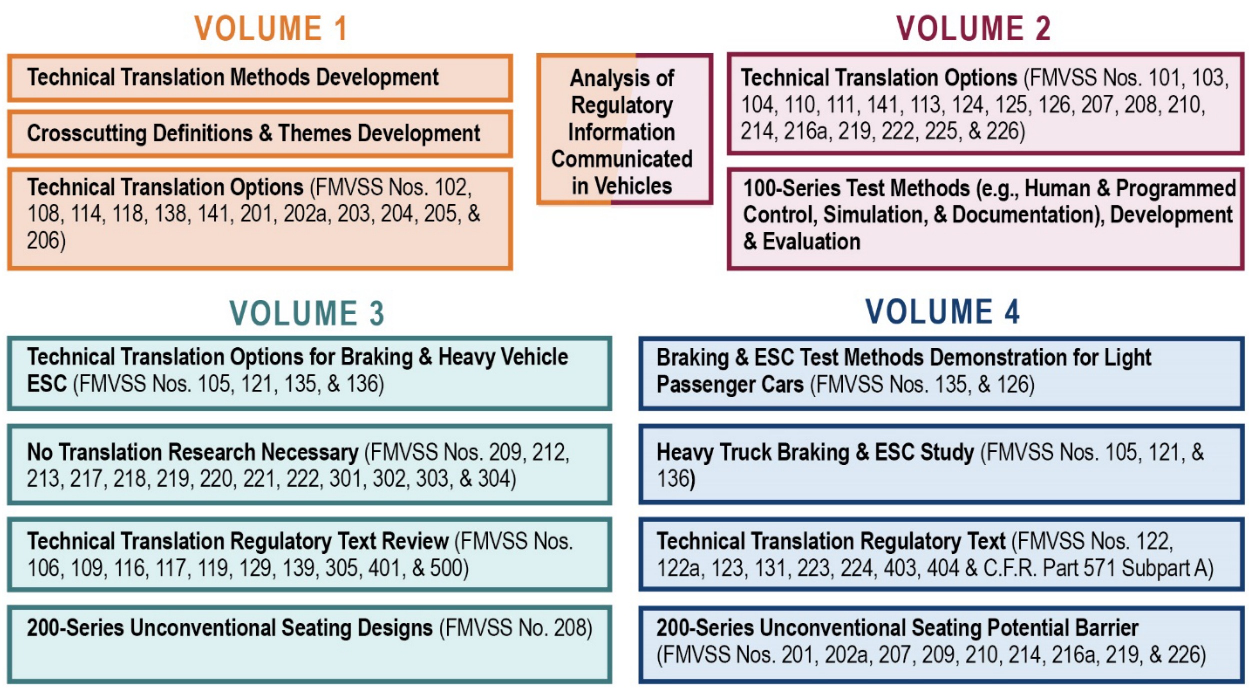

Figure 1. Brief overview of Volumes 1–4 approach

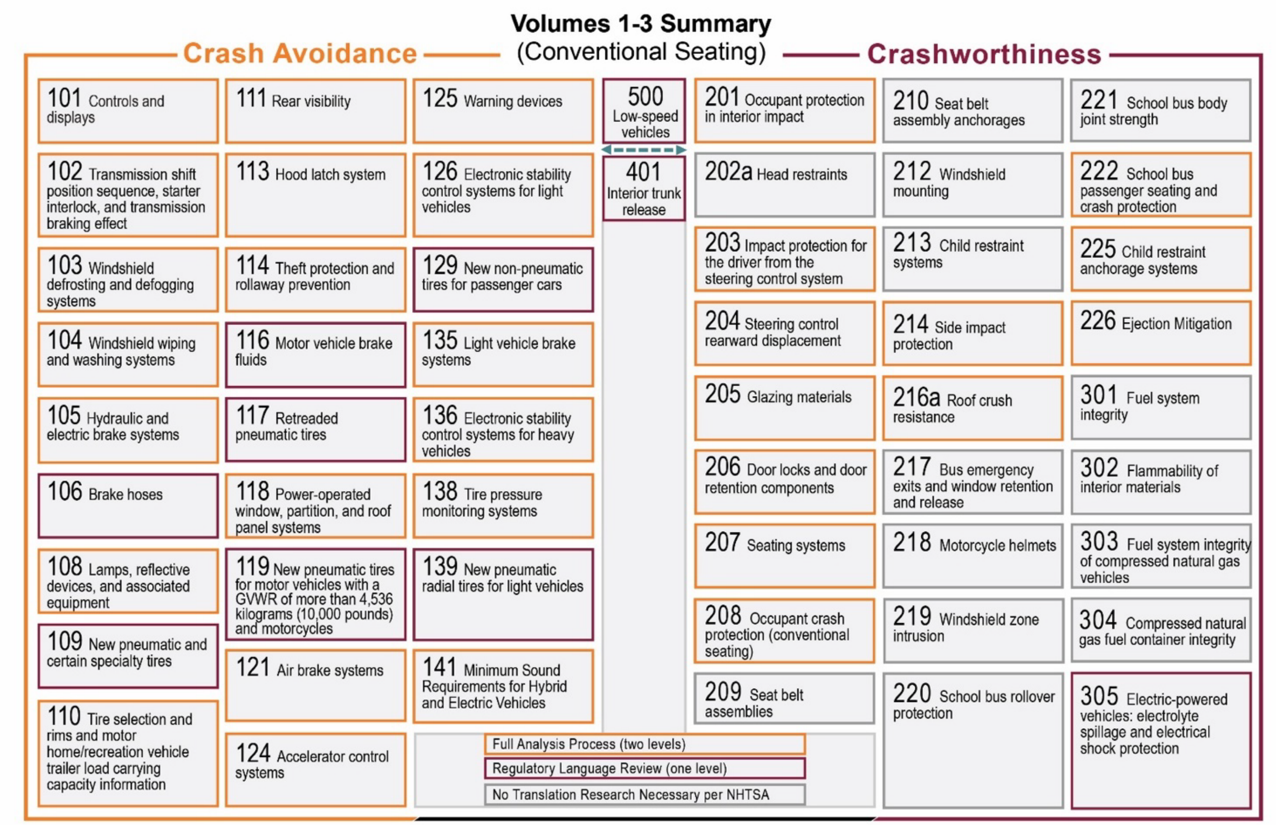

Figure 2. Technical translations performed for Volumes 1–3

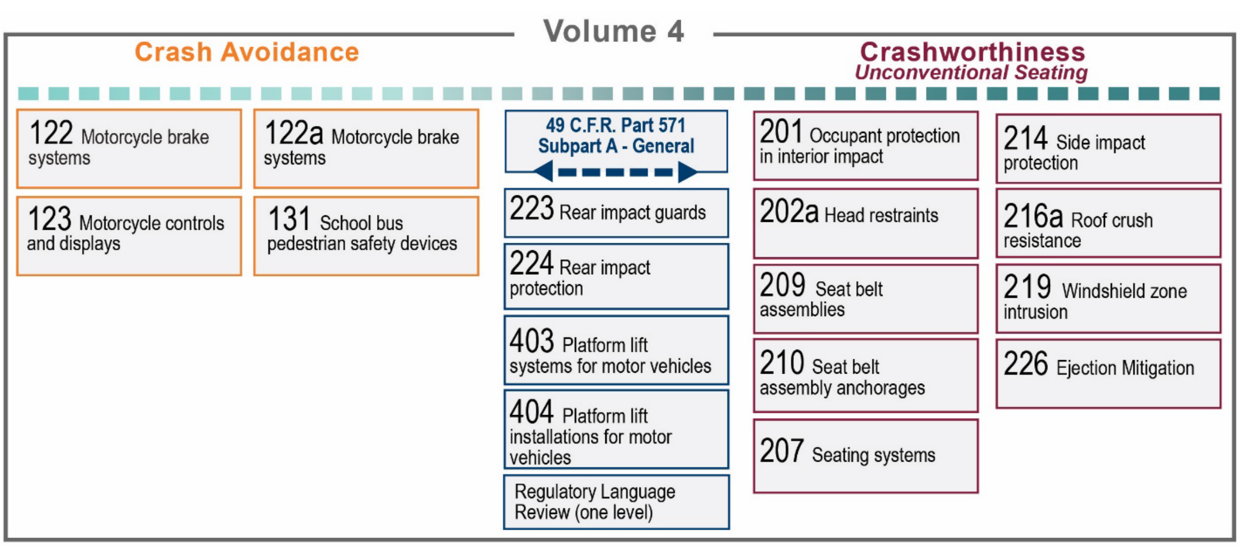

Figure 3. Technical translations performed for Volume 4

Bidirectional Vehicles

For bidirectional vehicles, it is possible that, depending on the vehicle's direction of travel, the hood becomes the trunk, the front doors become the rear doors, the front axles become the rear axles, the headlamps become the taillamps, and so on. While front and rear are referenced throughout the standards, they are not defined, which can make things unclear when discussing vehicles with bidirectional functionality. Bidirectional ADS-DVs were analyzed extensively in Volume 1 for the crash avoidance standards and potential bidirectional vehicle definition options, and application approaches were discussed. The implications of bidirectional vehicles for the crashworthiness standards were not considered in Volume 1 or any of the subsequent volumes.

Dual-Mode Vehicles

Since vehicles with manually operated driving controls can be designed to comply with the current FMVSS, this research does not attempt to resolve the potential regulatory issues associated with what is sometimes referred to as a "dual mode" vehicle. (Defined in SAE J3016_202104 as "An ADS-equipped vehicle designed to enable either driverless operation under routine/normal operating conditions within its given ODD (if any), or operation by an in-vehicle driver, for complete trips" [2021].) While the research focused on ADS-DVs the translation options contain language that would apply to "dual-mode" vehicles to facilitate potential future considerations. For example, some of the offered translations, particularly those in the 100-series, specify that a given requirement would apply to "all vehicles that can be operated by a human driver." The three emphasized words are not actually necessary for the translations within the scope of this research. A technical translation specifying "all vehicles operated by a human driver[sic]" without the "that can be" may not capture the dual mode when the ADS is operating the vehicle.

Unconventional Seating Configurations

Consistent with Volume 3, the technical translations for unconventional seating will focus on fixed face-to-face designated seating positions (DSPs) for the first and second rows (Figure 4**)**. The rationale for selecting this configuration includes the following: (1) maximizes use of conventional restraint systems, (2) aligns with current research initiatives, (3) offers the least amount of complexity, and more recently, (4) represents seating configurations currently being used in certain robotaxi designs.

Figure 4. Interior view of the ADS-DV unconventional seating concept

The approaches and themes identified in Volume 3 for FMVSS No. 208, Occupant crash protection for unconventional seating were used as a starting point for the remaining crashworthiness FMVSS. Volume 3 does not include considerations for bi-directional vehicles for the crashworthiness standards.

New to Volume 4 Overview

Further Evaluation of Test Methods (ESC and Braking)

One of the primary goals of the test method development was to identify a technically feasible path forward for execution of the test procedures associated with compliance verification. Volume 2 investigated six test method options, including human control, programmed control, ADS normal operation, technical documentation, simulation, and surrogate vehicle. This report presents the results from the human and programmed control test methods applied to FMVSS Nos. 126 and 135. The activities include results from the implementation and demonstration of both test methods with the Virginia Tech Transportation Institute (VTTI) ADS test vehicle for FMVSS No. 135 (results from FMVSS No. 126 with the VTTI test vehicle are in Volume 3). Several companies that are actively developing ADS-equipped vehicles agreed to engage as industry test partners (ITPs). These test partners implemented and executed their preferred test method for one or both of the two for a portion of the test procedure. This provided an opportunity to gain insight into how different companies may implement a test method and then execute the test procedure. For FMVSS No. 135, this also provided the opportunity to gain input on how the failure modes defined in the standard may be implemented on an ADS that may have redundancies and safety measures in place to preempt normal vehicle operation. Testing with the ITPs for FMVSS No. 126 provided an opportunity to evaluate additional considerations identified during the initial testing, including potential system input definitions and measurements, as well as associated mapping to current steering wheel parameters.

Assessment of LV Braking and ESC ADS Test Implementation for HVs

As reported in Volume 3, technical translations were applied to FMVSS Nos. 105, *Hydraulic and electric brake systems*, 121, *Air brake systems*, and 136, *Electronic stability control systems for heavy vehicles,* standards and test procedures where potential regulatory boundaries were found to exist. During this phase of the research, the systems and test methods for ESC and LV braking standards, meaning FMVSS Nos. 126 and 135, were assessed to understand the implementation suitability for HVs.

There were two purposes of this assessment. The first compared LV and HV steering, propulsion, and braking systems. The second compared ESC and braking test procedures to apply the findings from the ADS-DV implementation of LVs in FMCSS Nos. 126 and 135 and to determine their suitability for HVs. Even though the dynamic response between HVs and LVs is different, they share similar features. Therefore, the ESC test methods for gross vehicle weight rating (GVWR) vehicles weighing 26,001 lb or greater (Class 7 and 8) were compared to the test methods for LVs. Some HVs are equipped with hydraulic brakes but they are predominantly Class 3 to 6 vehicles with GVWR 10,001 to 26,000 lb—with rare exceptions for some Class 7 (GVWR 26,001 to 33,001 lb) hydraulic-braked-equipped vehicles—and are regulated according to FMVSS No. 105. Most Class 7 and 8 HVs are equipped with air brakes that are actuated and transfer power very differently than LVs and are regulated according to FMVSS No. 121. Therefore, the assessment of HV braking test methods to identify potential barriers focused on a comparison of air brake systems and FMVSS No. 121 to the LV test methods.

The objectives for the paper study were to:

- Assess HV test procedures based on lessons learned from testing LVs;
- Examine mechanical steering linkage functional similarities between HVs and LVs to determine implications for the J-turn procedure in FMVSS 136 while considering the implications of the procedure managing HV torque control;
- Examine differences between LV hydraulic (non-compressible) and HV air (compressible) braking systems to determine implications for the stopping distance procedure in FMVSS No. 121;
- Discuss test procedure translations with HV industry peers and identify equivalent procedures; and
- Evaluate if these differences may benefit from additional research.

Unconventional Seating Configurations

The approaches and themes identified in Volume 3 for FMVSS No. 208 for unconventional seating were used as a starting point for crashworthiness FMVSS Nos. 201, 202a, 207, 209, 210, 214, 216a, 219, and 226) and FMVSS Nos. 301, 303, 305, and 500 reviewed in this report. Any section that may require a further technical translation or additional research for an unconventional seating configuration has been given a theme to identify common areas of potential barriers. The themes identified when translating FMVSS No. 208 for unconventional seating included air bags; child restraints; unbelted occupants; injury criteria; Part 572 – anthropomorphic test devices (ATDs); as well as telltales, indicators, and auditory alerts. If the translation issue in a section of the remaining crashworthiness FMVSS did not correspond to one of these six identified themes, the theme was listed as "Other," with a potential theme identifier included in parentheses. Under potential considerations, this new theme is identified (e.g., fore/aft direction) and any potential barriers to the technical translation are described. In addition to the themes identified in the review of FMVSS No. 208 in Volume 3, the additional themes included: driver reference, test reference location may not be applicable, directionality, dummy positioning, front/rear differentiation, fore/aft control, and test setup (Table 17).

Chapter 2. Crash Avoidance Braking and ESC Test Methods

Overview/Key Considerations

The goals for the testing activities were primarily related to identifying potential new considerations for longitudinal control associated with FMVSS No. 135 and performing additional testing to clarify inputs and control considerations associated with FMVSS No. 126. The two test methods used were (1) human control via surrogate controls and (2) programmed control. In addition to the testing performed with the VTTI test vehicle, ITPs implemented the same test procedures on their ADS platforms to demonstrate how they would perform testing.

An evaluation of the HV braking and ESC test procedures was also performed to identify potential considerations or barriers associated with executing tests for compliance verification.

FMVSS No. 135: Light Vehicle Brake Systems

The stated purpose of FMVSS No. 135 "is to ensure safe braking performance under normal and emergency driving conditions" (49 CFR 571.135). To evaluate the performance of the brake system in emergency conditions, compliance is based on stopping distance both when the brake system is operating normally and when a failure has been introduced. These conditions may provide unique challenges to implement in an ADS-DV. The intent of this activity was to execute portions of the test procedures that would exercise unique braking requirements and sequences with and without different fault conditions defined in the standard. The two test methods used were (1) human control and (2) program control. The specific objectives are listed below.

1. Determine if an ADS can execute the test procedures as currently written
2. Identify what must be done outside of normal operation to execute test procedures
3. Identify what the ADS can and cannot do and why

Test Methods

Purpose

The purpose of the testing was to identify representative maneuvers from the standard and associated OVSC test procedures that would demonstrate unique functionality present throughout the conditions that may pose challenges to an ADS-DV. Table 1 provides a summary of the different test conditions defined in FMVSS No. 135. The table is ordered based on functionality: moving/static, transmission state (drive/neutral), and deceleration control (closed loop/open loop). Many of the conditions are the same for the different tests but are run with different faults introduced into the brake system. Since the goal of the tests is not to demonstrate compliance but to demonstrate a method that could replicate the functionalities, the team selected a subset of conditions that would demonstrate the functionalities and reveal potential challenges for an ADS associated with the different faults.

Table 1. Summary of Conditions for Test Defined in FMVSS No. 135

Test	Section	Transmission	Speed (km/h)	Pedal Force (N)	Deceleration	Performance Requirement
Burnish	7.1	in gear	80	n/a	3 m/s^2	n/a
Heating snubs	7.13	in gear	120	n/a	3 m/s^2	n/a
High speed	7.6	in gear	125 or 160	≤ 65; ≤ 500	n/a	S ≤ 0.10V + 0.0067V^2
Cold	7.5	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 70 m
Engine off	7.7	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 70 m
Failed antilock	7.8	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 85 m
Failed proportioning valve	7.9	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 110 m
Hydraulic circuit failure	7.10	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 168 m
Power brake unit failure	7.11	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 168 m
Hot performance	7.14	neutral	100	≤ ave. in S7.5; ≤ 500	n/a	see S7.14.4
Brake cooling	7.15	neutral	50/100	n/a	3 m/s^2	see S7.15
Recovery performance	7.16	neutral	100	≤ ave. in S7.5	n/a	See S7.16.4
Parking brake	7.12	neutral	n/a	≤ 400(h); ≤ 500(f)	n/a	hold for 5 min

The following provides a summary of the testing performed on the VTTI test platform and then with the ITPs.

Test Conditions

From the tests defined in FMVSS No. 135 (Table 1), the following sections provided the basis for testing.

1. S7.5: Baseline braking at or near maximum limit with no fault.
2. S7.7: Braking at or near maximum limit with engine off fault.
3. S7.8: Braking at or near maximum limit with failed antilock brake.

S7.5 provides a baseline condition in which the vehicle operates under normal conditions. The maximal braking level provides an opportunity to assess the effectiveness of the different test methods to be able to execute braking functionality at the limit of the braking system. For an internal combustion engine, the engine off condition (S7.7) cuts the vacuum to the brake boost. To achieve similar levels of braking, the force at the brake pedal must increase. While this is not relevant for the results in increased brake pedal force, the loss of brake pedal boost is likely not an issue for an ADS-DV since it will not have pedals and will likely be electric. However, the requirement to cut motive power to the vehicle may create a unique challenge for test execution, as it will likely elicit a unique fallback condition for an ADS-DV. When testing the current fault conditions, the fault is typically introduced in the system prior to the start of the run. While this will result in an error code and telltale, the vehicle operator can ignore this warning and operate the vehicle as prescribed. However, for an ADS-DV, introduction of a brake system fault prior to the start of the test sequence may cause the ADS to restrict operation of the vehicle such that the vehicle will not move. The failed antilock brake test, S7.8, was selected to identify how an ADS might address this condition. Note that other fault cases could also do this, and the ITPs suggested and implemented S7.11, power brake unit failure, instead.

VTTI Testing

The following provides an overview of the test platform, implementation, execution, and results.

Vehicle Configuration

The vehicle used for testing was a 2013 Cadillac SRX that was modified by VTTI to allow automated control of vehicle functionalities, including steering, braking, throttle, and gear selection. The modified vehicle supported both human and programmed control. The VTTI test platform used a game control steering wheel and foot pedal assembly for primary vehicle control (lateral and longitudinal). These were positioned in the front passenger seat with the center console housing additional controls for operation of functions such as gear selection, including neutral, which is required for FMVSS No. 135.

For programmed control, the test procedures were scripted to issue commands directly to the motion control system. In lieu of brake pedal force, the vehicle used a target deceleration level of 5.5 m/s^2 (the approximate constant deceleration level required to comply with FMVSS No. 135) to determine the brake command.

Data Captured

The data elements recorded during testing allowed for an investigation and evaluation of brake performance as well as potential intermediate states and conditions of the brake system that may be useful in quantifying input for the ADS-DV’s brakes without a brake pedal. These included the following elements for the VTTI test vehicle and similar data for the ITP test vehicles.

- **Longitudinal control**
    - Throttle command
    - Vehicle speed
    - Wheel speed
    - Brake command
    - Brake line pressure
- **Lateral control**
    - Steering wheel angle
    - Front wheel angle
- **Inertial measurement unit (IMU)**
    - X, Y, Z acceleration
    - X, Y, Z angular velocity
- **GPS**
    - Latitude
    - Longitude
- **State information**
    - Transmission state (PRNDL)
    - Failure state
    - Backup system enabled
    - Automation enabled
- **Reference**
    - Time
    - Forward camera view

Test Execution

The following steps defined in FMVSS No. 135 provided the basis for both the baseline and fault conditions. Since the research team had full access to the ADS, the fault conditions were able to be introduced prior to the start of the test. Each test condition was repeated eight times for all three test methods.

Tests 1–3: Baseline and fault execution (S7.5, S7.7, S7.8)

1. Position vehicle (manually)
2. Accelerate to 106–112 km/h
3. Close throttle (idle)
4. Coast to approximately 103 km/hr
5. Shift into neutral
6. At 100 km/h, apply brakes until vehicle comes to a complete stop

During development, the test team performed the above tests on the VTTI Smart Roads. However, due to safety considerations, they were run at reduced speeds. Final testing at the prescribed target speeds took place at Bosch Proving Grounds, in Flat Rock, Michigan, using a professional driver versed in FMVSS No. 135 compliance test procedure execution.

Results

Figure 5 and Figure 6 show a comparison of the baseline and fault conditions for one of the test repeats performed at VTTI at limited top speed and at Bosch Proving Grounds at the target speed specified in FMVSS No. 135. For clarity of presentation, results are shown for a representative trial. The standard deviation of the stopping times were within 8 percent of the mean for normal and surrogate operation and within 3 percent for program control. The top row of plots shows the brake line pressure and reflects the input to the brake system. The bottom row shows the resulting longitudinal acceleration. Moving left to right, the panels show the results for the test executed with the different test execution methods: normal operation using the standard manual controls, human control method using the surrogate controls, and via programmed control. Each plot shows the results for the baseline and two fault conditions.

Normal execution of the test provided a baseline to compare the potential ADS-DV test method options. The antilock braking system (ABS) fault did not impact the brake force required to achieve a given deceleration, so the shape of these curves was similar until the vehicle neared a full stop. For the engine off condition, the brake line pressure application rate was steeper, and the maximum line pressure was higher compared with the other two conditions. The resulting acceleration profile had a steeper onset with a greater level of deceleration. After 2.6 s, the brake pressure decreased as did the acceleration, resulting in the shortest stopping time for the cases shown.

The surrogate controls used for the human control method did not provide force feedback to the operator. In addition, since the brake actuator was sized to operate well within its limits, the maximum brake actuation force was limited by the ADS. Because the primary feedback provided to the driver was through kinesthetic and visual cues, the baseline (cold) and engine off condition resulted in similar actuation and response since the feel for the operator and resulting actuation of the vehicle was the same. For the ABS fault condition, the brake line pressure and corresponding deceleration levels were lower. This was likely due to perceived wheel slip. With the brake input being limited, the subsequent stopping times were slightly longer than stopping times recorded under normal operation.

For program control, a target acceleration level was defined. The results show a consistent acceleration profile between the cold and engine off conditions. However, the ABS fault condition resulted in wheel slip with the sudden onset of the brake application at approximately 2.6 s during maximum deceleration. While the ADS brake implementation was able to stop the vehicle at a similar stopping distance as seen in normal operation, in the ABS fault condition, the profile was not as consistent as for the cold and engine off condition. The results demonstrate that execution of the tests is possible for the two different ADS test methods implemented. The variability seen is a function of the implementation of the test method rather than the test method itself. Just as different brake systems demonstrate different characteristics due to the way they are implemented, it is reasonable to expect implementation of a particular test method could also result in intermediate differences while still complying with the standard.

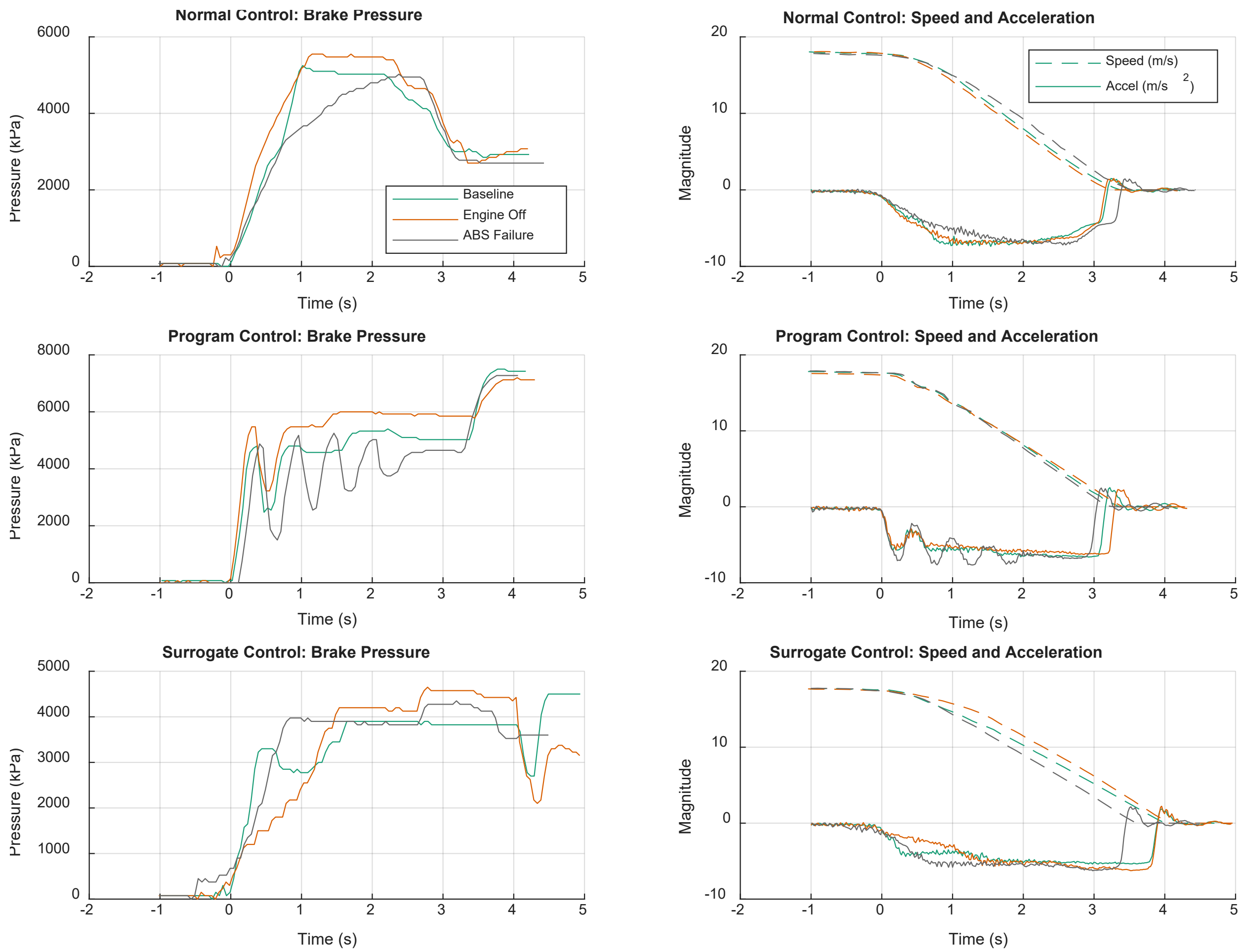

Figure 5. Comparison of the three test execution methods collected at limited speed conditions

Figure 6 shows the results for full speed testing executed by a professional driver. The left plots show the consistency that can be achieved by an experienced human driver. It is interesting to see how the brake line pressure decreased slightly during the braking event, which kept the deceleration level nearly constant at 5 m/s^2 for all three conditions. Using the surrogate controls with no force feedback, the driver was again able to produce consistent results across the three conditions. However, compared to normal operation, the brake line pressure increased through the braking event, which caused the resulting deceleration level to increase from 4 m/s^2 to 6 m/s^2 during the brake event. This resulted in a slightly shorter stopping time.

Between the first round of testing at the reduced speed and the final testing performed at full speed, the braking control algorithm was further refined to improve performance. We see this in the third frame compared to previous testing. Compared to normal operation, the program control had a similar deceleration profile at the higher initial speed. The cold test condition had a deceleration level approximately 1 m/s^2 lower than the other two conditions, resulting in a stopping time that was longer (1 s).

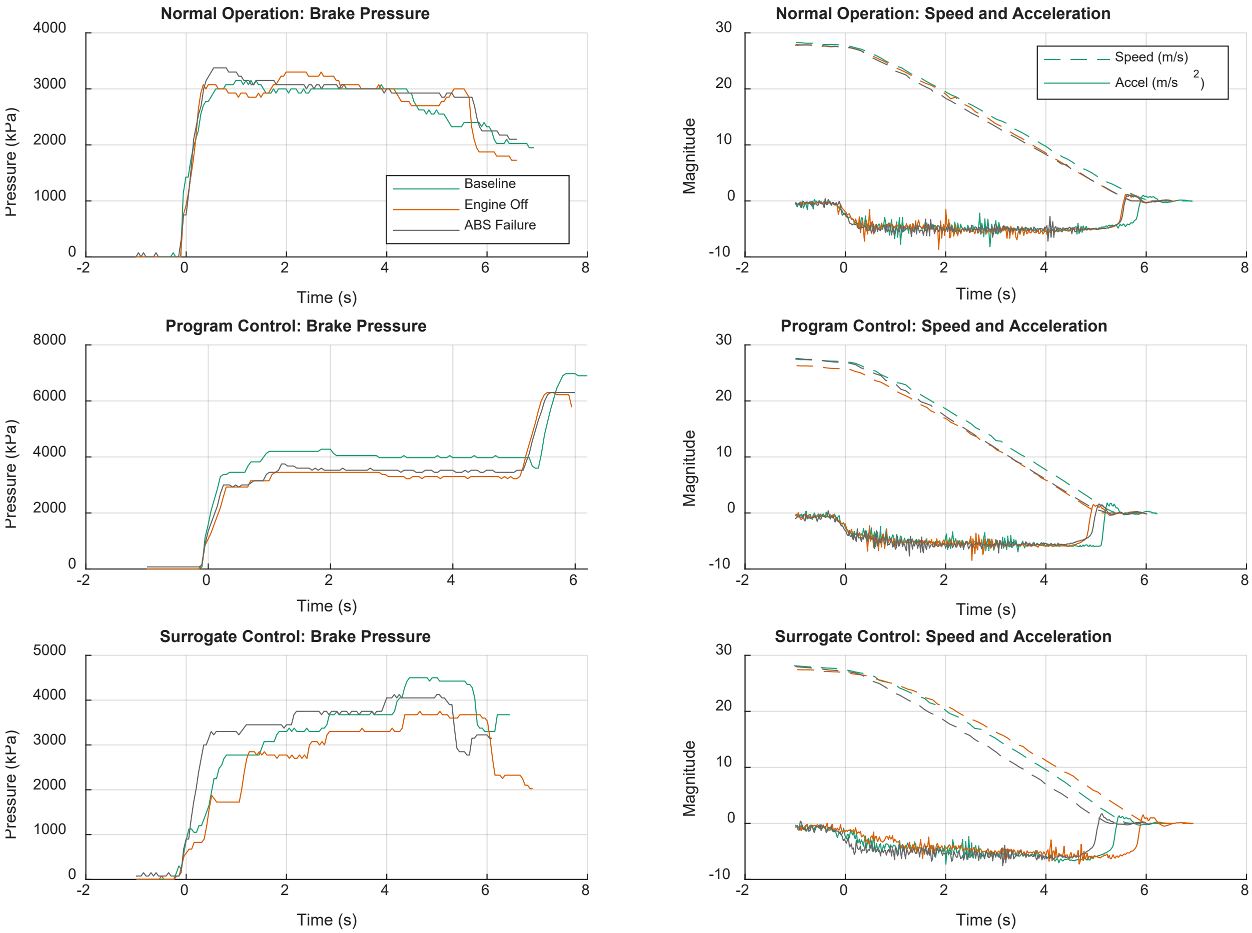

Figure 6. Comparison of the three test execution methods collected at target speed by professional driver

The results from testing with the VTTI test platform demonstrated the viability of the two test methods to perform the functionalities required for execution of the compliance test procedures. Results also showed that, as with testing today, the skill of the driver influences the consistency of the vehicle's operation. Similarly, the implementation of a control system for the ADS can also affect the vehicle's response behavior.

Discussion

The following provides a discussion of the results based on the objectives outlined in the introduction and restated here in bold

Determine if an ADS can execute the test procedures as currently written
The human control test method was capable of test procedures execution; however, without feedback on the surrogate control, the brake pedal force did not necessarily meet the intent of the input requirement. The program control produced repeatable results, as expected from a robotic control. Since an ADS is the only operator of an ADS-DV and the vehicle has no manual controls, input force may not have a meaningful analog since, by design, the ADS brake system will have to be designed to provide adequate inputs to comply with the stopping requirements.

Identify what the ADS cannot do and why
The ADS may not be able to run in programmed control if a fault state is introduced into the system that precludes the vehicle from moving. A fault introduced during the test procedure could initiate a predetermined response that is inconsistent with the defined test procedure.

Identify what must be done outside of normal operation to execute test procedures
A target deceleration level of 0.6 g was defined for the emergency brake tests rather than using a specific input force. While this provides a level that will allow the vehicle to meet the stopping distance requirements, it does not necessarily demonstrate the maximum braking force and thus the stopping distance that the vehicle is capable of, and which could be utilized in a real emergency condition.

Another requirement is that the fault states must be ignored. In normal operation, these fault states are likely to initiate a fallback condition that would preclude execution of the test.

ITP Testing

To further explore the applicability of the test methods identified as potential options for execution of the compliance verification test procedures, the VTTI team engaged companies actively developing ADS-DVs to provide input and perform the same test procedures or their variation of the procedures. The goals for doing this activity with the ITPs were as follows.

- Determine if an ADS can execute the test procedures as currently written;
- Identify what must be done outside of normal operation to execute test procedures;
- Identify what the ADS can and cannot do and why;
- Identify what ITPs think are equivalent procedures or other options for evaluating the intent of FMVSS No. 135 and, ideally, why; and
- Identify areas of the standard or test procedures that may not be applicable for ADS-DV (e.g., specific failure modes).

Three ITPs agreed to participate in the FMVSS No. 135 evaluation. These ITPs included a traditional OEM, a technology company, and a company focused on the development of ADS-DVs. These ITPs also provided examples of both the program test method and the human control test method, with one ITP implementing both methods and the other two implementing just one test method.

The VTTI team met with each ITP to discuss their intended approach for testing FMVSS No. 135, which test conditions might be most challenging or revealing for an ADS, which fault conditions they would recommend be implemented, and how they would implement the fault conditions. During the testing, a team from VTTI was also onsite to observe and to discuss the implementation and testing with the ITP representatives.

The following sections provide a description of the results for each of the ITPs. This is followed by a summary of the ITP testing.

ITP 1

This ITP showed that a power brake unit failure, rather than failed antilock, would be a better fault to demonstrate potential considerations for ADS-DV compliance verification testing. This approach could engage secondary systems and demonstrate a more challenging fault to introduce. The final conditions they implemented are shown in Table 2.

Table 2. ITP 1 Vehicle Conditions Tested

Test	Section	Transmission	Speed (km/h)	Pedal Force (N)	Deceleration	Performance Requirement
Cold	7.5	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 70 m
Engine off	7.7	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 70 m
Power brake unit failure	7.11	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 168 m

Vehicle and Fault Description

The vehicle provided by the ITP was designed to operate as an ADS-DV. There are redundancies present for driving and safety-critical systems, including computing, braking, throttle, sensing, power, and steering systems. The way that these redundancies were built into the system required the ITP to identify where and how to introduce the faults into the system. The ITP executed the tests using program control and surrogate control. The surrogate control was implemented using a remote control (RC) console external to the vehicle. The RC console is also how the ITP positioned the vehicle at the starting location for the program control tests.

For program control, the ADS had building blocks for the different functionalities. These building blocks or primitives had parameters that set the behavior for a given action. Assembling a script using the building blocks allowed a sequence of commands, such as those defined in the test procedures, that enabled the ADS to repeat the test in a consistent manner within the constraints of the vehicle during intended or expected operation.

The vehicle includes a primary and secondary brake system to create redundancy. Each system is configured with separate braking parameters. The primary brake system is configured to comply with the requirements of FMVSS No. 135. However, it limits the maximum level of deceleration to balance safety, comfort, and control. The secondary system, which activates in case of a failure in the primary system, does not limit the deceleration. Therefore, when a fault is introduced into the primary system, the secondary system may brake harder than the primary system, resulting in equal or shorter stopping distances.

To introduce a power brake unit failure, a wirelessly activated relay cut the power to the brake electronic control unit (ECU). The secondary system initiated a fallback braking condition when the system detected the fault. The testing explored if the switch's latency could impact compliance verification. To assess this condition, the fault injection occurred after the initial onset of braking.

The vehicle's primary power system had a 12-volt back up to allow the system to perform safety critical actions. To replicate the engine-off fault, a relay was introduced into the system as a high voltage supply interrupt. A wireless connection to the relay allowed the tester to activate the relay to execute the interruption during the test. The fallback condition for this failure brought the vehicle to a stop along the current planned path at a predefined deceleration.

Test Execution

The ITP used the same general test procedures implemented on the VTTI test platform as described previously. The procedures were defined using a sequence of driving primitives as described above. The fault was remotely triggered when the experimenter observed the brake lights come on, which introduced an element of human variability.

This same approach to fault detection was used for the human control method. While a single individual could conceivably remotely operate the vehicle and trigger the fault, for this testing, two individuals carried out these functions. This allowed the operator to focus on vehicle control.

For each of the two test methods, baseline conditions (i.e., cold condition) were run followed by three trials of both the power brake unit fault and the engine off fault. The wireless remote used to activate the fault relay had a limited range. Therefore, the experimenter initiating the fault had to be relatively close to the point where the onset of braking occurred.

Results

The plots on the following page (Figure 7, Figure 8, and Figure 9) summarize the test results. Both axes have been normalized based on the maximum magnitude and duration observed during testing. Each plot shows the speed, acceleration, front and rear brake pressure (in volts), and primary and secondary brake torque.

Program Control

Figure 7 shows three trials for the baseline condition. While the first trial (00062) shows some variability in the level of acceleration, the second two trials show a relatively constant acceleration between 25 percent and 35 percent of the maximum deceleration recorded, resulting in a linear decrease in speed from the initial speed to a full stop.

Figure 8 shows the results for the primary brake unit failure (which corresponds to the power brake unit failure) implemented by cutting power to the primary brake ECU. Since the fault was injected after the onset of braking, there was a similar shape and level to the acceleration at the start of the braking event, where the acceleration dropped to a low of between 25 percent and 50 percent of maximum deceleration before stabilizing. When the power was cut to the primary brake ECU, the primary commanded brake torque ("Brake torque 1") dropped to zero. At the same time, the secondary commanded brake torque had a step function to the value of the last primary commanded brake torque. During this failure event, the brake pressure dropped, resulting in a reduction in deceleration towards zero. This was also seen in the flat section in the speed curve. The secondary brake system continued to command higher torque values until the target acceleration level was reached (or exceeded), at which point the commanded torque and acceleration level were similar to the baseline condition. The latency during this transition was most salient in the speed, and for each we see that there is a lag time lasting a little less than 0.1s. For the first trial, the timing of the fault introduction, in conjunction with the slight overshoot in the initial deceleration level, may have caused the subsequent larger deceleration (the maximum shown), and thus the shorter time to stop. The subsequent trials where the fault injection occurred during near constant deceleration had a similar shape to the command and deceleration curves.

The engine off fault condition, shown in Figure 9, shows a deceleration profile very similar to the last two baseline conditions for the first 30 percent of the event. At that point (and shortly after the onset of the braking event in the third trial) we see the effect of the high voltage power being interrupted. For this fault, a higher level of braking was commanded, resulting in higher line pressure and a deceleration that was more than twice the nominal deceleration level during baseline braking. This subsequently resulted in a stopping distance that was shorter for this fault condition compared to baseline. We will discuss this further in the key findings section.

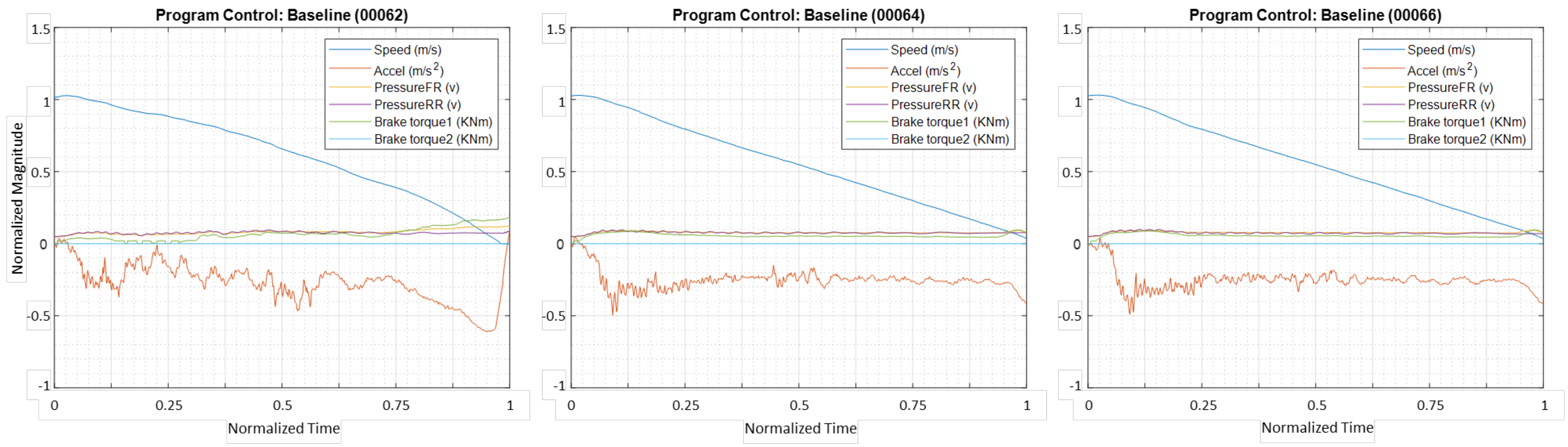

Figure 7. Program control baseline test results

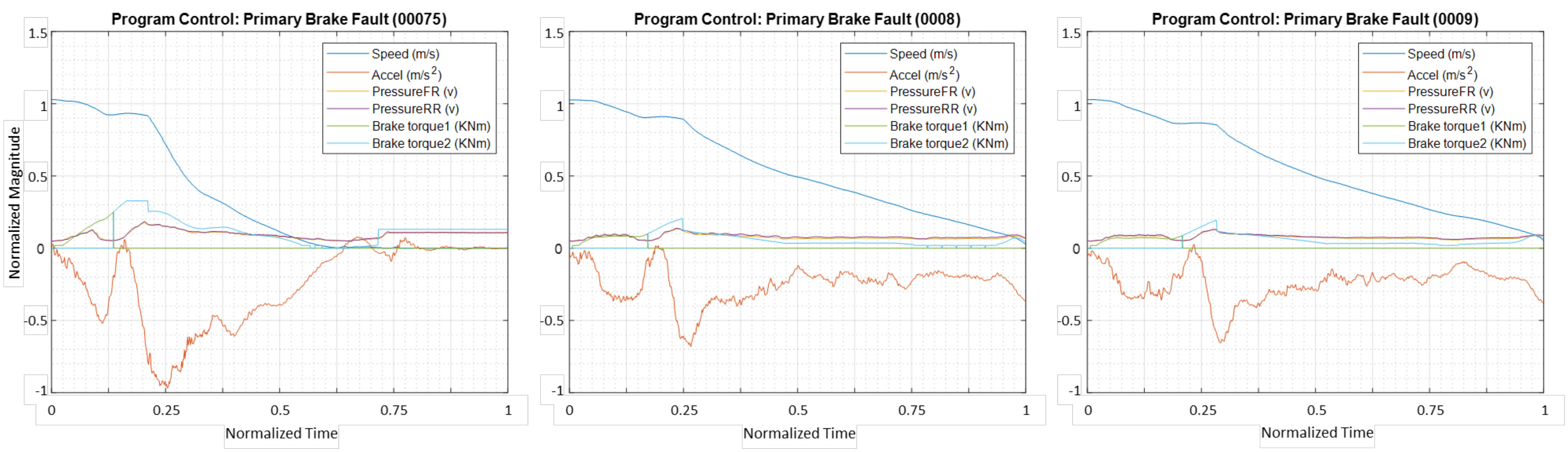

Figure 8. Program control primary brake fault

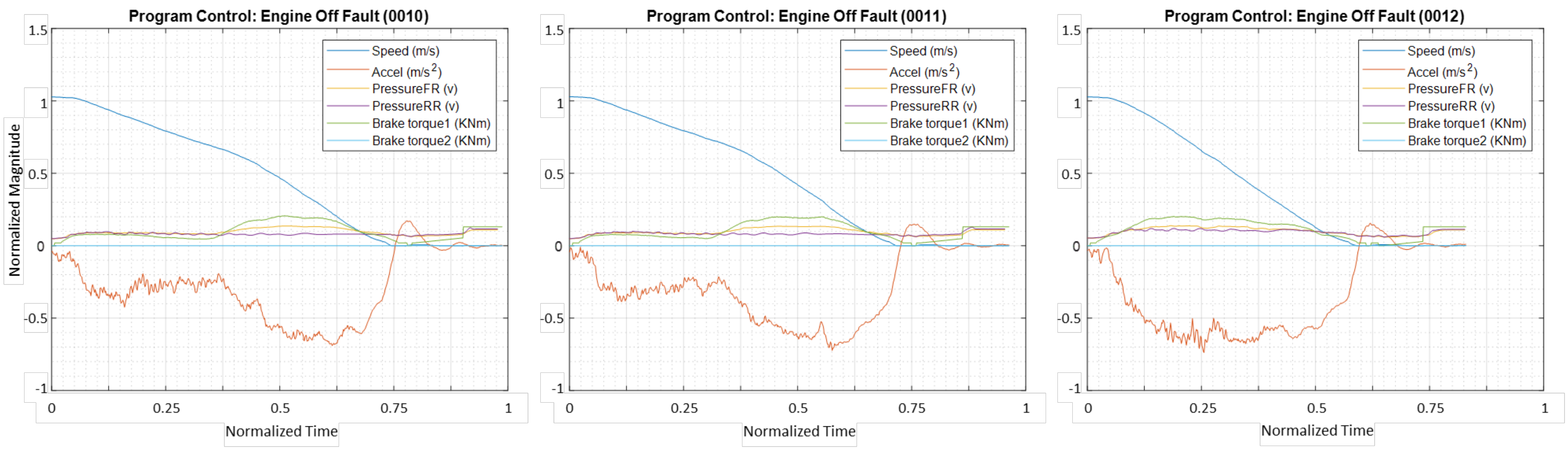

Figure 9. Program control engine off fault

Human Control

For the human control baseline condition, only two files were recorded. Figure 10 shows the baseline results from these trials. As discussed previously, human control for the vehicle was done external to the vehicle via an RC transmitter. The purpose of the control console was to allow movement and positioning of the vehicle outside the normal operational workflow of the vehicle (e.g., moving in and out of a garage area). While the console did allow for motion control of the vehicle, it did not provide feedback to the operator. Consequently, the only indication of speed and acceleration of the vehicle was through visual cues. This put more dependence on the skill of the operator when compared to programmed operation. A comparison of the requested brake force between the program (Figure 7) and human control (Figure 10) shows a greater variability with the human control. However, a skilled driver with an interface designed to mimic existing driver controls could have similar performance as the program control, as observed in the VTTI human controls testing (Figure 5 and Figure 6).

The plots shown in Figure 10 reflect the input variability for the brake torque and subsequent response. The starting speed was slightly lower, and the shape and magnitude of the acceleration profile were less consistent compared to the program control trials. This made identification of the brake event onset less obvious. This is particularly noticeable in the first of the two graphs. The step seen in the command torque at 0.6 indicates the onset of emergency braking. However, the preceding deceleration resulted in a 10 percent reduction in velocity. The variability shows the dependence on operator skill and potential to introduce noise into the results. For these two cases, the stopping distance, as reflected in braking time, was approximately 50 percent longer for the first trial and 50 percent shorter for the second compared to the program control, which was a normalized stopping time of one (Figure 7). However, if brake torque or the first large drop in acceleration is used to indicate brake onset for the first trial, the stopping time is in line with the program control. While the vehicle is compliant with the longer stopping time, it does demonstrate a potential consistency difference between the two test methods. Since the operator is remote, variability may be exacerbated by the lack of proprioceptive or controller feedback.

Figure 11 shows the results for the primary brake unit failure (which corresponds to the power brake unit failure) implemented by cutting power to the primary brake ECU. These plots correlate to the programmed control results shown in Figure 9. Looking at the first two graphs in Figure 11, we see that when the fault was introduced (at 0.14 s and 0.175 s), acceleration approached zero as speed remained nearly constant. As expected, the latency was the same for both the human and the program control (< 0.1 s). The third graph is slightly different: at the onset of the brake event, the fault was already introduced into the system (as seen in the brake torque 2 line) due to the variability in coordinating the fault introduction by the two operators. Consequently, there was no point when the speed profile flattened out corresponding to the primary to secondary switchover. This is another example of a potential challenge in performing compliance verification using this embodiment of human control—executed by two operators.

Since the engine off fault condition had a fall back condition independent of the requested brake torque, the brake levels shown in Figure 12 were similar to those for the program control in Figure 8, where a higher brake torque was requested, resulting in higher deceleration versus baseline conditions for program control. The reason for the more gradual onset of the brake torque request for the third trial is uncertain but may have been due to the higher initial speed.

However, as it is the vehicle response to a fallback condition, the vehicle does still execute the functionalities required during compliance verification.

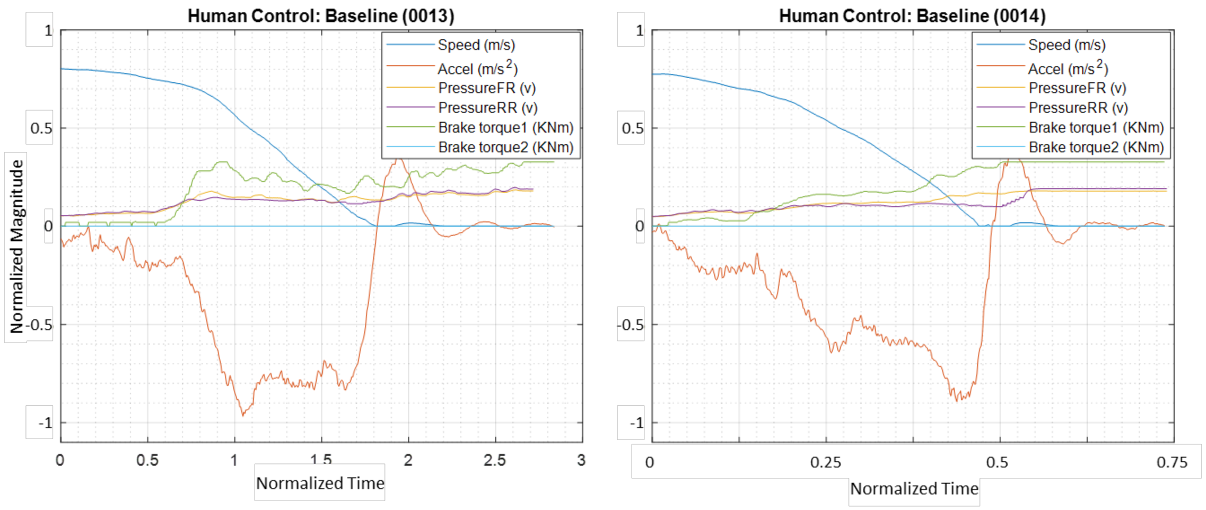

Figure 10. Human control baseline

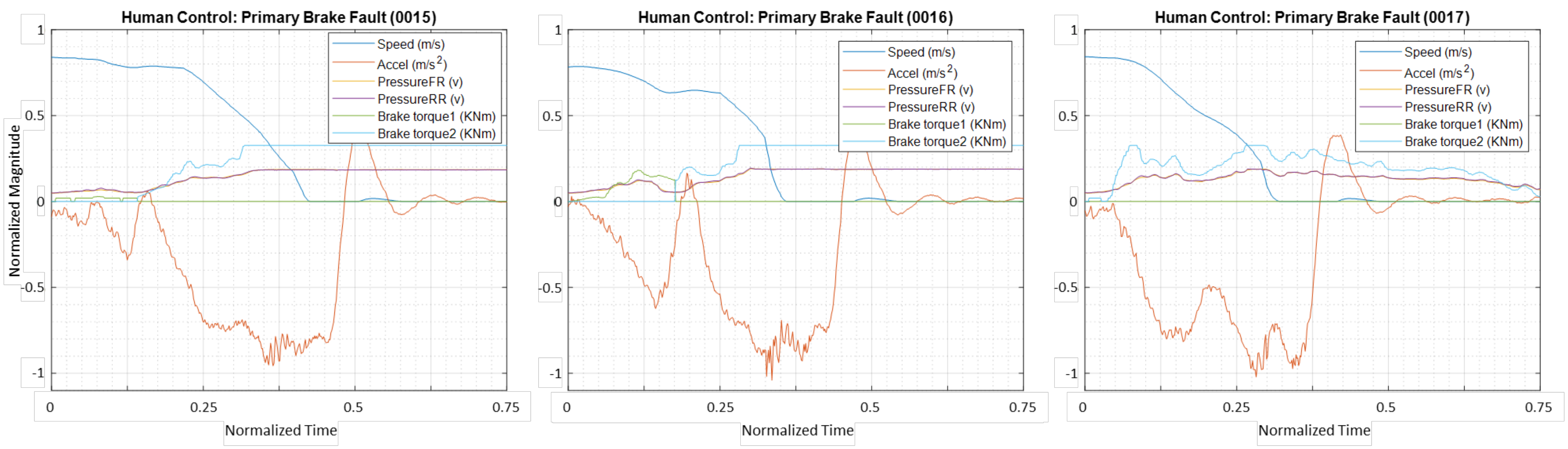

Figure 11. Human control primary brake fault

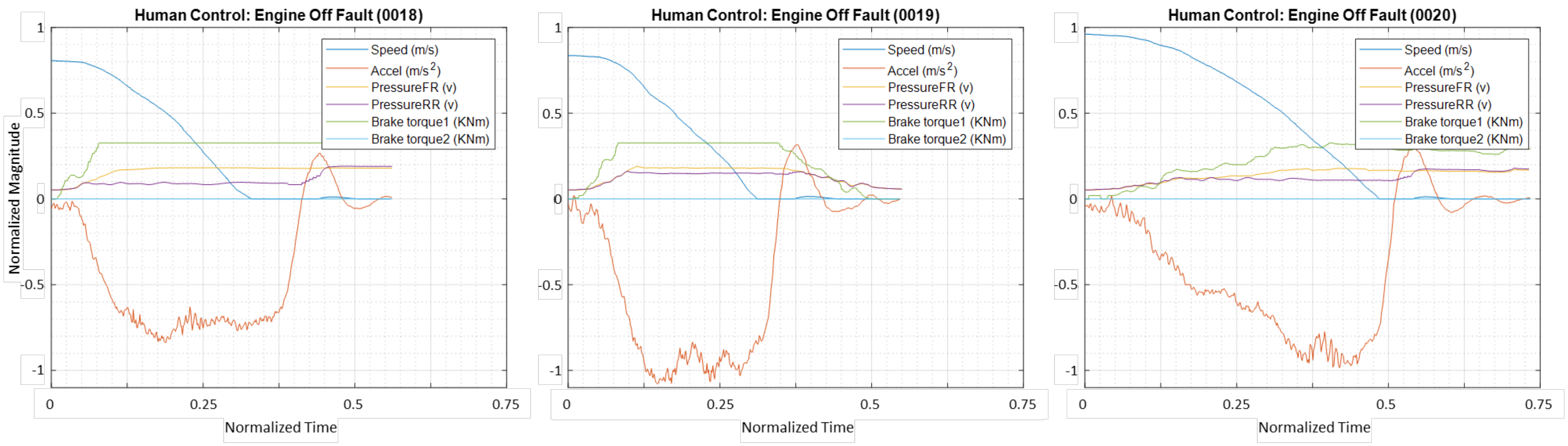

Figure 12. Human control engine off fault

Discussion

The following is a summary of considerations for FMVSS compliance verification testing based on discussions with the ITP about ADS-DV testing and the testing results.

It should be noted that for this ADS, a fault state requires a system reboot to reset the system. This was unique to this ITP and may not be indicative of other ADS-DVs' behavior. However, it is worth noting as a potential challenge, as a reboot does increase the test cycle time for the fault conditions.

- Program and human control methods were able to execute the functionalities, including the fault injection, used in the test procedures. However, as seen in the testing results using the VTTI test platform and with ITP 1, there is the potential for more variability based on the skill of the operator and the type of interface.
- With the safety measures and redundancy that are designed into the ADS-DV to ensure safe operation, the system had to be modified to introduce the fault during the test sequence. While other solutions may exist, such as modifying the software to allow the vehicle to operate with a known brake system fault, the approach that the ITP chose to implement captures the vehicle's response to a failure.
- Manually introducing the fault post brake onset demonstrates an effective method to interrupt normal operation. The way that the fault is injected could result in additional variability due to timing inconsistencies relative to braking onset.
- Secondary and redundant systems on an ADS-DV may allow the vehicle in a fault condition to perform similarly to normal emergency braking. In subsequent discussions with industry and NHTSA, this observation has raised the question about whether the current failure modes effectively evaluate the performance of the brake system and associated components in a fault condition.

ITP 2

ITP 2 also showed that a power brake unit failure would be a better fault to demonstrate potential considerations for ADS-DV compliance verification testing. The engine off failure is present to demonstrate the effect of losing vacuum brake assist. This ITP's vehicle did not use a vacuum boost; therefore, the engine off condition would not affect the brake system. Cutting the power to the power brake unit represented a more acute failure mode. In addition to cutting the power, this ITP also cut the communication channel to simulate another form of power brake unit failure. The final conditions they implemented are shown in Table 3.

Table 3. ITP 2 Vehicle Conditions Tested

Test	Section	Transmission	Speed (km/h)	Pedal Force (N)	Deceleration	Performance Requirement
Cold	7.5	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 70 m
Power brake unit failure	7.11	neutral	100	≤ 65; ≤ 500	n/a	S ≤ 168 m

Vehicle and Fault Description

The vehicle tested was designed to operate as an ADS-DV, though the vehicle also had manual controls. The ITP used the program control test method to implement the test procedures based on a defined sequence of driving primitives, which is the way they intend to verify compliance. The vehicle used included a test interface not present in the normal platform that consisted of both software and hardware allowing unique control of the ADS. This functionality allowed the ITP to introduce faults throughout the system, including the brake system, via software. The faults were initiated immediately prior to the programmed brake onset. Between trials, to expedite testing, the experimenter positioned the vehicle using the stock or manual driving controls. Other means to set the vehicle's initial position could have been used.

The ITP test vehicle had redundancies to ensure safe operation in case of a failure. Relevant for FMVSS No. 135 testing, these included redundancies in the brake system and communication channels. During the demonstration, the ITP chose to use different driving primitive control interfaces between the primary and secondary brake systems. For the primary brake control, the braking profile was defined to balance safe stopping and occupant comfort. The secondary control prioritized stopping. This can be seen by comparing the torque requested and resulting pressure for the primary and secondary brake systems (Figure 13 and Figure 14) and will be discussed further in the results section.

Test Execution

The ITP used the same general test procedures implemented on the VTTI test platform. Between the conclusion and start of each trial, the experimenter positioned the vehicle using the manual controls and executed a specific stop/go sequence. The baseline case was performed at the start and end of the power brake unit failure condition. The ITP performed six test runs in the fault condition as specified in FMVSS No. 135 test procedure (S14.18.3.E). In addition, a failure of the communication system to demonstrate the redundancy. As such, no difference was observed in the operation of the system.

Results

The data channels recorded during the test and used for comparison included these.

- Vehicle speed
- Acceleration
- Commanded brake torque
- Actual brake torque
- Brake pressure

The data shown are normalized. The performance of the system was consistent across repeated trials, showing a difference of less than five percent. For clarity, results are shown here from a representative trial. The right plots in Figure 13 and Figure 14 show a reduced set of data to highlight the timing of the command and response of the brake system (line pressure) and vehicle (acceleration). The brake torque and acceleration signs were switched to compare the signals more easily.

As mentioned, the control interface chosen for the test used a driving primitive that modified the requested command torque, which changed the brake pressure throughout the braking event to have a target deceleration profile. This profile tapered from a maximum deceleration to nearly zero as the vehicle slowed to a stop. This approach allowed the ADS to stop the vehicle within the minimum performance requirements set forth in FMVSS No. 135 with a profile that is less severe (based on jerk) and smoother to the occupant(s) (compare the deceleration curves in the right plot in Figure 13 and Figure 14).

In case of a power brake unit failure, the ITP configured the braking primitive, which commands a maximum brake torque throughout the braking event. The onset of this occurs with a step-like input. Given the redundancies in the ITP test vehicle, the different driving primitive, which maintained a higher average brake pressure through the braking event, resulted in the vehicle stopping sooner in the fault state than in the baseline condition.

The variation in brake profiles of the two primitives is analogous to how two people may apply the brakes differently. An example of this is shown in the results from the testing performed with the VTTI test vehicle using two different drivers (Figure 5 and Figure 6). The maximum braking was similar, but the first driver did not apply the brakes as quickly.

For both the primary and secondary system operation, the response of the system followed the commanded torque closely. The primary brake system stopped the vehicle with a standard error of 0.6 percent while the secondary stopped it with a standard error of 1.7 percent.

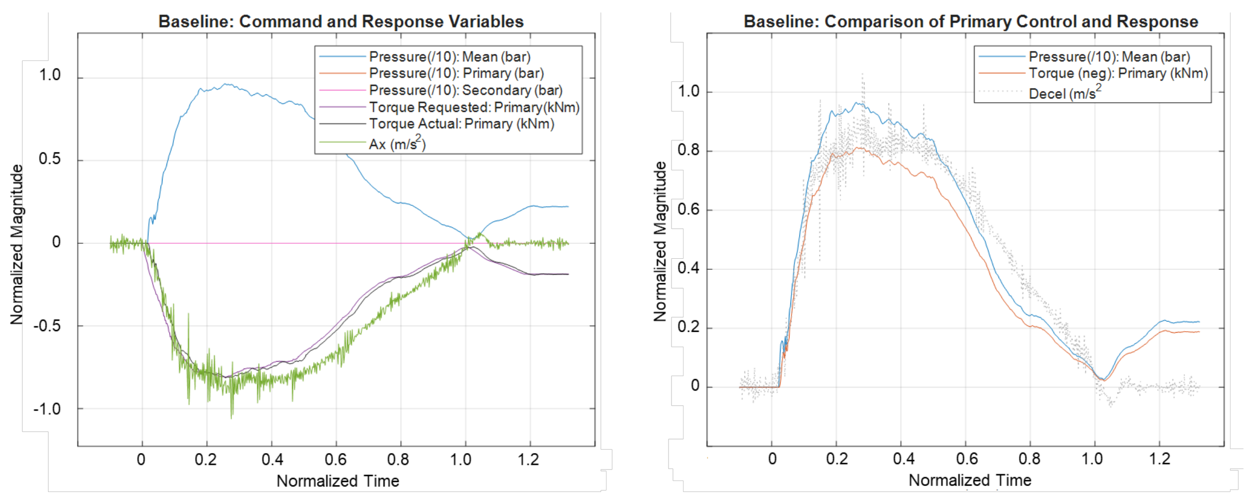

Figure 13. ITP 2 baseline brake system performance (normalized magnitude versus normalized time)

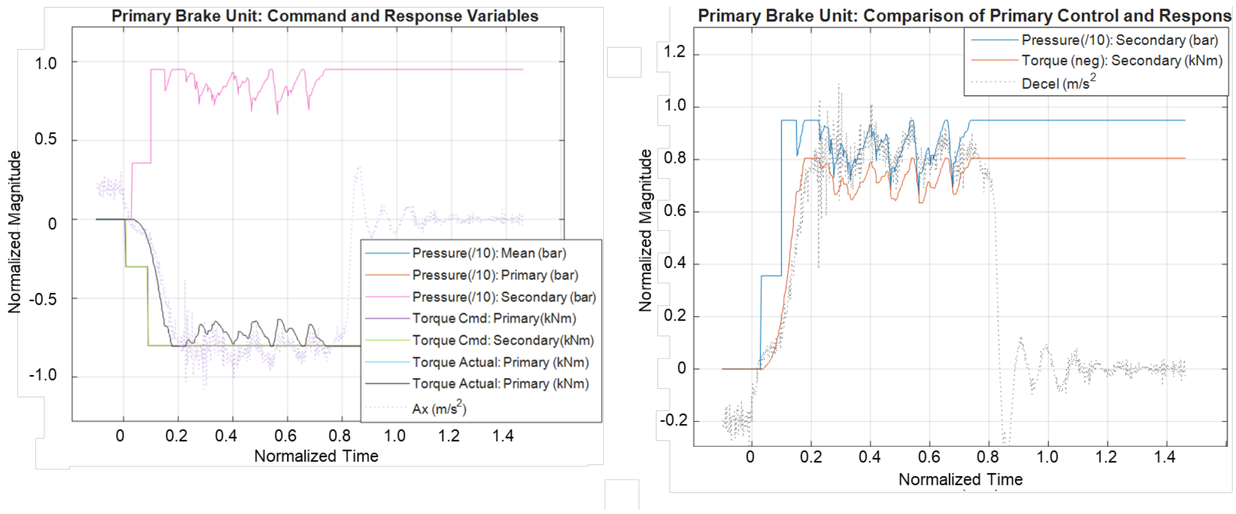

Figure 14. Power failure of primary brake unit (normalized magnitude over normalized time)

Discussion

The ADS required modifications to allow the execution of the current FMVSS No. 135 test procedures. For the fault conditions, the modifications provided a means to command braking as well as the hardware to inject the fault. These required the ITP's involvement to execute the test.

The requirements in FMVSS No. 135 imply that fault conditions, including a power brake unit failure, will degrade the stopping performance by specifying a stopping distance that is more than double the baseline condition (168 m versus 70 m). However, due to the difference in driving primitives used during the test, the baseline demonstrated longer stopping times compared with the fault condition in which the secondary brake was active. The redundancy eliminates the braking degradation that occurs in vehicles on the road today. Consequently, the fault conditions defined in the standard have the effect of confirming operation of the secondary system when a fault is introduced to the primary braking system.

ITP 3

At the time of testing, ITP 3's testing intent was to create a test buck that could be installed in their ADS-DV to allow full human control to allow them to perform compliance verification in accordance with the current OVSC test procedures. This was the only stakeholder and ITP that was pursuing a production level human control buck that would have similar functionality and feel to a production, non-ADS vehicle. This provided a unique opportunity to have access to an industry developed prototype (compared to a proof of concept) that provided insight into the potential effectiveness and challenges of compliance verification with human control. While the ITP's development schedule for the control buck allowed for operation of the vehicle to demonstrate the functionality in the ADS-DV, the integration of the electrical and electronic (E/E) systems did not support execution of the FMVSS No. 135 test procedures. Therefore, testing consisted of a demonstration of the functionality and capabilities of the interface that consisted of typical driving maneuvers for steering, starting, and stopping, including maximum braking.

Vehicle and Fault Description

The vehicle tested was designed to operate as an ADS-DV. To support human operation of the ADS-DV, the ITP developed an interface to the ADS that allowed manual access through standard controls (buttons, steering wheel, pedals, etc.) that had typical feel and function. The interface (Figure 15) was intended to provide a driver full control through the operating range of the vehicle with appropriate feedback to the operator. For compliance testing, this facilitates the execution of the OVSC test procedures as currently written.

Figure 15. Human control interface for ITP 3 ADS-DV

This was a full drive-by-wire configuration for the vehicle. As with current drive-by-wire systems in vehicles on the road, this made it possible to set the transfer function between the human control and the vehicle to obtain the desired performance characteristics. While not demonstrated, this configuration should allow the fault conditions to be introduced in a manner similar to the way they are done today.

Test Execution

As noted previously, the human control interface was still in development. As can be seen in Figure 15, the physical controls where present, however, the integration into the E/E systems was still in development. Since this integration was not complete, it was necessary to run the vehicle with the chassis controls (ABS, ESC, traction control system, etc.) were turned off. While this did not allow execution of the OVSC test procedures, it did demonstrate the driving functionalities (e.g., lateral control, longitudinal control, ability to coast, etc.) that are needed to execute these procedures. This highlights a potential challenge that was expressed during the symposiums and stakeholder meetings held as part of this project (Volumes 1 and 2, Blanco et al., 2020, Chaka et al., 2021). Integrating a test interface into the E/E system of an ADS-DV that supports execution of the test procedures creates an attack surface that would not necessarily exist otherwise. This may compromise the safe operation of the ADS-DV unless done in an intentional manner with security in mind.

The ITP ran two braking conditions: hard, controlled braking and maximum braking. These were selected to show the brake system's response to a large input and the controllability of the brake system. The procedures followed the basic structure for low-speed vehicle brake tests. The vehicle accelerated up to 25 mph, coasted to 23 mph, and force was then applied to the brake pedal.

Results

The data channels recorded during the test and used for comparison included these.

- Pedal force
- Vehicle speed
- Wheel speed
- Longitudinal acceleration

Figure 16 shows a comparison of the two conditions for the above response variables. The top plot shows the input force at the brake pedal, the middle shows acceleration, and the bottom plot shows vehicle and wheel speed. While the values have been normalized, the pedal force during maximum braking was near the upper operational range specified in FMVSS No. 135 that is 65–500 N. With the ABS disabled, the maximum braking condition resulted in wheel lockup, as expected. We see this in the second frame of Figure 16, where the wheel speed went to zero at 0.25 and the vehicle speed reached zero shortly before 0.7. We also see that even though the pedal force dropped by approximately 40 percent during the maneuver, the wheel lockup state remained. This would imply that the maximum pedal force exceeds the level required to lock up the wheels.

For the hard, controlled braking condition, the maximum pedal force was applied more gradually where the peak force was approximately 20 percent of the peak recorded during maximum braking. Unlike the previous condition, wheel slip only occurred briefly (starting at 0.6). This coincided with the maximum deceleration (0.6). At 0.65, we also see the acceleration curve starts to display similar characteristics shown for maximum braking where the vehicle "chatters" likely due to wheel hop. This divergence between wheel and vehicle speed indicates the vehicle was braking at the limit. However, the human control interface provided the driver with sufficient feel and control to be able to reduce brake force to minimize wheel slip.

The time scale is normalized; however, a sense of scale can be deduced based on the low-speed operation and the duration of the pulse seen in the acceleration and vehicle speed when the vehicle stops and pitches forward and back. There is a delay between when force is applied to the pedal and when the vehicle starts to decelerate. It is most apparent in the hard brake condition where pedal force starts to increase at zero, but the vehicle does not start to decelerate until approximately 0.13. This is likely in part due to a deadband for the initial travel of the pedal that is typical in vehicles.

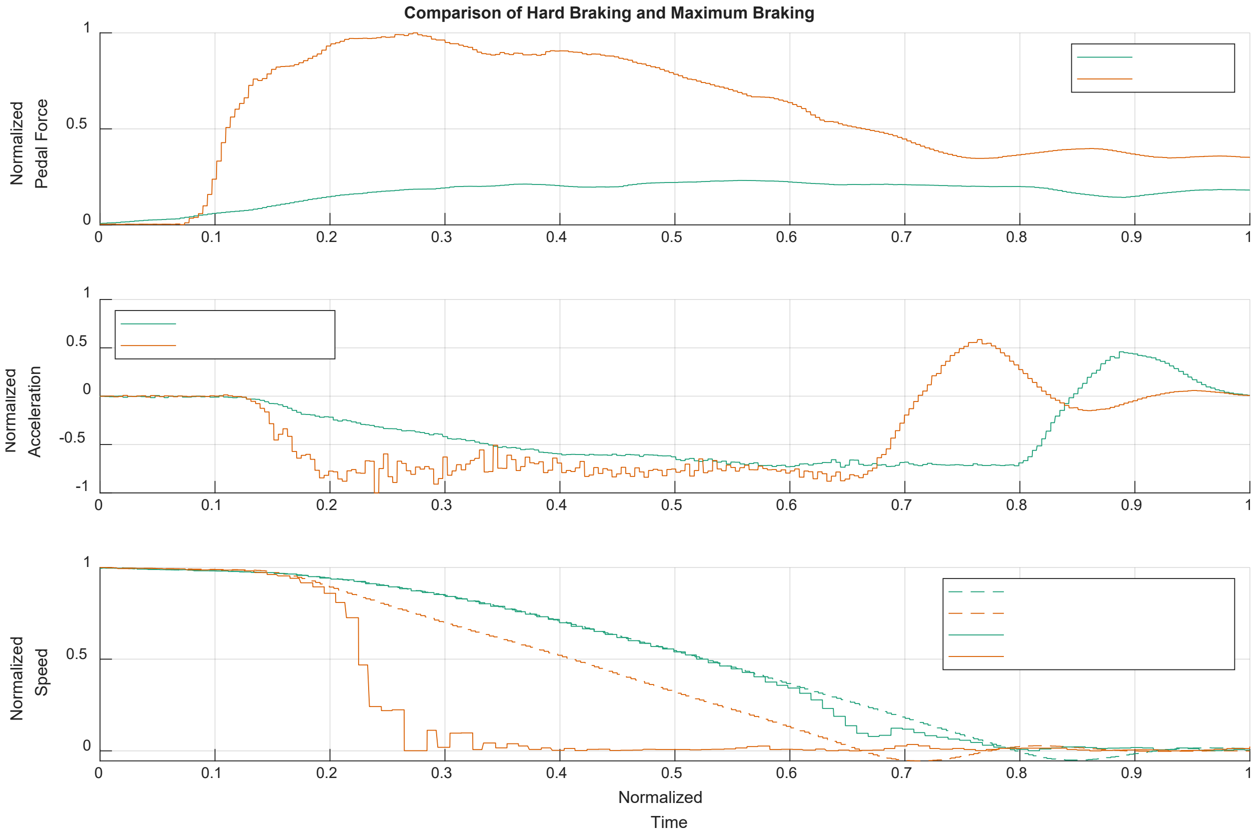

Figure 16. Results of hard and maximum brake application conditions

Discussion

Using this control approach, the vehicle required modifications to allow installation of the human controls and the injection of control commands. In addition, each vehicle required the pedal force to be mapped to an equivalent ADS-requested brake torque to ensure sufficient and controllable brake application. Once installed, the functionality was present to execute the existing test procedures. However, at present, this is not something that a third party would be able to do independent of the manufacturer.

As noted for other ADSs, the level of redundancy may limit operation of the vehicle with a significant failure mode introduced into the system. The ITP noted that redundancies built into an ADS, especially an ADS-DV, may allow the vehicle to stop comparably during a primary failure mode as it does in a non-fault condition. In addition, the ITP commented that the monitoring and redundancy built into an ADS-DV may limit the operation of the vehicle with the introduction of a significant failure mode. These factors may change the purpose of the fault condition testing from confirming a degraded stopping distance to verifying that redundant systems are present and operational.

Key Findings

Here's a summary of FMVSS No. 135 testing carried out by VTTI and the ITPs.

- The testing demonstrated that both program and human control methods were able to execute the functionalities required for compliance verification testing. For human control, the implementation could introduce additional variability based on the skill of the operator and the interface. Controls that more closely mimic those in a standard vehicle may yield more reproducible results.
- Due to the safety measures and redundancy designed into the ADS-DV, an ADS may need to be modified to allow the vehicle to operate or execute the defined driving conditions.
- Secondary and redundant systems on an ADS-DV may allow the vehicle in a fault condition to perform similarly to normal emergency braking. In addition, normal operation may tune the braking to limit jerk compared to redundant operation, resulting in shorter stopping distance in a fault condition (see Figure 7 and Figure 9). This may change the nature of the test from degraded stopping distance to confirmation of backup or secondary systems.
- Given the different implementation approaches of ADS-DVs, manufacturer involvement may be needed to execute the FMVSS No. 135 test procedures.

FMVSS No. 126: Light Vehicle Electronic Stability Control Systems

Test Methods

FMVSS No. 126, Electronic stability control systems for light vehicles specifies a sine with dwell maneuver. The test is made up of two conditioning procedures for brakes and tires, followed by the slowly increasing steer test and the sine with dwell test. The slowly increasing steer test provides a means to characterize a relationship between the steered input and vehicle's lateral response. Based on this relationship, the starting steering angle for the sine with dwell is defined as the steering angle associated with 0.3 g lateral acceleration response during the slowly increasing steer test. The sine with dwell test specifies a steering wheel (or handwheel) input that consists of a 0.7 Hz sine wave with a 500 ms delay during the second peak amplitude. The amplitude of the input is defined as follows:

$d_0 = 1.5*d_{0.3g}$ where $d_{0.3g}$ is the starting angle calculated from the slowly increasing steer test

$d_i = d_{i-1} + 0.5*d_0$ for $d_i \leq 6.5*d_0$ or 270°, whichever is less

To perform this maneuver in a consistent and repeatable manner, the automatic steering controller is mounted to the steering wheel and programmed to provide the steering input. The steering input is initiated at a coasting speed of 50 mph. The steering angle, yaw rate, and lateral acceleration are recorded.

One of the critical aspects of providing technical translations for the requirements specified in FMVSS No. 126 is to determine how the steering inputs for the manual steering wheel could be translated to another component of the vehicle's steering system. A multi-tiered approach was used to develop potential methodologies for such translations. This included a literature review trying to identify potential architectures, static and dynamic scaled-speed, full-scale physical testing using a VTTI platform, ITP testing, and ITP stakeholder feedback.

Research considerations were identified by evaluating the current steering architectures as well as potential architectures expected to be deployed in the future. This research encompassed passenger vehicles, including sedans, SUVs, sports cars, and light trucks. Sedans, sports cars, and SUVs typically use rack-and-pinion steering setups while parallelogram steering systems are more frequently used in light truck applications. Future systems have the potential to exclude a steering wheel entirely, and even traditional steering systems, such as rack-and-pinons, might be removed in favor of direct wheel actuation, with the potential of being actuated independently. After accounting for vehicle steering architectures, a list of required measurements was established to account for supporting potential future steering architectures. This list included the following: (1) pinion angle, (2) rack displacement, (3) road wheel angle, (4) suspension displacement, (5) lateral acceleration, (6) longitudinal acceleration, and (7) yaw rate.

VTTI Testing

The VTTI platform was a modified Cadillac SRX with programmed control for speed and pinion angle. Speed was controlled by tapping into the drive-by-wire throttle. Steering control was performed per the addition of a motor sized to achieve steering rates necessary for performing the sine with dwell maneuver outlined in FMVSS No. 126. The test vehicle sensor suite included sensors to appropriately measure pinion angle, rack displacement, suspension travel, road wheel angle, and an IMU for inertial vehicle response.

Based on the current and potential steering system architecture research, four different control methods were evaluated: (1) steering robot (primary), (2) roadwheel angle control using the average angle (alternate), (3) roadwheel angle control using the unloaded wheel (alternate), and (4) rack displacement control (alternate). The FMVSS No. 126 steering robot actuates the steering wheel and produces the desired angles per the standard. VTTI's testing platform was equipped with a steering motor coupled to the steering shaft to replicate the function of the steering robot and serve as the primary control of steering wheel angle for the testing. The alternate control methods tested included average road wheel angle, unloaded road wheel angle, and steering rack displacement. Average road wheel angle took the two road wheel angle encoders and averaged the results from each to return one value. Since many vehicles have Ackermann steering geometry in the steering system, the wheels are not always equal steering angles, which necessitates averaging the two. Unloaded road wheel angle reports out the value of the unloaded wheel in the sine with dwell maneuver. For example, if the vehicle was to dwell while turning to the right, then the right road wheel angle would be used since the left wheel is loaded when turning to the right. Steering rack displacement was also used. This returned measurements of the steering rack with zero displacement being equal to pointing straight ahead.

Full scale FMVSS No. 126 testing on the VTTI platform occurred at the Bosch Proving Grounds. The test procedure for each of the four control methods consisted of the following tests. First, the tires were warmed-up using the 400-foot radius circle at a speed of 35 mph for three laps in both clockwise and counterclockwise directions. Second, slowly increasing steer tests were executed to determine the lateral 0.3 g value for each control method. During the slowly increasing steer test, the vehicle accelerated to 50 +/-1 mph. The vehicle, starting at 0°, turned clockwise or counterclockwise at a rate of 13.5°/s for the steering motor, 0.82°/s for the road wheel angle, and 0.08755 in/s for rack displacement until the limits of 40 deg, 2.5 deg, and

0.26 in were reached, respectively, each time holding at the max angle for 2 s. Table 4 summarizes the measured 0.3 g lateral values.

Table 4. FMVSS No. 126 Slowly Increasing Steer Measured 0.3 g Lateral Values

Test Method	0.3 g Value	End Value
Steering Motor	-31°/30.3° (L/R)	270 deg
Road Wheel Angle Average	1.2 deg	16.58 deg
Road Wheel Angle Unloaded Wheel	1.5 deg	16.5 deg
Rack Displacement	0.17 in	1.87 in

Sine with dwell tests were performed using the VTTI platform via the vehicle's programmed control. The vehicle accelerated up to 54 +/-1 mph, then was allowed to coast down. When the speed reached 50 +/-1 mph, the sine with dwell steering maneuver would initiate. Upon completion of the maneuver, the test driver stopped the vehicle, then manually operated the vehicle back to the starting point where the next steering amplitude was tested. This process was repeated until the target ending values were achieved. For FMVSS No. 126, the sine with dwell amplitudes are defined by Equation 1.

$$\begin{gathered} Delta = 0.3g\ value \\ First\ Amplitude = 1.5 \times Delta \\ Following\ Amplitudes = \text{First Amplitude} + (0.5 \times Delta) \times (n - 1) \\ \text{where n} = \text{Run\#} \end{gathered}$$

Equation 1. Sine with dwell amplitudes

For the VTTI platform testing, the primary control method followed this formula. However, when testing the alternate controls—road wheel unloaded angle, road wheel average, and rack displacement—runs were incremented by 2 N. This was done to accomplish the tests in the given time window while keeping tire and weather conditions in mind for more accurate comparisons. Figure 17, below, shows the yaw responses of the sine with dwell runs in a single direction for the primary steering wheel control angle, unloaded road wheel angle control, and rack displacement control. The figure demonstrates that regardless of which control method was used, vehicle level yaw responses were nearly identical when the inputs were equivalent to one another.

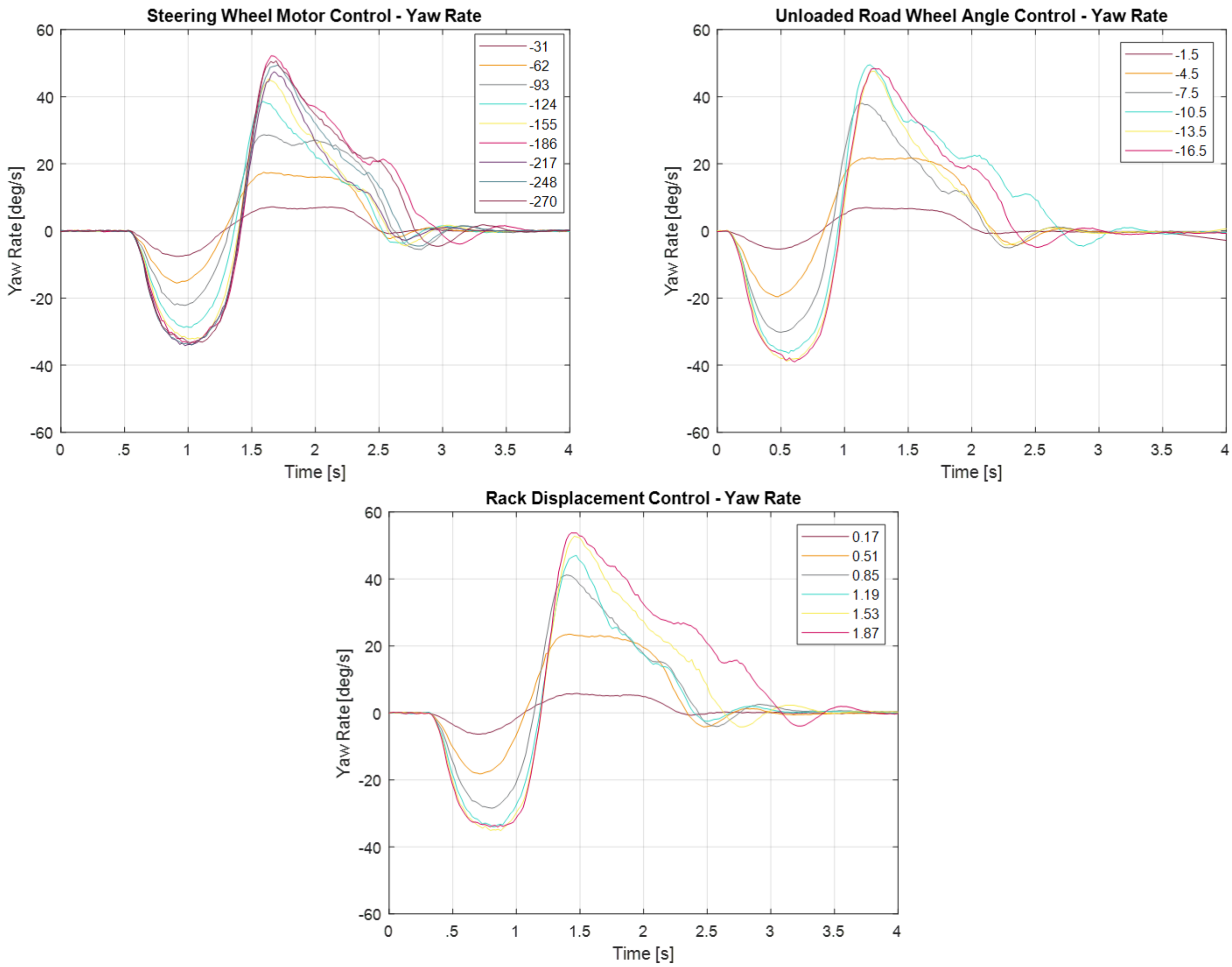

Figure 17. Yaw response of all sine with dwell tests for steering wheel, unloaded road wheel angle control and rack displacement control

To properly compare the steering wheel angle, road wheel angle, and steering rack displacement tests, equivalencies were developed that estimated the handwheel angle from the alternate control. Equation 2, below, details the equivalencies that were determined through static testing by performing several lock-to-lock steering sweeps. This testing was performed at five suspension displacements to ensure repeatability under loaded and unloaded conditions and then the equivalency relations were developed.

$$Equivalent\ Steering\ Input = \ X\ degrees\ road\ wheel \times 16.44\ degrees\ steering\ wheel$$

$$Equivalent\ Steering\ Input = \frac{X\ inches\ rack\ displacement}{0.0065\ in\ rack\ displacement}$$

Equation 2. Handwheel vs. alternate control equivalencies

Once all the tests were completed, comparison analyses were performed on the results. Since the tests were performed independently of one another, a direct comparison to the exact same equivalent angles was not possible. However, there were runs that had similar handwheel angles between the primary and three alternate control tests that can be used for comparison. Table 5 shows runs that were approximately equivalent.

Table 5. Alternate Control Equivalent Angles

Test Method	**Equivalent Amplitude (deg)**	**Steering Motor Control Amplitude (deg)**
Road Wheel Control- Unloaded Wheel	123.3	120
Road Wheel Control- Average Angle	59.2	60
Rack Displacement Control	235.4	240

When comparing the unloaded road wheel angle to the primary control, small differences were observed in the equivalent handwheel angle. Some of the differences may be attributed to controller tuning and additional compliances in the system. Since the motor was mounted in-line with the steering shaft, the load path of the steering system was transferred through the steering rack, by tie rods to the wheel while being acted upon and held in place by the lower A-arm and strut. Under higher load conditions, bushings in the suspension and steering system may have had an effect when compared to the desired wave form. However, the time history vehicle-level responses of lateral acceleration, yaw rate, and roll angle aligned closely, indicating that small variations from the desired wave form may not affect overall response in a significant way. shows the comparison at equivalent steering angles between the steering wheel control and unloaded road wheel angle alternate control, which is the inside wheel during the sine with dwell maneuver. Figure 18 shows the ideal handwheel input equivalent for the steering motor, rack displacement, and unloaded wheel angle controls in black. The red and blue lines indicate the actual command (blue) and feedback (red) for the unloaded wheel control transformed to steering motor, rack displacement and unloaded wheel angle control. Figure 19 denotes the lateral acceleration, yaw rate, and roll angle vehicle responses for the steer motor reference in red and the vehicle response for the unloaded wheel response in blue. Note that for the roll angle response, the x-axis duration of the plot is 4.5 seconds instead of 3.5 seconds like the other plots. This was done to show the entire roll angle vehicle response return to steady state while minimizing impact on the other plots.

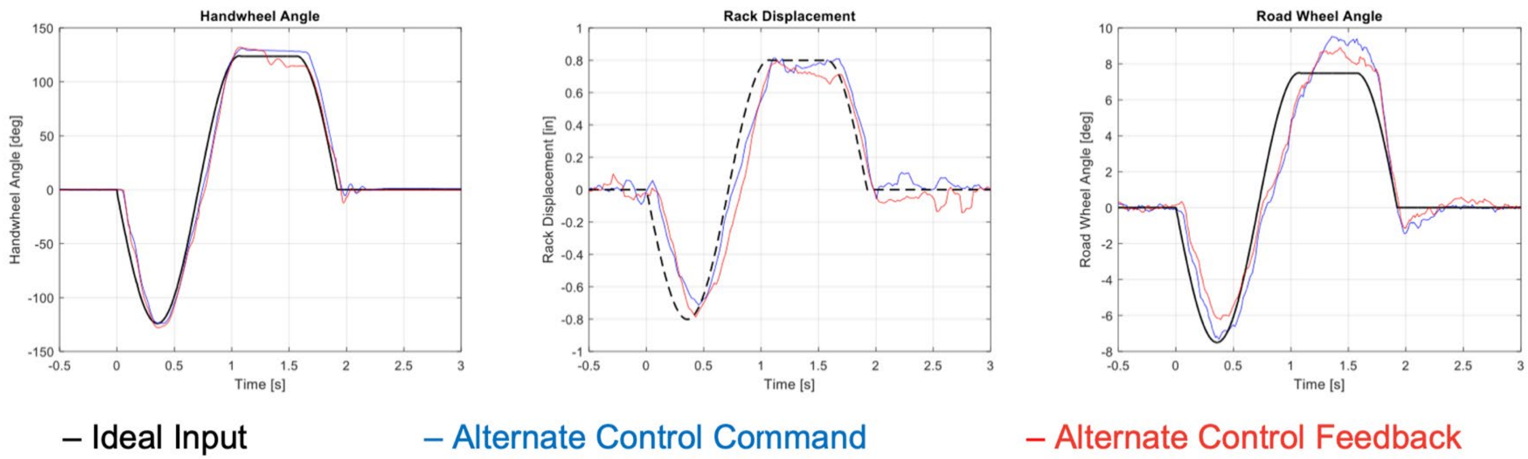

Figure 18. Unloaded road wheel angle compared to steering wheel angle equivalent (Pt. 1)

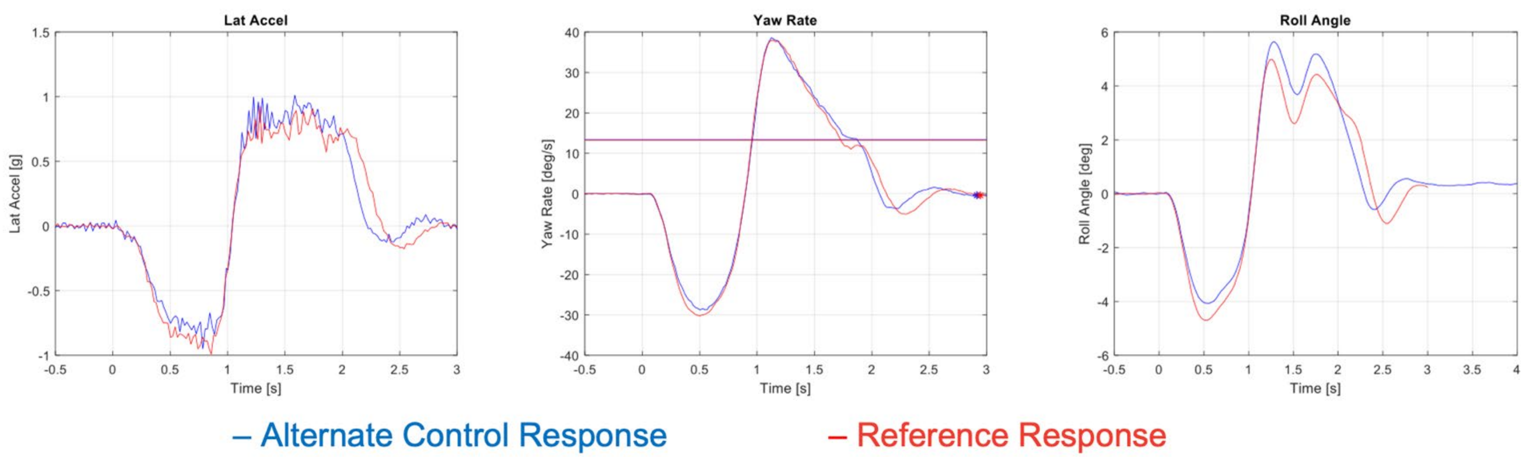

Figure 19. Unloaded road wheel angle compared to steering wheel angle equivalent (Pt. 2)

Comparing relative metrics outlined in FMVSS No. 126, such as 35 percent max yaw rate, 20 percent max yaw rate, and yaw rate completion of steer +1 second, the results were nearly identical, as outlined in Table 6 below.

Table 6. Unloaded Road Wheel Angle and Equivalent Steering Wheel Angle, Yaw Response Metrics

Test Method	Steering Motor Control (deg)	35% Max Yaw Rate (deg/s)	20% Max Yaw Rate (deg/s)	Yaw Rate COS + 1s (deg/s)
Steering Wheel Control	120	13.36	7.63	-0.39
Road Wheel Control-Unloaded Wheel	123.3	13.30	7.60	-0.40

Considering the comparison of average road wheel angle to the primary control, again small differences were seen. Since this method considered the average of both front left and front right road wheel angles, measurement resolution may have influenced signal quality, but the results show how averaging both road wheel angles could be an effective option for technically translating the performance requirements of FMVSS No. 126. Similar to the unloaded road wheel angle comparison from Table 6 and Figure 19, the average time histories align very closely, as do the metrics presented in Figure 18 and Figure 19. Figure 20 shows the ideal handwheel input equivalent for the steering motor, rack displacement, and average wheel angle controls in black. The red and blue lines indicate the actual command (blue) and feedback (red) for the average wheel control transformed to steering motor, rack displacement, and average wheel angle control. Figure 21 denotes the lateral acceleration, yaw rate, and roll angle vehicle responses for the steer motor reference in red and the vehicle response for the average wheel response in blue.

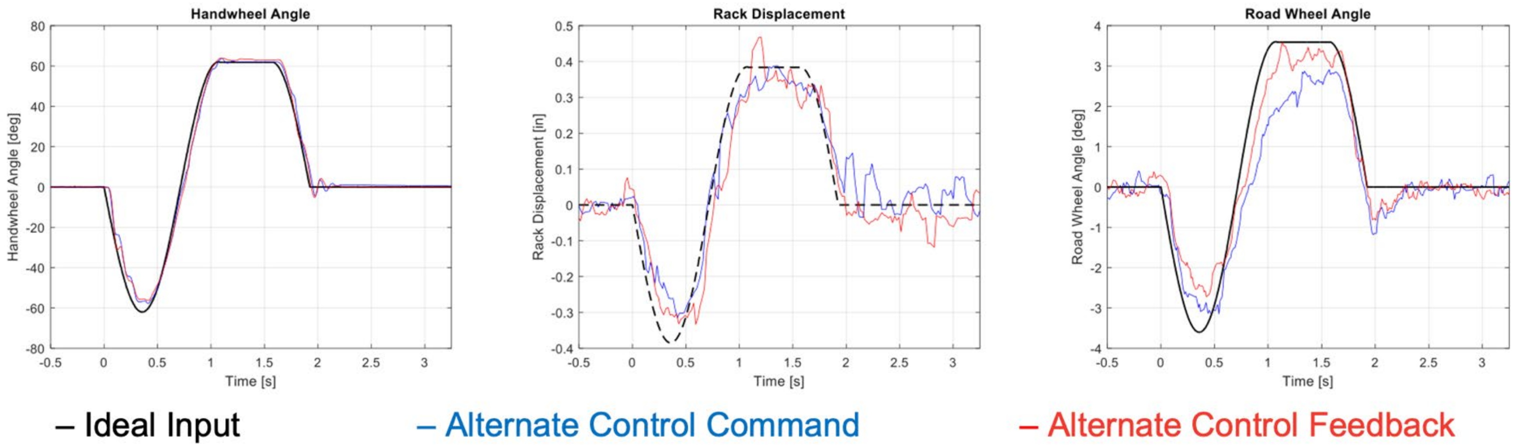

Figure 20. Average road wheel angle compared to steering wheel angle equivalent (Pt. 1)

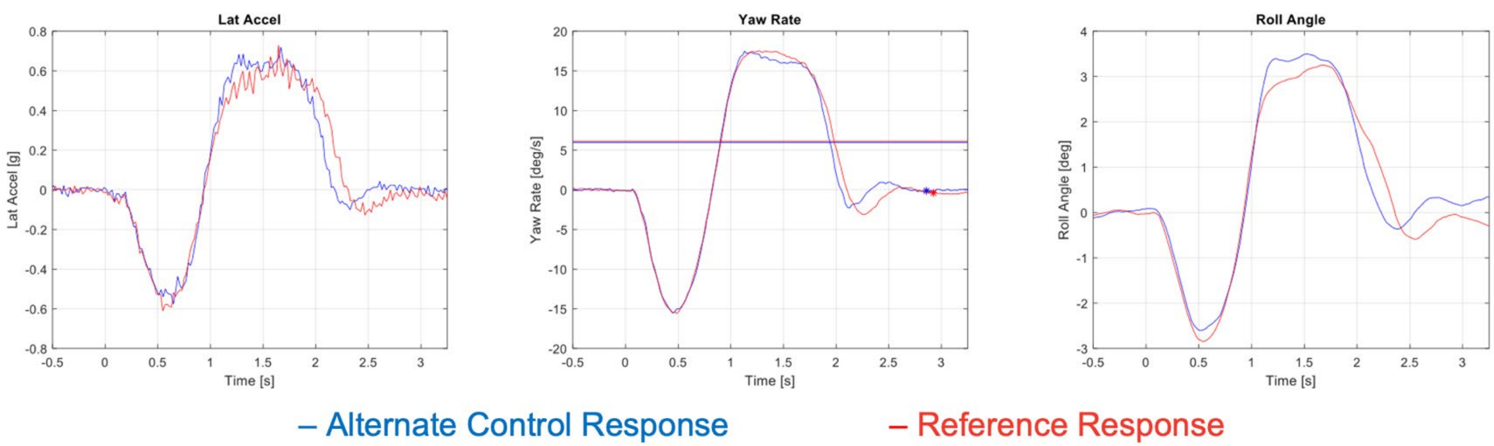

Figure 21. Average road wheel angle compared to steering wheel angle equivalent (Pt. 2)

Table 7. Average Road Wheel Angle and Equivalent Steering Wheel Angle, Yaw Response Metrics

Test Method	Steering Motor Control (deg)	35% Max Yaw Rate (deg/s)	20% Max Yaw Rate (deg/s)	Yaw Rate COS + 1s (deg/s)
Steering Wheel Control	60	5.98	3.42	-0.13
Road Wheel Control-Average Wheel	59.2	6.14	3.51	-0.38

The final alternate control method tested using the VTTI platform was rack displacement control. Small differences were observed but the signals aligned very closely, more so than both road wheel angle control options. This was expected since the rack is located closer in the steering system to the motor on the steering shaft. The time history results can be seen in Figure 22 and Figure 23 below, again showing very good alignment with respect to both the inputs and resulting vehicle level responses. Table 6 shows how closely the yaw metrics aligned between the two control methods. As with the previous figures, Figure 22 shows the ideal handwheel input equivalent for the steering motor, rack displacement, and average wheel angle controls in black. The red and blue lines indicate the actual command (blue) and feedback (red) for the rack displacement control transformed to steering motor, rack displacement and average wheel angle control. Figure 23 denotes the lateral acceleration, yaw rate, and roll angle vehicle responses for the steer motor reference in red and the vehicle response for the rack displacement control response in blue.

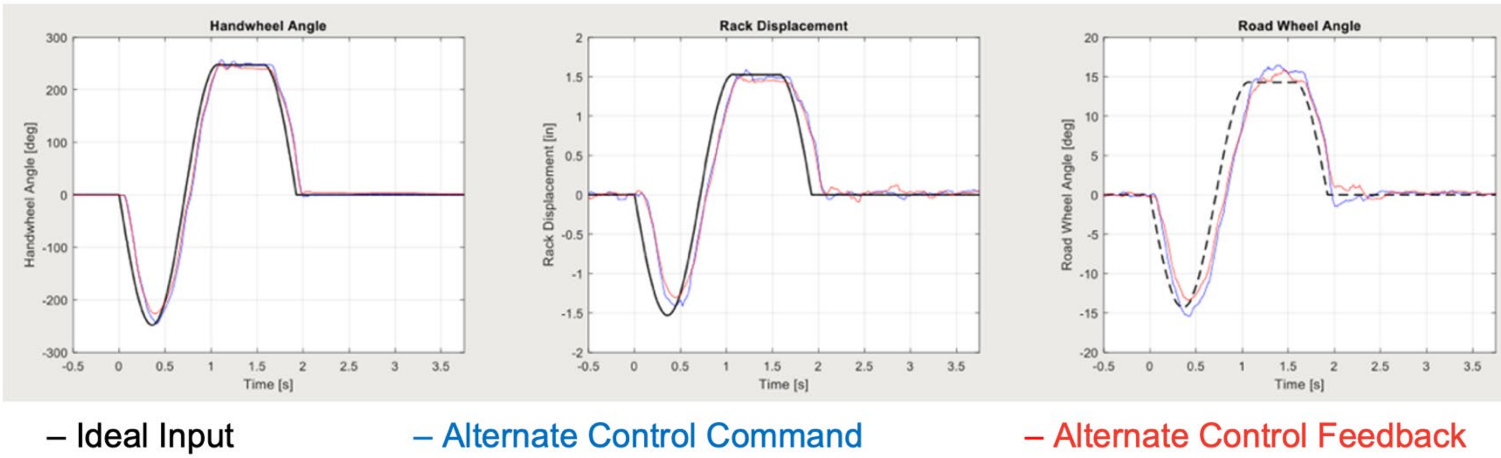

Figure 22. Rack displacement compared to steering wheel angle equivalent (Pt. 1)

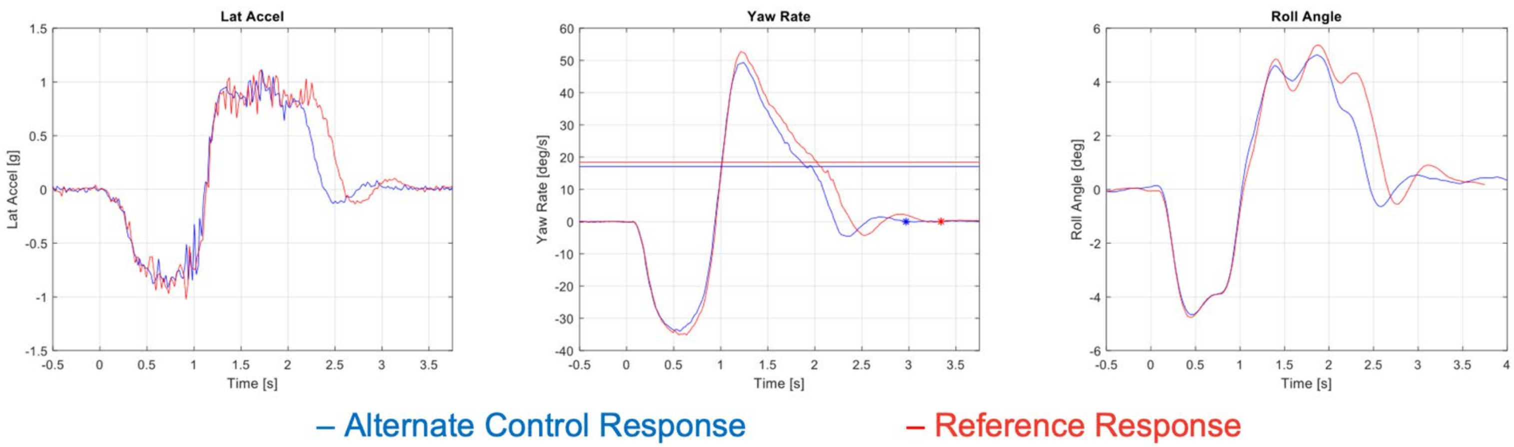

Figure 23. Rack displacement compared to steering wheel angle equivalent (Pt. 2)

Table 8. Rack Displacement and Equivalent Steering Wheel Angle, Yaw Response Metrics

Test Method	Steering Motor Control (deg)	35% Max Yaw Rate (deg/s)	20% Max Yaw Rate (deg/s)	Yaw Rate COS + 1s (deg/s)
Steering Wheel Control	240	17.08	9.76	-0.01
Road Wheel Control-Unloaded Wheel	235.4	18.46	10.55	0.05

To gain additional knowledge of the testing system under high load and dynamic conditions, additional static tests were performed. The intent of these tests was to observe the system's performance under ideal conditions, without any external loading conditions that may affect tire compliance. To accomplish this, the vehicle was stationary on Teflon plates to assist in alleviating tire compliances and the same inputs from the dynamic testing at Bosch Proving Grounds were commanded to the vehicle. When viewing the resulting time history comparison between the command, ideal response, and field-testing response, differences in the time history amplitudes were noted. These differences typically occurred at the peaks where the maximum loads would be present. The tests were performed in both directions to rule out any irregularities and at equivalent steering amplitudes of ~210°, well within the ESC engagement range. Figure 24 shows the differences while using steering wheel control, rack displacement, and unloaded wheel angle control.

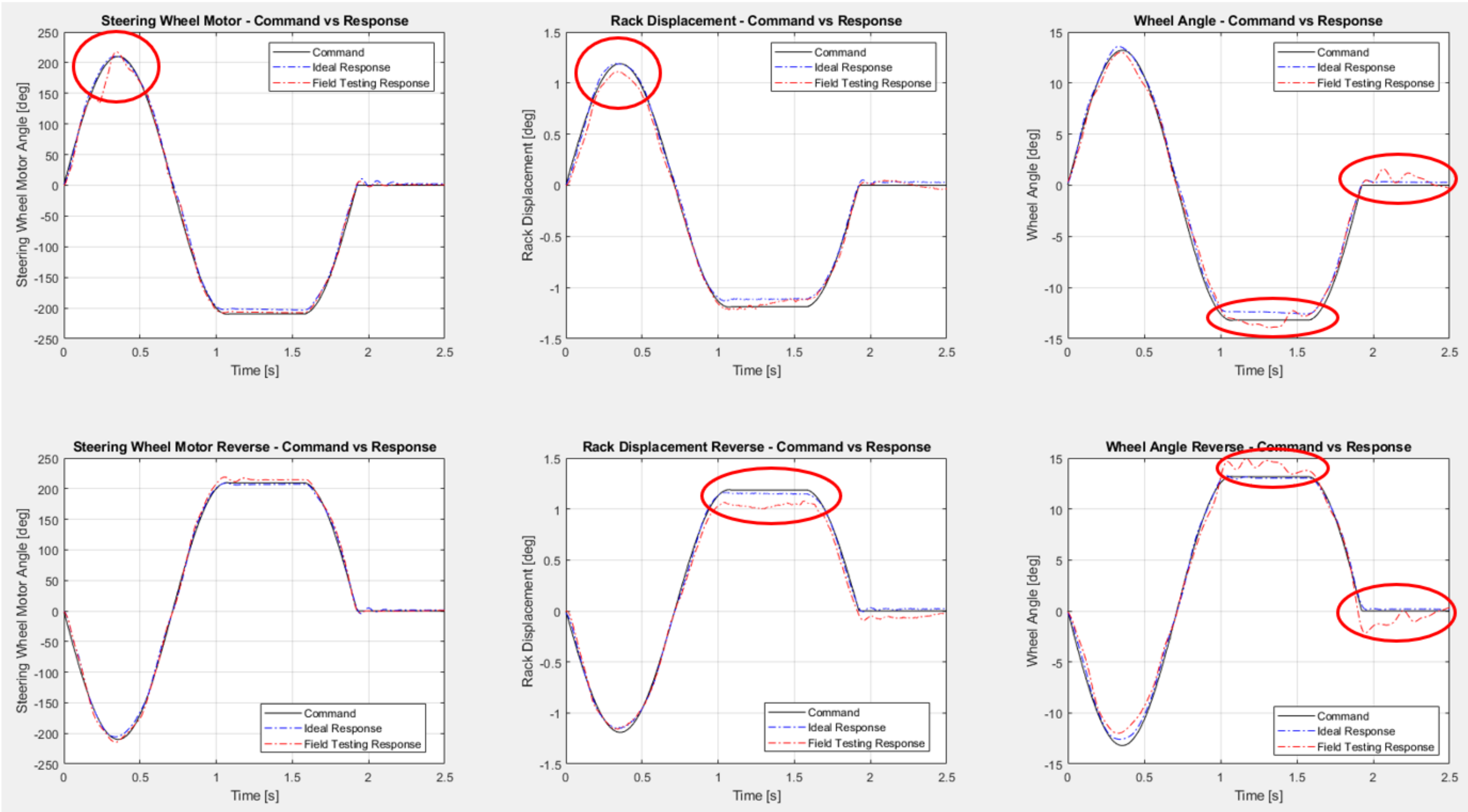

Figure 24. Ideal and field testing response comparison

An observation from these tests shown in Figure 24 is that the steering wheel motor control matched the ideal conditions relatively closely, while larger differences appeared in the rack displacement and unloaded road wheel angle responses. Moreover, the wheel angle differences were higher and seemingly more unpredictable than those of the steering rack displacement. This is potentially due to additional steering system compliances that added up as the control moved from the handwheel angle to the roadwheel angle. The steering rack compliances included the motor to shaft coupling along with the pinion and rack interface. The compliances at the wheel angle included the steering rack and the two ball joints of the tie rod as well as any A-arm bushings.

One final test on the VTTI platform was performed to assess the effects that input variations at the steering wheel had on vehicle response metrics and the overall intent of FMVSS No. 126. The test consisted of low speed sine with dwell testing where the input wave was corrupted. A central composite five level, five factor design of experiment tests was developed using the input corruption factors: (1) first peak amplitude, (2) second peak amplitude, (3) dwell time, (4) first peak frequency, and (5) second peak frequency. These tests were performed on a scaled down level using the parameters in Table 9 below.

Table 9. Scaled Waveform Variation Inputs

	Baseline Input	**Variation**
First Peak Amplitude (deg)	150	0.6, 0.8, 1.0, 1.2, 1.4 (gain)
Second Peak Amplitude (deg)	150	0.6, 0.8, 1.0, 1.2, 1.4 (gain)
Dwell Time (s)	0.5	0.1, 0.3, 0.5, 0.7, 0.9 (s)
First Peak Frequency (Hz)	0.7	0.3, 0.5, 0.7, 0.9, 1.1 (Hz)
Second Peak Frequency (Hz)	0.7	0.3, 0.5, 0.7, 0.9, 1.1 (Hz)

An analysis of the data showed that the main first and second peak yaw rate values were primarily influenced by the gain on the amplitude, with smaller secondary effects from the frequency. The time of first and second peak yaw values were more heavily influenced by the frequency of the waveform. In Figure 25 below, regression surface maps show the effects of the parameters for each of these metrics.

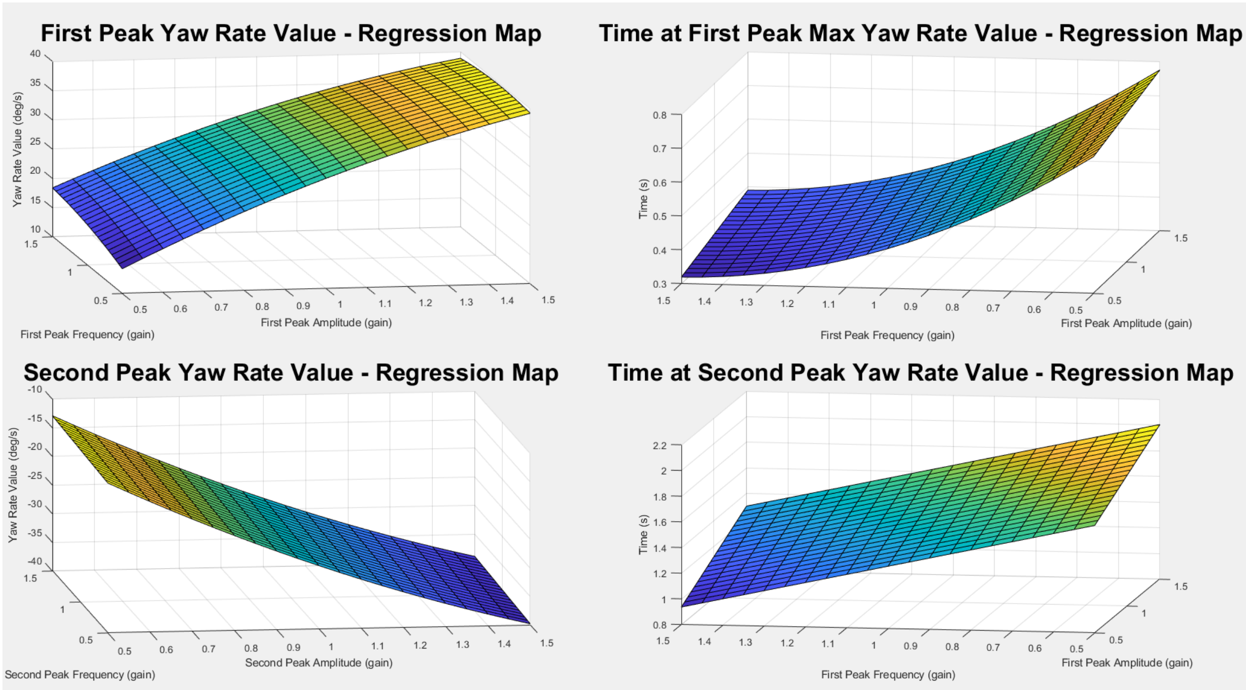

Figure 25. Regression surface map, scaled testing

The regression equations generated from the sine with dwell waveform variation testing process provide insight into how variations may affect the FMVSS compliance metrics. Analysis may be used to inform differences between the alternate control equivalent handwheel angle and steering wheel control tests. Differences can be mapped between alternate control equivalent steering wheel input like the sine with dwell distortions, then effects of the alternate control distortions on the vehicle response metrics can be evaluated. A standard second order regression equation was used to fit the data in Figure 25 for the Second Peak Yaw Rate Value plot, where PA2 is the second peak amplitude and PF2 is the second peak frequency.

$$\text{2nd Peak Yaw (deg/s)} = 5.09 - 43.09\ PA2 + 0.951\ PF2 + 8.56\ PA2*PA2 \qquad R^2 = 99.39\%$$

Equation 3. 2nd Order regression equation for 2nd peak yaw rate

The following example focuses on the comparison between the primary steering wheel command and the equivalent steering wheel angle of the unloaded road wheel, which showed a variation in the inputs. The main effects variables are shown in Figure 26 along with the regression equation for the second peak yaw rate. Figure 27 shows differences between the steering wheel control and the alternate controls, but the responses are very similar and would produce metrics of similar magnitudes.

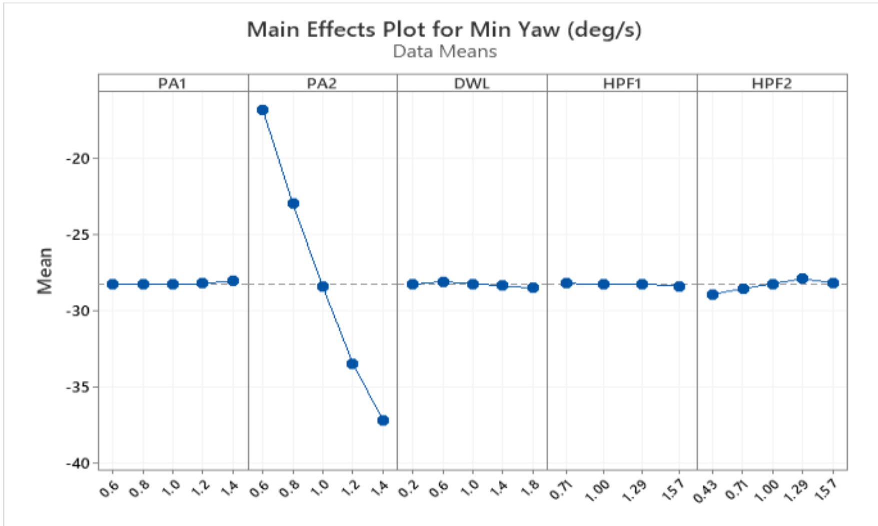

Figure 26. Main effects plot for second peak yaw rate

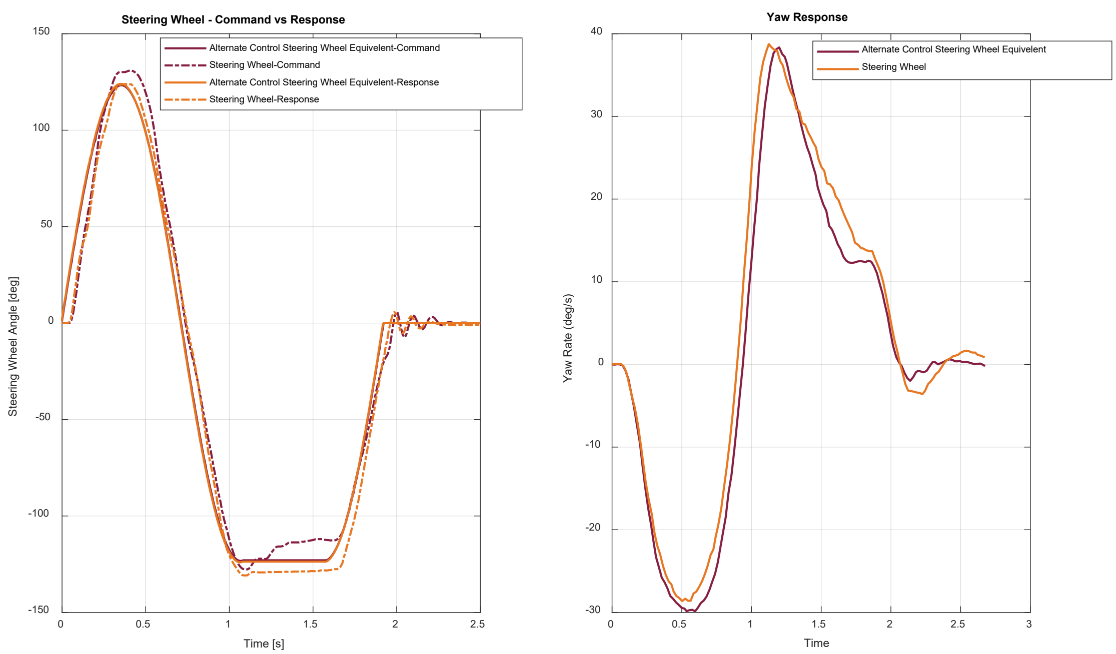

Figure 27. Command versus alternate control input and yaw response comparison

The following observations are from the low-speed sine with dwell variation testing, an example of which is shown in Figure 27 above. Small variations in first peak amplitude had little effect on the resulting maximum yaw response value. The regression equation for parameter sensitivity in Figure 26 developed from the scaled testing shows this as well. Variations are visible in the first peak amplitude but the maximum value for peak vehicle yaw responses were nearly identical. Figure 27 also shows that similar magnitudes for second peak amplitude and frequency can be seen with respect to the input response channels. Figure 26 shows that second peak amplitude and frequency values were the driving factors of the peak yaw response, since the two input amplitudes and frequencies were similar. In this case it is unsurprising that peak yaw response was similar. The results show that even though the waveform was distorted from the ideal trace, the yaw response and metrics did not differ from one another. Therefore, when small waveform variations were seen while using alternate controls, the desired output and vehicle level responses were similar. This indicates that small variations of the waveform can still result in a successful test execution of the FMVSS No. 126 test procedure.

ITP 1 performed full scale waveform variation testing. Information from the scaled testing was used to develop a more focused approach on what parameters should be varied. The decision was made to focus on the second peak amplitude, frequency, and dwell time, starting from a center baseline condition, 104° pinion angle. This value was chosen so that steering wheel angles would fall around the ESC's engagement point. The testing included both cases where the ESC would be enabled and those where it would be disabled. Table 10 shows the variations tested.

Table 10. Full Scale Input Variation Parameters

	Baseline Input	**Variation**
Second Peak Amplitude (deg)	104	84, 104, 124
Second Peak Frequency (Hz)	.7	0.63, 0.665, 0.7, 0.735 ,0.77
Dwell Time (s)	0.5	0.45, 0.475, 0.5, 0.525, 0.55

The results of 14 test runs with ESC enabled are shown in Figure 28 below. The figure contains the pinion angle along with the external rack displacement sensor, which the ITP used for verification. Yaw responses varied slightly given the input variations. These variations were specifically chosen to mimic smaller variations that could be seen when using an alternate control method, such as rack displacement or road wheel angle. Even though variations of the input signal existed, the yaw rate metrics were all well within the acceptable limits of FMVSS No. 126. Figure 28 displays the test inputs for the ESC on case and yaw rate response time histories.

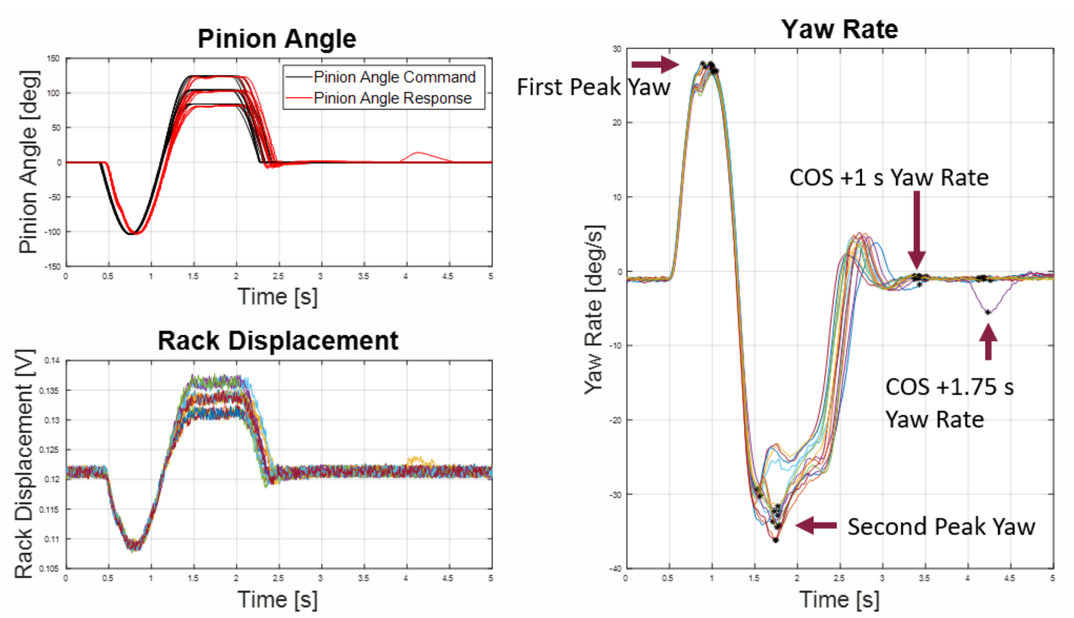

Figure 28. ESC on input variation plots

Table 11 highlights the vehicle response metrics for the variations associated with the two highest base amplitudes that required ESC intervention. As shown in the table, the yaw metrics do not significantly vary, indicating that the sensitivity to amplitude variation is minimal.

Table 11. ESC On – Yaw Metric Table

Run Amplitude	35% Second Peak Yaw Rate	1s COS Yaw Rate	20% Second Peak Yaw Rate	1.75 s COS Yaw Rate
103.6	-11.99	-1.79	-6.85	-1.07
82.6	-10.60	-1.04	-6.06	-0.88
103.4	-11.32	-0.89	-6.47	-1.02
123.8	-12.69	-0.77	-7.25	-0.85
81.6	-10.65	-1.05	-6.09	-1.14
123.8	-12.11	-0.68	-6.92	-1.23
82.1	-10.29	-0.89	-5.88	-0.94
81.7	-10.27	-0.97	-5.87	-0.88
103.8	-11.54	-0.85	-6.59	-1.07
103.6	-11.81	-0.85	-6.75	-5.51
124.1	-12.02	-0.62	-6.87	-0.85
124.3	-12.67	-0.59	-7.24	-0.90
103.4	-11.33	-0.77	-6.48	-1.04
103.1	-11.09	-0.63	-6.33	-0.96

In addition, ESC Off testing was performed around the same two high-amplitude cases to assess the vehicle's stability sensitivity to the input with ESC disengaged. Figure 29 shows how the input variations resulted in vehicle instabilities when the ESC was disengaged. The group of four runs, where yaw rate time history traces are shown holding the yaw rate for the longest time, were performed at a second peak amplitude of 124° with frequency and yaw variations. The middle amplitude group of three runs with sustained yaw in the yaw rate time history plot had more consistent and lower second wave amplitudes. The final group of stable responses contained lower second frequency amplitude values and zero yaw rate FMVSS No. 126 time statistics at the end of the test.

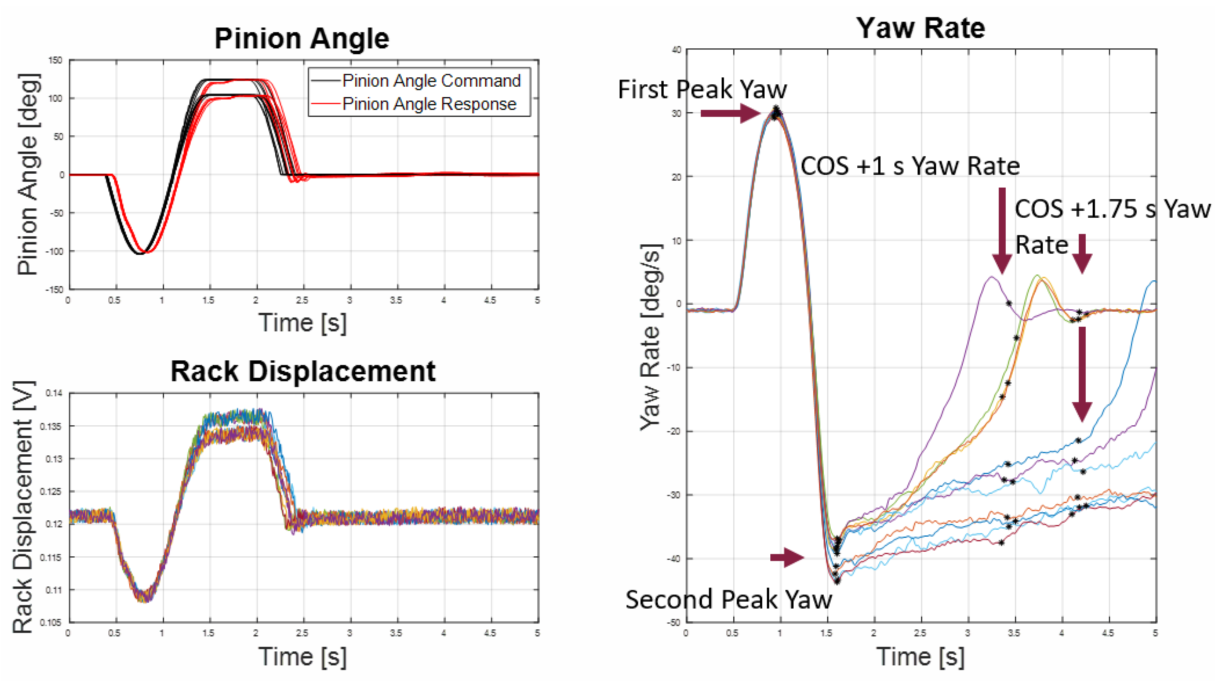

Figure 29. ESC off input variation plots

Table 12 shows the metric values for the ESC off variation runs.

Table 12. ESC Off – Yaw Metric Table

Run Amplitude	35% Second Peak Yaw Rate	1s COS Yaw Rate	20% Second Peak Yaw Rate	1.75 s COS Yaw Rate
104	-13.74	-25.16	-7.85	-21.45
124.6	-15.20	-34.95	-8.69	-31.96
103.5	-13.46	-27.62	-7.69	-24.57
124.5	-14.87	-33.51	-8.50	-30.34
124.8	-15.30	-37.47	-8.74	-33.01
103.9	-12.90	-5.35	-7.37	-1.66
103.5	-13.49	-14.61	-7.71	-2.54
124.2	-14.45	-34.10	-8.26	-31.70
103.7	-13.39	-27.94	-7.65	-26.34
103.7	-13.17	0.09	-7.52	-1.30
103.4	-12.99	-12.42	-7.42	-2.42

Discussion

The following provides a discussion of the results concerning the ability of alternate steering wheel angle control methods to provide inputs for evaluation of FMVSS No. 126.

Full-scale testing on the VTTI Cadillac SRX platform demonstrates how a technical translation using an alternate control method can be feasible when evaluating vehicles using FMVSS No. 126. Even if the alternate control method does not perfectly replicate the input waveform, variation testing has shown that depending on the variation level of the input signal from the desired waveform, the impact on the FMVSS No. 126 evaluation metrics may be minimal while still fulfilling the intent of the testing. This is important to keep in mind since, as shown above, some alternate control methods will vary slightly from the desired waveform. The main factors in waveform variations appear to be those caused by vehicle compliances; however, steering motor size, as well as control system tuning, may also contribute. Nevertheless, when variations due to compliances were noticed in the testing above, the vehicle was still able to successfully complete FMVSS No. 126 tests as written while passing the metric criteria.

ITP Testing

Since FMVSS No. 126 is a self-certified test performed by manufacturers, working with ITPs to determine how they will certify the standard is a highly useful exercise. For FMVSS No. 126, three ITPs participated in a paper study detailing proposed methodologies, one of which participated in a physical vehicle test with their ADS testing system, and another demonstrated the approach they are developing for ADS-DV compliance testing. The goals were similar to those for brake system testing.

- Confirm an ADS can execute the test procedures as currently written
- Identify what must be done outside of normal operation to execute test procedures
- Identify what the ADS cannot do and why
- Identify what ITPs think are equivalent procedures and, ideally, why
- Identify areas of standard or test procedures that may not be applicable for ADS-DV (e.g., specific failure modes)

ITP 1

ITP 1 participated in physical FMVSS No. 126 tests along with providing information in the form of a paper study. The test vehicle was a front wheel drive, full size sedan using open loop control on the steering rack pinion angle. Command signals were injected into the system, directly replacing the ADS motion planner outputs. A motion planner was not used during the testing since there was a potential that outriggers could block sensors, affecting the system’s output and making the sine with dwell wave form difficult to accurately reproduce. Shown below in Figure 30 is the high-level vehicle control diagram.

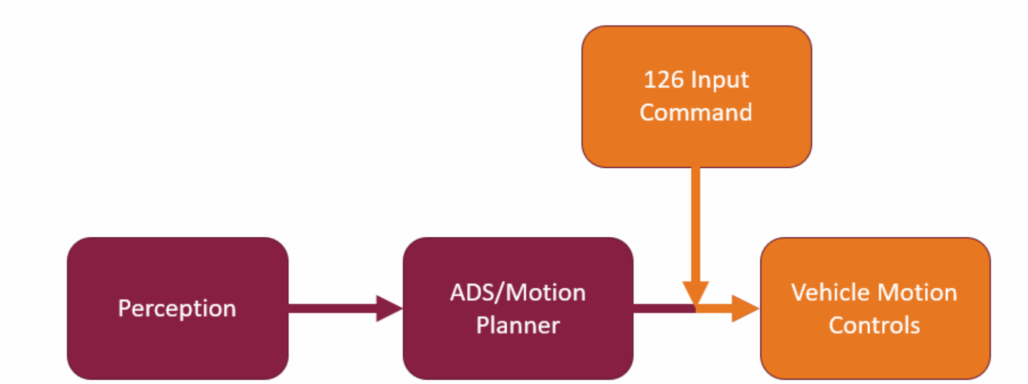

Figure 30. ITP high-level control diagram for FMVSS No. 126 testing

Instrumentation was present in the form of onboard controller area network-based sensors along with several other external sensors for independent verification. Onboard sensors that were considered consisted of pinion angle, lateral accelerometers, and yaw gyro. External sensors added to the vehicle included RT3000 GPS/IMU, brake pressure sensor at the wheel, steering rack displacement, and two cameras, one pointing forward and the other mounted on the fender looking top down at the front right wheel.

The test plan consisted of the appropriate tire conditioning performing constant radius, sine steers, and 0-130-0 braking. When determining the initial 0.3 g values, instead of using the 13.5°/s steering wheel angle input, the ITP used a constant jerk value of 0.16 g/s. The ITP evaluated a large number of vehicles and determined that ~50 percent of them had approximately this value during the 13.5°/s slowly increasing steer test. Based on these results, the ITP used the constant jerk of 0.16 g/s to determine the initial starting amplitudes for the sine with dwell tests using open loop programmed control of the pinion angle in the steering actuator. Below in Figure 31 are two displays of time history for lateral acceleration and lateral jerk time showing the results of four slowly increasing steer tests in each direction, with a constant jerk value of 0.16 g/s. On the left is a time history of lateral acceleration during testing and the right is a time history of the jerk.

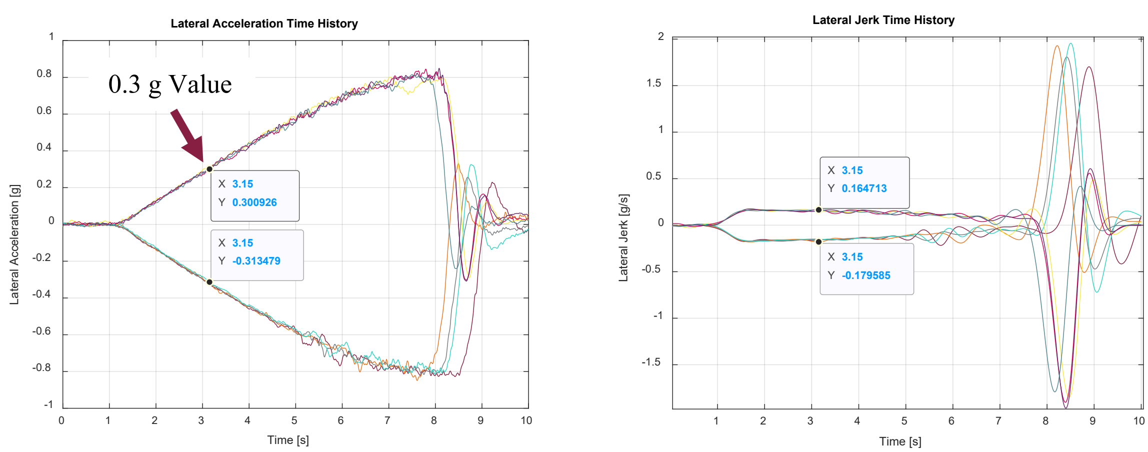

Figure 31. Slowly increasing steer lateral acceleration and jerk time history plots

The resuts of the slowly increasing steer test showed a value of ~26° at the steering wheel when the vehicle had a lateral acceleration of 0.3 g. Sine with dwell tests were performed bidirectionally to a factor of 13 in 0.5 increment steps where a factor of 1 was equal to 26°. Figure 32 shows time histories of pinion angle, rack displacement, and yaw rate during the sine with dwell manuver while the ESC was on. Notable values related to FMVSS No. 126 compliance are detailed on the yaw time history plot.

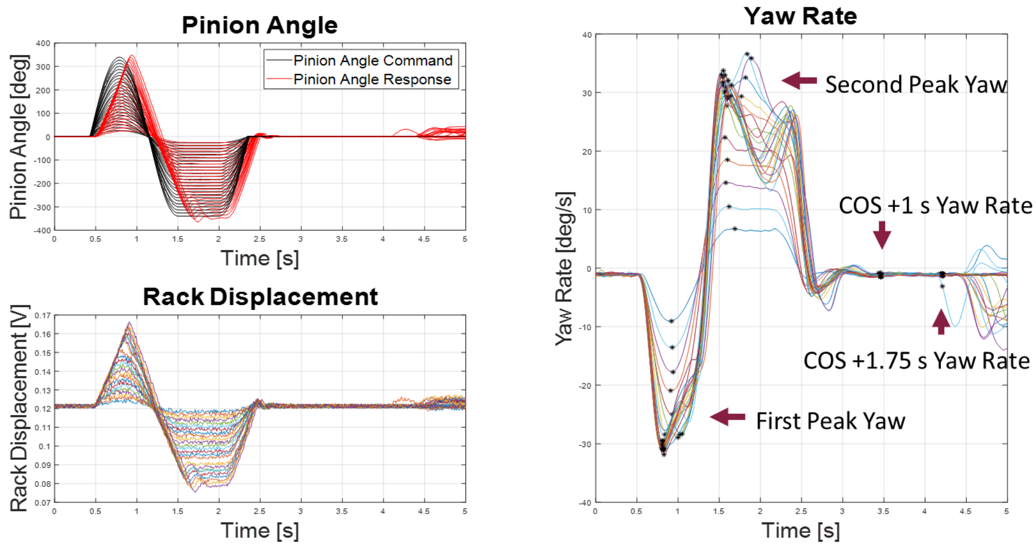

Figure 32. ITP ESC on sine with dwell testing results

Sine with dwell tests were also performed with the ESC off to demonstrate that a destabilizing input was achieved on input levels compared with the ESC on. Figure 33 shows the results during that portion of testing.

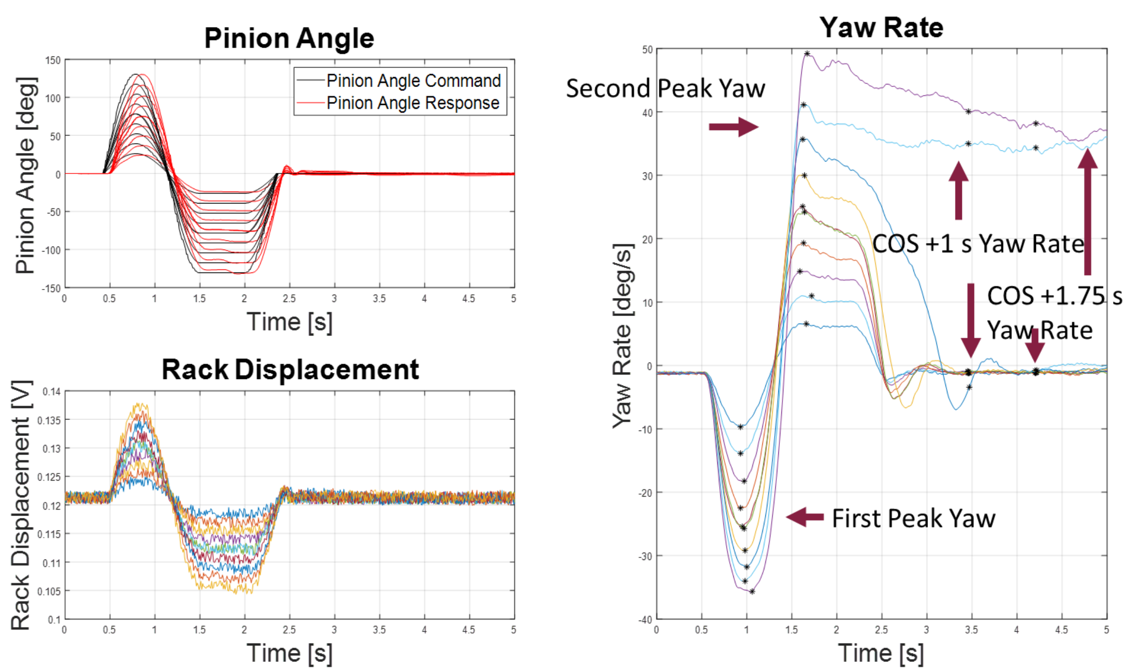

Figure 33. ITP ESC off sine with dwell testing results

Additionally, Figure 34 is a direct comparison with the ESC on and ESC off, shown in blue and red respectively, while performing the test at 130° on the pinion angle. The time history traces were identical for pinion angle and rack displacement while the yaw rates differed, indicating a failure of the standard when the ESC was off.

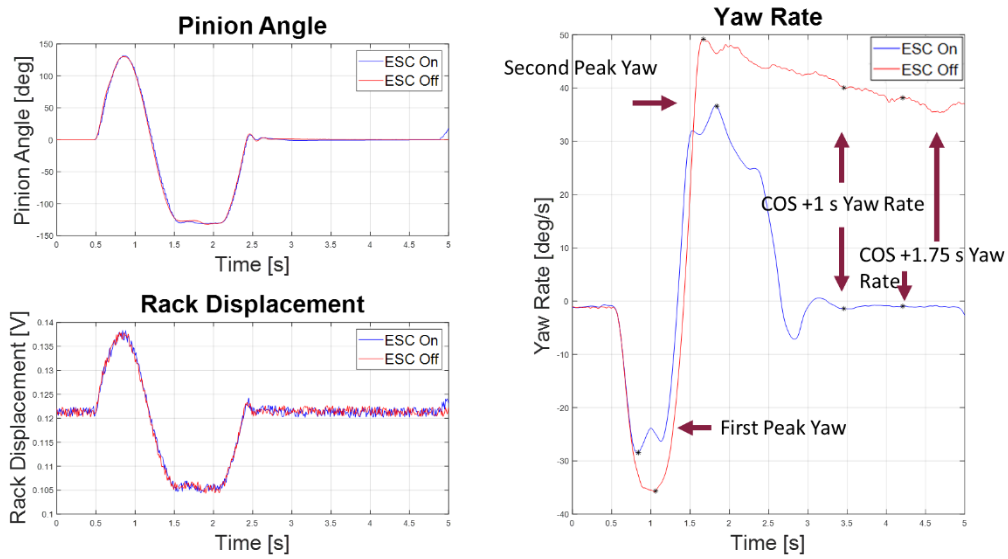

Figure 34. ESC on verses ESC off, sine with dwell response

Another factor observed during the ESC on versus off comparison was the change in longitudinal acceleration. The ITP proposed that it may be possible to use the longitudinal acceleration as an indicator of ESC engagement. Figure 35 shows a time history of the longitudinal acceleration during the 130° pinion angle input. A measurable difference can be seen in the figure, indicating the ESC is active in stabilizing the vehicle.

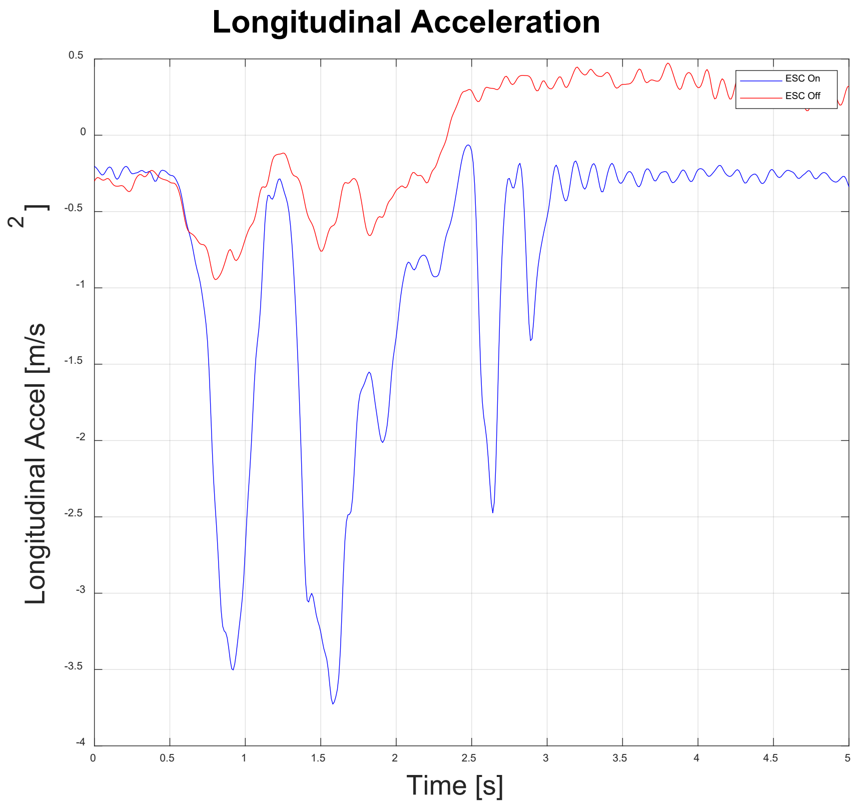

Figure 35. ESC on verses ESC off, sine with dwell longitudinal acceleration

Discussion

As currently written, the ITP would require the testing protocol to be translated from steering wheel to pinion angle since the ADS cannot measure steering wheel angle directly. Also, the test must be run as an open loop script independent of the perception and planning layer for vehicle motion. This does not necessarily mean that perception cannot be active, but rather that objects near the front of the vehicle could inhibit the vehicle from moving forward.

To successfully execute the test outside of normal operation, the ITP believes that NHTSA may need to work with manufacturers. A test procedure script would be required to run on the vehicle, which would need to bypass the perception and planning layers of the vehicle. It would also be necessary to ensure that the script would not introduce faults that preclude test execution. In addition, instead of using a steering robot to drive the steering wheel, programmed control must be used to inject the proper test command into the vehicle motion controller to produce the proper FMVSS No. 126 waveform at the pinion gear. Another item outside of the normal FMVSS No. 126 operation procedures is in the determination of the 0.3 g lateral acceleration values shown in Figure 31. This ITP chose to use a lateral jerk value ranging between 0.14–0.16 g/s as an equivalency for the 13.5°/s steering input and found that this worked well for their testing across a wide range of their vehicle lineup.

There were several procedures that the ITP thought may be equivalent to the current standard, such as determining the 0.3 g values using a constant jerk of 0.14 to 0.16 g/s. Another procedure the ITP thought might be equivalent is to inject the desired steering commands driven by an onboard motor to control pinion angle and speed commands into the vehicle controller to execute the procedure through the proper test waveforms and speed profile. The ITP suggested that additional sensors could be installed for independent verification of the testing procedure, similar to the external sensors implemented in the exercise above (i.e., IMU/GPS, displacement sensor, and cameras).

The ITP suggested that there were several areas where standards or test procedures may not be applicable for ADS-DVs, such as the need to bypass the ESC disengaged fault to support the testing in this work. Even though disengaging the ESC is not a consideration associated with evaluation of FMVSS No. 126, it highlights potential challenges associated with testing ADS-DVs. Meeting potential requirements of standards or test procedures may be difficult since ADS-DVs may have failsafe modes that will not allow operation of the vehicle while in a faulted state.

ITP 2

ITP 2 participated in physical tests along with providing information in the form of a paper study. The test vehicle was a rear wheel drive, multi-purpose vehicle, which was speed controlled for initial testing to operate at low speeds without traditional hand controls or a human-machine interface. This ITP's approach to performing the FMVSS No. 126 test on a vehicle that may not have traditional controls is unique from the two other ITPs. They proposed that the test be performed by installing a system with traditional controls into the vehicle, then using a steering robot to input the test waveform. This system consisted of all necessary controls found in a traditional vehicle, such as a steering wheel, gas pedal, brake pedal, gear selection, accessory panel, status indicators, and ECU boxes. Due to intellectual property concerns, pictures of the installed system cannot be published.

The installed system was a true drive-by-wire setup, and therefore additional steps were required for validating that the input to the steering wheel was commanding the proper outputs to the road wheels. After the external human control systems were installed in the vehicle, additional instrumentation, such as a string potentiometer measuring steering rack displacement and an IMU, were installed. The vehicle was then placed in a steering rig, which was composed of low friction turn tables with encoders on the front left and right wheels. Figure 36 shows the left front wheel on the steering rig with the wheel pointed straight then turned to the left.

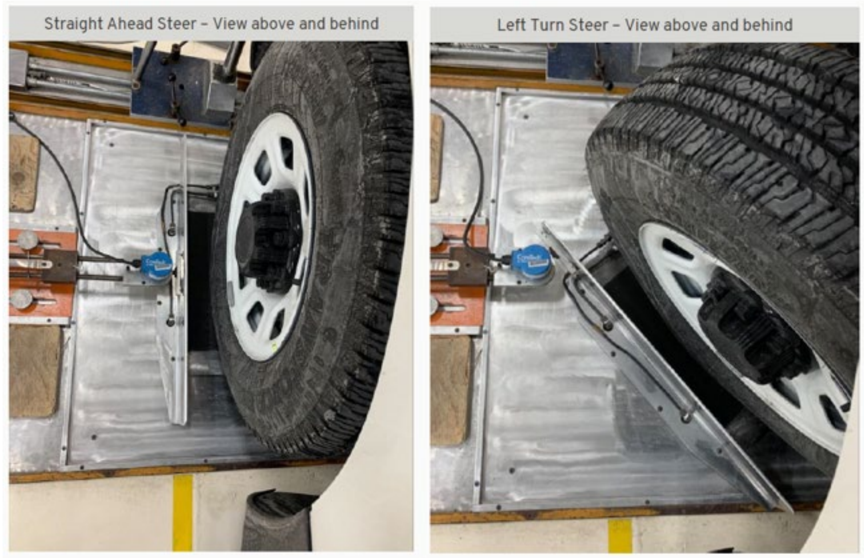

Figure 36. Road wheel angle measurement fixture

Data was collected and synchronized from the encoders measuring road wheel angles, string potentiometers measuring rack travel and pinion angle, and external controllers measuring steering wheel angle. A fourth order polynomial was then fitted to the rack displacement and road wheel angle, resulting in Equation 4 and Equation 5 below for each wheel.

$$LF = -3E\text{-}08\ x^4 + 5E\text{-}06\ x^3 - 3E\text{-}05\ x^2 + 0.3557\ x + 0.1504$$

Equation 4

$$RF = 2E\text{-}08\ x^4 + 5E\text{-}06\ x^3 - 0.0002\ x^2 + 0.3568\ x + 0.2093$$

Equation 5

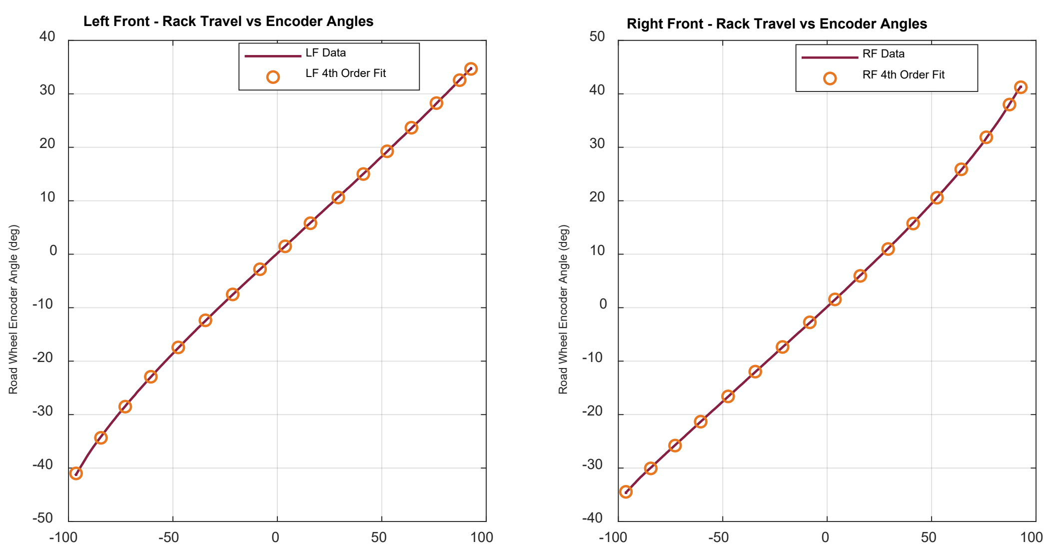

Figure 37. Rack travel versus left and right road wheel angle fits

Once equations were fitted for steering rack travel versus road wheel angles, the next step was relating the drive-by-wire steering wheel angle to the road wheel encoders. Figure 38 below shows this relationship, which is linear in the primary operating range while showing the typical nonlinearity at extreme steering angles due to steering geometries.

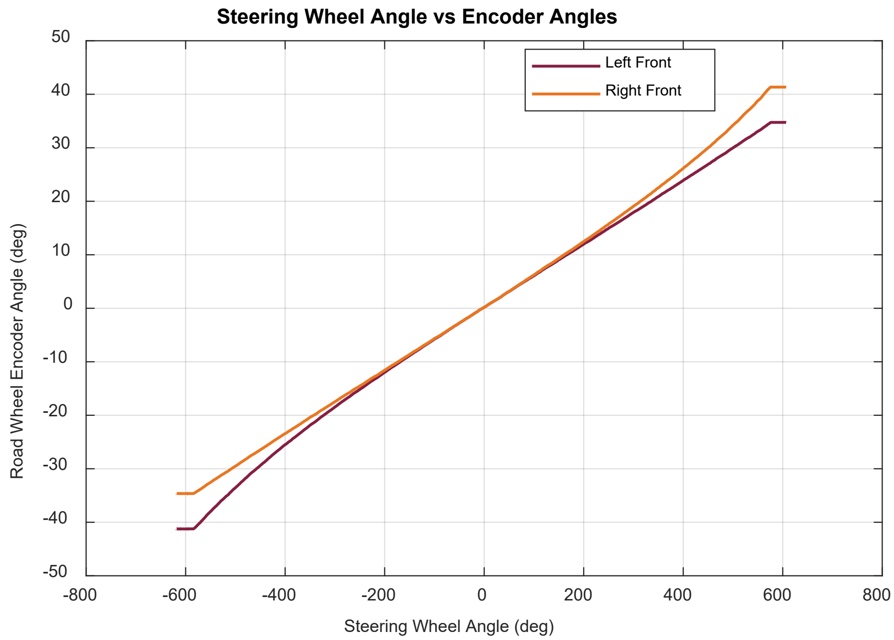

Figure 38. Drive-by-wire steering wheel and encoder steering sweep comparison

Next, a relationship between the drive-by-wire steering wheel and rack displacement was created and a steering ratio was calculated. In this case, the steering ratio was 16.81, which was taken as the average value from a -90 to a +90 steering wheel angle. The fitted plot is shown in Figure 39 below.

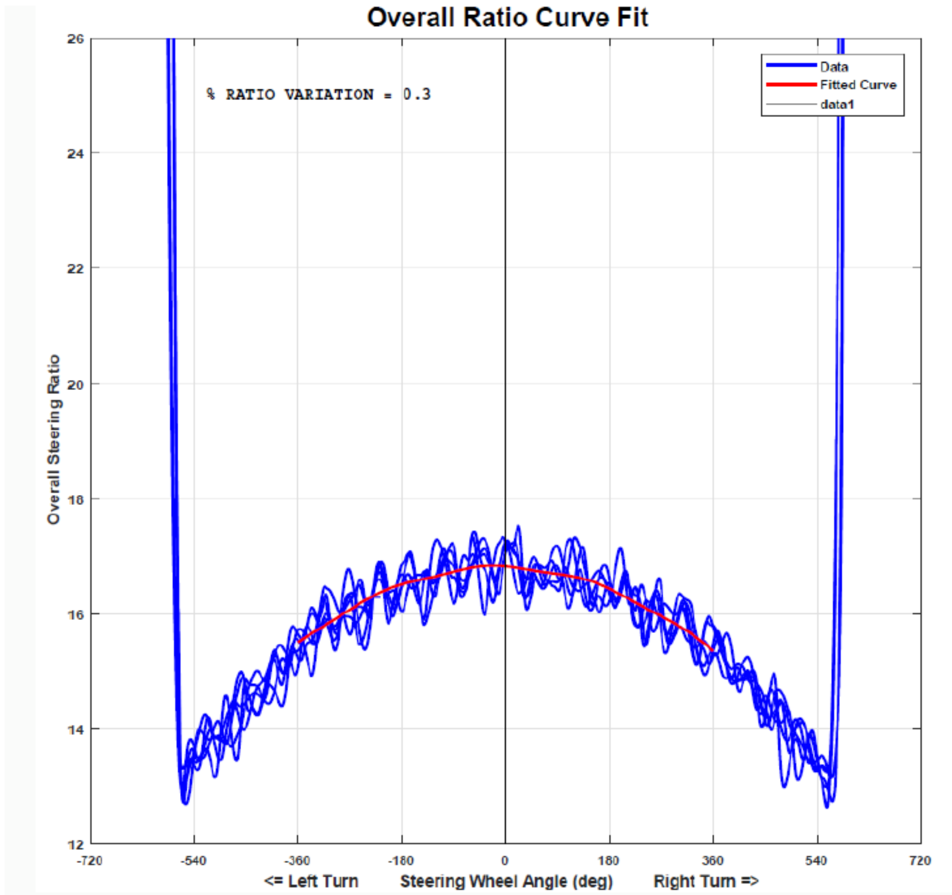

Figure 39. Steering ratio fit

With the external control system calibrated, a sine with dwell test was then performed. In future testing, the ITP intends to perform the maneuver using a steering robot on this system, but the vehicle was not currently ready to deploy this testing method due to the timing in the vehicle's development cycle. For demonstration purposes, the ITP elected to have the vehicle programmed to execute a sine with dwell-like maneuver. The vehicle was accelerated to 25 mph, then allowed to coast to 20 mph, at which point a sine with dwell representative waveform of 130° amplitude at the steering wheel was performed. Figure 40 shows the results.

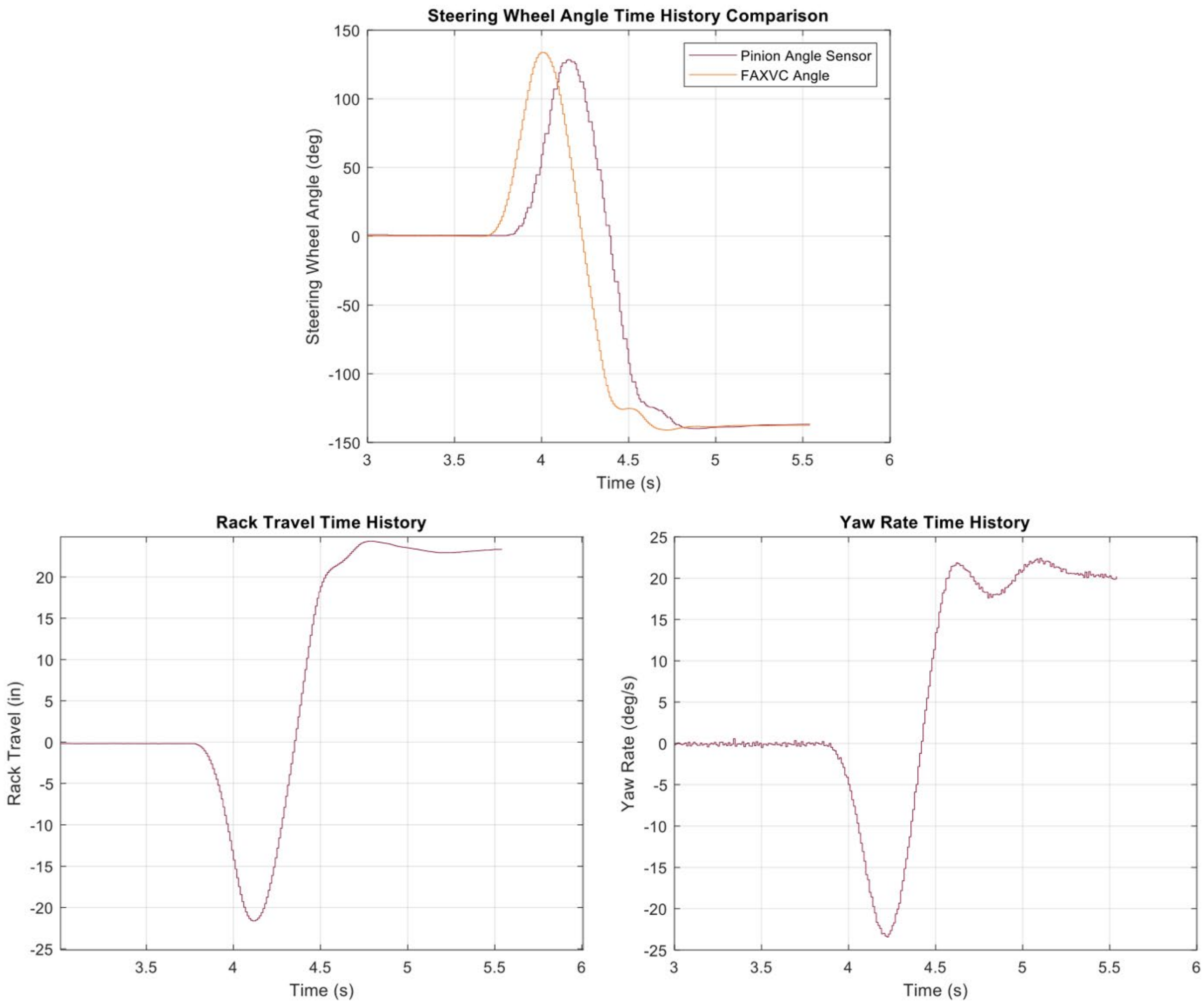

Figure 40. Time history traces during sine with dwell representative maneuver

Discussion

Based on the representative testing, it is important to note that the drive-by-wire steering wheel angle matched the pinion angle in both magnitude and frequency. If a manufacturer was inclined to improve test results, any major discrepancies between steering wheel and pinion angle would be visible here. The typical control loop lag can be seen; this was also present in other command feedback loops that were tested. Another notable feature is that the frequencies of the rack travel and yaw rate also matched the input frequency of the drive-by-wire steering wheel input, showing that the signal was unaltered. This scaled proof of concept test illustrates that the approach could be feasible for a full-scale test.

Key Findings

VTTI Platform Testing and Evaluation

When conducting the FMVSS No. 126 testing protocol on the VTTI platform, the vehicle could execute the test procedures as written given the fact that the vehicle was equipped with a physical steering wheel. However, for operation during this testing, it was also equipped with a steering motor to allow for evaluation of alternate control strategies. Assuming the vehicle did not have a physical steering wheel, considerations were made to instead use either pinion angle, rack displacement, or road wheel angles that would allow the vehicle to perform the test through one of those alternate control approaches. Outside of normal operation, the vehicle would require a translation to allow for control and measurement of the rack displacement or the road wheel angle. The FMVSS No. 126 procedure would be completed using one of these methods to find the 0.3 g value through a slowly increasing steer test. Then, the appropriate steps would be determined to perform the sine with dwell maneuvers until the road wheel angle reached the predetermined end point value. Using a translation is equivalent to steering wheel angle since there is a constant, measurable relationship between the steering wheel angle and the alternate control—either rack displacement or road wheel angle.

ITP 1 Testing

ITP 1 determined that for the ADS to execute the tests as currently written, a translation would be required to use pinion angle instead of steering wheel angle. The ITP would then run an open loop script that would function independently of the perception and planning layer of the vehicle's motion controller. One limitation might be that the outriggers typically deployed for safety may create a fault condition that could prevent the vehicle from moving forward. NHTSA may also need to work with the manufacturer to execute the testing since a specific script would need to be run to bypass the perception system for proper execution without any system faults. Other items outside of normal operation required to execute the test would be the way that 0.3 g values are determined. The ITP suggested and demonstrated how lateral jerk values of 0.14–0.16 are equivalent to having a 13.5°/s steering wheel rate. Instead of using a steering robot to execute the test waveforms, the programed controlled script would be injected into the vehicle. The ITP believes that these procedures are equivalent and that they produce the same results in the vehicle's motion and resulting yaw responses, while suggesting external sensors could be installed for verification. Areas that may not be applicable to the test involve anything that requires running the vehicle in a faulted state. This was evident while performing the ESC disengaged tests where running the vehicle with ESC disengaged produced a fault in the vehicle control platform.

ITP 2 Concept Demonstration and Paper Study

This ITP argued that, depending on the ADS-DV, the driving system may not be able to produce the steering rates necessary to properly execute the FMVSS No. 126 maneuver, which is the case for their current vehicle. They suggested that if an ADS-DV lacks manual controls, a "Full Authority External Vehicle Controller" (FAXVC) would be used to run the test in the same manner as performed on vehicles with manual controls. The FAXVC system includes a seat, steering wheel, pedal, and interface, acting as a complete bypass to the ADS, allowing for steering wheel angle and road wheel angle to steer at the required rates in accordance with the FMVSS No. 126's sine with dwell waveform. A steering ratio for the FAXVC system would be chosen based on the ITP's other vehicles, ranging from 18:1 to 14:1. To fully demonstrate the ESC system's capability, sine with dwell tests would be performed using several steering ratios within this range. External road wheel sensors would be added to verify that the FAXVC steering wheel angle is being correctly transposed to the road wheel angle and an output file would be produced for validation.

ITP 3 Paper Study

ITP 3 did not perform physical testing for this research but did participate in a paper study of how they anticipated executing the FMVSS No. 126 test.

This ITP noted the purpose of the original FMVSS No. 126 test was to prevent fatalities and injuries caused by human error while driving, primarily from oversteering events. As future ADS-DVs are being developed without a steering wheel, this removes the potential for a human to cause an error that would result in an oversteer event, and therefore the steering inputs that FMVSS No. 126 requires may be out of scope for an ADS-DV. Arguments could be made for low surface friction cases, but the ITP believes that these situations may be out of bounds.

However, if a direct replication was required for an ADS-DV, the ITP would use several equivalencies to accomplish the standard. The ITP proposed that road wheel angle would have the best equivalence to steering angle. The ITP would use the end of the test case for road wheel angle; this is approximately equivalent to 270° at the steering wheel. The ITP does state that in any vehicle that has ADS capabilities and a steering wheel present, the FMVSS No. 126 procedure should be run as the standard is written since the potential for human error remains present.

FMVSS Nos. 105, 121, and 136: Braking and ESC System Heavy Vehicle Standards

The optional translations for ADS-DV HV standards FMVSS Nos. 105, 121, and 136 and related test procedures were performed in a previous phase of this project and are reported in Volume 3. The purpose of this investigation was to compare LV standard test procedures to HV standard test procedures and identify functionalities that are similar or different. Where LV functionalities were found to be similar, lessons from LV ADS-DV demonstrations were applied. A high–level summary of the analysis is provided in Figure 41.

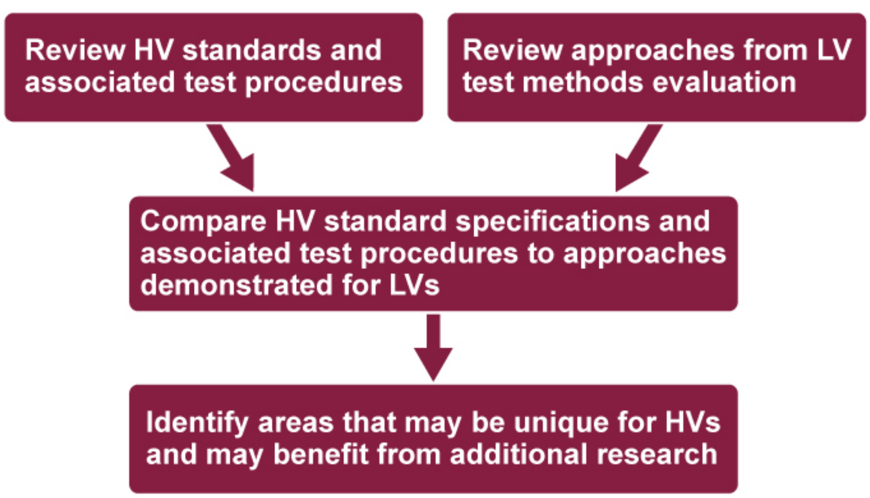

Figure 41. High level approach to HV test functionalities analysis

Approach and Scope

The evaluation of the HV standards' test procedures involved a system review and a regulatory review. The HV systems in the comparison were braking, throttle, and steering. Where differences were apparent, those differences were evaluated against the ADS-DV test methods or unique ADS architectures. Following the system review, the functionalities among standards with the greatest system differences were evaluated to determine how the human-controlled and program-controlled test methods would apply to the HV standard test procedures. The evaluation steps are organized in Figure 42.

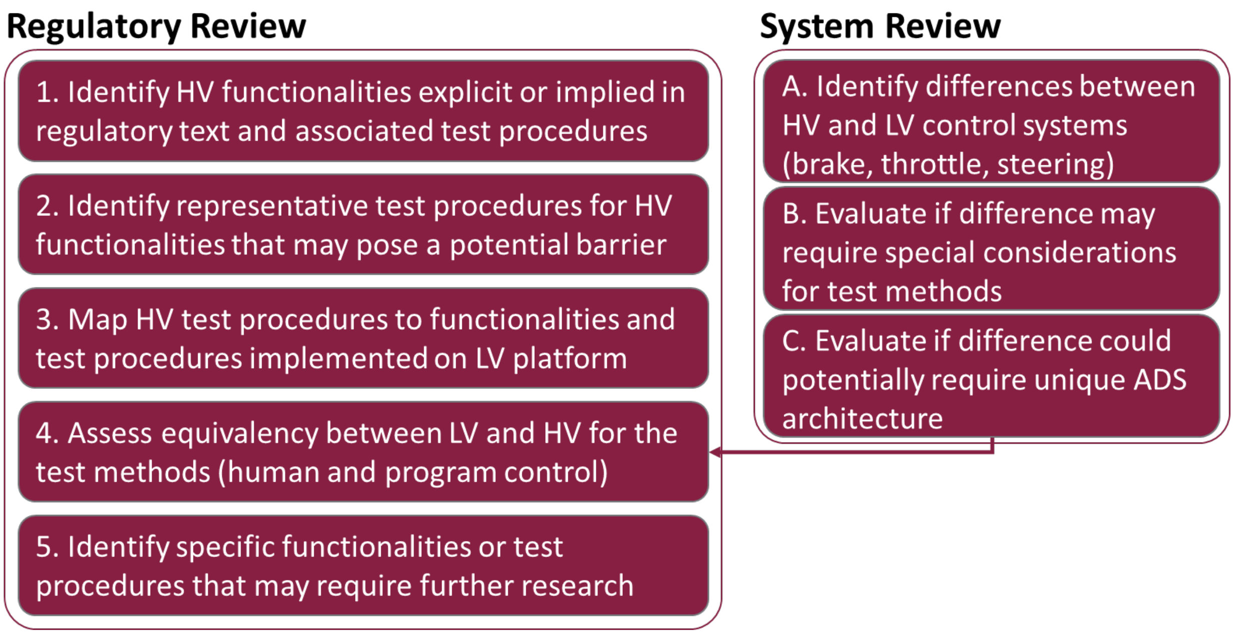

Figure 42. Evaluation steps of the HV test functionalities for ADS-DVs

The following functionalities identified in Figure 43 are based on previous work and create the foundation for the evaluation. The HV braking and ESC standard functionalities highlighted were the focus of the contextual evaluation.

Category	Functionality	Volume 1						Volume 2									Volume 3			
		102	108	114	118	138	141	101	103	104	110	111	113	124	125	126	135	105	121	136
Driving Tasks	Steering control			●		●	●				●	●				●	●	●	●	●
	Speed control (vehicle/engine)			●		●	●		●	●	●	●		●		●	●	●	●	●
	Service brake application			●		●	●				●	●				●	●	●	●	●
	Parking brake			●			●					●					●	●	●	
	Gear selection	●		●		●	●		●	●	●	●				●	●	●	●	●
Vehicle Communications	Telltales/warnings/indicators	●	●	●		●		●						●		●	●	●	●	●
Key/Ignition Function	Key insertion/removal			●																
	Ignition start/stop	●		●	●	●			●	●	●	●		●		●	●	●	●	●
	Accessory mode			●	●												●			
Non-driving Tasks	Door open/close			●	●															
	Non-driving controls		●		●				●	●		●								
Environment Awareness	Visibility							●	●	●		●	●							

Figure 43. Functionalities identified in Volume 1, 2, and 3. The braking and ESC related FMVSS are highlighted

System Review

There are both similarities and differences between the LV and HV steering, propulsion, and braking systems. For example, the steering systems for both LVs and HVs primarily use mechanical systems (e.g., rack-and-pinion or Pitman arm configuration) with some form of power assist to make the vehicle easier to steer. The propulsion systems among LVs and HVs are also similar, powered predominantly by internal combustion engines (ICE) where speed control is managed through driveline transmission gearing. While the steering systems and throttle systems are fundamentally similar today, Class 7 and 8 HVs in a weight class for gross vehicle weight ratings (GVWRs) greater than 26,000 lb are predominantly equipped with air braking systems unlike the hydraulic systems in Class 3–6 HVs and LVs.

The typical steering system configurations are rack-and-pinion for LVs and Pitman arm for HVs. However, both use power-assisted mechanical linkages. Despite the different system dynamics among LVs (e.g., Ford F–350 versus Fiat 500), their design is fundamentally the same. Some potential architectural considerations are that different steering systems accommodate system constraints due to the vehicle design (e.g., weight and steering force requirements). While this may influence ADS component selection, it should not require unique architectural changes for the ADS. Steering system differences are not expected to introduce control challenges for either human or program control requirements.

The typical speed or propulsion system configurations are ICE and battery electric vehicle. ICEs account for approximately 98 percent of the LV market and greater than 98 percent of the HV market (DeSilver, 2021; Xie, 2024). The diesel ICE is used in both HV and LV applications. Considerations for the differences in the propulsion systems for LVs and HVs are primarily associated with the vehicle scale and tuning and do not introduce unique architecture differences. Similar to steering, propulsion system differences should not introduce control challenges for either human or program control requirements for compliance verification.

The difference in the actuation and power transfer method of the two braking systems was considered. Among air braking systems, a lag in response exists between the wheel end and the input valve. Air systems are designed to address lag (and drag) across the primary (i.e., rear) axle and secondary (i.e., front) axle. This requires different tuning of control parameters, but commercially available HV AEB systems have been tested and the viability of accounting for these differences has been demonstrated in full production systems. When considering the ADS-DV test methods among hydraulic brake systems, human control using surrogate, game-type controls may respond differently from standard controls. While the use of air requires differences in the brake system architecture, it should not require unique architectural changes to an ADS since the control input is a valve. Brake system differences are not expected to pose a technical challenge for executing vehicle control during compliance verification.

Regulatory Review

A regulatory review started with identifying the functionalities present in the HV braking and ESC standards. The functionalities identified in the standards are listed in Figure 44. The functionalities fit into two categories: static driving and dynamic driving. The static driving functionalities are highlighted in Figure 44 and include parking brake, gear selection, telltales/warnings/indicators, and ignition start/stop. The review of the static functionalities was performed as a regulatory language comparison. The structure of the information includes example regulatory HV test procedures that may be impacted by different test methods in performance of those functionalities, their analogue in the LV test procedures, and a following conclusion.

Category	Functionality	Volume 1						Volume 2									Volume 3			
		102	108	114	118	138	141	101	103	104	110	111	113	124	125	126	135	105	121	136
	Steering control			●		●	●				●	●				●	●	●	●	●
Driving Tasks	Speed control (vehicle/engine)			●		●	●		●	●	●	●		●		●	●	●	●	●
	Service brake application			●		●	●				●	●				●	●	●	●	●
	Parking brake			◆			●					●					●	●	◎	
	Gear selection	●		◆		●	●		●	●	●	●				●	●	●	◎	●
Vehicle Communications	**Telltales/warnings/indicators**	●	●	●		◆		●						●		●	●	●	●	◎
	Key insertion/removal			●																
Key/Ignition Function	**Ignition start/stop**	●		◆	●	●			●	●	●	●		●		●	●	●	◎	●
	Accessory mode			●	●												●			
Non-driving Tasks	Door open/close			●	●															
	Non-driving controls		●		●				●	●		●								
Environment Awareness	Visibility							●	●	●		●	●							

◆ = LV Standards Compared **● = Functionalities Identified in Previous Volumes** **◎ = Applicable Functionalities to both HVs and LVs**

Figure 44. HV Static functionalities considered

The functionalities of the parking brake, gear selection, and key/ignition can be examined in the HV test procedure for FMVSS No. 121 S5.6.2 Grade holding. “With all parking brakes applied, the vehicle shall remain stationary facing uphill and facing downhill…” The OVSC test procedure for FMVSS No. 121 I. *Grade holding test* includes: (5) Ascend 20% grade…

(6) Apply and hold service brakes…to hold vehicle stationary.

(7) Place vehicle transmission in neutral.

(8) Turn engine off.

(9) Apply parking brakes.

(10) Release service brakes.

Similar methods exist in LV FMVSS No. 114 S6.2.2 test procedure methods to:

(a) Drive the vehicle forward up a 10 percent grade and stop it with the service brakes.

(b) Apply the parking brake…

(c) Move the gear selection control to “park” …

(d) Note the vehicle position.

(e) Release the parking brake. Release the service brakes.

(f) Remove the key.

Comparing these static test procedure requirements to the HV requirements for the Grade Holding Test, we see similar functionality requirements. Referencing the previous lists, items (6) and (9) in the HV above are comparable to (b) and (e) for the parking brake functionalities; (7) in the HV is comparable to (c) for the gear selection functionality; similar functionality is in (8) for the HV and paragraph (f) for the LV (since the key removal requires an engine off state). These LV test methods were demonstrated as feasible for ADS-DV execution using both human and program control in Volume I.

The functionalities for vehicle communication telltales, warnings, and indicators among the HV test procedures for FMVSS No. 136 were considered in paragraphs S7.8.1. LV test procedure methods were compared from FMVSS No. 138 paragraph S6.f.3, which also provides telltale guidelines. Testing for FMVSS No. 138 demonstrated a time capturing system for telltale activation that could also be used for other telltales/indicators in LVs and HVs. General requirements for “controls, telltales, and indicators” are defined in FMVSS No. 101 and are applicable to both LVs and HVs. The implementation should also be the same, and though they may be different communication protocols, the method used to monitor and record the signal should be analogous between LVs and HVs.

In summary, the evaluation comparing HV to LV static parking brake, gear selection and key/ignition functionalities found that FMVSS No. 121, *Grade holding*, is analogous to FMVSS No. 114 according to the test methods demonstrated in Volume I. Additionally, the evaluation comparing HV to LV static telltales/warnings/indicators functionalities found that the timed indicator illumination test requirement in FMVSS No. 136 is analogous to the demonstration of telltale state logged as a function of time in FMVSS No. 138.

The dynamic driving functionalities include steering control, speed (i.e., propulsion) control, and service brake application. The evaluation of the dynamic functionalities was also performed as a regulatory language comparison. Similar to the comparison of static functionalities, the structure of the dynamic functionalities included example regulatory HV test procedures that may be impacted by different test methods in performance of those functionalities, their analogue in the LV test procedures, and a following conclusion. The comparison of the dynamic functionalities is examined in Figure 45.

Category	Functionality	Volume 1						Volume 2									Volume 3			
		102	108	114	118	138	141	101	103	104	110	111	113	124	125	126	135	105	121	136
Driving Tasks	Steering control			●		●	●				●	●				● (maroon)	● (maroon)	●	◉	◉
	Speed control (vehicle/engine)			●		●	●		●	●	●	●		●		● (maroon)	● (maroon)	●	●	◉
	Service brake application			●		●	●				●	●				●	● (maroon)	●	◉	◉
	Parking brake			●			●					●					●	●	●	
	Gear selection	●		●		●	●		●	●	●	●				●	●	●	●	●
Vehicle Communications	Telltales/warnings/indicators	●	●	●		●		●						●		●	●	●	●	●
Key/Ignition Function	Key insertion/removal			●																
	Ignition start/stop	●		●	●	●			●	●	●	●		●		●	●	●	●	●
	Accessory mode			●	●												●			
Non-driving Tasks	Door open/close			●	●															
	Non-driving controls		●		●				●	●		●								
Environment Awareness	Visibility							●	●	●		●	●							

● (maroon) = LV Standards Compared ● = Functionalities Identified in Previous Volumes ◉ = Applicable Functionalities to both HVs and LVs

Figure 45. HV dynamic functionalities considered

Two elements of HV steering control functionalities were reviewed. The first is the functionality of the steering control according to a defined path. The example of the HV steering control defined path functionality was selected from FMVSS No. 136 S7.7.1.1. The standard test procedure states that, "…During any test run, if any of the wheels of the truck tractor or bus depart the lane at any point within the first 120° of radius arc angle, the test run is repeated at the same entrance speed." The steering control functionality requires the vehicle to follow a path while maintaining constant velocity, meaning by following a closed-loop control of lateral position and speed. The LV analogue is FMVSS No. 126, S7.5.1. The standard test procedure states that, "The test vehicle is driven around a circle 30 meters (100 feet) in diameter at a speed that produces a lateral acceleration of approximately 0.5 to 0.6 g for three clockwise laps followed by three counterclockwise laps." The LV standard requires that the vehicle follow a path while adjusting speed to maintain constant lateral acceleration, which is an example of similar closed-loop control. The HV steering according to a defined path functionality is represented by this similar LV standard test procedure functionality.

The second element of steering is the functionality of maintaining steering control. The example of the HV requirement to maintain control during steering was selected from FMVSS No. 121, S5.3.6. The standard test procedure states that the vehicle must be steered while maintaining it "…within the 12-foot lane, without any part of the vehicle leaving the roadway." This requires input to the vehicle to make corrective actions as necessary to follow a path. The LV analogue is FMVSS No. 135, S6.5.4.2. The standard test procedure states that, "Stops are made without any part of the vehicle leaving the lane and without rotation of the vehicle about its vertical axis of more than ±15° from the center line of the test lane at any time during any stop." If the vehicle begins to deviate from the intended path, the ADS may provide lateral input to maintain proper heading. The HV steering to maintain path functionality has a representative LV analogue. It is worth noting that during the LV test demonstration execution, the vehicle never rotated during braking to an extent that required corrective action.

The example of the HV speed control within tolerance functionality was selected from FMVSS No. 136 S7.7.1.1. The standard test procedure states that, "During any test run, the driver attempts to maintain the selected entrance speed throughout the J-Turn test maneuver…the entrance speed is 32 km/h ±1.6 km/h (20 mph ±1.0 mph) and is incremented 1.6 km/h (1.0 mph) for each subsequent test run." The speed control functionality requires the vehicle to maintain a constant speed within a given tolerance. The LV analogue is FMVSS No. 126, S7.6, which states that "The vehicle is subjected to two series of runs of the Slowly Increasing Steer Test using a constant vehicle speed of 80 ±2 km/h (50 ±1 mph)." The LV standard also requires that the vehicle maintain a constant speed within a given tolerance. The HV speed control within tolerance functionality is represented by this similar LV standard functionality.

The input requirements of the speed control functionality were also examined. The examples of the HV speed control input functionality were selected from FMVSS No. 136 S7.7.2.1, which states that "…the driver fully depresses the accelerator pedal from the time when the vehicle crosses the start gate until the vehicle reaches the end gate" and FMVSS No. 136 S7.7.3.2, which states that "… the driver will release the accelerator pedal after the ESC system has slowed vehicle by more than 4.8 km/h (3.0 mph) below the entrance speed." The LV analogue is FMVSS No. 135, S7.13.3(g), which states that the vehicle should "Accelerate as rapidly as possible to the initial test speed immediately after each snub." Additionally, FMVSS No. 135, S6.5.5.1 states that input be applied to "(a) Exceed the test speed… (b) Close the throttle…" The

HV and LV procedures both require a discrete control change from fully on to fully off into the speed control. While the signal of interest is engine torque in the HV functionality, the input is binary and therefore does not pose a unique requirement compared to LV functionality.

Two service brake application functionalities were examined, one that requires braking at a deceleration value and another that requires braking at the maximum level. The examples of service brake application for set value were selected from FMVSS No. 136 S7.4.1.1, which requires the vehicle to "…make 500 snubs between 64 km/h (40 mph) and 32 km/h (20 mph) at a deceleration rate of 0.3g" and FMVSS No. 121 S6.1.8, which requires the vehicle to "…make 500 snubs between 40 mph and 20 mph at a deceleration rate of 10 f.p.s.p.s." The LV analogue is FMVSS No. 135, S7.13.3(d), which requires the vehicle to "(1) Maintain a constant deceleration rate of 3.0 m/s2 (9.8 fps^2). (2) Attain the specified deceleration within 1 second and maintain it for the remainder of the snub." The HV functionality requires the vehicle to brake at a given deceleration level through closed-loop control. The LV functionality requires that the vehicle reach a target deceleration level within a given period and maintain that level until the target speed is reached. Therefore, the LV functionality represents the HV functionality.

The HV requirement example of service brake application at the maximum level was selected from FMVSS No. 121 S6.1.8, which requires the vehicle to "…make 500 snubs between 40 mph and 20 mph at a deceleration rate of 10 f.p.s.p.s." The LV analogue is FMVSS No. 135, S7.5.2(g), which states that the tester must "For each stop, bring the vehicle to test speed and then stop the vehicle in the shortest possible distance." The HV functionality requires the vehicle brakes be fully applied, whereas the LV functionality requires the vehicle brake at or near maximum braking or in a distance that is less than the value specified in the performance requirements. Once again, the LV functionality reflects the HV functionality.

Compare HV Standard Specifications and Associated Test Procedures

Key Findings

Relative to compliance, verification of system-level differences (e.g., hydraulic versus air brakes) between LVs and HVs should not preclude drawing inferences between the LV test method (human and program control) research and the application to HVs. Secondly, static and dynamic functionalities are similar for both LVs and HVs and therefore should not introduce additional challenges for the test methods evaluated. While there is not a one-to-one mapping of the test procedures or driving maneuvers between the braking and ESC standards for LVs and HVs, the functionality requirements are similar. As a result, they should not pose unique challenges that might preclude one or more of the evaluated test methods.

Stakeholder Input

Stakeholder feedback was requested and provided on the independence of the ESC from the ADS control approach considered in FMVSS No. 136, which addresses steering control to maintain control. The research team informed stakeholders that the expectation has been for ESC to continue to coexist and function separately from the ADS in future ADS-DVs. Therefore, vehicle stability performance can be satisfied at the ESC subsystem level through wheel-end braking among LVs or engine torque reduction among HVs, whether it is a human driver's intent to maintain speed with accelerator pedal control or the design intent of an ADS to maintain speed with throttle control. The research team determined that vehicle speed will be maintained by the

ADS without changing the nature of the J-Turn Test Maneuver in FMVSS No. 136. Additionally, the research team concluded that a comparison of speed control in FMVSS No. 136 during J-Turn Test Maneuver to FMVSS No. 126 during the Slowly Increasing Steer Test is appropriate if limited to the scope of comparing functionalities between ADS test methods.

Chapter 3. Technical Translations of Remaining Standards

Performing Technical Translation Overview

This chapter summarizes the technical translation options for the remaining crash avoidance and crashworthiness standards that were published at the time of the research and covered in Volume 4 research. This includes any definitions included in Subpart A of 49 CFR Part 571, §571.3, Definitions that were not addressed in the prior volumes and FMVSS Nos. 122, 122a, 123, 131, 223, 224, 403, and 404. The remaining standards cover a wide range of topics that include motorcycle brake systems, motorcycle controls and displays, school bus pedestrian safety devices, rear impact guards for trailers and semi-trailers, and platform lift systems. Where possible, the goal of this effort was to provide options for translating the language of any remaining definition and each standard to accommodate ADS-DVs while maintaining the current requirements for conventional (i.e., non-ADS-equipped) vehicles.

49 C.F.R. Part 571 Subpart A – General

Purpose

Subpart A of 49 CFR Part 571, *General*, specifies provisions that apply to numerous FMVSS, so the provisions do not need to be repeated throughout the FMVSS. For example, §571.3, Definitions, sets out definitions of terms that appear in more than one standard, so that those definitions do not need to be included in each standard in which they appear. Similarly, §571.4, Explanation of usage, explains how the word "any," which appears in the test procedures of numerous standards, should be construed. §571.10, Designation of seating positions ("DSP," which is a term that appears in many standards), describes how the agency and vehicle manufacturers can determine how many DSPs there are in each row of a vehicle.

Technical Translations

Section 571.3, Definitions, is the only section in Subpart A with potential barriers that may require technical translations. Several of the definitions contained in section 571.3 were addressed in Volume 1, as summarized below. The definition of "Forward Control" was newly identified as a potential barrier and is discussed below.

Volume 1 Definitions

Volume 1 identified the need to develop technical translations of many existing definitions and newly defined terms (e.g., manually operated driving controls) that may address barriers associated with the following themes: driver (operator) and driver/passenger position/presence. The aim was to create definitions that would support the technical translations across all the standards. The amendments included by NHTSA in the *Occupant Protection for Vehicles With Automated Driving Systems* Final Rule (49 CFR Part 571, 2022) added or revised the definitions to the following terms: "Driver air bag," "Driver dummy," "Driver's designated seating position," "Passenger seating position," and "Outboard designated seating position." The new term and definition of "Manually operated driving controls" was added. The definition of "Steering control system" was revised and relocated into part 571.3, "Definitions" and the definition of "Row" was relocated from FMVSS No. 226 into part 571.3, "Definitions." These revised definitions include clarifications regarding the application of occupant protection requirements in order to remove potential barriers to ADS-DVs with conventional seating (i.e., forward-facing seats). The potential barriers and revised definitions are shown in Table 13 below with the revisions highlighted in red text. Several of the examples defining DSPs and vehicle controls are consistent with NHTSA's Final Rule and are aligned with Volumes 1 and 2. While unchanged in the Final Rule, the technical translation for "driver" was developed in Volume 1 and was used in the other Volumes. The driver definition options were used consistently in the development of technical translations of the standards.

Table 13. Potential Barriers and Revised Definitions in FMVSS Part 571 Subpart-A General

FMVSS Part 571 Subpart-A General		
Regulatory Text	**Translation Assessment**	**Translation Example**
Forward control means a configuration in which more than half of the engine length is rearward of the foremost point of the windshield base and the steering wheel hub is in the forward quarter of the vehicle length.	Limited research may be beneficial	*Forward control* means a configuration in which more than half of the engine length is rearward of the foremost point of the windshield base and the forwardmost DSP is in the forward quarter of the vehicle length
Driver means the occupant of a motor vehicle seated immediately behind the steering control system.	Definition not revised in Final Rule	*Option 1: Driver* means the occupant of a motor vehicle seated immediately behind the manually operated driving controls. *Option 2: Driver* means: (1) the occupant (human driver) of a motor vehicle seated immediately behind the manually operated driving controls, and (2) the ADS (ADS driver), for ADS-equipped vehicles when the ADS is engaged. When the ADS is not engaged, the definition in paragraph (1) applies.
Driver air bag means the air bag installed for the protection of the occupant of the driver's designated seating position.	New definition of existing term added in Final Rule	
Driver dummy means the test dummy positioned in the driver's designated seating position	New definition of existing term added in Final Rule	

FMVSS Part 571 Subpart-A General		
Regulatory Text	**Translation Assessment**	**Translation Example**
Driver's designated seating position means a designated seating position providing immediate access to manually operated driving controls. As used in this part, the terms "driver's seating position" and "driver's seat" shall have the same meaning as "driver's designated seating position."	New definition of existing term added in Final Rule	
Manually operated driving controls means a system of controls: (1) That are used by an occupant for real-time, sustained, manual manipulation of the motor vehicle's heading (steering) and/or speed (accelerator and brake); and (2) That are positioned such that they can be used by an occupant, regardless of whether the occupant is actively using the system to manipulate the vehicle's motion.	New definition added in Final Rule	
Outboard designated seating position means a designated seating position where a longitudinal vertical plane tangent to the outboard side of the seat cushion is less than 12 inches from the innermost point on the inside surface of the vehicle at a height between the design H-point and the shoulder reference point (as shown in fig. 1 of Federal Motor Vehicle Safety Standard No. 210) and longitudinally between the front and rear edges of the seat cushion. As used in this part, the terms "outboard seating position" and "outboard seat" shall have the same meaning as "outboard designated seating position."	Modification of existing definition in Final Rule	
Passenger seating position means any designated seating position other than the driver's designated seating position, except as noted below. As used in this part, the term "passenger seat" shall have the same meaning as "passenger seating position." As used in this part, "passenger seating position" means a driver's	New definition of existing term added in Final Rule	

FMVSS Part 571 Subpart-A General		
Regulatory Text	**Translation Assessment**	**Translation Example**
designated seating position with stowed manual controls.		
Row means a set of one or more seats whose seat outlines do not overlap with the seat outline of any other seats, when all seats are adjusted to their rearmost normal riding or driving position, when viewed from the side.	Relocation from FMVSS No. 226.	
Steering control system means the manually operated driving control(s) used to control the vehicle heading and its associated trim hardware, including any portion of a steering column assembly that provides energy absorption upon impact. As used in this part, the term "steering wheel" and "steering control" shall have the same meaning as "steering control system."	Relocation from FMVSS No. 203 and revised	

Forward Control

The term "forward control" is used to describe a specific type of vehicle configuration. These vehicles are typically known as cabover or low cab forward trucks. In forward control vehicles, the occupant compartment sits over the front axle with the engine between the front outboard occupants, creating a flat-front vehicle. An example of a forward control vehicle is shown in Figure 46.

Figure 46. Chevrolet low-cab forward 6500XD with electric powertrain

The current definition of "forward control" references the steering wheel hub to describe the nature of the human driver position relative to the engine position. The term appears in FMVSS No. 208, *Occupant crash protection*, 212, *Windshield mounting*, and 219, *Windshield zone* *intrusion*. FMVSS No. 208 uses forward control to specify seat belt assembly adjustment requirements and FMVSS Nos. 212 and 219 use forward control in the application section (S3) of the standard to clarify that these standards do not apply to forward control vehicles.

Key Findings

For the Volume 1 definitions, the 200-series technical translations focused on removing the reference to driver and using DSP in conjunction with manually operated driving controls. A few of the 200-series technical translations retained the reference to "driver" using definition options 1 and 2. These were for FMVSS No. 205 (driver visibility) and FMVSS No. 203 (impact protection for the driver from the steering control system). In general, the 100-series standards provided options that removed the reference to a "driver" and clarified requirements through the use of "ADS-DV" or "vehicle with manually operated driving controls." When a provision required a direct reference to a human driver or an ADS, the translations used driver definition options 1 and 2. This approach used in the 100-series evolved during the development of the different volumes.

The definition of Forward Control may need to evolve not just for ADS-DVs but also for vehicles with battery-electric propulsion systems. The intent of the forward control definition is to accommodate the uniqueness of the occupant compartment and flat front design of the vehicle. Perhaps this could be accomplished by translating the steering wheel hub to the forwardmost DSP as the measurement point relative to the forward quarter of the vehicle length. The reason for the use of the forwardmost DSP is to ensure that the forward control definition does not include rear-engine or mid-engine vehicles by only defining based on the engine position. The proposed translation to forwardmost DSP may require confirmation to ensure the original intent of the forward control definition is maintained.

Stakeholder and SME Review Input

Feedback from stakeholders for Volume 1 definitions can be found in this report. Stakeholders reviewed the forward control technical translation, and no specific feedback was provided.

Crash Avoidance Remaining Standard Technical Translations

Motorcycle Regulations and Bus Regulations

A review of industry developments related to advanced driver assistance systems and ADS-equipped motorcycles yielded multiple results. For example, the BMW R 1200 GS (Figure 47) includes an automated engine start, and is able to recognize turns, accelerate, and brake to a full stop (Shazzad, 2020). The goal of these technologies is to support driving in dangerous situations such as turns and crossroads (TechAcute, 2020). The Honda Riding Assist also aims to assist the driver by providing self-balance (without use of gyroscopes or the driver) and allows for autonomous movements for short trips without a rider (Honda, 2017). Similar to the Honda Riding Assist, the Yamaha Motoroid is capable of moving by itself. The Motoroid incorporates Yamaha's Active Mass Centering Control System and a haptic human-machine interface, in addition to artificial intelligence with the ability to recognize the owner's face (via facial recognition) and command gestures (Yamaha Motor Co., 2021).

Figure 47. BMW R 1200 GS (BMW press photo); Honda Riding Assist Technology Self-Balancing Motorcycle (Honda press photo); Yamaha Motoroid (Yamaha press photo)

FMVSS No. 122: Motorcycle Brake Systems

The purpose of FMVSS No. 122 "is to ensure safe motorcycle braking performance under normal and emergency conditions." The standard "specifies requirements for motorcycle service brake systems and, where applicable, associated parking brake systems" and applies to categories 3-1, 3-2, 3-3, 3-4, and 3-5 motorcycles as defined in section S4.

Technical Translations

There are a few common topics that are consistent with those found in FMVSS No. 135. Consequently, the same approach can be used to provide potential translations in FMVSS No. 122. These topics include the driver, indicators, use of controls for brake activation or application, specific reference to hand and foot controls, and force specifications for hand and foot controls. The terms "driver" and "rider" are both used in the standard, with the term rider being used twice (eight times) as often as driver (four times). There is not a definition for rider though its use is consistent with common use in relationship to the operation of a motorcycle. Three of the times driver is used is related to the loading of the motorcycle. The fourth use is a subclause for warning lamps where rider is also used to indicate the visibility of the indicator to the vehicle operator. Given the use of the two terms, the proposed definitions for driver (Appendix A: Definitions) could be applied to rider or rider could be replaced by driver in the text.

The same approach for the indicators used for the potential translation options for FMVSS No. 135 is likely applicable for FMVSS No. 122. This includes using the term "signal" instead of "indicator" along with the first driver definition. Additionally, the distinction between the human driver/rider and ADS can be used to provide additional potential translations.

As discussed previously regarding FMVSS No. 135 testing, the force requirements may not be relevant for an ADS-DV as the brake system, including the actuators, will be designed to apply the necessary input to activate the service brakes. Note that the current driver definition may be inclusive enough to apply to an ADS-DV with the driver/rider defined as either the human or ADS (the first driver definition option). The table below (Table 14) shows examples of the potential translation options for FMVSS No. 122.

Table 14. Technical Translation Options for FMVSS No. 122

FMVSS No. 122, S5.1.10 Warning lamps.			
Regulatory Text	**Translation Options**		**Potential Considerations**
Warning lamps. All warning lamps shall be mounted in the rider's view.	**Option 1**	Warning signal. (a) For a motorcycle equipped with manually operated driving controls, all warning signals shall be mounted in the rider's view. (b) For an ADS-DV, the information and warnings specified in S5.1.10 shall be communicated to the ADS.	Applies driver definition 1 to rider. Does not require the information to be communicated to rider of an ADS-DV. Does not necessarily provide direct means to verify compliance. Does not provide specific communication method requirements. Does not provide requirement that the information be communicated to a party responsible for the care of the motorcycle.
	Option 2	Warning signal. (a) For a motorcycle equipped with manually operated driving controls, all warning signals shall be mounted in the rider's view. (b) For an ADS-DV, the information and warnings specified in S5.1.10 shall be communicated to the ADS and shall have one or more visual brake system warning indicators, mounted in front of and in clear view of the rider.	Applies driver definition 2 to rider. Retains basic language for a motorcycle operated by a human driver and adds condition for an ADS. Does not specify a means to verify compliance in an ADS-DV. Does not provide specific communication method requirements. Does not provide requirement that the information be communicated to a party responsible for the care of the motorcycle.
	Option 3	Retain current language.	Assumes rider may be actively involved in dynamic driving task (DDT) or passive and the ADS is the driver. Does not require the information to be communicated to occupants of an ADS-DV.

FMVSS No. 122, S7.2.2. Baseline Test.(c)			
Regulatory Text	**Translation Options**		**Potential Considerations**
Pedal force: ≤ 65N (14.6 lbs), ≤ 500N (112.4 lbs). (d) Brake actuation force. (1) Hand control: ≤ 200 N. (2) Foot control: (i) ≤ 350 N for motorcycle categories 3-3 and 3-4. (ii) ≤ 500 N for motorcycle category 3-5.	**Option 1**	Brake actuation input: (1) For human riders: (1.1) Hand control ≤ 200N. (1.2) Foot control (i) < 350N for motorcycle categories 3-3 and 3-4. (ii) ≤ 500 N for motorcycle category 3-5. (2) For an ADS-DV: sufficient service brake input to achieve the applicable performance requirements.	Applies driver definition 1 to rider. The performance criteria is the stopping distance for the compliance verification. Hand and foot force requirements are present to ensure that a wide range of human drivers, with a wide range of strengths, are able to safely stop any motorcycle they are operating. For an ADS-DV, there is only one "driver" and the motorcycle will have to be designed in such a way to put sufficient input into the braking system to meet the stopping distance criterion. Specifying a range of inputs may also be meaningless if the actuation force is applied directly to the friction surface as there would be no gain in the system to accommodate lower input forces.
	Option 2	Brake actuation input: (1) For human riders: (1.1) Hand control ≤ 200N. (1.2) Foot control (i) < 350N for motorcycle categories 3-3 and 3-4. (ii) ≤ 500 N for motorcycle category 3-5. (2) For an ADS-DV, service brake inputs are consistent with normal operation of the ADS.	Uses driver definition 2. Provides option for the ADS to operate the brake system as designed for normal operation. There is no way to confirm that "normal operation" under test conditions is the same as "normal operation" during typical riding.
	Option 3	Brake actuation input: (1) For human riders: (1.1) Hand control ≤200N. (1.2) Foot control (i) < 350N for motorcycle categories 3-3 and 3-4. (ii) ≤ 500 N for motorcycle category 3-5. or equivalent brake system input	Allows testing at different input levels for additional brake system embodiments. Does not specify the equivalent input levels.

Key Findings

The requirements for motorcycle brake systems are similar to those for LVs as specified in FMVSS No. 135. For consistency, the general translations approaches used in the automotive applications were applied to translations for motorcycle brake systems.

Stakeholder and SME Review Input

No feedback received.

FMVSS No. 122a

FMVSS No. 122 supersedes FMVSS No. 122a.

FMVSS No. 123: Motorcycle Controls and Displays

The purpose of this standard is to minimize crashes caused by operator error in responding to the motoring environment by standardizing certain motorcycle controls and displays.

Technical Translations

This standard specifies requirements for the location, operation, identification, and illumination of motorcycle controls and displays, and requirements for motorcycle stands and footrests. This standard applies to motorcycles equipped with handlebars, except for motorcycles that are designed, and sold exclusively for use by law enforcement agencies. By definition (Appendix A: Definitions), an ADS-DV does not have manually operated driving controls such as handlebars. Consequently, this standard does not apply to ADS-DVs, and no technical translation was performed.

Stakeholder and SME Review Input

No feedback received.

FMVSS No. 131: School Bus Pedestrian Safety Devices

The scope of this "…standard establishes requirements for devices that can be installed on school buses to improve the safety of pedestrians in the vicinity of stopped school buses. (S1)" The standard applies "…to school buses other than multifunction school activity buses (S3)," and the requirements in the standards are concentrated on stop signal arm equipment. A stop signal arm is "…a device that can be extended outward from the side of a school bus to provide a signal to other motorists not to pass the bus because it has stopped to load or discharge passengers. (S4)"

Technical translations were developed to remove potential regulatory barriers in S5.4.1 (b) regarding the installation location of the stop signal arm and S5.5 regarding the function of the stop signal arm when it is equipped with an optional device that prevents the automatic extension of the stop signal arm. The location for the installation of the stop signal arm references the bus driver's window. This window height relative to the driver's seat and manually operated driving controls is similar between different bus makes and models today, while the height of the driver from the ground varies by bus make/model. Therefore, if the manually operated driving controls are removed in future school buses, a new reference is needed. Additionally, among school buses not equipped with manually operated driving controls, the operation of an optional stop signal arm prevention device that is performed by a driver today may be performed in some other automated manner or by an onboard vehicle supervisor tomorrow.

Technical Translations

Three technical translation options for S5.4.1 (b) were developed and are listed in Table 15. The original text is provided followed by three options. The original text identified in red italics is removed in at least one option. New text in the translation options is identified with red italics, and text that may be removed is crossed out. Technical translation options for S5.4.1 (b), use driver definitions 1 and 2. Technical translation options 1 and 2 include separate text for manually operated driving control and ADS-DV equipped school buses. Technical translation option 3 does not distinguish between as-equipped school buses. Instead, a translation replacing "driver's window" with a reference to the "forwardmost passenger window" is proposed.

Table 15. Technical Translation Options for FMVSS No. 131, S5.4.1(b)

FMVSS No. 131, S5.4.1 (b)		
Regulatory Text	**Translation Options**	
S5.4.1 (b) The top edge of the stop signal arm is parallel to and not more than 6 inches from a horizontal plane tangent to the lower edge of the frame of the passenger window immediately behind the driver's window; and	**Option 1**	*On each bus equipped with manually operated driving controls,* the top edge of the stop signal arm is parallel to and not more than 6 inches from a horizontal plane tangent to the lower edge of the frame of the passenger window immediately behind the *human* driver's window; *and on each ADS-DV bus, the top edge of the stop signal arm is parallel to and not more than 6 inches from a horizontal plane tangent to the lower edge of the frame of the forwardmost passenger window*; and
	Option 2	*On each bus equipped with manually operated driving controls,* the top edge of the stop signal arm is parallel to and not more than 6 inches from a horizontal plane tangent to the lower edge of the frame of the passenger window immediately behind the driver's window; *and on each ADS-DV bus, the top edge of the stop signal arm is parallel to and not more than 6 inches from a horizontal plane tangent to the lower edge of the frame of the forwardmost passenger window;* and
	Option 3	The top edge of the stop signal arm is parallel to and not more than 6 inches from a horizontal plane tangent to the lower edge of the frame of the *forwardmost* passenger window; and

Three technical translation options for S5.5 were developed and are listed in Table 16. The original text is provided first followed by three options. The original text identified in red italics is removed in at least one option. New text in the translation options is identified with red italics and text that may be removed is crossed out. Technical translation options 1 and 3 for S5.5, use driver definition 1; driver definition 2 was used for option 2. Technical translation options 1 through 3 include separate text for manually operated driving control and ADS-DV equipped school buses. The only difference between the text translations in option 1 and 2 is the driver definition. The differences between options 1 and 3 relate to the requirements for communication of the state of the stop signal arm prevention device warning. The reference to the "manual" operation of the stop signal override is removed for both manually operated driving control and ADS-DV equipped school buses in all translation options.

Table 16. Technical Translation Options for FMVSS No. 131, S5.5

FMVSS No. 131, S5.5		
Regulatory Text		**Translation Options**
The stop signal arm shall be automatically extended in such a manner that it complies with S5.4.1, at a minimum whenever the red signal lamps required by S5.1.4 of Standard No. 108 are activated; except that a device may be installed that prevents the automatic extension of a stop signal arm. The mechanism for activating the device shall be within the reach of the driver. While the device is activated, a continuous or intermittent signal audible to the driver shall sound. The audible signal may be equipped with a timing device requiring the signal to sound for at least 60 s. If a timing device is used, it shall automatically recycle every time the service entry door is opened while the engine is running, and the manual override is engaged.	**Option 1**	The stop signal arm shall be automatically extended in such a manner that it complies with S5.4.1, at a minimum whenever the red signal lamps required by S5.1.4 of Standard No. 108 are activated; except that a device may be installed that prevents the automatic extension of a stop signal arm. *On each bus equipped with manually operated driving controls,* the mechanism for activating the device shall be within the reach of the *human* driver. While the device is activated, a continuous or intermittent signal audible to the *human* driver shall sound. *On each ADS-DV bus the mechanism for activating the device shall be located within the reach of an occupant in the manufacturer's DSP. While the device is activated, a continuous or intermittent signal visible and audible in the manufacturer's DSP shall sound.* The audible signal may be equipped with a timing device requiring the signal to sound for at least 60 s. If a timing device is used, it shall automatically recycle every time the service entry door is opened while the engine is running, and the override is engaged.
	Option 2	The stop signal arm shall be automatically extended in such a manner that it complies with S5.4.1, at a minimum whenever the red signal lamps required by S5.1.4 of Standard No. 108 are activated; except that a device may be installed that prevents the automatic extension of a stop signal arm. *On each bus equipped with manually operated driving controls* the mechanism for activating the device shall be within the reach of the driver. While the device is activated, a

FMVSS No. 131, S5.5		
Regulatory Text		Translation Options
		continuous or intermittent signal audible to the driver shall sound. *On each ADS-DV bus the mechanism for activating the device shall be located within the reach of an occupant in the manufacturer's DSP. While the device is activated, a continuous or intermittent signal visible and audible in the manufacturer's DSP shall sound.* The audible signal may be equipped with a timing device requiring the signal to sound for at least 60 s. If a timing device is used, it shall automatically recycle every time the service entry door is opened while the engine is running, and the override is engaged.
	Option 3	The stop signal arm shall be automatically extended in such a manner that it complies with S5.4.1, at a minimum whenever the red signal lamps required by S5.1.4 of Standard No. 108 are activated; except that a device may be installed that prevents the automatic extension of a stop signal arm. *On each bus equipped with manually operated driving controls* the mechanism for activating the device shall be within the reach of the *human* driver. While the device is activated, a continuous or intermittent signal audible to the *human* driver shall sound. *On each ADS-DV bus the mechanism for activating the device shall be located within the reach of an occupant in the manufacturer's DSP. While the device is activated, a continuous or intermittent signal visible and audible in the manufacturer's DSP shall sound and be communicated to the ADS.* The audible signal may be equipped with a timing device requiring the signal to sound for at least 60 s. If a timing device is used, it shall automatically recycle every time the service entry door is opened while the engine is running, and the override is engaged.

Key Findings

During outreach to stakeholders, a stakeholder asked a question regarding the activation of the stop signal lamp. The question highlights a key finding for ADS-DV school buses. The question was phrased as, "How does an ADS-DV make the decision that it is in pick-up/drop-off student mode and needs to activate the red signal lamps and stop arm?" The point the stakeholder was making is a reasonable question since the ADS-DV should not activate the red signal lamps and stop signal arm unless it is picking up or dropping off students. While it seems reasonable that a future ADS-DV school bus may be activated in a student pick-up mode based on time and location, human drivers currently make a judgement regarding the safety and need to stop the bus and open the doors. This finding might suggest that while an ADS-DV may not be operated by a human driver, it is possible that the presence of a human safety supervisor may be necessary. The decision about whether to stop for student loading may be worth consideration in future ADS-DV school bus operations, but the requirement is about the activation of the stop signal lamp not the decision to stop.

Stakeholder and SME Review Input

Two manufacturers of school buses in North America were asked by the VTTI research team to review the technical translation options and provide feedback. One stakeholder stated that school buses are not likely to be developed into ADS-DVs in the near-term. Another stakeholder agreed to review the technical translation options. The research team also asked this stakeholder to provide guidance on the applications when the prevention device is used to override the stop signal arm. The stakeholder told the research team that it is an optional device ordered by some school bus fleets to prevent the stop signal arm from activating while in tight spaces, such as school bus parking lots and lanes.

The same stakeholder was asked to comment on the standard technical translation options text. This stakeholder provided input to the text and suggested changing the location reference from a driver window to the "forwardmost passenger window." This stakeholder recommended against adjusting the reference to a height above ground due to the variability in school bus floor heights in buses made by different manufacturers, and even among different types of buses made by the same manufacturer, for example large conventional engine school buses and minibuses.

Crashworthiness Remaining Standard Technical Translations

FMVSS No. 223: Rear Impact Guards

The purpose of this standard is to reduce the number of deaths and serious injuries that occur when LVs collide with the rear end of trailers and semitrailers.

Technical Translations

Regulation Translation Assessment: Not performed

This standard specifies requirements for rear impact guards for trailers and semitrailers. This standard applies to rear impact guards for trailers and semitrailers subject to FMVSS No. 224, Rear Impact Protection (§571.224).

As written, this would be applicable to vehicles with manual steering controls as well as ADS-DVs.

Stakeholder and SME Review Input

No feedback has been requested.

FMVSS No. 224: Rear Impact Protection

The purpose of this standard is to reduce the number of deaths and serious injuries occurring when light duty vehicles impact the rear of trailers and semitrailers with a GVWR of 4,536 kg or more.

Technical Translations

Regulation Translation Assessment: Not performed

This standard establishes requirements for the installation of rear impact guards on trailers and semitrailers with a GVWR of 4,536 kg or more. The standard does not apply to pole trailers, pulpwood trailers, road construction controlled horizontal discharge trailers, special purpose vehicles, wheels-back vehicles, or temporary living quarters as defined in 49 CFR 529.2. If a cargo tank motor vehicle, as defined in 49 CFR 171.8, is certified to carry hazardous materials, and has a rear bumper or rear end protection device conforming with 49 CFR Part 178 located in the area of the horizontal member of the rear underride guard required by this standard, the guard need not comply with the energy absorption requirement (S5.2.2) of 49 CFR 571.223.

As written, this would be applicable to vehicles with manual steering controls as well as ADS-DVs.

Stakeholder and SME Review Input

No feedback has been requested.

FMVSS No. 403: Platform Lift Systems for Motor Vehicles, and FMVSS No. 404: Platform Lift Installations in Motor Vehicles

The purpose of these standards is to prevent injuries and fatalities to passengers and bystanders during the operation of platform lifts installed in motor vehicles.

Technical Translations

These standards specify requirements for platform lifts used to assist persons with limited mobility in entering or leaving a vehicle. They apply to platform lifts manufactured on and after April 1, 2005, that are designed to carry passengers, who may be aided by canes or walkers, as well as persons seated in wheelchairs, scooters, and other mobility aids, into and out of motor vehicles, and to vehicles manufactured after July 1, 2005, that are equipped with such lifts.

FMVSS No. 403 specifies audible notifications to the human lift operator when the lift is in use. It also requires a clear and unobstructed view of the platform lift passenger and the passenger's mobility aid for the lift operator when operating the lift and identifies lift interlock requirements that do not include the operator applying the service brakes. The paragraphs that may require technical translations are set out in the following tables. With respect to FMVSS No. 403, S6.2.4 Maximum noise level of public use lifts; S6.7.7 Control location for public use lifts; and S6.10.2.2 could be addressed with straightforward translations. FMVSS No. 404 also specifies that, for public use lifts, the control operator must have a direct, unobstructed view of the platform lift passenger and/or the passenger's mobility aid. Table 17 captures the regulatory text and potential translation examples for FMVSS Nos. 403 and 404.

Table 17. FMVSS Nos. 403 and 404 Potential Barriers and Translation Examples

FMVSS No. 403, S6.2.4 Maximum noise level of public use lifts.	
Regulatory Text	**Translation Example**
Except as provided in S6.1.5, throughout the range of passenger operation specified in S7.9.4 through S7.9.7, the noise level of a public use lift may not exceed 80 dBa as measured at any lift operator's position designated by the platform lift manufacturer for the intended vehicle and in the area on the lift defined in S6.4.2.1. Lift operator position measurements are taken at the vertical centerline of the control panel 30.5 cm (12 in) out from the face of the control panel. In the case of a lift with a pendant control (i.e., a control tethered to the vehicle by connective wiring), measurement is taken at the vertical centerline of the control panel 30.5 cm (12 in) out from the face of the control panel while the control panel is in its stowed or stored position. For the lift operator positions outside of the vehicle, measurements are taken at the intersection of a horizontal plane 157 cm (62 in) above the ground and the vertical centerline of the face of the control panel after it has been extended 30.5 cm (12 in) out from the face of the control panel.	Except as provided in S6.1.5, throughout the range of passenger operation specified in S7.9.4 through S7.9.7, the noise level of a public use lift may not exceed 80 dBa as measured at any human lift operator's position…

FMVSS No. 403, S6.7.7 Control location for public use lifts.	
Regulatory Text	Translation Example
In public use lifts, except for the backup operation specified in S6.9, all control panel switches must be positioned together and in a location such that the lift operator has a direct, unobstructed view of the platform lift passenger and the passenger's mobility aid, if applicable. Verification with this requirement is made throughout the lift operations specified in S7.9.3 through S7.9.8. Additional controls may be positioned in other locations.	In public use lifts, except for the backup operation specified in S6.9, all control panel switches must be positioned together and in a location such that any lift operator has a direct…locations.
FMVSS No. 403, S6.10.2.2	
Regulatory Text	Translation Example
Operation of the platform lift from the stowed position until forward and rearward mobility of the vehicle is inhibited, by means of placing the transmission in park or placing the transmission in neutral and actuating the parking brake or the vehicle service brakes by means other than the operator depressing the vehicle's service brake pedal. Verification with this requirement is made throughout the lift operations specified in S7.9.2 and S7.9.3.	Operation of the platform lift from the stowed position until forward and rearward mobility of the vehicle is inhibited, by means of placing the transmission in park or placing the transmission in neutral and actuating the parking brake or the vehicle service brakes by means other than a human driver depressing the vehicle's service brake…

FMVSS No. 404, S4.3.2 Public use lift.	
Regulatory Text	Translation Example
In addition to meeting the requirements of S4.3.1, for vehicles equipped with public use lifts, as defined in 49 CFR 571.403, any and all controls provided for the lift by the platform lift manufacturer other than those provided for back-up operation of the platform lift specified in S5.9 of 49 CFR 571.403, must be located together and in a position such that the control operator has a direct, unobstructed view of the platform lift passenger and/or their mobility aid throughout the lift's range of passenger operation. Additional power controls and controls for back-up operation of the lift may be located in other positions.	In addition to meeting the requirements of S4.3.1, for vehicles equipped with public use lifts, as defined in 49 CFR 571.403, any and all controls provided for the lift by the platform lift manufacturer other than those provided for back-up operation of the platform lift specified in S5.9 of 49 CFR 571.403, must be located together and in a position such that any control operator has a direct, unobstructed view of the platform lift passenger and/or their mobility aid.

Potential Considerations

The sections identified in the above table specify requirements for the lift operator to ensure the safe operation of platform lifts designed to carry passengers and their mobility aids into and out of motor vehicles. All the above citations (except FMVSS No. 403 S6.10.2.2) are specific in identifying a lift or control operator. This approach supports many different potential human operators, including the human driver in a vehicle with manually operated driving controls, any occupant of a vehicle, or the passenger using the lift itself. The noise level specification and the "direct, unobstructed view" requirement, in this context, are specific audio or visual requirements provided to a human control operator. This approach would also support the potential option of the ADS operating the platform lift under the supervision of a human. In this case, additional research may be required if the ADS performed this role to address the human-centered nature of the audio and visual specifications (S6.2.4 and S6.7.7) and the related verification requirements (S7.9.2 and S7.9.3).

For FMVSS No. 403 S6.10.2.2, the term "operator" can be maintained since this term is somewhat synonymous with driver and has been used in prior translations. In this instance, there may be benefit in providing additional clarification as to who the "operator" may be. One potential option would be to replace "operator" with "driver" or "human driver" to provide further clarification regarding who has the ability to depress the service brake pedal (or not to depress it in this case).

For FMVSS No. 404, S4.3.2, the term "the control operator" was revised to "any control operator" to be consistent with FMVSS 403, S6.7.7 and to address the possibility that the lift operator might not be a human.

Stakeholder and SME Review Input

No feedback has been requested.

Crashworthiness Standards for Unconventional Seating

Crashworthiness FMVSS Nos. 201, 202a, 207, 209, 210, 214, 216a, 219, and 226 were reviewed to identify any sections that may require a technical translation or further research. The technical translations from Volume 1 and 2 and the amendments included by NHTSA in the *Occupant Protection for Vehicles With Automated Driving Systems* Final Rule (49 CFR Part 571, 2022*)* were used as the basis for the review to determine their suitability for an unconventional seating configuration. The translations from Volume 1, 2, and the Final Rule only considered conventional seating (i.e., forward facing). For the purposes of this evaluation, fixed face-to-face DSPs for the first and second rows were used. The approaches and themes identified in Volume 3 for FMVSS No. 208 for unconventional seating were used as a starting point for the remaining crashworthiness FMVSS.

Any section that may require a further technical translation or additional research for an unconventional seating configuration has been given a theme to identify common areas of potential barriers. The themes identified when translating FMVSS No. 208 for unconventional seating included air bags, child restraints, unbelted occupants, injury criteria, Part 572 –ATDs, as well as telltales, indicators, and auditory alerts. If the translation issue in a section does not correspond to one of these six identified themes, the theme is listed as "Other," with a potential theme in parentheses. Under potential considerations, this new theme will be identified (e.g., fore/aft direction) and any potential barriers to the technical translation will be described. Table 18 lists the other themes that were identified in the review of FMVSS Nos. 201, 202a, 207, 209, 210, 214, 216a, 219, and 226 as well as the six themes for FMVSS No. 208 found in Volume 3. Appendix D lists each section of the crashworthiness FMVSS identified as having a potential barrier or an area that may require research. The theme and potential considerations for each section are also listed in each table of Appendix C.

Table 18. Potential Barrier Themes for Unconventional Seating Configurations

Theme	FMVSS									
	208 (V3)	201	202a	207	209	210	214	216a	219	226
Air bags	●									
Child restraints	●									
Unbelted occupant	●									
Injury criteria	●		●							
Part 572 ATD	●						●			
Telltales	●									●
Driver reference		●								
Test reference location may not be applicable		●							●	
Directionality		●								●
Dummy positioning		●					●	●		
Front/rear differentiation			●							
Fore/aft control			●	●		●	●			
Test setup							●			●

FMVSS No. 201: Occupant Protection in Interior Impact

"This standard specifies requirements to afford impact protection for occupants." (S1)

Potential Considerations

FMVSS No. 201 establishes requirements for instrument panels, seat backs, interior compartment doors, armrests, and sun visors in S5, and upper interior components in S6 through S10.

The definition of A-pillar in S3 was previously translated from "any pillar that is entirely forward of a transverse vertical plane passing through the seating reference point of the *driver's seat*" to

> any pillar that is entirely forward of a transverse vertical plane passing through the seating reference point of the *driver's designated seating position or, if there is no driver's designated seating position, any pillar that is entirely forward of a transverse vertical plane passing through the seating reference point of the rearmost designated seating position in the front row of seats*.

Since the seating reference point for a DSP in a rear-facing front row of seats may be closer to the front of the vehicle than in a conventional front-facing front row, this definition may not be appropriate for unconventional seating designs, as the seating reference point could be forward of the A-pillar.

In S5.1, the requirements for a headform impacting the instrument panel are listed. Since an instrument panel may not be present in an ADS-DV with rear-facing front seats, the requirements may not be applicable. Any other structure or surface that could be between the first and second row of seats may require a similar impact test to demonstrate adequate occupant protection. A translation for this area in a vehicle with an unconventional seating configuration may be necessary. In addition, S5.1.1 uses the instrument panel and the steering wheel as reference points for areas that do not fall under the requirements of S5.1, and therefore some technical translations may be required for such vehicles. Sun visors constructed with energy-absorbing material are required for each front outboard DSP in S5.4. Research may be required to determine if this requirement is necessary or appropriate for vehicles with unconventional seating configurations.

An area that may require substantial research is not only redefining current existing points in the interior of the vehicle to test but establishing additional requirements for forward-facing second row occupants and rear-facing first row occupants. While seat backs, compartment doors, armrests, and sun visors are identified as areas to test in S5, the scope of surfaces in the vehicle may need to be expanded to address an unconventional seating configuration. An occupant's head, as well as the headform, may be able to contact more areas in this configuration than in a conventional vehicle. Other impact locations, such as along the A-pillar, would not necessarily have to be tested for a rear-facing front row since those points are unlikely to be impacted in a frontal crash. Occupants currently benefit from the compartmentalization of the steering wheel, windshield, and seat backs. However, unconventional seating configurations present new impact locations in the interior of the vehicle and possibly between occupants of the first and second row, especially unbelted occupants. Determining which additional surfaces could be included in S5 for unconventional seating configurations may require more research to maintain the current level of safety required by FMVSS No. 201.

S6 through S10 of FMVSS No. 201 apply to the upper interior components of the vehicle. The location of the head center of gravity used in the test procedure for upper interior targets of the vehicle is specified in S8.12. There are designations for rearmost and forwardmost head center of gravity (CG-F). The rearmost CG-F is found with the front outboard DSP in the rearmost normal design driving or riding position and the forwardmost is found with the seat in the forwardmost adjustment position. A rear-facing front seat could have the opposite locations with the rearmost CG-F being closer to the front of the vehicle. Additional studies may be required to ensure the proper locations are set in unconventional seating configurations. This process is important because each target for upper interior impact is determined based on the initial CG-F locations. The launch angles for the headform impacting several different targets are listed in S8.13.4. A forward-facing front seat was contemplated when NHTSA determined the launch angles in the existing standard, so research may be required to determine the appropriate launch angles for a rear-facing front seat.

The target locations for upper interior impact tests are specified in S10.1 through S10.16. Target locations are described along the A-pillar, B-pillar, other pillars (if applicable), rearmost pillar, side rails between each pillar, front header, upper roof, and rear header. APR (AP1) is a point between the A-pillar and roof structure that is used to determine almost every other target location in the vehicle. Any changes to the upper roof structure may alter the APR location and change every other target. This could be more critical for unconventional seating configurations, as the structure of the windshield and roof may differ from the structure in a vehicle with conventional seating. S6.1(a) states that the "requirements do not apply to any target that cannot be located using the procedures of S10." If an ADS-DV is constructed such that APR cannot be located per the current procedure, an alternative method may be required to establish subsequent target locations. Table 19 includes the sections of FMVSS No. 201 that may warrant technical translations to address vehicles with rear-facing front seats.

Stakeholder and SME Review Input

Some reviewers stated “a longer-term phase should look at an alternative method of determining head impact locations. Define protection zones by using simulation to determine where a belted occupant’s head could reach in the vehicle.” Other feedback suggested the current FMVSS No. 201 Upper Interior markup procedure should be evaluated to ensure it can be applied to different seating configurations. The head CG, as noted previously, will be in a different location for rear-facing front seats such that the markup procedure will break down. Similarly, “novel vehicle designs may not have a traditional intersection between the windshield and roof structure. This changes the reference point that drives the A-pillar targets. There should be another way to define this.” More feedback suggested that sun visors (S5.4) should be optional for vehicles with rear-facing front seats as they are designed for a human driver facing forward in the vehicle.

FMVSS No. 202a: Head restraints

“This standard specifies requirements for head restraints to reduce the frequency and severity of neck injury in rear-end and other collisions.” (S1)

Potential Considerations

The role of the head restraints is to reduce neck injuries primarily in rear-end collisions. Although the standard is not explicitly limited to front-facing seats, that was clearly the context in which it was promulgated. If NHTSA concludes that FMVSS No. 202a should apply to rear-facing front seats, research may be required to determine appropriate injury criteria and test procedures for those head restraints.

The requirements of S4.2 or S4.3 apply to “each forward-facing outboard designation seating position equipped with a head restraint.” For the dynamic performance requirements of S4.3, the injury criteria in S4.3.1 and the test procedures in S5.3 contemplate a forward acceleration of the test platform. If a rear-facing front seat is to meet the dynamic performance requirements in S4.3, the test would have to be conducted with a rearward acceleration of the test platform. As currently written, a rear-facing front seat would only have to meet the static performance requirements in S4.2. The requirements for head restraints in the rear row could be changed to replicate the level of safety currently required by head restraints for front row forward-facing seats.

The procedure in S5.3.4 requires use of the fore/aft controls to adjust the seating position. A straightforward technical translation may be necessary for rear-facing seats to ensure the procedure is clear, as the terms “forwardmost” and “rearmost” are used. For a fixed rear-facing front row this is not an issue. Much of the dummy positioning procedure in S5.3.7 follows the procedure described in FMVSS No. 208. Table 20 includes the sections of FMVSS No. 202a that may warrant technical translations to address vehicles with rear-facing front seats.

Stakeholder and SME Review Input

From feedback provided in Volume 1 related to unconventional seating configurations, reviewers proposed that head restraints could be mandatory for all seating positions if occupants are more likely to sit in the rear seat of an ADS-DV. Two reviewers noted that FMVSS No. 202a should be limited to forward-facing seats and research may be required for head restraints in rear-facing front seats because the head restraints will be engaged when the vehicle is impacted from a direction other than a rear-end collision. Other feedback suggested removing the differentiation of "front outboard" and "rear outboard" and applying the current regulations for the front row uniformly to all seating positions.

Other feedback suggested that rear-facing front seats shall meet the S4.2 Dimensional and static performance requirements and may be required to be taller, for example, to meet the injury criteria of FMVSS No. 208 in a frontal crash if the vehicle weight category requires it. Research may be needed to develop a high-speed frontal crash protection requirement for rear-facing seats if the vehicle weight category does not require FMVSS No. 208. The current low-speed dynamic test that applies to only forward-facing seats may not be sufficient.

FMVSS No. 207: Seating systems

"This standard establishes requirements for seats, their attachment assemblies, and their installation to minimize the possibility of their failure by forces acting on them as a result of vehicle impact." (S1)

Potential Considerations

The standard already accommodates both forward-facing and rearward-facing seats. The term "rearward-facing seat" appears in FMVSS No. 207, *Seating systems*, so the use of the terms "rearmost" and "forward" may be interpreted as the direction the seat faces and not vehicle orientation and thus, a technical translation would not be necessary.

Stakeholder and SME Review Input

A reviewer noted that while the regulation already applies to forward-facing and rear-facing seats, clarification of this point could be added.

FMVSS No. 209: Seat belt assemblies

"This standard specifies requirements for seat belt assemblies." (S1)

Potential Considerations

This standard applies to seat belt assemblies for use in passenger cars, multipurpose passenger vehicles, trucks, and buses and is primarily related to the webbing and hardware of seat belts. As written, the standard should apply to vehicles with manually operated driving controls and ADS-DVs with unconventional seating configurations, such as a rear-facing front row of seats. The definition for "seat back retainer" uses the phrase "forward movement of a seat back" but this already applies to rear-facing seats, as it refers to the direction the seat faces and not the vehicle's orientation.

Stakeholder and SME Review Input

Feedback suggested that S4.5(b) could require further research to allow more flexibility in the use of load limiters that do not comply with the elongation requirements in FMVSS No. 209.

FMVSS No. 210: Seat belt assembly anchorages

"This standard establishes requirements for seat belt assembly anchorages to ensure their proper location for effective occupant restraint and to reduce the likelihood of their failure." (S1)

Potential Considerations

As written, FMVSS No. 210, Seat belt assembly anchorages would not require any technical translation for an ADS-DV with fixed or adjustable rear-facing front seats. This standard already applies to the seat belt anchorages in rear-facing seats. In addition, S4.3 Location currently addresses this issue: "As used in this section, 'forward' means the direction in which the seat faces, and other directional references are to be interpreted accordingly." The only section that may require clarification is S4.3.2. In this section, the seat is set in its "rearmost" and "downward" position and specifies "the upper end of the upper torso restraint shall be located within the acceptable range shown in [the specified figure]." Research will be required to determine the acceptable range of locations for the upper end of the upper torso restraints in the specified figure (Figure 1 in the standard) to accommodate the shape, recline, and orientation for the rear-facing front seating positions. Table 21 includes the section of FMVSS No. 210 that may warrant technical translations to address vehicles with rear-facing front seats.

Stakeholder and SME Review Input

No feedback received.

FMVSS No. 214: Side impact protection

"This standard specifies performance requirements for protection of occupants in side impacts." (S1)

> The purpose of this standard is to reduce the risk of serious and fatal injury to occupants of passenger cars, multipurpose passenger vehicles, trucks, and buses in side impacts by specifying strength requirements for side doors, limiting the forces, deflections and accelerations measured on anthropomorphic dummies in test crashes, and by other means. (S1)

Potential Considerations

Potential barrier themes in FMVSS No. 214, Side impact protection include directionality, fore/aft control, dummy positioning, Part 572 – ATDs and test setup. There are multiple subsections in S8.3 related to seat adjustment and determination of the forwardmost and rearmost position of the seat. For this review, the scope was limited to fixed rear-facing seats in the front row, but research may be required if a rear-facing front row has fore/aft adjustment. Similar language can be found in S10.3.2.2, Other seat adjustments, and the dummy positioning procedures in S12.1.2, S12.2.1, and S12.3.3. Language such as "push rearward" can still apply to a rear-facing seat, as long as it is clear that "rearward" is with respect to the seat and not the vehicle orientation. Other procedures use the toeboard and floorpan when positioning the feet of the dummy, but the toeboard may not be applicable for a rear-facing front seat in what is currently the driver's DSP. These procedures may require some technical translations for rear-facing front seats to ensure the feet of the dummy are placed similarly as seen in the rear seat positioning procedures detailed in S12.3.4 of FMVSS No. 214.

For the vehicle-to-pole test in FMVSS No. 214, the vehicle is struck along the impact reference line defined in S10.11. This line is along a vertical plane that passes through the center of gravity of the head of a dummy seated in a front outboard DSP. For vehicles with unconventional seating, research may be required to identify the appropriate impact reference line, as the dummy's head is likely to be more forward in the vehicle and closer to the A-pillar. Table 22 includes the sections of FMVSS No. 214 that may warrant technical translations to address vehicles with rear-facing front seats.

Stakeholder and SME Review Input

No feedback received.

FMVSS No. 216a: Roof Crush Resistance – Upgraded Standard

"This standard establishes strength requirements for the passenger compartment roof." (S1)

"The purpose of this standard is to reduce deaths and injuries due to the crushing of the roof into the occupant compartment in rollover crashes." (S2)

Potential Considerations

The seat adjustment procedure described in S8.3.1 of FMVSS No. 214 is referenced in S7.2 of FMVSS No. 216, Roof Crush Resistance. Any technical translations to the seating procedure should be consistent in both standards. For a rear-facing front row, the headform of the dummy could be closer to the front of the vehicle and the windshield, if present. S5.1(b) of the current standard states that "No load greater than 222 Newtons (50 lb) may be applied to the headform specified in S5.2 of 49 CFR 571.201 located at the head position of a 50th percentile adult male in accordance with S7.2 of this section." Additional research could determine if the same load limit should be used in a rear-facing front row since the headform may be closer to the windshield and/or roof of the vehicle if you were to turn the front row of seats around in current vehicle designs. Another option would be to consider the maximum displacement of the roof in lieu of the headform load limit.

Table 23 includes the sections of FMVSS No. 216a that may warrant technical translations to address vehicles with rear-facing front seats.

Stakeholder and SME Review Input

No feedback received.

FMVSS No. 219: Windshield zone intrusion

"This standard specifies limits for the displacement into the windshield area of motor vehicle components during a crash." (S1)

"The purpose of this standard is to reduce crash injuries and fatalities that result from occupants contacting vehicle components displaced near or through the windshield." (S2)

Potential Considerations

An area that may require either translations or further research is related to the "protected zone template." In S6.1 of FMVSS No. 219, Windshield zone intrusion, the requirements state that "no part of the vehicle outside the occupant compartment, except windshield molding and other components designed to be normally in contact with the windshield, shall penetrate the protected zone template….” Part of this zone is defined by placing a rigid sphere between the windshield glazing and the surface of the instrument panel. This language may not apply to ADS-DVs with rear-facing front seats if the traditional "instrument panel" is not applicable. Alternative language could be added for vehicles that do not have an instrument panel. Table 24 includes the sections of FMVSS No. 219 that may warrant technical translations to address vehicles with rear-facing front seats.

Stakeholder and SME Review Input

Based on the research in Volumes 1 and 2, some reviewers noted that more unconventional vehicle designs may require clearer language if a traditional windshield is not present.

FMVSS No. 226: Ejection mitigation

"This standard establishes requirements for ejection mitigation systems to reduce the likelihood of complete and partial ejections of vehicle occupants through side windows during rollovers or side impact events." (S1)

Potential Considerations

There are some sections of FMVSS No. 226, Ejection mitigation that may require further research or technical translations for fixed rear-facing front seats. S4.2.2 lists requirements for a readiness indicator in the event of a rollover. The technical translation from Volume 2 was to state the indicator must be visible "from the driver's designated seating position and clearly visible from any designated seating position if no driver's seating position is occupied or present." This translation should still apply to ADS-DVs with rear-facing front seats.

One theme identified in FMVSS No. 226 is related to Test Setup. Target locations on the side windows are identified in S5.2 for an impact test. The primary target locations are defined in S5.2.3 and the secondary target locations are defined in S5.2.4. For a rear-facing front row, the primary and secondary target locations for the front windows could change due to the reversed orientation between the occupant in the front seat and the front window. The current primary targets are the forward-lower and rearward-upper quadrant of the front window. If these targets are changed for rear-facing front seats, the secondary targets may require a translation as well since their location is based on the primary targets. However, the impact points for the front and rear rows are currently mirrored relative to each other despite the front and rear rows being generally forward facing. Since the primary and secondary targets are primarily based on window geometry, FMVSS No. 226 may not require any translations for an ADS-DV with a rear-facing front row. Table 25 includes the sections of FMVSS No. 226 that may warrant technical translations to address vehicles with rear-facing front seats.

Stakeholder and SME Review Input

A reviewer noted that vehicles without any passengers (cargo only vehicles) should be excluded from the requirements of FMVSS No. 226. Another reviewer commented that they do not believe the target location should necessarily be changed. The impact points for the first and second targets are based on the geometry of the window and not where an occupant may be seated relative to the impact points. These impact points provide for a robust evaluation of the retention capability over the entire window opening. For instance, the impact points for the front and rear rows are mirrored relative to each other despite the fact that the occupants in all seating rows are usually forward facing. The primary reason for the different layout between front and rear rows is the geometric differences of the side window openings (not the seating locations) which are not expected to change with the rear facing front seats.

Chapter 4. Summary of Research Findings

Crash Avoidance

The primary focus of the research was to identify and evaluate potential barriers related to compliance verification testing associated with braking and stability control. For the LV standards (FMVSS Nos. 126 and 135), a representative subset of the OVSC test procedures were identified and performed with the human or program control test methods developed in Volume 1. These were performed with the VTTI test platform and ITP test platforms. In addition, some ITPs provided a paper assessment of the FMVSS No. 126 test procedures.

FMVSS No. 135 testing demonstrated the effectiveness of both program and human control methods. The failure mode conditions specified in FMVSS No. 135 may cause the ADS to limit the vehicle's operation due to the safety measures designed into the ADS-DV. Consequently, an ADS or the procedure may need to be modified to allow the vehicle to operate in a known fault condition. Redundancies in the braking system may afford a similar level of stopping performance as the primary braking system. Given the complexity of an ADS-DV and the fault requirements in the standard, the ITPs thought that manufacturer involvement would likely be needed to implement and execute compliance verification testing.

The primary focus for FMVSS No. 126 testing was to further investigate input definitions. Without a steering wheel, system input could be defined by pinion angle, rack displacement, or road wheel angles. The relationship between the steering wheel angle and the associated input measurement point would be needed to map the current steering wheel definitions to the selected input location. One ITP used pinion angle instead of steering wheel angle. It was also necessary, however, for the ITP to modify the motion control system so that it worked independently of the perception and planning layer. Consequently, it was noted that NHTSA may need to work with the manufacturer to execute the testing. Another ITP demonstrated a manual control system that replicated normal manually operated driving controls so that all current test procedures, including FMVSS Nos. 126 and 135, could be executed without modification. As demonstrated, this level of modification would require manufacturer involvement.

The evaluation of the HV braking and ESC standards showed that the HV standards did not present any significant differences in the functionalities demonstrated with the LV testing. Consequently, the test procedures should not pose unique challenges or barriers for executing the test procedures with the identified test methods.

Crashworthiness

In addition to summarizing the technical translation options for the remaining standards, this effort also focused on an assessment of FMVSS Nos. 201, 202a, 207, 209, 210, 214, 216a, 219, and 226 to identify any sections that may require a technical translation or further research for ADS-DVs with fixed rear-facing front row seating. The technical translations from Volume 1 and 2 and the amendments included by NHTSA in the *Occupant Protection for Vehicles With Automated Driving Systems* Final Rule (49 CFR 571, 2022), were used as the basis for the review to determine their suitability for an unconventional seating configuration. In the Volume 3 review of FMVSS No. 208, recurring themes (i.e., suitability of current ATDs, presence and requirement of air bags for front seats, child restraint test procedures, unbelted testing requirements, dummy positioning procedures, and injury criteria) were identified when considering how to maintain the current level of occupant protection for ADS-DVs.

When reviewing the remaining 200 series standards identified above for unconventional seating, additional themes surfaced that may represent potential regulatory barriers. Potential considerations are also included where the current language for both front outboard seating positions may require translation to address forward-facing and rear-facing front seats. From the assessment, these additional potential barriers may also require additional exploration for unconventional seating configurations. Additional research could be performed to determine the suitability of current test reference locations (e.g., instrument panel) specified in the standards, the need to specify directionality for rear-facing front seats (e.g., rearward, rearmost) when locating centers of gravity, dummy positioning (interior impact, side impact, and roof strength testing), front and rear head restraint differentiation, fore/aft adjustable seats, and test setup (i.e., impact reference line location) for these standards using a rear-facing front seat.

Additional Research

Rear Seat Frontal Crash Protection for the 50th-percentile Male with Application to Vehicles with Automated Driving Systems. Ongoing research supports potential translation of FMVSS No. 208 that would extend the standard to occupants seated behind the front seat. This research represents a proactive examination of potential issues that will reduce the time required to make decisions and to institute subsequent efforts. In support of this ongoing research, there are seven related areas designed to examine the expected incidence and outcomes of rear-seated occupants in an ADS-DV with conventional (forward-facing) seats, to develop dummy positioning procedures for rear-seated ATDs for FMVSS No. 208 frontal crash testing, to assess candidate injury criteria for rear-seated occupants for FMVSS No. 208 frontal crash testing, and to assess ATD performance for rear-seated occupants for FMVSS No. 208 frontal crash testing. These research areas are as follows:

1. *ATD Finite Element Methods (FEMs):* Examine how well the ATD FEMs represent the actual ATDs.
2. *Rear Seat Design Versus ATD Performance:* Examine the key relationships between vehicle design and vehicle safety performance for the rear/second row seat.
3. *Rear Versus Front Seat Comparison:* Examine how the rear/second row seat safety performance results obtained from the ATD sled test relate to existing test results for the front seat.
4. *FEM Rear Seat Design Optimization:* Use an FEM parametric investigation to examine what vehicle design characteristics, or optimization thereof, could provide improved passenger protection in the rear/second row seat.
5. *Post-mortem Human Surrogate (PMHS) Testing:* Determine whether the responses of the PMHS (kinematics, injury prediction, etc.) are accurate for the rear/second row seats.
6. *Global Human Body Models Consortium (GHBMC) FEM:* Examine the GHBMC 50th male model (most valid and stable version) in the second/rear row seat under the same conditions as the PMHS tests.
7. *Fleet Characteristics:* Determine how the vehicles tested on the sled relate to the existing fleet in terms of design characteristics and provide an approximation of the potential real-

world scenario in terms of the range of injury incidence and severity as occupants migrate to the rear seat.

Seating Preference Study

This research will examine several questions that stem from aspects related to seating preference in future vehicle designs precipitated by the adoption of ADS-DVs. Moreover, the way in which various information is presented to the occupants of ADS-DVs could be dependent on the seating configuration. Due to the nature of ADS-DVs and the potential changes as seating configurations evolve, the two main goals for this study are as follows:

1. What are occupants' preferred seating positions and prevalence of seat belt use in an ADS-DV?
2. How is FMVSS information communicated to occupants, and do they understand it?

A range of ADS-DV concepts will be considered and a human-machine interface reference design developed. This research will create methods to evaluate participants in a closed-track course to examine participant behavior associated with closing doors, seat selection and positioning, using restraints, starting the ride, and potentially requesting an early ride termination (i.e., Passenger-initiated Emergency Stop).

References

49 CFR Part 571. Federal Motor Vehicle Safety Standards. www.ecfr.gov/cgi-bin/retrieveECFR?gp=&SID=dd8241e71294ed932a05d90d1bb3eacb&mc=true&n=pt49.6.571&r=PART&ty=HTML

87 F.R. 61, 18560, *Occupant Protection for Vehicles With Automated Driving Systems*, March 30, 2022. www.govinfo.gov/content/pkg/FR-2022-03-30/pdf/2022-05426.pdf

Blanco, M., Chaka, M., Stowe, L., Gabler, H. C., Weinstein, K., Gibbons, R. B., Neurauter, L., McNeil, J., Fitzgerald, K. E., Tatem, W., & Fitchett, V. L. (2020, April). *FMVSS considerations for vehicles with automated driving systems: Volume 1* (Report No. DOT HS 812 796). National Highway Traffic Safety Administration. https://www.nhtsa.gov/sites/nhtsa.gov/files/documents/ads-dv_fmvss_vol1-042320-v8-tag.pdf

Chaka, M., Blanco, M., Stowe, L., McNeil, J., Kefauver, K., Fitchett, V. L., Fitzgerald, K. E., Trimble, T. E., Kizyma, D., Neurauter, L., Hardy, W. N., Anderson, G. T., Schultz, J., Thorn, E., Harper, C., & Weinstein, K. (2021, January). *FMVSS considerations for vehicles with automated driving systems: Volume 2* (Report No. DOT HS 813 024). National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/54442/dot_54442_DS1.pdf

Chaka, M., Stowe, L., Krum, A., Kizyma, D., McNeil, J., Fitchett, V. L., Kefauver, K., Schultz, J., Weinstein, K., Hardy, W. N., Fitzgerald, K. E., Trimble, T. E., Anderson, G. T. (2025). *FMVSS considerations for vehicles with automated driving systems: Volume 3* (Report No. DOT HS 813 716) National Highway Traffic Safety Administration. https://rosap.ntl.bts.gov/view/dot/85074

DeSilver, D. (2021, June 7). *Today's electric vehicle market: Slow growth in U.S., faster in China, Europe*. Pew Research Center. https://www.pewresearch.org/short-reads/2021/06/07/todays-electric-vehicle-market-slow-growth-in-u-s-faster-in-china-europe/

Honda. (2017, Jan. 5). *Honda riding assist* [Video]. YouTube. www.youtube.com/watch?v=VH60-R8MOKo

SAE International. (2021). *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles* (SAE Standard No. J3016_202104).

SAE International. (2018). *Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles* (SAE Standard No. J3016_201806).

Shazzad, R. (2020, Dec. 16). *BMW paves the way for automated motorcycle technology.* TechAcute.com. https://techacute.com/bmw-motorrad-paves-the-way-for-automated-motorcycle-technology/

TechAcute. (2020, Dec. 16). *BMW R 1200 GS is the self-driving motorcycle* [Video].YouTube. www.youtube.com/watch?v=0jItRQURFco

Yamaha Motor Co. Ltd. (2021). *Yamaha Motor concept model: Motoroid.* https://global.yamaha-motor.com/design_technology/design/concept/motoroid/

Xie, Y. (2024, June 18). *Zero-emission bus and truck market in the United States: A 2022–2023 update.* International Council on Clean Transportation. https://theicct.org/publication/zero-emission-bus-and-truck-market-in-the-us-2022-2023-update-june24/

Appendix A: Definitions

ADS-Related Definitions Incorporated from SAE International's Recommended Practice J3016, Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles	
Automated Driving System (ADS)	The hardware and software that are collectively capable of performing the entire dynamic driving task (DDT) on a sustained basis, regardless of whether it is limited to a specific operational design domain (ODD); this term is used specifically to describe a Level 3, 4, or 5 driving automation system (SAE International, 2021, p. 6).
Operational Design Domain (ODD)	Operating conditions under which a given driving automation system or feature thereof is specifically designed to function, including, but not limited to, environmental, geographical, and time-of-day restrictions, and/or the requisite presence or absence of certain traffic or roadway characteristics (SAE International, 2021, p.17).
Dynamic Driving Task (DDT)	All of the real-time operational and tactical functions require to operate a vehicle in on-road traffic, excluding the strategic functions such as trip scheduling and selection of destinations and waypoints, and including, without limitation, the following subtasks: • Lateral vehicle motion control via steering (operational); • Longitudinal vehicle motion control via acceleration and deceleration (operational); • Monitoring the driving environment via object and event detection, recognition, classification, and response preparation (operational and tactical); • Object and event response execution (operational and tactical); • Maneuver planning (tactical); and • Enhancing conspicuity via lighting, signaling, and gesturing, etc. (tactical) (SAE International, 2021, p.9).
Automated Driving System - Dedicated Vehicle (ADS-DV)	Based on Section 3.32.3 of SAE International (2021) "An ADS-equipped vehicle designed for driverless operation under routine/normal operating conditions during all trips within its given ODD (if any)."
Translation Note	ADS-related definitions are interchangeable with the driver, seating, and driving control definitions options. SAE International's definition of ADS-DV indicates that some ADS-DVs could contain driving controls and be used to describe a Level 3 driving automation system as well as Level 4 and Level 5 systems. For the purposes of this project, the FMVSS technical translation options focused on a particular type of ADS-DV, a vehicle designed to be operated exclusively by an SAE Level 4 or Level 5 ADS for all trips, and where the vehicle is not equipped with manually operated driving controls.

Driver Definitions		
Currently specified in 49 CFR § 571.3	*Driver* means the occupant of a motor vehicle seated immediately behind the steering control system.	
	Potential Option 1	**Potential Option 2**
Driver	*Driver* means: (1) the occupant (human driver) of a motor vehicle seated immediately behind the manually operated driving controls, and (2) the ADS (ADS driver), for ADS-equipped vehicles when the ADS is engaged. When the ADS is not engaged, the definition in paragraph (1) applies.	*Driver* means the occupant of a motor vehicle seated immediately behind the manually operated driving controls.
Translation Note	Driver definition Options 1 or 2 are interchangeable with the ADS-related, seating, and driving control definitions.	
	Option 1 incorporates the ADS into the definition of "driver." Therefore "driver" would refer to either a human driver or an ADS. "Human driver" is used when only (1) applies, and "ADS driver" is used when only (2) applies.	Under Option 2, the "driver" always refers to a human driver. The ADS would perform the driving of an ADS-DV and be incorporated into the standards independently from "driver."

Designated Seating Positions and Driving Controls Definitions		
Currently specified in 49 CFR § 571.3	*DSP* means a seat location that has a seating surface width, as described in section 571.10(c), of at least 330 mm (13 inches), and section 571.10 provides a method for calculating the number of DSPs based on the width of the seat.	
	Potential Set 1	**Potential Set 2**
Driver's Designated Seating Position (driver's seat or driver's seating position)	Means a DSP immediately behind the manually operated driving controls positioned such that an occupant can operate the manual driving controls, regardless of whether the occupant is in active control of the vehicle.	Means a DSP providing immediate access to the manually operated driving controls.
Manually Operated Driving Controls	Means the system used by an occupant to manipulate the vehicle's lateral (steering) and/or longitudinal (acceleration and deceleration) motion in real time.	Means (a) the system used by an occupant for real-time sustained manipulation of the motor vehicle's heading (steering) and/or speed (accelerator and brake); (b) positioned such that they can be used by an occupant; (c) regardless of whether the occupant is actively manipulating the vehicle's motion.
	Potential Set (1 or 2) A	**Potential Set (1 or 2) B**
Passenger Designated Seating Position (Passenger Seat or Passenger Seating Position)	Means any DSP other than the driver's DSP.	Means any DSP other than the driver's DSP. Specifically, a seating position with stowed manually operated driving controls is a passenger DSP.
Steering Control (Wheel)	Means the manually operated driving control used to manipulate the vehicle's heading.	
Translation Note	Driver's DSP and manually operated driving controls are grouped into sets. The definitions of "passenger DSP" and "steering control" are the same for both Set 1 and Set 2. There are two options (A and B) for the definition of passenger DSP.	
	Driver's DSP definition from Set 1 should be used in conjunction with the manually operated driving controls definition from Set 1.	Driver's DSP definition from Set 2 should be used in conjunction with the manually operated driving controls definition from Set 2.

Bidirectional Vehicle Definitions		
	Potential Option 1	**Potential Option 2**
Bidirectional Vehicle	Means an ADS-equipped vehicle without manually operated driving controls that can perform the DDT across an equivalent range of speed and heading control in two opposite directions.	Means a motor vehicle that operates across an equivalent range of speed and heading control in two opposite directions.
Translation Note	Instead of translating within each standard, bidirectional vehicles could be addressed generically in Subpart A of 49 CDR Part 571. In addition to the Section 571.3 definition, a new section could be added to clarify the application.	

Applicability of the FMVSS to Bidirectional Vehicles	
Bidirectional Vehicle	Each applicable standard set forth in Subpart B of this Part shall apply to bidirectional vehicles in both directions of travel.
Translation Note	A new subsection (g) of section 571.7, or a new section 571.11 could be added to clarify the translations for the applicability of the FMVSS to bidirectional vehicles.

Appendix B: Stakeholders and SME Involvement

FMVSS No. 101
Advocates for Highway and Auto Safety
American Honda Motor Company
American Safety Council
Apple, Inc.
Auto Alliance
Global Automakers
Insurance Institute for Highway Safety
NIO
Tesla
Truck and Engine Manufacturers Association
Valeo
Waymo

FMVSS No. 105
Advocates for Highway and Auto Safety
Alliance for Automotive Innovation
Apple, Inc.
Insurance Institute for Highway Safety
Truck and Engine Manufacturers Association

FMVSS No. 121
Advocates for Highway and Auto Safety
Alliance for Automotive Innovation
Truck and Engine Manufacturers Association

FMVSS No. 126
American Honda Motor Company
American Safety Council
Apple, Inc.
Auto Alliance
Bosch
Global Automakers
Honda
Insurance Institute for Highway Safety
NIO
Tesla
Waymo

FMVSS No. 131
Daimler
Navistar

FMVSS No. 135
Advocates for Highway and Auto Safety
Alliance for Automotive Innovation

FMVSS No. 135
American Honda Motor Company
Apple, Inc.
Center for Auto Safety
Continental AG
General Motors
Insurance Institute for Highway Safety
Nuro
Waymo

FMVSS No. 136
Advocates for Highway and Auto Safety
Apple, Inc.
Bosch
Truck and Engine Manufacturers Association
Waymo

FMVSS No. 201
American Honda Motor Company
American Safety Council
Apple
Auto Alliance
General Motors
Insurance Institute for Highway Safety

FMVSS No. 201
NIO
Nissan North America, Inc.
Waymo
Zoox

FMVSS No. 202a
American Honda Motor Company
American Safety Council
Apple, Inc.
Auto Alliance
General Motors
Insurance Institute for Highway Safety
NIO
Nissan North America, Inc.
Waymo
Zoox

FMVSS No. 207
General Motors
Nissan North America, Inc.
Zoox

FMVSS No. 209
General Motors
Nissan North America, Inc.
Zoox

FMVSS No. 210
General Motors
Nissan North America, Inc.
Zoox

FMVSS No. 214
General Motors
Nissan North America, Inc.
Zoox

FMVSS No. 216a
General Motors
Nissan North America, Inc.
Zoox

FMVSS No. 219
American Honda Motor Company
Apple, Inc.
Auto Alliance
General Motors

FMVSS No. 219
NIO
Nissan North America, Inc.
Waymo
Zoox

FMVSS No. 226
General Motors
Nissan North America, Inc.
Zoox

Controls, Telltales, Indicators, and Auditory Alerts
Advocates for Highway and Auto Safety
American Honda Motor Company
Truck and Engine Manufacturers Association

Appendix C: Crash Avoidance Data Collection Variables

The following lists the variables were collected to support the light vehicle test method evaluations discussed in Chapter 2.

Data Collection Variables		Braking Protocol	ESC Protocol
Longitudinal control	Throttle command	X	X
	Vehicle speed	X	X
	Wheel speed	X	X
	Brake command	X	X
	Brake line pressure	X	
Lateral control	Steering wheel angle	X – only for vehicles that maintained a manual steering wheel	X
	Pinion angle		X
	Rack displacement		X
	Front road wheel angle		X
Inertial Measurement Unit (IMU)	Acceleration longitudinal (x)	X	X
	Acceleration lateral (y)	X	X
	Acceleration vertical (z)	X	X
	Angular velocity longitudinal (x)	X	X
	Angular velocity lateral (y)	X	X
	Angular velocity vertical (z)	X	X
Global Positioning System (GPS)	Latitude	X	X
	Longitude	X	X
State information	Transmission state (PRNDL)	X	X
	Failure or malfunction state(s)	X	X
	Redundant system active	X	X
	Automation active	X	X
Reference	Time	X	X
	Forward camera view	X	X
	Camera view of front tires		X – only for the ITP testing

Appendix D: Crashworthiness Standards – Potential Barriers for Unconventional Seating

Table 19. Potential Barriers in FMVSS No. 201

FMVSS No. 201			
Section	**Standard**	**Theme**	**Potential Considerations**
S3. Definitions	*A-pillar* means any pillar that is entirely forward of a transverse vertical plane passing through the seating reference point of the driver's seat. *Pillar* means any structure, excluding glazing and the vertical portion of door window frames, but including accompanying moldings, attached components such as safety belt anchorages and coat hooks, which: (1) Supports either a roof or any other structure (such as a rollbar) that is above the driver's head, or (2) Is located along the side edge of a window.	Driver Reference	The proposed translation for the A-pillar states "any pillar that is entirely forward of a transverse vertical plane passing through the seating reference point of the rearmost designated seating position in the front row of seats." In a forward-facing front row, "rearmost" could be with respect to the seat itself or the vehicle. Also, if what is traditionally the A-pillar is rearward of the seating reference points for rear-facing front seats, the definition would not apply to that pillar, which would affect many other provisions in the rest of the standard.
S5.1 Instrument Panels	Except as provided in S5.1.1, when that area of the instrument panel that is within the head impact area is impacted in accordance with S5.1.2 by a 6.8 kilogram, 165 mm diameter headform at— (a) A relative velocity of 24 kilometers per hour for all vehicles except those specified in paragraph (b) of this section, (b) A relative velocity of 19 kilometers per hour for vehicles that meet the occupant crash protection requirements of S5.1 of 49 CFR	Other (Test reference location may not be applicable)	In addition to the fact that ADS-DVs may not have "instrument panels," as that term is currently construed for conventional vehicles, if the front seats are rear-facing, there

FMVSS No. 201			
Section	**Standard**	**Theme**	**Potential Considerations**
	571.208 by means of inflatable restraint systems and meet the requirements of S4.1.5.1(a)(3) by means of a Type 2 seat belt assembly at the right front designated seating position, the deceleration of the headform shall not exceed 80 g continuously for more than 3 milliseconds.		may be some other panel or structure between the first and second row of seats. The definition of the "head impact area" should be examined from the H-point of the front seat, and protection of the rear seat occupants may need to be considered if a control panel or other obstruction is present between the first and second rows of designated seating positions.
S5.1.1	The requirements of S5.1 do not apply to: (a) Console assemblies; (b) Areas less than 125 mm inboard from the juncture of the instrument panel attachment to the body side inner structure; (c) Areas closer to the windshield juncture than those statically contactable by the headform with the windshield in place; (d) Areas outboard of any point of tangency on the instrument panel of a 165 mm diameter headform tangent to and inboard of a vertical longitudinal plane tangent to the inboard edge of the steering wheel; or (e) Areas below any point at which a vertical line is tangent to the rearmost surface of the panel.	Other (Test reference point may not be applicable)	If no steering wheel is present, S5.1.1(d) may not apply. A technical translation for this section may therefore be unnecessary. S5.1.1(b) could then apply to both sides of the vehicle, assuming an instrument panel is present in the vehicle.
S5.1.2 Demonstration procedures	Tests shall be performed as described in SAE Recommended Practice J921 (1965) (incorporated by reference, see §571.5), using the specified instrumentation or instrumentation that meets the performance requirements specified in SAE Recommended Practice J977 (1966) (incorporated by reference, see §571.5), except that:	Other (Test reference point may not be applicable)	Similar to S5.1, the scope of this provision may need to be expanded to include protection of second row occupants.

FMVSS No. 201			
Section	**Standard**	**Theme**	**Potential Considerations**
	(a) The origin of the line tangent to the instrument panel surface shall be a point on a transverse horizontal line through a point 125 mm horizontally forward of the seating reference point of the front outboard passenger designated seating position, displaced vertically an amount equal to the rise which results from a 125 mm forward adjustment of the seat or 19 mm; and (b) Direction of impact shall be either: (1) In a vertical plane parallel to the vehicle longitudinal axis; or (2) In a plane normal to the surface at the point of contact.		
S5.4.1	A sun visor that is constructed of or covered with energy-absorbing material shall be provided for each front outboard designated seating position.	Other	For rear-facing front seats, sun visors presumably would not be needed at each front outboard position.
S6.3	A vehicle need not meet the requirements of S6.1 through S6.2 for: (a) Any target located on a convertible roof frame or a convertible roof linkage mechanism. (b) Any target located rearward of a vertical plane 600 mm behind the seating reference point of the rearmost designated seating position. For altered vehicles and vehicles built in two or more stages, including ambulances and motor homes, any target located rearward of a vertical plane 300 mm behind the seating reference point of the driver's designated seating position (tests for altered vehicles and vehicles built in two or more stages do not include, within the time period for measuring HIC(d), any free motion headform contact with components rearward of this plane). If an altered vehicle or vehicle built in two or more stages is equipped with a transverse vertical partition positioned between the seating reference point of the driver's designated seating position and a vertical plane 300 mm behind the seating reference point of the driver's designated seating position, any target located rearward of the vertical partition is excluded.	Driver Reference	In 6.3(b), a translation option for "driver's designated seating position" was "the seating reference point of the driver's designated seating position or the rearmost designated seating position in the front row of seats, if there is no driver's designated seating position…." The terms "rearmost" and "rearward" may need a translation to specify whether they refer to the seat orientation or to the front of the vehicle.

FMVSS No. 201			
Section	**Standard**	**Theme**	**Potential Considerations**
			The exclusions for altered vehicles and vehicles built in two or more stages reference a driver's designated seating position which would not be applicable in the case of rear-facing front seats. Research may be required to determine how to apply these exclusions in rear-facing seating configurations.
S8.12 Location of head center of gravity.	(a) Location of head center of gravity for front outboard designated seating positions (CG-F). For determination of head center of gravity, all directions are in reference to the seat orientation. (1) Location of rearmost CG-F (CG-F2). For front outboard designated seating positions, the head center of gravity with the seat in its rearmost normal design driving or riding position (CG-F2) is located 160 mm rearward and 660 mm upward from the seating reference point. (2) Location of forwardmost CG-F (CG-F1). For front outboard designated seating positions, the head center of gravity with the seat in its forwardmost adjustment position (CG-F1) is located horizontally forward of CG-F2 by the distance equal to the fore-aft distance of the seat track. (b) Location of head center of gravity for rear outboard designated seating positions (CG-R). For rear outboard designated seating positions, the head center of gravity (CG-R) is located 160 mm rearward, relative to the seat orientation, and 660 mm upward from the seating reference point.	Other (Seat Directionality)	May need to specify directionality for rear-facing front seats (e.g., rearward, rearmost). However, S8.12(a) states "all directions are in reference to the seat orientation." Rear-facing front seats in their rearmost normal riding positions may affect the location of points CG-F1 and CG-F2. Research may be required to determine if rear-facing front seats affect the markup procedure in this case.

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S8.15 Upper Roof.	The upper roof of a vehicle is determined according to the procedure specified in S8.15 (a) through (h). (a) Locate the transverse vertical plane A at the forwardmost point where it contacts the interior roof (including trim) at the vehicle centerline. (b) Locate the transverse vertical plane B at the rearmost point where it contacts the interior roof (including trim) at the vehicle centerline. (c) Measure the horizontal distance (D1) between Plane A and Plane B. (d) Locate the vertical longitudinal plane C at the leftmost point at which a vertical transverse plane, located 300 mm rearward of the A-pillar reference point described in S10.1(a), contacts the interior roof (including trim). (e) Locate the vertical longitudinal plane D at the rightmost point at which a vertical transverse plane, located 300 mm rearward of the A-pillar reference point described in S10.1(a), contacts the interior roof (including trim). (f) Measure the horizontal distance (D2) between Plane C and Plane D. (g) Locate a point (Point M) on the interior roof surface, midway between Plane A and Plane B along the vehicle longitudinal centerline. (h) The upper roof zone is the area of the vehicle upper interior surface bounded by the four planes described in S8.15(h)(1) and S8.15(h)(2): (1) A transverse vertical plane E located at a distance of (.35 D1) forward of Point M and a transverse vertical plane F located at a distance of (.35 D1) rearward of Point M, measured horizontally. (2) A longitudinal vertical plane G located at a distance of (.35 D2) to the left of Point M and a longitudinal vertical plane H located at a distance of (.35 D2) to the right of Point M, measured horizontally.	Other (Test reference point may not be applicable)	The horizontal distance (D2) in S8.15(f) may be affected by vehicle geometry if the A-pillar definition does not apply given the vehicle geometry. Plane G is dependent on distance D2 so it may be undefined if D2 cannot be determined.
S8.27.1	The anthropomorphic test dummy used for evaluation of a vehicle's head impact protection shall conform to the requirements of subpart M of part 572 of this chapter (49 CFR part 572, subpart M). In a test in which the test	Other (Dummy Positioning)	In a rear-facing front seat, the dummy will be struck on its left side if the vehicle

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	vehicle is striking its left side, the dummy is to be configured and instrumented to strike on its left side, in accordance with subpart M of part 572. In a test in which the test vehicle is striking its right side, the dummy is to be configured and instrumented to strike its right side, in accordance with subpart M of part 572.		is struck on the right side, and on the right side if the vehicle is struck on the left side. Language should be added for this scenario.
S8.28 Positioning procedure for the Part 572 Subpart M Test Dummy—vehicle to pole test.	The part 572, subpart M, test dummy is initially positioned in the front outboard seating position on the struck side of the vehicle in accordance with the provisions of S12.1 of Standard 214 (49 CFR 571.214), and the vehicle seat is positioned as specified in S8.3.2.1 and S8.3.2.2 of that standard. The position of the dummy is then measured as follows. Locate the horizontal plane passing through the dummy head center of gravity. Identify the rearmost point on the dummy head in that plane. Construct a line in the plane that contains the rearward point of the front door daylight opening and is perpendicular to the longitudinal vehicle centerline. Measure the longitudinal distance between the rearmost point on the dummy head and this line. If this distance is less than 50 mm (2 inches) or the point is not forward of the line, then the seat and/or dummy positions is adjusted as follows. First, the seat back angle is adjusted, a maximum of 5 degrees, until a 50 mm (2 inches) distance is achieved. If this is not sufficient to produce the 50 mm (2 inches) distance, the seat is moved forward until the 50 mm (2 inches) distance is achieved or until the knees of the dummy contact the dashboard or knee bolster, whichever comes first. If the required distance cannot be achieved through movement of the seat, the seat back angle is adjusted even further forward until the 50 mm (2 inches) distance is obtained or until the seat back is in its fully upright locking position.	Other (Dummy Positioning)	Translations, if any, to the test procedure and seat positioning provisions of FMVSS No. 214 should apply to this section.
S10 Target Locations.	(a) The target locations specified in S10.1 through S10.16 are located on both sides of the vehicle and, except as specified in S10(b), are determined using the procedures specified in those paragraphs.		

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	(b) Except as specified in S10(c), if there is no combination of horizontal and vertical angles specified in S8.13.4 at which the forehead impact zone of the free motion headform can contact one of the targets located using the procedures in S10.1 through S10.16, the center of that target is moved to any location within a sphere with a radius of 25 mm, centered on the center of the original target, which the forehead impact zone can contact at one or more combination of angles. (c) If there is no point within the sphere specified in S10(b) which the forehead impact zone of the free motion headform can contact at one or more combination of horizontal and vertical angles specified in S8.13.4, the radius of the sphere is increased by 25 mm increments until the sphere contains at least one point that can be contacted at one or more combination of angles.		
S10.1 A-pillar targets	(a) A-pillar reference point and target AP1. On the vehicle exterior, locate a transverse vertical plane (Plane 1) which contacts the rearmost point of the windshield trim. The intersection of Plane 1 and the vehicle exterior surface is Line 1. Measuring along the vehicle exterior surface, locate a point (Point 1) on Line 1 that is 125 mm inboard of the intersection of Line 1 and a vertical plane tangent to the vehicle at the outboard most point on Line 1 with the vehicle side door open. Measuring along the vehicle exterior surface in a longitudinal vertical plane (Plane 2) passing through Point 1, locate a point (Point 2) 50 mm rearward of Point 1. Locate the A-pillar reference point (Point APR) at the intersection of the interior roof surface and a line that is perpendicular to the vehicle exterior surface at Point 2. Target AP1 is located at point APR. (b) Target AP2. Locate the horizontal plane (Plane 3) which intersects point APR. Locate the horizontal plane (Plane 4) which is 88 mm below Plane 3. Target AP2 is the point in Plane 4 and on the A-pillar which is closest to CG-F2 for the nearest seating position. (c) Target AP3. Locate the horizontal plane (Plane 5) containing the highest point at the intersection of the dashboard and the A-pillar.	Other (Test reference point may not be applicable)	In S10.1(a), Target AP1 is determined using Point APR. Point APR, Point 2 and Plane 2 are determined using Point 1. APR and Point 1 may be affected by the A-pillar definition and how it is applied to unconventional seating configurations and ADS-DV vehicle design. In S10.1(b), Plane 3, Plane 4, and Target AP2 are dependent on the location of Point APR. Plane 5 is dependent on the presence of a dashboard. Plane 6 is dependent on

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	Locate a horizontal plane (Plane 6) half-way between Plane 3 and Plane 5. Target AP3 is the point on Plane 6 and the A-pillar which is closest to CG-F1 for the nearest seating position.		Plane 3 and Target AP3 is dependent on the A-pillar, Plane 5, and Plane 6. The current meaning of the rearmost point of the windshield rim could be expanded upon for other possible conditions in ADS-DVs.
S10.4 Rearmost pillar targets	(a) Rearmost pillar reference point and target RP1. Locate the point (Point 7) at the corner of the upper roof nearest to the pillar. The distance between Point M, as described in S8.15(g), and Point 7, as measured along the vehicle interior surface, is D. Extend the line from Point M to Point 7 along the vehicle interior surface in the same vertical plane by (3*D/7) beyond Point 7 or until the edge of a daylight opening, whichever comes first, to locate Point 8. The rearmost pillar reference point (Point RPR) is at the midpoint of the line between Point 7 and Point 8, measured along the vehicle interior. Target RP1 is located at Point RPR. (b) Target RP2. (1) Except as provided in S10.4(b)(2), target RP2 is located in accordance with this paragraph. Locate the horizontal plane (Plane 16) through Point RPR. Locate the horizontal plane (Plane 17) 150 mm below Plane 16. Target RP2 is located in Plane 17 and on the pillar at the location closest to CG-R for the nearest designated seating position. (2) If a seat belt anchorage is located on the pillar, Target RP2 is any point on the anchorage.	Other (Test reference location may not be applicable)	In S10.4(a), Point 7 is dependent on the defined Upper Roof, Distance D is dependent on Point 7, Point 8 is dependent on Distance D and Point 7, Point RPR is dependent on Point 7 and Point 8. In S10.4(b)(1), Plane 16 is dependent on Point RP2, Plane 17 is dependent on Plane 16, and Target RP2 is dependent on Plane 17.
S10.5 Front header targets.	(a) Target FH1. Locate the contour line (Line 2) on the vehicle interior trim which passes through the APR and is parallel to the contour line (Line 3) at the upper edge of the windshield on the vehicle interior. Locate the point (Point 9) on Line 2 that is 125 mm	Other (Test reference location may not be applicable)	Point APR is necessary for determining the front header targets, so the definition of A-

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	inboard of the APR, measured along that line. Locate a longitudinal vertical plane (Plane 18) that passes through Point 9. Target FH1 is located at the intersection of Plane 18 and the upper vehicle interior, halfway between a transverse vertical plane (Plane 19) through Point 9 and a transverse vertical plane (Plane 20) through the intersection of Plane 18 and Line 3. (b) Target FH2. (1) Except as provided in S10.5(b)(2), target FH2 is located in accordance with this paragraph. Locate a point (Point 10) 275 mm inboard of Point APR, along Line 2. Locate a longitudinal vertical plane (Plane 21) that passes through Point 10. Target FH2 is located at the intersection of Plane 21 and the upper vehicle interior, halfway between a transverse vertical plane (Plane 22) through Point 10 and a transverse vertical plane (Plane 23) through the intersection of Plane 21 and Line 3. (2) If a sunroof opening is located forward of the front edge of the upper roof and intersects the mid-sagittal plane of a dummy seated in either front outboard seating position, target FH2 is the nearest point that is forward of a transverse vertical plane (Plane 24) through CG-F(2) and on the intersection of the mid-sagittal plane and the interior sunroof opening.		pillar may need to be modified for vehicles with for rear-facing front rows and for ADS-DVs with novel designs. In S10.5(a), Line 2 is dependent on Point APR, Point 9 is dependent on Line 2, Plane 18 is dependent on Point 9, and Target FH1 is dependent on Plane 18 and Point 9. In S10.5(b), Point 10 is dependent on Point APR and Line 2, Plane 21 is dependent on Point 10, Target FH2 is dependent on Plane 21 and Plane 22, Plane 22 is dependent on Point 10, and Plane 23 is dependent on Plane 21. With rear-facing front row seats, there should be consideration given to locating a target on the front header at the mid-sagittal plane of the outboard occupants, similar to the rear header target definition.
S10.6 Targets on the side rail	(a) Target SR1. Locate a transverse vertical plane (Plane 25) 150 mm rearward of Point	Other (Test reference	In S10.6(a), Plane 25 is dependent on

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between the A-pillar and the B-pillar or rearmost pillar in vehicles with only two pillars on each side of the vehicle.	APR. Locate the point (Point 11) at the intersection of Plane 25 and the upper edge of the forwardmost door opening. Locate the point (Point 12) at the intersection of the interior roof surface, Plane 25 and the plane, described in S8.15(h), defining the nearest edge of the upper roof. Target SR1 is located at the middle of the line between Point 11 and Point 12 in Plane 25, measured along the vehicle interior. (b) Target SR2. Locate a transverse vertical plane (Plane 26) 300 mm rearward of the APR or 300 mm forward of the BPR (or the RPR in vehicles with no B-pillar). Locate the point (Point 13) at the intersection of Plane 26 and the upper edge of the forwardmost door opening. Locate the point (Point 14) at the intersection of the interior roof surface, Plane 26 and the plane, described in S8.15(h), defining the nearest edge of the upper roof. Target SR2 is located at the middle of the line between Point 13 and Point 14 in Plane 26, measured along the vehicle interior.	location may not be applicable)	Point APR, Point 11 is dependent on Plane 25, Point 12 is dependent on Upper Roof, and Target SR1 is dependent on Point 11 and Point 12 In S10.6(b), Plane 26 is dependent on APR, Point 13 is dependent on Plane 26, Point 14 is dependent on Upper Roof, and Target SR2 is dependent on Point 13 and Point 14.
S10.9 Upper roof target (target UR)	Target UR is any point on the upper roof.	Other (Test reference location may not be applicable)	The location of the "upper roof" is dependent on the planes identified in S8.15.
S10.10 Sliding door track target (target SD).	Locate the transverse vertical plane (Plane 29) passing through the middle of the widest opening of the sliding door, measured horizontally and parallel to the vehicle longitudinal centerline. Locate the point (Point 19) at the intersection of the surface of the upper vehicle interior, Plane 29 and the plane, described in S8.15(h), defining the nearest edge of the upper roof. Locate the point (Point 20) at the intersection of Plane 29 and the upper edge of the sliding door opening. Target SD is located at the middle of the line between Point 19 and Point 20 in Plane 29, measured along the vehicle interior.	Other (Test reference location may not be applicable)	Point 19 is dependent on Upper Roof, and Target SD is dependent on Point 19. Since the points determined using the A-pillar may be affected in unconventional seating configurations, this section may be affected.
S10.14 Door frame targets.	(a) Target DF 1. Locate the point (Point 21) on the vehicle interior at the intersection of the horizontal plane passing through the highest point of the forward door opening and a transverse vertical plane (Plane 32) tangent to	Other (Test reference location may not be applicable)	In S10.14(a), Point 22 is dependent on Upper Roof, Point DFR is dependent on Point 22, and

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	the rearmost edge of the forward door, as viewed laterally with the adjacent door open. Locate the point (Point 22) at the intersection of the interior roof surface, Plane 32, and the plane, described in S8.15(h), defining the nearest edge of the upper roof. The door frame reference point (Point DFR) is the point located at the middle of the line from Point 21 to Point 22 in Plane 32, measured along the vehicle interior surface. Target DF1 is located at Point DFR. (b) Target DF2. If a seat belt anchorage is located on the door frame, Target DF2 is located at any point on the anchorage. (c) Target DF3. Locate a horizontal plane (Plane 33) which intersects Point DFR. Locate a horizontal plane (Plane 34) that passes through the lowest point of the adjacent daylight opening forward of the door frame. Locate a horizontal plane (Plane 35) half-way between Plane 33 and Plane 34. Target DF3 is the point located in Plane 35 and on the interior surface of the door frame, which is closest to CG-F2 for the nearest seating position. (d) Target DF4. Locate a horizontal plane (Plane 36) half-way between Plane 34 and Plane 35. Target DF4 is the point located in Plane 36 and on the interior surface of the door frame that is closest to CG-R for the nearest seating position.		Target DF1 is dependent on Point DFR. In S10.14(c), Plane 33 depends on Point DFR, Plane 35 depends on Plane 33, and Target DF3 depends on DFR and Plane 35. In S10.14(d), Plane 36 is dependent on Plane 35, and Target DF4 is dependent on DFR and Plane 36.

Table 20. Potential Barriers in FMVSS No. 202a

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S1. Purpose and scope	This standard specifies requirements for head restraints to reduce the frequency and severity of neck injury in rear-end and other collisions.	Other	For rear-facing front seats, the head restraint will be engaged for a vehicle in a frontal collision. Research may be required to ensure non-forward-facing seats meet the standard for head

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			restraints in low and high severity collisions (such as in FMVSS Nos. 208 and 214). However, frontal and side collisions could be considered "other collision" as currently written
S4.1 Performance levels	In each vehicle other than a school bus, a head restraint that conforms to either S4.2 or S4.3 of this section must be provided at each front outboard designated seating position. In each equipped with rear outboard head restraints, the rear head restraint must conform to either S4.2 or S4.3 of this section. In each school bus, a head restraint that conforms to either S4.2 or S4.3 of this section must be provided for the driver's seating position. At each designated seating position incapable of seating a 50th percentile male Hybrid III test dummy specified in 49 CFR part 572, subpart E, the applicable head restraint must conform to S4.2 of this section.	Other (Front/Rear differentiation)	To avoid differentiating between front and rear rows in unconventional seating configurations, the following could be added: "For ADS-DVs, a head restraint that conforms to either 4.2 or 4.3 must be provided at each designated seating position."
S4.2.1 Minimum height.	(a) Front outboard designated seating positions. (1) Except as provided in S4.2.1(a)(2) of this section, when measured in accordance with S5.2.1(a)(1) of this section, the top of a head restraint located in a front outboard designated seating position must have a height not less than 800 mm in at least one position of adjustment. (2) Exception. The requirements of S4.2.1(a)(1) do not apply if the interior surface of the vehicle at the roofline physically prevents a head restraint, located in the front outboard designated seating position, from attaining the required height. In those instances, in which this head restraint cannot attain the required height, when measured in accordance with S5.2.1(a)(2), the maximum vertical distance between the top of the head restraint and the interior surface of the vehicle	Other (Front/Rear differentiation)	The front and rear head restraints have slightly different requirements in this section. However, there are exceptions listed for each position. Research may be required for unconventional seating configurations in which the head restraints in the front outboard seating positions are limited by the

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	at the roofline must not exceed 50 mm for convertibles and 25 mm for all other vehicles. Notwithstanding this exception, when measured in accordance with S5.2.1(a)(2), the top of a head restraint located in a front outboard designated seating position must have a height not less than 700 mm in the lowest position of adjustment. (b) All outboard designated seating positions equipped with head restraints. (1) Except as provided in S4.2.1(b)(2) of this section, when measured in accordance with S5.2.1(b)(1) of this section, the top of a head restraint located in an outboard designated seating position must have a height not less than 750 mm in any position of adjustment. (2) Exception. The requirements of S4.2.1(b)(1) do not apply if the interior surface of the vehicle at the roofline or the interior surface of the backlight physically prevent a head restraint, located in the rear outboard designated seating position, from attaining the required height. In those instances, in which this head restraint cannot attain the required height, when measured in accordance with S5.2.1(b)(2), the maximum vertical distance between the top of the head restraint and the interior surface of the vehicle at the roofline or the interior surface of the backlight must not exceed 50 mm for convertibles and 25 mm for all other vehicles.		design of the vehicle (roofline). If the regulation is to be applied to all occupant seating positions in an ADS-DV, the term “outboard” could be removed or a section that applies to any seating position with a head restraint could be added.
S4.2.2 Width.	When measured in accordance with S5.2.2 of this section, 65 ±3 mm below the top of the head restraint, the lateral width of a head restraint must be not less than 170 mm, except the lateral width of the head restraint for front outboard designated seating positions in a vehicle with a front center designated seating position, must be not less than 254 mm.	Other (Front/Rear differentiation)	Front outboard seating positions have a different requirement if there is a front center designated seating position. If the standard is to be applied uniformly to all seating positions, research may be required to determine which width requirements apply to rear-facing front rows

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			with or without a center designated seating position.
S4.2.3 Front Outboard Designated Seating Position Backset.	When measured in accordance with S5.2.3 of this section, the backset must not be more than 55 mm, when the seat is adjusted in accordance with S5.1. For adjustable restraints, the requirements of this section must be met with the top of the head restraint in any height position of adjustment between 750 mm and 800 mm, inclusive. If the top of the head restraint, in its lowest position of adjustment, is above 800 mm, the requirements of this section must be met at that position. If the head restraint position is independent of the seat back inclination position, the head restraint must not be adjusted such that backset is more than 55 mm when the seat back inclination is positioned closer to vertical than the position specified in S5.1.	Other (Front/Rear differentiation)	Research may be required to determine whether the backset and height ranges are applicable for rear-facing front seating positions.
S4.3 Dynamic performance and width.	At each forward-facing outboard designated seating position equipped with a head restraint, the head restraint adjusted midway between the lowest and the highest position of adjustment, and at any position of backset adjustment, must conform to the following:	Other (Front/Rear differentiation)	Research may be required to determine whether the following performance criteria should be applied to rear-facing front seats. Rear and front-end collisions may be required to test the head restraint performance for unconventional seating configurations. A section on the performance criteria for ADS-DVs could be added or the “forward-facing” designation could be removed if the current criteria is to be applied to

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			each seating position.
S4.3.1 Injury Criteria.	When tested in accordance with S5.3 of this section, during a forward acceleration of the dynamic test platform described in S5.3.1, the head restraint must: (a) Angular rotation. Limit posterior angular rotation between the head and torso of the 50th percentile male Hybrid III test dummy specified in 49 CFR part 572, subpart E, fitted with sensors to measure rotation between the head and torso, to 12 degrees for the dummy in all outboard designated seating positions; (b) Head injury criteria. Limit the maximum HIC15 value to 500. HIC15 is calculated as follows—For any two points in time, t1 and t2, during the event which are separated by not more than a 15 millisecond time interval and where t1 is less than t2, the head injury criterion (HIC15) is determined using the resultant head acceleration at the center of gravity of the dummy head, are, expressed as a multiple of g (the acceleration of gravity) and is calculated using the expression: [HIC equation]	Injury Criteria	Research may be required to determine if the injury criteria is applicable for rear-facing front seats. May require a rearward acceleration to test rear-facing seats.
S5.2.1 Procedure for height measurement.	Demonstrate compliance with S4.2.1 of this section in accordance with S5.2.1 (a) and (b) of this section, using the headroom probe scale incorporated into the SAE Standard J826 JUL95 (incorporated by reference, see §571.5) manikin with the appropriate offset for the H-point position or an equivalent scale, which is positioned laterally within 15 mm of the head restraint centerline. If the head restraint position is independent of the seat back inclination position, compliance is determined at a seat back inclination position closest to the design seat back angle, and each seat back inclination position less than the design seat back angle. (a) (1) For head restraints in front outboard designated seating positions, adjust the top of the head restraint to the highest position and measure the height. (2) For head restraints located in the front outboard designated seating positions that are prevented by the interior surface of the vehicle	Other (Front/Rear differentiation)	Specifies different regulation for "front outboard" and "rear outboard" DSPs. The front outboard DSP requirements could be applied to every DSP with a head restraint or research may be required to determine the appropriate requirements for head restraints in rear-facing front seats.

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	at the roofline from meeting the required height as specified in S4.2.1(a)(1), measure the clearance between the top of the head restraint and the interior surface of the vehicle at the roofline, with the seat adjusted to its lowest vertical position intended for occupant use, by attempting to pass a 25 mm sphere between them. Adjust the top of the head restraint to the lowest position and measure the height. (b) (1) For head restraints in all outboard designated seating positions equipped with head restraints, adjust the top of the head restraint to the lowest position other than allowed by S4.4 and measure the height. (2) For head restraints located in rear outboard designated seating positions that are prevented by the interior surface of the vehicle at the roofline or the interior surface of the rear backlight from meeting the required height as specified in S4.2.1(b)(1), measure the clearance between the top of the head restraint or the seat back and the interior surface of the vehicle at the roofline or the interior surface of the rear backlight, with the seat adjusted to its lowest vertical position intended for occupant use, by attempting to pass a 25 mm sphere between them.		
S5.2.6 Procedures for height retention.	Demonstrate compliance with S4.2.6 of this section in accordance with S5.2.6(a) through (e) of this section. For head restraints that move with respect to the seat when occupant loading is applied to the seat back, S5.2.6(a) through (e) may be performed with the head restraint fixed in a position corresponding to the position when the seat is unoccupied. (a) Adjust the adjustable head restraint so that its top is at any of the following height positions at any backset position— (1) For front outboard designated seating positions— (i) The highest position; and (ii) Not less than, but closest to 800 mm; and (2) For rear outboard designated seating positions equipped with head restraints— (i) The highest position; and (ii) Not less than, but closest to 750 mm.	Other (Front/Rear differentiation)	Specifies different regulation for "front outboard" and "rear outboard" DSPs. The rear seat requirements could be removed and the front outboard DSP requirements could be applied to every DSP with a head restraint. [Same comment as above.]

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S5.2.7 Procedures for backset retention, displacement, and strength.	Demonstrate compliance with S4.2.7 of this section in accordance with S5.2.7(a) and (b) of this section. The load vectors that generate moment on the head restraint are initially contained in a vertical plane parallel to the vehicle longitudinal centerline. (a) Backset retention and displacement. For head restraints that move with respect to the seat when occupant loading is applied to the seat back, S5.2.7(a)(1) through (8) may be performed with the head restraint fixed in a position corresponding to the position when the seat is unoccupied. This fixation is applied to the member(s) that first transmit(s) the seat back loading from the occupant to the head restraint. (1) Adjust the head restraint so that its top is at a height closest to and not less than: (i) 800 mm for front outboard designated seating positions (or the highest position of adjustment for head restraints subject to S4.2.1(a)(2)); and (ii) 750 mm for rear outboard designated seating positions equipped with head restraints (or the highest position of adjustment for rear head restraints subject to S4.2.1(b)(2)).	Other (Front/Rear differentiation)	Specifies different regulation for "front outboard" and "rear outboard" DSPs. The rear seat requirements could be removed and the front outboard DSP requirements could be applied to every DSP with a head restraint. [Same comment as above.]
S5.3 Procedures for dynamic performance.	Demonstrate compliance with S4.3 of this section in accordance with S5.3.1 though S5.3.9 of this section with a 50th percentile male Hybrid III test dummy specified in 49 CFR part 572 subpart E, fitted with sensors to measure head to torso rotation. The dummy with all sensors is to continue to meet all specifications in 49 CFR part 572 subpart E. The restraint is positioned midway between the lowest and the highest position of adjustment, and at any position of backset.	Injury Criteria	Research may be required to determine whether the following performance criteria should be applied to rear-facing front seats. Rear and front-end collisions may be required to test the head restraint performance for unconventional seating configurations. A section on the performance criteria for ADS-DVs could be added or the “forward-facing”

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Section	**Standard**	**Theme**	**Potential Considerations**
			designation could be removed if the current criteria is to be applied to each seating position.
S5.3.4 Seat Adjustment.	The following seat adjustments specify conditions to be met concurrently and are not a sequential list of adjustments. At each outboard designated seating position, using any control that primarily moves the entire seat vertically, place the seat in the lowest position. Using any control that primarily moves the entire seat in the fore and aft directions, place the seat midway between the forwardmost and rearmost position. If an adjustment position does not exist midway between the forwardmost and rearmost positions, the closest adjustment position to the rear of the midpoint is used. Adjust the seat cushion and seat back as required by S5 of this section. If the seat back is adjustable, it is set at an inclination position closest to 25 degrees from the vertical, as measured by SAE Standard J826 JUL95 (incorporated by reference, see §571.5) manikin. If there is more than one inclination position closest to 25 degrees from the vertical, set the seat back inclination to the position closest to and rearward of 25 degrees. If the head restraint is adjustable, adjust the top of the head restraint to a position midway between the lowest position of adjustment and the highest position of adjustment. If an adjustment position midway between the lowest and the highest position does not exist, adjust the head restraint to a position below and nearest to midway between the lowest position of adjustment and the highest position of adjustment.	Other (Fore/Aft Control)	The term "outboard" could be removed if head restraints are equipped at all DSPs. For seat adjustments, "rear of the midpoint" could be translated for rear-facing front seats to reference either the vehicle coordinate system or the DSP coordinate system.

Table 21. Potential Barriers in FMVSS No. 210

FMVSS No. 210			
Section	**Standard**	**Theme**	**Potential Considerations**
S4.3.2 Seat belt anchorages for the upper torso portion of Type 2 seat belt assemblies.	Adjust the seat to its full rearward and downward position and adjust the seat back to its most upright position. Except a small occupant seating position as defined in 49 CFR 571.222, with the seat and seat back so positioned, as specified by subsection (a) or (b) of this section, the upper end of the upper torso restraint shall be located within the acceptable range shown in Figure 1, with reference to a two-dimensional drafting template described in SAE Standard J826 MAY87 (incorporated by reference, see §571.5). The template's "H" point shall be at the design "H" point of the seat for its full rearward and full downward position, as defined in SAE Recommended Practice J1100 JUN84 (incorporated by reference, see §571.5), and the template's torso line shall be at the same angle from the vertical as the seat back. (a) For fixed anchorages, compliance with this section shall be determined at the vertical centerline of the bolt holes or, for designs using another means of attachment to the vehicle structure, at the centroid of such means. (b) Except for seating positions on school bus bench seats, compliance with this section shall be determined with adjustable anchorages at the midpoint of the adjustment range of all adjustable positions. For seating positions on school bus bench seats, place adjustable anchorages and torso belt height adjusters in their uppermost position.	Other (Fore/Aft Control)	May need to be more specific for rear-facing seats with fore/aft controls. Research may be required to determine if the acceptable range of locations for the upper end of the upper torso restraints in Figure 1 is applicable for rear-facing front seating positions.

Table 22. Potential Barriers in FMVSS No. 214

FMVSS No. 214			
Section	**Standard**	**Theme**	**Potential Considerations**
S7.2.2 Vehicles manufactured on or after September 1, 2014.	(a) Subject to S7.2.4 of this section, each vehicle manufactured on or after September 1, 2014, must meet the requirements of S7.2.5 and S7.2.6, when tested with the test dummy specified in those sections. (b) Place the Subpart U ES-2re 50th percentile male dummy in the front seat and the Subpart V SID-IIs 5th percentile female test dummy in the rear seat. The test dummies are placed and positioned in the front and rear outboard seating positions on the struck side	Part 572 ATD	This may not require translation for unconventional seating. Existing ATD's may be suitable for rear facing applications.

FMVSS No. 214			
Section	**Standard**	**Theme**	**Potential Considerations**
	of the vehicle, as specified in S11 and S12 of this standard (49 CFR 571.214).		
S7.2.4 Exceptions from the MDB phase-in; special allowances.	(a)(1) Vehicles that are manufactured by an original vehicle manufacturer that produces or assembles fewer than 5,000 vehicles annually for sale in the United States are not subject to S7.2.1 of this section (but vehicles that will be manufactured on or after September 1, 2014, are subject to S7.2.2). (2) Vehicles that are manufactured by a limited line manufacturer are not subject to S7.2.1 of this section (but vehicles that will be manufactured on or after September 1, 2014, are subject to S7.2.2). (3) Convertibles manufactured before September 1, 2015, are not subject to S7.2.1 or S7.2.2 of this section. These vehicles may be voluntarily certified to meet the MDB test requirements prior to September 1, 2015. Vehicles manufactured on or after September 1, 2015, are subject to S7 and S7.2.2. (b) Vehicles that are altered (within the meaning of 49 CFR 567.7) before September 1, 2016, after having been previously certified in accordance with part 567 of this chapter, and vehicles manufactured in two or more stages before September 1, 2016, are not subject to S7.2.1. Vehicles that are altered on or after September 1, 2016, and vehicles that are manufactured in two or more stages on or after September 1, 2016, must meet the requirements of S7.2.5 and S7.2.6, when tested with the test dummy specified in those sections. Place the Subpart U ES-2re 50th percentile male dummy in the front seat and the Subpart V SID-IIs 5th percentile female test dummy in the rear seat. The test dummies are placed and positioned in the front and rear outboard seating positions on the struck side of the vehicle, as specified in S11 and S12 of this standard (49 CFR 571.214).	Part 572 ATD	This may not require translation for unconventional seating. Existing ATD's may be suitable for rear facing applications.
S8.3.1.3.1	Using only the controls that primarily move the seat and seat cushion independent of the seat back in the fore and aft directions, move the seat cushion reference point (SCRP) to the rearmost position. Using any part of any control, other than those just used, determine	Other (Fore/Aft Control)	For this review, the scope was limited to fixed rear-facing seats in the front row. Research may be

FMVSS No. 214			
Section	**Standard**	**Theme**	**Potential Considerations**
	the full range of angles of the seat cushion reference line and set the seat cushion reference line to the middle of the range. Using any part of any control other than those that primarily move the seat or seat cushion fore and aft, while maintaining the seat cushion reference line angle, place the SCRP to its lowest position.		required if rear-facing front row seats have fore/aft adjustability.
S8.3.1.3.2	Using only the control that primarily moves the seat fore and aft, move the seat cushion reference point to the mid travel position. If an adjustment position does not exist midway between the forwardmost and rearmost positions, the closest adjustment position to the rear of the midpoint is used.	Other (Fore/Aft Control)	For this review, the scope was limited to fixed rear-facing seats in the front row. Research may be required if rear-facing front row seats have fore/aft adjustability.
S8.3.2.1 Adjustable seats.	Adjustable seats are placed in the adjustment position midway between the forward most and rearmost positions, and if separately adjustable in a vertical direction, are at the lowest position. If an adjustment position does not exist midway between the forward most and rearmost positions, the closest adjustment position to the rear of the mid-point is used.	Other (Fore/Aft Control)	For this review, the scope was limited to fixed rear-facing seats in the front row. Research may be required if rear-facing front row seats have fore/aft adjustability.
S8.3.3.2 Other seat adjustments.	Position any adjustable parts of the seat that provide additional support so that they are in the lowest or non-deployed adjustment position. Position any adjustable head restraint in the lowest and most forward in-use position. If it is possible to achieve a position lower than the effective detent range, the head restraint should be set to its lowest possible position. A non-use position as specified by S4.4 of FMVSS No. 202a, is excluded from being considered as the lowest possible position.	Other (Fore/Aft Control)	For this review, the scope was limited to fixed rear-facing seats in the front row. Research may be required if rear-facing front row seats have fore/aft adjustability.
S8.3.3.3 Seat position adjustment.	Using only the controls that primarily move the seat and seat cushion independent of the seat back in the fore and aft directions, move	Other (Fore/Aft Control)	For this review, the scope was limited to fixed

FMVSS No. 214			
Section	**Standard**	**Theme**	**Potential Considerations**
	the seat cushion reference point (SCRP) to the rearmost position. Using any part of any control, other than those just used, determine the full range of angles of the seat cushion reference line and set the seat cushion reference line to the middle of the range. Using any part of any control other than those that primarily move the seat or seat cushion fore and aft, while maintaining the seat cushion reference line angle, place the SCRP to its lowest position. Mark location of the seat for future reference. If the non-struck side seat adjusts independently of the struck side seat, adjust the seat in the manner specified in this section.		rear-facing seats in the front row. Research may be required if rear-facing front row seats have fore/aft adjustability.
S8.11 Impact reference line.	Place a vertical reference line at the location described below on the side of the vehicle that will be struck by the moving deformable barrier.		
S8.11.1 Passenger cars.	(a) For vehicles with a wheelbase of 2,896 mm (114 inches) or less, 940 mm (37 inches) forward of the center of the vehicle's wheelbase. (b) For vehicles with a wheelbase greater than 2,896 mm (114 inches), 508 mm (20 inches) rearward of the centerline of the vehicle's front axle.	Other (Test Setup)	For vehicles with unconventional seating, research may be required to identify the appropriate location for the impact reference line.
S8.11.2 Multipurpose passenger vehicles, trucks, and buses.	(a) For vehicles with a wheelbase of 2,489 mm (98 inches) or less, 305 mm (12 inches) rearward of the centerline of the vehicle's front axle, except as otherwise specified in paragraph (d) of this section. (b) For vehicles with a wheelbase of greater than 2,489 mm (98 inches) but not greater than 2,896 mm (114 inches), 940 mm (37 inches) forward of the center of the vehicle's wheelbase, except as otherwise specified in paragraph (d) of this section. (c) For vehicles with a wheelbase greater than 2,896 mm (114 inches), 508 mm (20 inches) rearward of the centerline of the vehicle's front axle, except as otherwise specified in paragraph (d) of this section.	Other (Test Setup)	For vehicles with unconventional seating, research may be required to identify the appropriate location for the impact reference line.

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Section	**Standard**	**Theme**	**Potential Considerations**
	(d) At the manufacturer's option, for different wheelbase versions of the same model vehicle, the impact reference line may be located by the following: (1) Select the shortest wheelbase vehicle of the different wheelbase versions of the same model and locate on it the impact reference line at the location described in (a), (b) or (c) of this section, as appropriate. (2) Measure the distance between the seating reference point (SgRP) and the impact reference line. (3) Maintain the same distance between the SgRP and the impact reference line for the version being tested as that between the SgRP and the impact reference line for the shortest wheelbase version of the model. (e) For the compliance test, the impact reference line will be located using the procedure used by the manufacturer as the basis for its certification of compliance with the requirements of this standard. If the manufacturer did not use any of the procedures in this section or does not specify a procedure when asked by the agency, the agency may locate the impact reference line using either procedure.		
S10.3.2.2 Other seat adjustments.	Position any adjustable parts of the seat that provide additional support so that they are in the lowest or non-deployed adjustment position. Position any adjustable head restraint in the lowest and most forward in-use position. If it is possible to achieve a position lower than the effective detent range, the head restraint should be set to its lowest possible position. A non-use position as specified by S4.4 of FMVSS No. 202a, is excluded from being considered as the lowest possible position.	Other (Fore/Aft Control)	For this review, the scope was limited to fixed rear-facing seats in the front row. Research may be required if rear-facing front row seats have fore/aft adjustability.
S10.3.2.3.1	Using only the controls that primarily move the seat and seat cushion independent of the seat back in the fore and aft directions, move the seat cushion reference point (SCRP) to the rearmost position. Using any part of any control, other than those just used, determine the full range of angles of the seat cushion reference line and set the seat cushion	Other (Fore/Aft Control)	For this review, the scope was limited to fixed rear-facing seats in the front row. Research may be required if rear-facing front row

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Section	**Standard**	**Theme**	**Potential Considerations**
	reference line to the middle of the range. Using any part of any control other than those that primarily move the seat or seat cushion fore and aft, while maintaining the seat cushion reference line angle, place the SCRP to its lowest position.		seats have fore/aft adjustability.
S10.3.2.3.2	Using only the control that primarily moves the seat fore and aft, move the seat reference point to the most forward position.	Other (Fore/Aft Control)	For this review, the scope was limited to fixed rear-facing seats in the front row. Research may be required if rear-facing front row seats have fore/aft adjustability.
S10.11 Impact reference line.	The impact reference line is located on the striking side of the vehicle at the intersection of the vehicle exterior and a vertical plane passing through the center of gravity of the head of the dummy seated in accordance with S12 in the front outboard designated seating position. The vertical plane forms an angle of 285 (or 75) degrees with the vehicle's longitudinal centerline for the right (or left) side impact test. The angle is measured counterclockwise from the vehicle's positive X-axis as defined in S10.13.	Other (Test Setup)	For vehicles with unconventional seating, research may be required to identify the appropriate location for the impact reference line.
S12.1.2 Positioning a Part 572 Subpart F (SID) dummy in the front outboard seating position.	(a) Torso. Hold the dummy's head in place and push laterally on the non-impacted side of the upper torso in a single stroke with a force of 66.7-89.0 N (15-20 lb) towards the impacted side. (1) For a bench seat. The upper torso of the test dummy rests against the seat back. The midsagittal plane of the test dummy is vertical and parallel to the vehicle's longitudinal centerline, and the same distance from the vehicle's longitudinal centerline as would be the midsagittal plane of a test dummy positioned in the driver position under S12.1.1(a)(1). (2) For a bucket seat. The upper torso of the test dummy rests against the seat back. The midsagittal plane of the test dummy is vertical	Other (Dummy Positioning)	Research may be necessary to determine if this positioning procedure is appropriate for a rear-facing front row seat.

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Section	**Standard**	**Theme**	**Potential Considerations**
	and parallel to the vehicle's longitudinal centerline and coincides with the longitudinal centerline of the bucket seat. (b) Pelvis. (1) H-point. The H-points of each test dummy coincide within 12.7 mm (1/2 inch) in the vertical dimension and 12.7 mm (1/2 inch) in the horizontal dimension of a point that is located 6.4 mm (1/4 inch) below the position of the H-point determined by using the equipment for the 50th percentile and procedures specified in SAE Standard J826-1980 (incorporated by reference, see §571.5), except that Table 1 of SAE J826-1980 is not applicable. The length of the lower leg and thigh segments of the H-point machine are adjusted to 414 and 401 mm (16.3 and 15.8 inches), respectively. (2) Pelvic angle. As determined using the pelvic angle gauge (GM drawing 78051-532 incorporated by reference in part 572, Subpart E of this chapter) which is inserted into the H-point gauging hole of the dummy, the angle of the plane of the surface on the lumbar-pelvic adaptor on which the lumbar spine attaches is 23 to 25 degrees from the horizontal, sloping upward toward the front of the vehicle. (c) Legs. … (d) Feet. The feet of the test dummy are placed on the vehicle's toeboard with the heels resting on the floorpan as close as possible to the intersection of the toeboard and floorpan. If the feet cannot be placed flat on the toeboard, they are set perpendicular to the lower legs and placed as far forward as possible so that the heels rest on the floorpan.		
S12.2.1 Positioning an ES-2re dummy in all seating positions.	Position a correctly configured ES-2re test dummy, conforming to the applicable requirements of part 572 of this chapter, in the front outboard seating position on the side of the test vehicle to be struck by the moving deformable barrier or pole. Restrain the test dummy using all available belt systems in the seating positions where the belt restraints are provided. Place any adjustable anchorages at the manufacturer's nominal design position	Other (Dummy Positioning)	Research may be necessary to determine if this positioning procedure is appropriate for a rear-facing front row seat.

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Section	**Standard**	**Theme**	**Potential Considerations**
	for a 50th percentile adult male occupant. Retract any folding armrest. (a) Upper torso. (1) The plane of symmetry of the dummy coincides with the vertical median plane of the specified seating position. (2) Bend the upper torso forward and then lay it back against the seat back. Set the shoulders of the dummy fully rearward. (b) Pelvis. … (c) Arms. For the driver seating position and for the front outboard passenger seating position, place the dummy's upper arms such that the angle between the projection of the arm centerline on the mid-sagittal plane of the dummy and the torso reference line is 40° ±5°. The torso reference line is defined as the thoracic spine centerline. The shoulder-arm joint allows for discrete arm positions at 0-, 40-, and 90- degree settings forward of the spine. (d) Legs and Feet. Position the legs and feet of the dummy according to the following: (1) For the driver's seating position, … (2) For other seating positions, without inducing pelvis or torso movement, place the heels of the dummy as far forward as possible on the floor pan without compressing the seat cushion more than the compression due to the weight of the leg. Set the knees of the dummy such that their outside surfaces are 150 ±10 mm (5.9 ±0.4 inches) from the plane of symmetry of the dummy.		
S12.3.3 5th percentile female front passenger dummy positioning.	(a) Passenger torso/head/seat back angle positioning. (1) With the seat at the mid-height in the full-forward position determined in S10.3.2, use only the control that primarily moves the seat fore and aft to place the seat in the rearmost position, without adjusting independent height controls. If the seat cushion reference line angle automatically changes as the seat is moved from the full forward position, maintain, as closely as possible, the seat cushion reference line angle determined in S10.3.2.3.3, for the final forward position when measuring the pelvic angle as specified in S12.3.3(a)(11). The seat cushion reference	Other (Dummy Positioning)	Research may be necessary to determine if this positioning procedure is appropriate for a rear-facing front row seat.

FMVSS No. 214			
Section	**Standard**	**Theme**	**Potential Considerations**
	line angle position may be achieved through the use of any seat or seat cushion adjustments other than that which primarily moves the seat or seat cushion fore-aft. (2) Fully recline the seat back, if adjustable. Place the dummy into the passenger's seat, such that when the legs are positioned 120 degrees to the thighs, the calves of the legs are not touching the seat cushion. (3) Bucket seats. Place the dummy on the seat cushion so that its midsagittal plane is vertical and passes through the SgRP within ±10 mm (±0.4 in). (4) Bench seats. Position the midsagittal plane of the dummy vertical and parallel to the vehicle's longitudinal centerline and the same distance from the vehicle's longitudinal centerline, within ±10 mm (±0.4 in), as the midsagittal plane of the driver dummy. (5) Hold the dummy's thighs down and push rearward on the upper torso to maximize the dummy's pelvic angle. (6) Place the legs at 120 degrees to the thighs. Set the initial transverse distance between the longitudinal centerlines at the front of the dummy's knees at 160 to 170 mm (6.3 to 6.7 in), with the thighs and legs of the dummy in vertical planes. Push rearward on the dummy's knees to force the pelvis into the seat so there is no gap between the pelvis and the seat back or until contact occurs between the back of the dummy's calves and the front of the seat cushion. (7) Gently rock the upper torso relative to the lower torso laterally in a side-to-side motion three times through a ±5 degree arc (approximately 51 mm (2 in) side to side). (8) If needed, extend the legs slightly so that the feet are not in contact with the floor pan. Let the thighs rest on the seat cushion to the extent permitted by the foot movement. With the feet perpendicular to the legs, place the heels on the floor pan. If a heel will not contact the floor pan, place it as close to the floor pan as possible. Using only the control that primarily moves the seat fore and aft, attempt to return the seat to the full forward position. If a dummy leg contacts the vehicle		

FMVSS No. 214			
Section	**Standard**	**Theme**	**Potential Considerations**
	interior before the full forward position is attained, position the seat at the next detent where there is no contact. If the seats are power seats, position the seat to avoid contact while assuring that there is a maximum of 5 mm (0.2 in) distance between the vehicle interior and the point on the dummy that would first contact the vehicle interior. (9) Head leveling. (i) Vehicles with fixed seat backs. Adjust the lower neck bracket to level the transverse instrumentation platform angle of the head to within ±0.5 degrees. If it is not possible to level the transverse instrumentation platform to within ±0.5 degrees, select the neck bracket adjustment position that minimizes the difference between the transverse instrumentation platform angle and level. (ii) Vehicles with adjustable seat backs. While holding the thighs in place, rotate the seat back forward until the transverse instrumentation platform angle of the head is level to within ±0.5 degrees, making sure that the pelvis does not interfere with the seat bight. If it is not possible to level the transverse instrumentation platform to within ±0.5 degrees, select the seat back adjustment position that minimizes the difference between the transverse instrumentation platform angle and level, then adjust the neck bracket to level the transverse instrumentation platform angle to within ±0.5 degrees if possible. If it is still not possible to level the transverse instrumentation platform to within ±0.5 degrees, select the neck bracket angle position that minimizes the difference between the transverse instrumentation platform angle and level. (10) Measure and set the dummy's pelvic angle using the pelvic angle gage. The angle is set to 20.0 degrees ±2.5 degrees. If this is not possible, adjust the pelvic angle as close to 20.0 degrees as possible while keeping the transverse instrumentation platform of the head as level as possible by adjustments specified in S12.3.2(a)(9). (11) If the dummy is contacting the vehicle interior after these adjustments, move the seat		

FMVSS No. 214			
Section	**Standard**	**Theme**	**Potential Considerations**
	rearward until there is a maximum of 5 mm (0.2 in) between the contact point of the dummy and the interior of the vehicle or if it has a manual seat adjustment, to the next rearward detent position. If after these adjustments, the dummy contact point is more than 5 mm (0.2 in) from the vehicle interior and the seat is still not in its forwardmost position, move the seat forward until the contact point is 5 mm (0.2 in) or less from the vehicle interior, or if it has a manual seat adjustment, move the seat to the closest detent position without making contact, or until the seat reaches its forwardmost position, whichever occurs first. (b) Passenger foot positioning. (1) Place the front passenger's feet flat on the toe board. (2) If the feet cannot be placed flat on the toe board, set them perpendicular to the leg center lines and place them as far forward as possible with the heels resting on the floor pan. (3) If either foot does not contact the floor pan, place the foot parallel to the floor pan and place the lower leg as perpendicular to the thigh as possible. (c) Passenger arm/hand positioning. Place the dummy's upper arm such that the angle between the projection of the arm centerline on the midsagittal plane of the dummy and the torso reference line is 45° ±5°. The torso reference line is defined as the thoracic spine centerline. The shoulder-arm joint allows for discrete arm positions at 0, ±45, ±90, ±135, and 180 degree settings where positive is forward of the spine.		

Table 23. Potential Barriers in FMVSS No. 216a

FMVSS No. 216a			
Section	**Standard**	**Theme**	**Potential Considerations**
S7.2	Adjust the seats in accordance with S8.3.1 of 49 CFR 571.214. Position the top center of the headform specified in S5.2 of 49 CFR 571.201 at the location of the top center of the Head Restraint Measurement Device (HRMD) specified in 49 CFR 571.202a, in the front outboard designated seating position on the side of the vehicle being tested as follows: (a) Position the three-dimensional manikin specified in SAE Standard J826 JUL95 (incorporated by reference, see §571.5), in accordance to the seating procedure specified in that document, except that the length of the lower leg and thigh segments of the H-point machine are adjusted to 414 and 401 millimeters, respectively, instead of the 50th percentile values specified in Table 1 of SAE J826 JUL95. (b) Remove four torso weights from the three-dimensional manikin specified in SAE J826 (July 1995) (two from the left side and two from the right side), replace with two HRMD torso weights (one on each side), and attach and level the HRMD headform. (c) Mark the location of the top center of the HRMD in three-dimensional space to locate the top center of the head form specified in S5.2 of 49 CFR 571.201.	Other (Dummy Positioning)	References the seat positioning procedures in FMVSS No. 214, the specifications of the headform in FMVSS No. 201, and the Head Restraint Measurement Device in FMVSS No. 202a. For a rear-facing front seat, the head position would be closer to the front of the vehicle but if the other standards referenced are followed, the test device should still make contact with the roof. The intent of this standard should be maintained for vehicles with rear-facing front seats.

Table 24. Potential Barriers in FMVSS No. 219

FMVSS No. 219			
Section	**Standard**	**Theme**	**Potential Considerations**
S6.1	The lower edge of the protected zone is determined by the following procedure (See Figure 1). (a) Place a 165 mm diameter rigid sphere, with a mass of 6.8 kg in a position such that it simultaneously contacts the inner surface of the windshield glazing and the surface of the instrument panel, including padding. If any accessories or equipment such as the steering control system obstruct positioning of the sphere, remove them for the purposes of this procedure.	Other (Test reference point may not be applicable)	The reference to an "instrument panel" may need to be adjusted for rear-facing seating configurations lacking a traditional instrument panel.

FMVSS No. 219			
Section	**Standard**	**Theme**	**Potential Considerations**
	(b) Draw the locus of points on the inner surface of the windshield contactable by the sphere across the width of the instrument panel. From the outermost contactable points, extend the locus line horizontally to the edges of the glazing material. (c) Draw a line on the inner surface of the windshield below and 13 mm distant from the locus line. (d) The lower edge of the protected zone is the longitudinal projection onto the outer surface of the windshield of the line determined in S6.1(c).		

Table 25. Potential Barriers in FMVSS No. 226

FMVSS No. 226			
Section	**Standard**	**Theme**	**Potential Considerations**
S3. Definitions	*Row* means a set of one or more seats whose seat outlines do not overlap with the seat outline of any other seats, when all seats are adjusted to their rearmost normal riding or driving position, when viewed from the side.	Other (Directionality)	Rearmost may require some clarification if it is not clear that it refers to the seat direction.
S4.2.2	Vehicles that have an ejection mitigation countermeasure that deploys in the event of a rollover must have a monitoring system with a readiness indicator. The indicator shall monitor its own readiness and must be clearly visible from the driver's designated seating position. The same readiness indicator required by S4.5.2 of FMVSS No. 208 may be used to meet the requirement. A list of the elements of the system being monitored by the indicator shall be included with the information furnished in accordance with S4.2.3.	Telltales, Indicators, and Auditory Alerts	The option used for the same readiness indicator in FMVSS No. 208 was to state the indicator must be visible "from the driver's designated seating position and clearly visible from any designated seating position if no driver's seating position is occupied or present."
S5.2.3.1 Front windows.	For any side daylight opening forward of the vehicle B-pillar, the primary quadrants are the forward-lower and rearward-upper.	Other (Test Setup)	Research may be necessary to determine if the specified primary and secondary target locations are appropriate for a rear-facing front seat.

FMVSS No. 226			
Section	**Standard**	**Theme**	**Potential Considerations**
S5.2.3.2 Rear windows.	For any side daylight opening rearward of the B-pillar, the primary quadrants are the forward-upper and rearward-lower.	Other (Test Setup)	Research may be necessary to determine if the specified primary and secondary target locations are appropriate for a rear-facing front seat.
S5.2.4.1 Front windows.	Measure the horizontal distance between the centers of the primary targets. For a side daylight opening forward of the B-pillar, place one secondary target center rearward of the forward primary target by one-third of the horizontal distance between the primary target centers and tangent with upper portion of the offset-line. Place another secondary target center rearward of the forward primary target by two-thirds of the horizontal distance between the primary target centers and tangent with the lower portion of the offset-line (see figure 4) (figure provided for illustration purposes).	Other (Test Setup)	Research may be necessary to determine if these targeting procedures are appropriate for a rear-facing front seat.
S5.2.4.2 Rear windows.	For side daylight openings rearward of the B-pillar, place one secondary target center rearward of the forward primary target by one-third of the horizontal distance between the primary target centers and tangent with lower portion of the offset-line. Place another secondary target center rearward of the forward primary target by two-thirds of the horizontal distance between the primary target centers and tangent with the upper portion of the offset-line (see Figure 4) (figure provided for illustration purposes).	Other (Test Setup)	Research may be necessary to determine if these targeting procedures are appropriate for a rear-facing front seat.

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