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HEAVY TRUCK CRASHWORTHINESS - PHASE III

- Restraint System Test Procedure Development
- Cab Interior Component Test Development
- Cab Structural Test Procedure Development

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**HEAVY TRUCK CRASHWORTHINESS
Testing and Analysis for
Recommended Practice Development**

Volume 1

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EXECUTIVE SUMMARY

This document represents the Phase III final report for the Heavy Truck Crashworthiness Investigation sponsored by the Society of Automotive Engineers (SAE). This report summarizes work conducted by Failure Analysis Associates, Inc. (FaAA) over the period from February 1994 through September 1996 and, where relevant, references work from earlier Phases. The goal of Phase III was to develop, evaluate, and recommend test procedures that could be used to evaluate occupant protection in heavy trucks. Reports detailing the work performed in Phases I and II have been previously submitted. The Phase I report is currently available as SAE Publication CRP-9 "Heavy Truck Crashworthiness (Statistics, Accident Reconstruction, Occupant Dynamics Simulation)." The Phase II report is available as SAE Publication CRP-12 "Heavy Truck Crashworthiness (180-degree Dynamic Rollover, Static Roof Crush Simulation)."

Through the Phase I analysis of fatal-to-the-occupant heavy truck accidents, it was confirmed that key elements in the crashworthiness of heavy truck tractors were the structure of the cab and its ability to maintain space for the occupant, the ability of the restraint system(s) to limit the contact of the occupant with interior components, and the aggressivity of interior components that the occupant may contact. In Phase III, draft SAE Recommended Practices (RPs) were developed for tests that evaluate each of these elements in manners consistent with typical real-world accident sequences as identified in Phase I.

To address the various aspects of evaluating heavy truck crashworthiness, the Phase III investigation was divided into three tasks. In Task A, test procedures for occupant restraint system evaluation in frontal impact and 90-degree rollover conditions were developed. Task B involved development of test procedures for evaluating interior component impacts by occupants. In Task C, quasi-static and dynamic test procedures were developed for the evaluation of the structural integrity of heavy truck cabs in both frontal impacts and rollovers. The report sections that follow describe the development of the various test procedures for each of the Tasks. At the beginning of each Task discussion section is a review of existing test procedures potentially relevant to the type of testing developed by each Task. These reviews were conducted to confirm that test procedures developed in this project were reasonably consistent with existing state-of-the-art.

Task A - Restraint System Evaluation

Test procedures designed to evaluate restraint system effectiveness were developed. Three different test types were defined: 1) Component-Level, Frontal Impact Test; 2) System-Level, Frontal Impact Test; and 3) System-Level, 90-Degree Lateral Rollover Test. In each test, a crash pulse defined in Phase I was applied to the test fixture so that occupant response could be evaluated. For the frontal impact tests, a deceleration sled was used as the test fixture, while for lateral rollover simulation, a special roll fixture was developed.

The component-level sled test involved subjecting a seat, restraint system hardware (i.e., seat belt webbing, retractor and related mounting hardware), and test dummy to a representative crash pulse approximating the frontal impact pulse defined in Phase I. For this test type, no interior cab components were included as part of the test fixture. The ultimate purpose of this test was to evaluate the forward excursion of the test dummy head, upper torso, and knees during the crash pulse. Two sled tests were conducted for the component-level test evaluation using a Hybrid III 50th-percentile male anthropomorphic dummy. In the first test the dummy was restrained with a 2-point belt, while a 3-point restraint was used in the second test.

The system-level sled test involved subjecting a seat(s), restraint system hardware, and test dummy(ies) to a representative crash pulse while located in a heavy truck cab environment. For this test type, the interior components of a heavy truck cab are represented on the sled platform either by fabricated mock-ups or by using an actual cab with interior components intact. For the evaluation test conducted as part of this project, a cab-over-engine (COE) cab was mounted on the sled to provide the cab interior environment for the test dummy. As with the component-level test, the purpose of this test was to evaluate the forward excursion of the test dummies, identify which interior components may be contacted during the crash pulse, and measure the severity of any such contact. Four system-level sled tests were conducted. Two dummies were used in two of the system-level sled tests. Both dummies were restrained with 2-point restraints in one test and 3-point restraints in the other. The remaining two system-level sled tests were conducted with unrestrained driver and passenger dummies. The driver dummy was modified for the purpose of evaluating the frangible abdomen studied in Task B.

Hybrid-III 50th-percentile male test dummies were used for all of the frontal impact testing. Though the primary objective of the frontal impact testing was the evaluation of occupant excursion, useful information regarding the severity of any interior contacts and the effectiveness of restraint systems may be obtained through the acquisition of test dummy data, for example through the use of head and chest accelerometers and neck and femur load cells. Specific test

dummy instrumentation set-ups for the component-level and system-level tests conducted for this investigation are summarized in report sections below. Other relevant instrumentation included seat belt webbing load cells for belt tension measurement and sled platform accelerometers for recording the crash pulse. High-speed film cameras were used to record dummy motion during the crash pulse, allowing test engineers to plot paths of travel for the dummy head and knee in each of the evaluation tests, thereby establishing the excursion ranges for the dummy.

In order to evaluate restraint system effectiveness in 90-degree rollover accidents, a Lateral Rollover Simulator (LRS) was developed. The LRS design was based upon the single-degree-of-freedom model developed in Phase I in which the rotational axis was the tire/ground contact patch centerline of the leading side tractor tires. The LRS consists of a platform that can be hydraulically actuated and rotated through 90 degrees. A conventional tractor cab with all relevant interior components was mounted on the platform for purposes of the evaluation tests conducted in this project. The platform was accelerated to match the analytically derived angular velocity and then decelerated by crushing a honeycomb stack after 90 degrees of rotation. The shape of the honeycomb stack was designed to produce a deceleration pulse comparable to that derived in Phase I.

All of the evaluation tests conducted with the LRS simulated driver-side leading 90-degree rollovers. Instrumented Hybrid III 50th-percentile dummies were used to evaluate occupant excursion and contact severity. Four evaluation tests were conducted with various dummy and restraint configurations (driver only, 3-point restraint; driver and passenger, 3-point restraint; and driver and passenger, 2-point restraint). On-board high-speed film cameras and off-board high-speed film and standard video cameras recorded fixture and dummy motion. The off-board cameras did not provide a sufficient view of the dummies to facilitate analysis of interior contacts. The on-board cameras, while adequately documenting occupant motion and contact, required wide-angle lenses due to their proximity to the dummies and thus were not useful for precise film analysis due to lens distortion effects. Head and chest accelerometers in the dummies recorded accelerations in good agreement with those predicted by the MADYMO simulations performed in Phase I using the analytical rollover crash pulse.

Three draft RPs were prepared based upon the sled and LRS evaluation testing. Two practices describe procedures for conducting component- and system-level sled tests including a generic heavy truck deceleration pulse. The third practice describes design of and testing with the LRS, again including a generic heavy truck deceleration pulse for 90-degree lateral rollovers.

Task B - Interior Component Evaluation

Laboratory procedures were developed for evaluating the performance of individual interior components in a heavy truck collision. The utility of these tests ties together results obtained in both the restraint system and cab structural evaluations. The excursion of occupants permitted by the restraint system coupled with the extent of interior component motion due to collision-generated intrusion can be combined to determine what cab components are likely to be impacted by the occupant and how severe those contacts are likely to be. With that determination, component test procedures can be used as a tool to aid in altering the injury causing potential of anticipated contacts by testing only those contacts rather than full-scale crash tests for each new component concept.

In addition to the review of existing testing procedures for vehicle interior components, research conducted elsewhere pertaining to the development of advanced devices for assessing steering wheel induced abdominal injury was reviewed in Task B.

Four different devices were evaluated to determine their utility in testing heavy truck interior components. The devices evaluated were the SAE J984 steel headform, the free motion headform (FMH), the SAE J944 body block, and the frangible abdomen. The FMH is a modified Hybrid III dummy head.

Test evaluation in Task B was divided into two groups. First, for head impacts, the steel headform and FMH response characteristics were directly compared in a series of impacts into a simulated A-pillar. The FMH was then selected to impact a variety of actual COE cab interior components including the door frame, windshield header, instrument panel, and steering wheel. Secondly, for chest and abdominal impacts, the body block and frangible abdomen were used in evaluating a test procedure for the steering wheel only.

For both headforms and the body block, the body form was propelled into the target surface/object by an air cannon. Impact speed of the body form was measured with a photoelectric speed trap and by integrating the data from an accelerometer mounted within the body form. The frangible abdomen was evaluated by including this device in an unrestrained Hybrid III 50th-percentile male test dummy in sled tests. Two such frangible abdomen evaluation sled tests were conducted.

Two draft RPs were prepared based upon the interior component testing evaluation. The first describes the procedure for conducting interior component tests with the FMH. The second draft

RP describes the procedure for testing steering control systems with the body block. A draft RP was not developed for the frangible abdomen because the evaluation test in which the frangible element contacted the steering wheel produced such significant damage to the frangible element that it was unusable for injury assessment. Additionally, at this time there is insufficient biomechanical research to support use of the frangible abdomen for assessing steering wheel induced injuries.

The draft RP prepared for the FMH testing was based primarily upon Federal Motor Vehicle Safety Standard (FMVSS) 201U for passenger cars. The primary difference in the procedure developed for heavy trucks is that specific target locations and impact angles are not defined for heavy trucks as they are for passenger cars. Geometric differences between passenger cars and heavy trucks and even among heavy trucks are such that it is unreasonable to require specific test locations and angles. It was decided that, by not specifying test locations and angles, the flexibility and utility of the test procedures would be maximized. The draft RP includes a list of recommended target components that includes the steering wheel and instrument panel.

The draft RP prepared for steering control system testing with the body block was based upon the current FMVSS 203 test procedure. The two primary differences in the procedures involve the steering wheel orientation and the vertical alignment of the body block. For the heavy truck procedure, it is recommended that the steering wheel be turned such that its most rigid spoke is aligned with the impact direction of the body block. The body block for the heavy truck test is elevated such that its center of gravity is at the same level as the lower edge of the steering wheel rim. In FMVSS 203, the body block is positioned vertically relative to the seating reference point (SRP).

Task C - Cab Structure Evaluation

Test procedures were developed for evaluating heavy truck cab structural strength properties. Based upon the statistical analysis and accident review conducted in Phase I, tractor cab structural performance in two accident modes were of interest for further study: frontal strength of a COE cab impacting the rear end of a heavy truck trailer, and roof strength in 180-degree rollovers. The goals of Task C included developing procedures to test cab strength in manners consistent with real-world accident loading.

A survey of van, flatbed, and tanker trailers was conducted in order to gather information concerning typical construction and dimensions for structural elements at the rear ends of these trailer types. It was concluded that van trailers represented the worst case of typical trailers that

might be impacted. This conclusion was based upon a combination of observations from Phase I and survey measurements indicating that these trailer types most regularly had their stiffest structures high enough to clear the frame rails of typical tractors.

A large, flat platen was fabricated as a test device to replicate the approximate rear end geometry of a van trailer and two similar model COE cabs were obtained for testing. The platen was sized to be wider than the overall width of the test cabs and tall enough that it extended to about the roof of the cabs. The platen was mounted to a rolling carriage allowing it to be loaded quasi-statically into the front of one test cab and dynamically impacted into the front of the other cab. Both cabs were mounted to frame rails with their standard cab mounts, and the frame rails were rigidly affixed to the ground. The bottom of the platen was elevated on the carriage such that, relative to normal tractor geometry, it was 46 inches above the ground. This elevation was consistent with the trailer survey measurements, encompassing heights of significant structure in the majority of typical trailers.

Quasi-static loading was accomplished using four hydraulic cylinders to pull the platen and carriage into the front of the cab. The load on the front of the cab was reacted through the cab mounts and frame rails and into the face of FaAA's crash barrier. The load was measured by four load cells mounted between the platen and carriage. The displacement of the platen and rear cab wall relative to the barrier were measured. In addition, displacements of the windshield header, steering wheel hub and instrument panel relative to the cab floor were measured. While plastic deformation of the forward cab mounts did occur, there was no total failure of these mounts at this load and displacement.

The dynamic impact of the second COE test cab was conducted by rolling the platen/carriage into the front of the cab. The impact speed was selected such that the kinetic energy was approximately the same as the force-displacement energy imparted quasi-statically to the first cab. In the dynamic test, similar cab displacements were measured and platen load was recorded by the same load cells; however, platen displacement was determined by twice integrating the platen/carriage deceleration recorded by two accelerometers on the carriage. As was the case with quasi-static loading, there was plastic deformation of the forward cab mounts, but no total failure.

The type of damage imparted to the COE cab front ends in both the quasi-static and dynamic tests was consistent with the damage observed in the real-world National Transportation Safety Board (NTSB) and National Accident Sampling System (NASS) accidents examined. While the

extent of damage differed between test and accident cabs, the observed creasing of the front cab face just above the frame rails and the rearward displacement of the cab matched characteristic damage patterns of actual rear end collisions.

Draft RPs were developed for both the quasi-static and dynamic frontal cab testing. For the quasi-static loading, the mechanism for constraining the motion of the platen is not described (i.e. the platen/carriage used by FaAA is not a specified mechanism) and it is left to the discretion of the testing entity to control the platen travel within some specified guidelines. For the dynamic loading, options for platen motion control are presented including a pendulum and a platen/carriage (as used by FaAA). For each of the platen options presented, some guidance is provided so that the ultimate test conducted remains consistent with the procedures evaluated by FaAA.

Two-stage test procedures for cab roof strength (for 180-degree rollovers) were developed for both quasi-static and dynamic loading. It was clear from the Phase I study that heavy truck rollover mechanics differed from rollover mechanics for passenger cars. Since roll rates are not very high and heavy trucks do not vault in the roll process, the leading side of the tractor cab will impact the ground as part of the progressive roll onto the roof. This impact transmits most of its load along the side roof rail, typically parallelogramming or “matchboxing” the cab section above the belt line (greenhouse). These mechanics suggested that roof strength evaluation tests would be most representative if the greenhouse was matchboxed with a pre-load prior to loading the roof.

The NTSB and NASS accident compilation provided information about the level of damage to be anticipated in 90- and 180-degree rollovers, but did not provide sufficient information to facilitate the design of the pre-load procedure. A conventional tractor was obtained and several tipover tests were conducted to study the interaction of the cab with the ground. Based on these tipover tests, an energy level for the pre-load procedure was determined that produced cab damage representative of real-world accidents.

To pre-load the cabs for subsequent roof testing, the platen/carriage system used in the frontal testing was again employed. Cabs were mounted to framerail sections using their standard cab mounts. The frame rails were rigidly affixed to the ground and the driver-side of the cab was impacted with the platen. As discussed above, the damage energy after the first 90 degrees of roll is focused at the leading side roof rail. To accomplish this energy focusing in the pre-load, the platen was leaned 20 degrees toward the cab. The 20 degree angle was selected based upon

the damage geometry in the tipover tractor (described above) and upon damage geometry observed in the NTSB and NASS accidents.

Both quasi-static and dynamic roof load tests were evaluated. For each of these tests, the pre-loaded cabs were rotated 90 degrees (impacted side down) along with their frame rails and mounts. The vertical platen (with carriage) was then hydraulically forced or dynamically impacted into the roof of the cab.

The quasi-static roof loading was accomplished with four hydraulic cylinders and the platen load was reacted through the cab into the face of FaAA's crash barrier. Load cells between the platen and carriage measured the applied load, and displacement transducers measured the motion of the platen. Displacement transducers were also placed inside the cab (floor to roof) and outside the cab (cab bottom to barrier) at both the driver and passenger seating positions. These transducers allowed division of the platen travel into how much the roof was intruding into the occupant compartment and how much of the travel was due to the cab being pushed down around its mounts.

The dynamic impact of the second pre-loaded test cab was accomplished by rolling the platen/carriage into the roof of the cab. The impact speed was selected such that the impact kinetic energy was approximately the same as the force-displacement energy imparted quasi-statically to the first cab. In the dynamic test, similar cab displacements were measured and platen load was recorded by the same load cells; however, platen displacement was determined by twice integrating the platen/carriage deceleration recorded by two accelerometers on the carriage. For both the quasi-static and dynamic roof tests, the geometry of the final roof damage was consistent with that observed in real-world accident vehicles.

Draft RPs were prepared for both the quasi-static and dynamic roof tests. In both cases the procedure for cab roof pre-loading is described. As was the case in the dynamic frontal test, options for platen motion control are described for the pre-load impact. For the quasi-static roof load, cab mounting options are discussed including mounting the cab on its side (the configuration evaluated by FaAA) or in its normal orientation — in which case the platen would be pulled (or pushed) into the roof from above. For the dynamic roof loading, pendulum and rolling carriage options are discussed for controlling platen motion.

Conclusion

Over the past several years, the Heavy Truck Crashworthiness Project has combined information and analyses from a variety of sources in order to develop standardized testing procedures for heavy trucks and their components. In the beginning of this project, statistical analyses and study of compilations of real-world accident reports and photographs generated a rationale with which to guide creation of the types of tests that would be relevant to heavy trucks. With the guidance of this work, a number of test procedures were designed and evaluated for heavy trucks and their components. For these procedures, draft SAE RPs were prepared so that others could be guided in the conduct of these tests. Draft RPs were developed to aid in the evaluation of occupant restraint systems (in both collision and lateral rollover environments) and cab interior layout (based upon occupant excursion), interior component aggressivity, and cab structural properties (in both frontal collision and 180-degree rollover environments).

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INTRODUCTION

Over the past several years, there has been considerable and growing interest in heavy truck safety issues. Federal agencies, private groups, manufacturers, and researchers have emphasized the need to address heavy truck crashworthiness. The current FMVS Standards are focused primarily on passenger cars and are not generally applicable to heavy trucks.

Research has demonstrated that the behavior of heavy trucks involved in accidents differs significantly from the accident behavior of passenger cars. Numerous factors related to the operating environment, vehicle, and driver contribute to heavy truck accident performance. While passenger car crashes typically involve relatively high decelerations over short time durations, heavy truck crashes typically consist of comparatively low decelerations over long time durations. This is because moving heavy trucks possess significantly more kinetic energy than do passenger cars. For many heavy truck accidents involving truck occupant fatality, dissipation of this kinetic energy involves a complex sequence of accident events such as skidding, minor and major impacts, jackknifing and rollover. It is therefore evident that many of the current FMVSS tests and requirements are not relevant to heavy trucks.

In 1991, the SAE undertook sponsorship of a three-phase research program to investigate heavy truck crashworthiness. The program goal was to develop practical test procedures that could be used to evaluate heavy truck occupant protection for certain classes of typically fatal accidents considered potentially survivable. Phase I of this program developed deceleration time histories (crash pulses) that best characterized heavy truck accident scenarios producing occupant fatalities. Also developed in Phase I was the capability of simulating occupant dynamics in heavy truck crashes using the characteristic crash pulses. Phase II of this program included development of a numerical finite element model of a typical heavy truck cab structure, a parametric study of structural modifications of selected cab components, and computer simulation of a dynamic 180-degree tractor-trailer rollover. In Phase III, test procedures were developed to evaluate heavy truck restraint systems, cab interior components, and cab structural integrity. Many of these test procedures were configured to replicate components of accident scenarios found in Phase I to characterize heavy truck accidents resulting in occupant fatalities.

Program Background

In Phase I, FaAA examined the Fatal Accident Reporting System (FARS) to develop accident sequences that characterize heavy truck accidents resulting in occupant fatality. That examination generated a relative ranking of accident sequences, permitting selection and further

evaluation of prominent accident components affecting overall truck occupant safety. It was determined that collision accidents were primarily frontal in nature and that, when it occurred in an accident sequence, a rollover was typically the most harmful event in the sequence. Although a heavy truck accident sequence may be complex, it was concluded that there is generally a single event during that accident sequence that produces the deceleration or intrusion that results in occupant injury.

Deceleration profiles (crash pulses) were developed for the identified prominent accident sequence components. To identify engineering parameters for crash pulse development, FaAA conducted an in-depth review of heavy truck fatal accidents compiled by the NTSB and approximately 25 additional heavy truck accident files from the NASS. Reconstruction of a subset of representative accidents from this compilation generated crash pulses for three prominent accident components:

1. Frontal collision
2. 90-degree rollover without subsequent collision
3. 90-degree rollover with subsequent collision

It was concluded that 180-degree rollovers were too complex for a meaningful crash pulse to be developed from available accident data for the portion of the rollover between 90 and 180 degrees. For frontal collisions, the developed crash pulse was based upon the impact of a tractor-trailer into the rear end of another tractor-trailer. This type of collision was relatively common and generally did not result in total tractor destruction, as was the case with most of the fixed-object collisions, suggesting that improvement in the survivability of rear end collisions was at least possible. The crash pulse derived for the rear end impacts was based upon the limitation that, above an average deceleration of 5 to 6 g (11 g peak), kingpin or fifth wheel failures were regularly observed in the real-world accidents, resulting in crushing of the impacting tractor cab between its own trailer and the impacted trailer. This deceleration level thus represented a reasonable upper bound to target for evaluating restraint system effectiveness since cab crush typically rendered restraint performance irrelevant above that level. A rollover deceleration pulse for impact of the tractor side with the ground after rolling 90 degrees was also derived using reconstruction of the sample accidents and theoretical analysis of rollover dynamics.

As a result of the first portions of the Phase I investigation, the capability of simulating occupant dynamics was developed to predict peak occupant excursions, demonstrate changes in occupant response for different restraint configurations, and provide information for the design of test procedures. The MADYMO computer program was used for occupant dynamics simulation. Data from an existing frontal impact and rollover crash test were used to benchmark the

simulation effort. It was determined that the simulation process could be used to satisfactorily predict heavy truck occupant dynamics. MADYMO was then used to analyze occupant dynamics in each of the three accident sequence components listed above for typical COE and conventional tractor designs and for three restraint conditions (unrestrained, lap belt only, and 3-point belt).

In Phase II, the LS-DYNA3D computer program was used to conduct finite element analyses of a typical heavy truck cab structure. Two COE cabs were crushed quasi-statically to provide data for validating the analytical model. Parametric analyses were conducted with the model to assess the effect of thickening the roof bow, A-pillars, and door frame. A rigid tractor chassis and trailer were added to the cab finite element model for simulation of cab structure loading and deformation in a 180-degree rollover. A rigid-body simulation of a 180-degree rollover was created by TACOM using the DADS computer program. The output of this simulation was provided to FaAA and used for initial conditions in analyzing the cab structural response during a 180-degree rollover.

Phase III - Test Procedure Development

The report sections which follow summarize work from Phase III of the Heavy Truck Crashworthiness Program as conducted by FaAA over the period from February 1994 through September 1996 and, where relevant, references work from earlier Phases. The goal of Phase III was to develop, evaluate, and recommend test procedures that could be used to evaluate occupant protection in heavy trucks.

In the development of any test procedure, it is important to establish the purpose of the intended test. With the defined purpose understood, the proper test parameters (i.e. data acquisition requirements, photographic coverage, etc.) can be defined. Therefore, in order to develop test procedures appropriate for evaluation of heavy truck restraint systems, a thorough understanding of the nature of heavy truck accidents and the resulting occupant injury mechanisms is necessary.

Through the Phase I analysis of fatal-to-the-occupant heavy truck accidents, it was determined that key elements in the crashworthiness of heavy truck tractors were: the structure of the cab and its ability to maintain space for the occupant; the ability of the restraint system(s) to limit the contact of the occupant with interior components; and the aggressivity of interior components that the occupant may contact. In Phase III, draft SAE RPs were developed to evaluate each of these elements in manners consistent with typical real-world accident sequences as identified in Phase I.

To address the various aspects of evaluating heavy truck crashworthiness, the Phase III investigation was divided into three Tasks. In Task A, test procedures for occupant restraint system evaluation in frontal impact and 90-degree rollover conditions were developed. Task B involved development of test procedures for evaluating interior component impacts by occupants. In Task C, quasi-static and dynamic test procedures were developed for the evaluation of the structural integrity of heavy truck cabs in both frontal impacts and rollovers. The report sections that follow describe the development of the various test procedures for each of the Tasks. At the beginning of each Task discussion section is a review of existing test procedures potentially relevant to the type of testing developed by each Task.

Task A - Restraint System Evaluation

Test procedures designed to evaluate restraint system effectiveness were developed. Three different test types were defined: 1) Component-Level, Frontal Impact Test; 2) System-Level, Frontal Impact Test; and 3) System-Level, 90-Degree Lateral Rollover Impact Test. In each test, a crash pulse defined in Phase I was applied to the test fixture so that occupant response could be evaluated. For the frontal impact tests, a deceleration sled was used as the test fixture, while for 90-degree lateral rollover simulation, a special roll fixture was developed.

The component-level sled test involved subjecting a seat, restraint system hardware (i.e., seat belt webbing, retractor, and related mounting hardware), and test dummy to a representative crash pulse approximating the frontal impact pulse defined in Phase I. For this test type, no interior cab components were included as part of the test fixture. The system-level sled test involved subjecting a seat(s), restraint system hardware, and test dummy(ies) to a representative crash pulse while located in a heavy truck cab environment. For the evaluation test conducted as part of this project, a COE cab was mounted on the sled to provide the cab interior environment for the test dummy.

In order to evaluate restraint system effectiveness in 90-degree rollover accidents, an LRS was developed. The LRS design was based upon the single-degree-of-freedom model developed in Phase I in which the rotational axis was the tire/ground contact patch centerline of the leading side tractor tires. The LRS consists of a platform that can be hydraulically actuated through 90 degrees of rotation. A conventional tractor cab with all relevant interior components was mounted on the platform for purposes of the evaluation tests conducted in this project. The platform was accelerated to match the analytically derived angular velocity and then decelerated by crushing a honeycomb stack after 90 degrees of rotation.

Task B - Interior Component Evaluation

Laboratory procedures were developed for evaluating the performance of individual interior components in a heavy truck collision environment. In addition to the review of existing testing procedures for vehicle interior components, research conducted elsewhere pertaining to the development of advanced devices for assessing steering wheel induced abdominal injury was reviewed in Task B. Four different devices were evaluated to determine their utility in testing heavy truck interior components. The devices evaluated were the SAE J984 steel headform, the FMH, the SAE J944 body block, and the frangible abdomen.

Task C - Cab Structure Evaluation

Test procedures were developed for evaluating heavy truck cab structural strength properties. Based upon the statistical analysis and accident review conducted in Phase I, tractor cab structural performance in two accident modes were of interest for further study: frontal strength in an impact of the front of a COE cab with the rear end of a heavy truck trailer, and roof strength in 180-degree rollovers. The goals of Task C included developing procedures to test cab strength in manners consistent with real-world accident loading.

It was concluded in Phase I that collisions of COE tractors into the rear of van-type trailers represented the worst-case loading for the front structure of a cab in which intrusion would be directly relevant to the occupant in potentially survivable collisions. A survey of various van, flatbed, and tanker trailers was conducted in order to gather information concerning typical construction and dimensions for structural elements at the rear ends of these trailer types.

A large, flat platen was fabricated as a test device to replicate the approximate rear end geometry of a van trailer and two similar model COE cabs were obtained for testing. The platen was loaded quasi-statically into the front of one test cab and dynamically impacted into the front of the other cab. Both cabs were mounted to frame rails with their standard cab mounts, and the frame rails were rigidly affixed to the ground. The engine and transmission were also present. The bottom of the platen was elevated on the carriage such that, relative to normal tractor geometry, it was 46 inches above the ground. This elevation was consistent with the trailer survey measurements, encompassing heights of significant structure in the majority of typical trailers.

Two-stage test procedures for cab roof strength evaluation were developed for both quasi-static and dynamic loading. The observed mechanics of heavy truck rollovers suggested that roof strength evaluation tests would be most representative if the cab greenhouse was matchboxed

with a pre-load prior to loading the roof. A full conventional tractor was obtained and several tipover tests were conducted to study the interaction of the cab with the ground. As a result of the tip-over tests, an energy level for the pre-load procedure was determined that produced cab damage and greenhouse matchboxing in the test tractor that were representative of the damage patterns observed in the real-world accidents reviewed.

To pre-load the cabs for subsequent roof testing, the platen/carriage system used in the frontal testing was again employed. Cabs were mounted to frame rail sections using their standard cab mounts. The frame rails were rigidly affixed to the ground and the driver-side of the cab was impacted with the platen. The platen was leaned 20 degrees toward the cab based upon the damage geometry in the tip-over tractor (described above) and upon damage geometry observed in the NTSB and NASS accidents.

Both quasi-static and dynamic roof load tests were evaluated using the pre-loaded cabs after rotating them 90 degrees (driver-side down) along with their frameroils and mounts. The vertical platen (with carriage) was then hydraulically forced or dynamically impacted into the roof of the cab.

Scope of Report

The sections which follow provide detailed discussion of the process by which each of the test procedures outlined above was developed. Results from evaluation tests of each procedure are also presented and discussed. Where relevant, comparison of test results to Phase I MADYMO simulations or real-world accident vehicles is made.

The appendices contain the full text for each of the draft RPs. A complete collection of data plots for each of the evaluation tests and photographs documenting test set-up, conduct, and results are cataloged in the appendices. An index of film and video footage generated in Phase III testing is also contained in the appendices.

A. RESTRAINT SYSTEM TEST PROCEDURE DEVELOPMENT

A1 INTRODUCTION

As stated earlier, heavy truck accidents are typically characterized by a series of complex events; however, it was usually a single event during the complex sequence that resulted in occupant injury. Further, it was found that fatal injuries often resulted from occupant excursion or ejection. An important element of limiting occupant excursion and eliminating ejection is providing an adequate restraint system. To evaluate restraint system effectiveness, three different test types have been defined. They are 1) Component-Level Frontal Impact, 2) System-Level Frontal Impact and 3) System-Level 90-degree Lateral Rollover Impact. The goal of Task A of Phase III was to develop procedures for the defined tests and actually conduct these tests to evaluate and further refine the procedures.

A1.1 Scope of Task A Report

In Section A2, other existing suggested test procedures related to restraint systems are reviewed. These include procedures for passenger car, wheelchair, child and commercial and civilian aircraft restraint systems.

Section A3 discusses the procedures related to component-level and system-level sled tests for frontal impact conditions. The FaAA deceleration sled facility is described and test results for various restraint conditions are presented. Also, the draft SAE RP's developed as a result of this effort are summarized.

In Section A4 the test procedures for a simulated 90-degree rollover are discussed. The design and development of FaAA's LRS is described and test results for various restraint

conditions and number of occupants are presented. The draft SAE RP developed as a result of this effort is also summarized.

A2 REVIEW OF EXISTING RESTRAINT SYSTEM TEST PROCEDURES

In this section, test procedures relating to various restraint systems are reviewed. The procedures reviewed are not an exclusive set of procedures, rather they represent a sample of the procedures that can be found in the SAE Handbook, the Code of Federal Regulations, the Federal Aviation Regulations and technical literature. The objective of the review was to develop an understanding of existing restraint system test procedures with particular interest in the manner in which the test protocol details are presented for use by various testing facilities. In this way we built confidence that test procedure specifications developed in this project were reasonably consistent with existing state-of-the-art.

A2.1 Occupant Restraint System Evaluation - Passenger Cars (SAE J128)

This SAE Information Report outlines testing procedures for the evaluation of passenger car restraint systems. Its purpose is to facilitate the development of passenger car restraint systems by proposing standardized testing methods so that lab-to-lab comparison of test results can be effectively made. The procedures and test considerations described in the Information Report pertain primarily to frontal and rear impact conditions. Rollover and side impact crash conditions are mentioned; however, at the time the report was written (1969) no satisfactory test procedures had been developed for these crash conditions. The Information Report suggests evaluating the restraint systems under impact conditions for all designated seating positions for a given vehicle. It is noted that generally, it may be impractical to test all seating position simultaneously.

For the frontal impact test, reference is made to SAE J850 - Fixed Rigid Barrier Collision Tests, which specifies a nominal impact speed of 30 mph into a 0-degree fixed barrier. SAE J972 - Moving Rigid Barrier Collision is referenced for conduct of the rear

impact test. No mention of a specific test speed is made in SAE J972; however, the Information Report suggests a nominal impact speed of 20 mph. Though the Information Report references full-scale crash testing, it does recognize that for restraint testing, other methods of simulating an impact (i.e., sled testing) may be desirable if certain impact variables such as impact pulse and structural performance are adequately reproduced.

A2.2 Occupant Crash Protection (Code of Federal Regulations, Title 49, Part 571.208)

This FMVSS outlines occupant protection requirements for a variety of motor vehicles including passenger cars, light trucks, heavy trucks and buses. Section 4.3 of this standard describes the occupant protection requirements for trucks and multipurpose vehicles with a Gross Vehicle Weight Rating (GVWR) of more than 10,000 pounds. For vehicles manufactured after January 1, 1972 and before September 1, 1990, there are two options for meeting the standard's requirements. The first option is for the vehicle to meet the crash test protection requirements outlined in Section 5 of the standard by passive means. The second option states that each designated seating position shall have either a Type 1 or a Type 2 seat belt assembly that conforms to part 571.209 (Seat Belt Assemblies). For vehicles manufactured after September 1, 1990, there are also two options available, with the first option having the same requirements as the first option described above. The second option is similar to that described above; however, further requirements are made on the latch mechanisms and the retractors. Adherence to this part of the standard requires no dynamic testing of active seat belt systems relative to occupant injury criteria.

A2.3 Seat Belt Assemblies (Code of Federal Regulations, Title 49, Part 571.209)

This FMVSS outlines requirements of seat belt assemblies for passenger cars, multipurpose passenger vehicles, trucks and buses. It includes specifications for seat belt system components such as the webbing, buckles, retractors and various hardware. The

standard also describes various performance demonstration tests for the components. These demonstrations include webbing elongation and breaking tests, temperature and corrosion resistance tests for various components, button release force tests for buckle assemblies and retractor performance and strength tests.

A2.4 Seat Belt Assembly Anchorages (Code of Federal Regulations, Title 49, Part 571.210)

This FMVSS standard outlines the strength requirements for seat belt assembly anchorages. The standard is applicable to passenger cars, multipurpose passenger vehicles, trucks and buses. The tests specified in this standard are quasi-static tests where the seat belt anchorage loads are applied through the seat belt webbing via various body blocks that are described in the standard.

A2.5 Child Restraint Systems (Code of Federal Regulations, Title 49, Part 571.213)

Section 6 of this FMVSS describes the dynamic test procedures for vehicles with built-in and add-on child restraints. Two test configurations are described for both the built-in restraints and the add-on restraints; they are Test Configuration I and Test Configuration II. The applicable test configuration depends on the type of restraint system that is to be tested. Newborn infant, nine-month-old infant, three-year-old child and six-year-old child test dummies may be used depending on the type of restraint system.

Test Configuration I calls for a 30 mph frontal impact test, while Test Configuration II calls for a 20 mph frontal impact test. For both of these tests, either a frontal barrier crash test generally following the test procedure found in FMVSS 208, or a sled test are acceptable. In the case of the sled test, the acceleration pulse is defined as essentially any pulse that results in the nominally required ΔV and whose acceleration-time curve is contained within the limits that are presented graphically in the standard. The pulse

limits present a maximum acceleration level at any given time during the duration of the pulse. The ultimate dynamic performance of a child restraint system is evaluated based on the structural integrity of the system, and specified occupant excursion limits test dummy Head Injury Criteria (HIC) and Chest Injury Criteria (CIC).

A2.6 Guidelines For Evaluating Child Restraint System Interactions With Deploying Airbags (SAE J2189)

This SAE Information Report describes guidelines for test procedures to evaluate the interactions between small children restrained in child restraint systems (CRS) and deploying airbags. The Information Report describes both static and dynamic test procedures relating to frontal impacts with the CRS located in either the center front or right front seating position of a given vehicle. Though no complete test matrix is formally defined, various combinations of test dummy age representation (infant to 6-year old), CRS type (front-facing, rear-facing, lateral-facing and booster seat), and CRS restraint style are described.

For the dynamic test procedures, two generic sled test pulses are defined; the mild-severity crash pulse and the high-severity crash pulse. Both of the generic pulses are ideally realized by a half-sine wave with a peak acceleration level and prescribed pulse duration. For the mild-severity pulse, the peak acceleration level is 6.5 to 7 g's with a pulse duration of 150 milliseconds, resulting in a ΔV of 16 mph. For the high-severity pulse the peak acceleration level is 23 to 24 g's with a pulse duration of 80 milliseconds, resulting in a ΔV of 30 mph. The mild-severity pulse is intended to represent a pulse that is just severe enough to deploy the airbag, while the high-severity pulse is representative of the pulse specified in FMVSS 213 of 49 CFR, Part 571 and can, therefore, be compared to known CRS performance. The Information Report acknowledges the appropriateness of using vehicle-specific pulses if they are known.

A2.7 Guidelines For Evaluating Out-Of-Position Vehicle Occupant Interactions With Deploying Airbags (SAE J1980)

This SAE Information Report describes guidelines for test procedures to evaluate the interactions between out-of-position occupants and deploying airbags. The Information Report describes both static and dynamic test procedures relating to frontal impacts with the occupant located in one of the front seating positions of a given vehicle. Though no complete test matrix is formally defined, various combinations of test dummy age representation (3-year-old to adult), test dummy size (small child to large adult male) and occupant positioning are described.

For the dynamic test procedures, two generic sled test pulses are defined; the mild-severity crash pulse and the moderate-severity crash pulse. Both of the generic pulses are ideally realized by a half-sine wave with a peak acceleration level and prescribed pulse duration. For the mild-severity pulse the peak acceleration level is 6.5 to 7 g's with a pulse duration of 150 milliseconds, resulting in a ΔV of 16 mph. For the moderate-severity pulse, the peak acceleration level is 12 g's with a pulse duration of 110 milliseconds, resulting in a ΔV of 18 mph. The mild-severity pulse is intended to represent a pulse that is just severe enough to deploy the airbag. Since small children are more susceptible to being out of position due to pre-impact braking than adults, this pulse is recommended for use in evaluating child dummy interactions with a deploying airbag. Since adult occupant position is less susceptible to preimpact braking, the moderate-severity pulse is recommended for testing with adult dummies. The Information Report also acknowledges the appropriateness of using vehicle-specific pulses if they are known.

A2.8 Dynamic Evaluation Of Seat Restraint Systems & Occupant Protection on Transport Airplanes (Federal Aviation Regulations, Parts 23, 25, 27 and 29)

This Federal Aviation Regulation (FAR) describes the test procedure and acceptance criteria for the evaluation of seat restraint systems and occupant protection under dynamic crash conditions. Procedures are described for various civil and commercial transport aircraft as well as rotorcraft. There are two types of dynamic sled test conditions that an occupant and seat/restraint system are subjected to. They are simply called the Type-1 test and the Type-2 test. For the Type-1 test the seat is oriented to simulate a 30-degree aircraft nose-up pitch angle. For the Type-2 test the seat is oriented to simulate a ± 10 -degree aircraft yaw angle. In addition, for the Type-2 test, the seat may be mounted on fixtures that can be articulated to represent floor warping at the seat mounts.

The sled pulse for both types of tests are specified as a minimum peak acceleration level, with a maximum time to achieve the minimum acceleration level. In addition, minimum ΔV levels are also specified. The specific values for the acceleration, time and ΔV levels depends upon which part of the FAR the particular aircraft pertains to. The ultimate goal of these tests is to evaluate the structural performance of the seat and the Hybrid II 50th-percentile male test dummy's response to the seat/restraint system under dynamic crash conditions. Test dummy head, chest, lumbar and femur data are recorded and compared to existing injury criteria, also seat mount forces and seat belt webbing loads are recorded. In addition, film analysis is often performed for the Type-2 test to evaluate occupant excursion and establish head strike potential with interior components.

A2.9 Interlaboratory Study of Proposed Compliance Test Protocol For Wheelchair Tiedown and Occupant Restraint Systems (SAE 942229)

This SAE paper outlines a study that was conducted with the assistance of four different testing laboratories to determine lab-to-lab test result variability while using the same test procedure for Wheelchair Tiedown and Occupant Restraint Systems (WTORS). At the time the paper was written, several organizations, including the SAE, the Canadian Standards Association (CSA) and the International Organization for Standardization (ISO), were in the process of developing dynamic test procedures for WTORS used with forward facing wheelchairs and occupants.

Each of the test facilities conducted three identical sled tests where a Hybrid II 50th-percentile male dummy was seated in a rigid surrogate wheelchair attached to the sled with four tiedown straps and subjected to a crash pulse that was to fall within the sled pulse corridor described in ISO 7862 which ultimately results in a nominal ΔV of 30 mph. Test dummy head and chest accelerations were recorded, as well as tie down loads, restraint webbing loads and wheelchair accelerations. Film analysis was used to determine occupant and wheelchair excursion limits. Acceptably low variability in results was observed, which led to a redefinition of the lower bound of the sled pulse corridor.

A3 DEVELOPMENT OF FRONTAL IMPACT TEST PROCEDURES

In this section, the test procedures for component-level and system-level frontal impacts are discussed. FaAA's deceleration sled test facility is described and test results for various component-level and system-level test configurations are reviewed.

A3.1 Component-Level and System-Level Sled Testing

The component-level sled test simply involves subjecting only a seat, restraint system hardware (i.e., seat belt webbing, retractor and related mounting hardware), and test dummy to a representative crash pulse. For this test type, no interior cab components need be included as part of the test fixture. The ultimate purpose of this test is to evaluate the forward excursion of the test dummy head, upper torso, and knees.

In the component-level evaluation testing conducted for this report, the seat was rigidly mounted to the sled platform using the manufacturer-designed mounting locations. Restraint system components (i.e., D-ring, retractor, tether anchor, etc.) were mounted to the seat and sled platform according to the manufacturer-designed mounting locations. Since the manufacturer-specified nominal seat positions were not known, the adjustable features were set at the mid-point of the adjustment range. For seats with air-cushioned bases, the seats were set to ride at the mid-point of the adjustment range with the test dummy positioned in the seat, and the seat tethers were set to be taut at the full vertical position. Seat backs were set at a position to allow for satisfactory positioning of the test dummy. Often this resulted in seat backs positioned rearward of the vertical-most position. Useful information may also be obtained by conducting tests with the seat set at various other positions; however, for the purposes of this report and the development of the test procedures, the mid-point positions were used.

The system-level sled testing involved subjecting a seat(s), restraint system hardware, and test dummy(ies) to a representative crash pulse while located in a heavy truck cab environment. For this test type, the interior components of a heavy truck cab are represented on the sled platform either by fabrication of mock-ups or by using an actual cab with interior components intact. The purpose of the system-level test is to evaluate the forward excursion of the test dummy and to measure occupant response to any contacted interior components.

In the evaluation testing conducted for this report, a COE cab was acquired and installed on FaAA's sled platform. Rigid areas of the cab structure were used as support locations to minimize the deformation of the cab during the impact event. Seats were purchased and installed in the cab design locations. The restraint system component hardware was also installed in the design locations. For the 3-point restraint system test it was necessary to install D-ring anchorages, since the test cab was originally designed for a 2-point restraint system. The procedure for seat positioning in the system-level test was the same as that described above for the component-level testing.

Hybrid III 50th-percentile male test dummies, conforming to Code of Federal Regulations (CFR), Title 49, Part 572, subpart E, were used for this testing. Pertinent Hybrid III 50th-percentile male test dummy measurements are listed in Table A1. In all tests, the dummies were positioned according to the dummy positioning procedures outlined in CFR, Title 49, Part 571.208, Section 11. Other relevant instrumentation included seat belt webbing load cells for belt tension measurement and sled platform accelerometers for recording the crash pulse. The typical measurement units and SAE filter classes are also included in Table A1. All data acquisition and post-test processing conformed to the current version of SAE J211, as revised in 1988.

Table A1. Typical measurements for a Hybrid III 50th-percentile male test dummy

Typical Test Measurement	Units	SAE Filter Class
Head Accelerations	g	60
Upper Neck Forces	lbf	1000
Upper Neck Moments	in-lbf	600
Lower Neck Forces	lbf	1000
Lower Neck Moments	in-lbf	600
Chest Accelerations	g	180
Chest Deflection	in	180
Lumbar Forces	lbf	1000
Lumbar Moments	in-lbf	1000
Pelvic Accelerations	g	1000
Femur Forces	lbf	600
Seat Belt Webbing Loads	lbf	60
Sled Accelerations	g	60

In Task A of Phase I of this project, typical frontal crash pulses were defined analytically in the form of a haversine wave expressed as:

$$a(t) = \frac{1}{2} A \left(1 - \cos \left(\frac{2\pi}{T} t \right) \right)$$

where $A = 11 \text{ g's}$, and $T = 130 \text{ milliseconds}$. The acceleration-time curve and the ΔV -time curve for the defined pulse are presented in Figures A1 and A2, respectively. This pulse definition provided the basis for designing the sled deceleration pulse used for both the component-level and system-level testing. In reality, impact sled facilities may not be able to precisely match the defined analytical crash pulse as the mechanical limitations of a given sled system will govern what the ultimate pulse shape will be. They will, however, be able to approximate the acceleration pulse and achieve the necessary total ΔV . In Section A3.2 of this report, FaAA's sled facility is described and typical sled pulse data approximating the analytical definition is presented in Section A3.3.

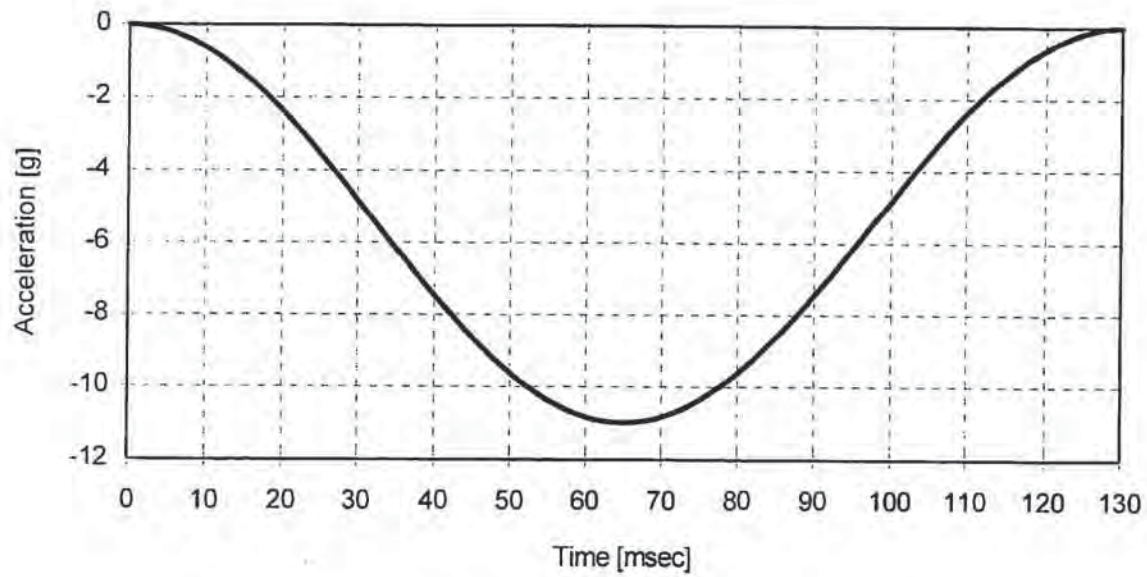


Figure A1. Acceleration-time curve for a frontal impact

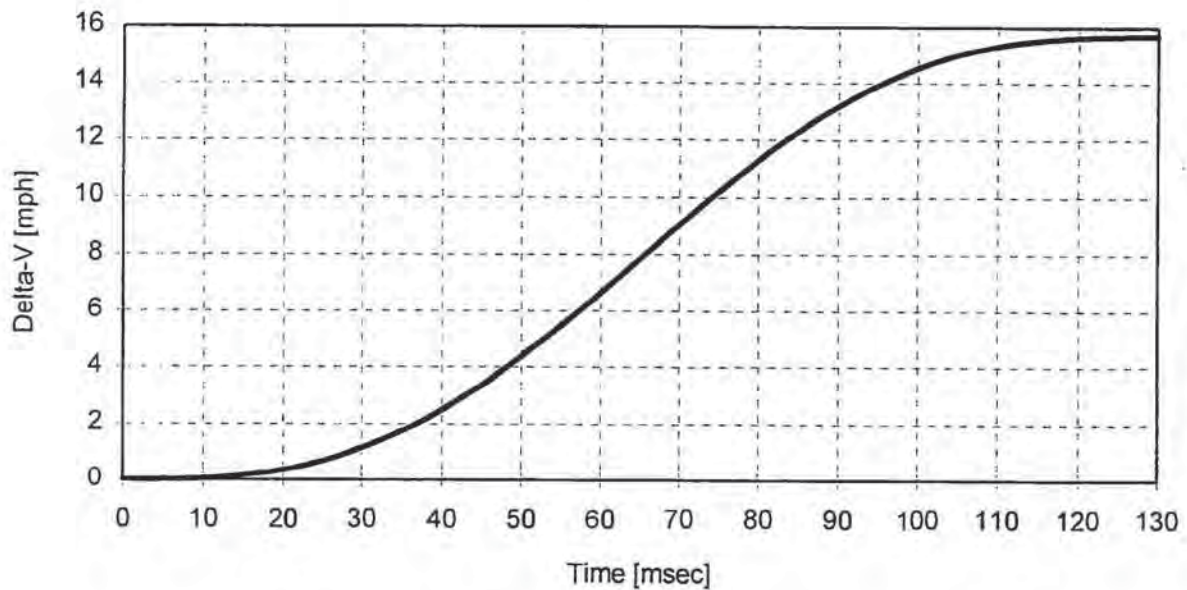


Figure A2. ΔV -time curve for a frontal impact

To facilitate the evaluation of test dummy excursion, high-speed film cameras were used to document the testing. These cameras operated at a nominal frame rate of 500 frames/sec and, wherever possible, were positioned such that the viewing axis of the

camera was perpendicular to the plane of motion of the test dummy. High-speed film cameras were also mounted on the cab for the system-level testing, to obtain unobstructed views of the occupant space that could not be viewed with the off-board camera coverage. For the component-level tests, targets were placed on the sled frame, the seat base and the dummy's head and knees to assist in the tracking of these locations for post-test film analysis. For the system-level testing, targets were also placed on the exterior of the cab body to establish a cab-relative reference frame in which to track dummy motion. Measurements defining the location of the high-speed cameras relative to the various tracking targets were recorded prior to the conduct of each test. Measurements of this type are essential to successfully analyze high-speed film. Each of the high-speed cameras used in this testing created 100 Hz timing marks on the film. These marks make it possible to determine the actual operating frame rate for a given camera. This is necessary to establish an accurate time base for any film analysis that is to be performed.

A3.2 Failure Analysis Associates, Inc. Sled Test Facility

FaAA operates a deceleration sled facility at its Test and Engineering Center in Phoenix, Arizona. This sled facility is comprised of several components: drop tower, sled platform, sled guide rail, impact barrier and deceleration material. A photograph of the FaAA sled facility with a COE cab mounted on a sled platform is shown in Figure A3. Prior to a sled test, the sled platform, which is mounted on polyurethane rollers, is coupled to the sled guide rail. The sled guide rail is comprised of two parallel steel wide-flange beams running for a length of approximately 150 feet. The polyurethane rollers rest on top of the beam flanges and allow for low friction travel along the length of the guide rail. Since this is a deceleration sled system, the sled platform must first be accelerated to a desired impact speed. To attain the proper impact speed, the sled platform is connected to a drop weight by a wire rope passing through a series of pulleys on the 80-foot drop tower. A winch is used to pull the sled back along the guide rail. Simultaneously, the drop weight is raised up the tower. The distance the sled is pulled back is dependent on the desired impact speed, the respective sled and drop weights and

friction losses in the pulleys and rollers. After the sled has been pulled back the proper distance, a safety chain is connected to the sled and final checkout of data acquisition and camera systems is performed. Once all systems are ready for test, the safety chain is unhooked and the sled is released from the winch. After release from the winch, the sled accelerates toward the impact barrier where it is decelerated by compression of aluminum honeycomb material. Just prior to impact with the aluminum honeycomb, the drop weight, which is falling as the sled is accelerating, is stopped by impacting a sand pit, allowing the sled to "free-wheel" before being decelerated by the honeycomb.

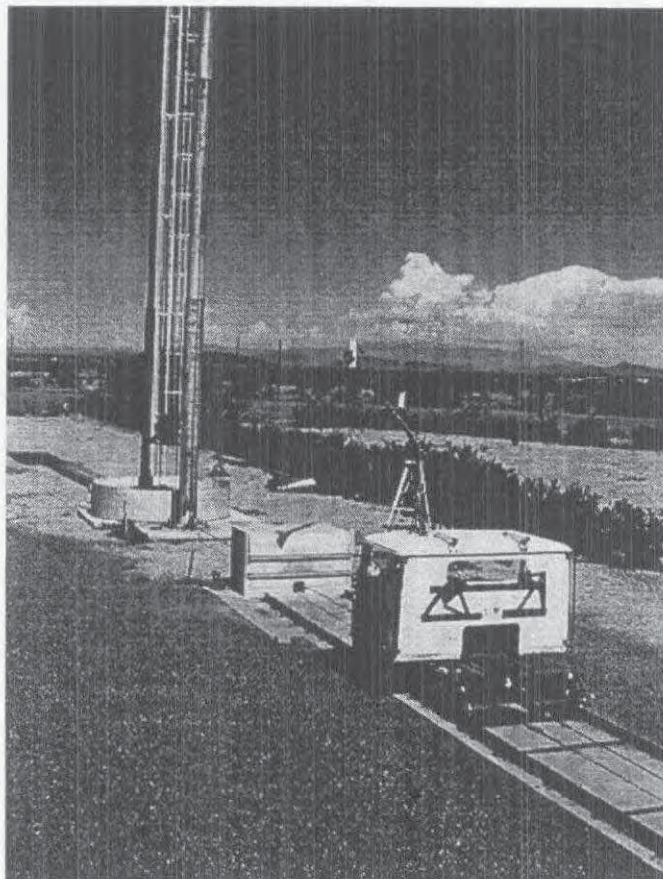


Figure A3. FaAA's deceleration sled facility

Before a sled test is conducted, the aluminum honeycomb material used to decelerate the sled platform is cut into a wedge shape. The size and shape of the wedge depends on the material properties of the honeycomb, the weight of the sled, the impact speed, the desired deceleration peak and the time after impact in which the deceleration peak is to

occur. The resulting deceleration rise up to the peak value is approximately sinusoidal in shape. After the peak value has been reached, the shape of the deceleration curve depends on several factors. The aluminum honeycomb has very low restitution, and as a result, if the sled has little kinetic energy after the peak level is reached, the deceleration will fall off very rapidly. However, if significant kinetic energy remains, the deceleration level may remain somewhat constant and then fall off rapidly after the kinetic energy is dissipated. A photograph of a typical honeycomb wedge is shown in Figure A4.

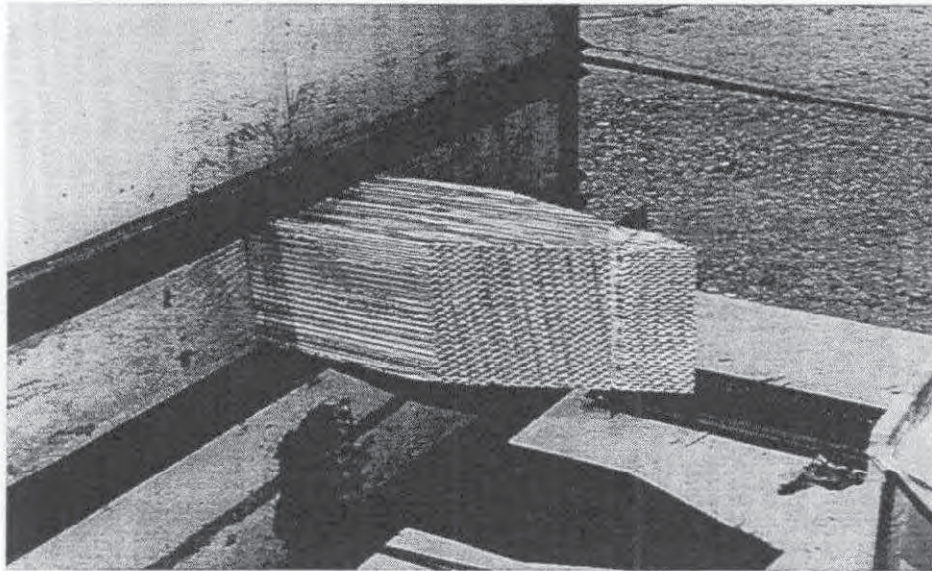


Figure A4. A typical aluminum honeycomb wedge

The dynamics of the test dummy motion can have an effect on the resulting pulse shape as well. Since the test dummy mass is essentially uncoupled from the sled mass until the dummy is effectively restrained, the sled system mass being decelerated is altered, thereby potentially changing the peak deceleration and also the time at which the peak value is achieved. This effect becomes more significant if multiple dummies are being used as the uncoupled dummy mass becomes a larger percentage of the total sled system mass. It is also significant when unrestrained test dummies are used, since the dummies are completely uncoupled until contact is made with a steering wheel, dash panel, A-pillar, etc. Further, the ultimate contact with an interior component or loading of seat

belt webbing results in forces being applied to the sled system that are uncontrollable and can, therefore, change the deceleration pulse shape.

A3.3 Sled Testing Results

FaAA conducted a total of six sled tests for the purposes of developing test procedures for component-level and system-level testing. These tests are listed in Table A2 along with the resulting peak deceleration and total ΔV .

Table A2. FaAA sled testing matrix

Test Type	Peak Decel.	Total ΔV
Component-Level, 2-Point Restraint	12.0 g	16.1 mph
Component-Level, 3-Point Restraint	12.5 g	16.4 mph
System-Level, 2-Point Restraint	11.2 g	16.3 mph
System-Level, 3-Point Restraint	11.7 g	16.4 mph
System-Level, Unrestrained	10.6 g	16.6 mph
System-Level, Unrestrained	11.6 g	16.4 mph

Specific set-up information and data plots for each of these tests are presented in Appendix A-1. Typical acceleration-time and ΔV -time plots for the component-level tests are shown in Figures A5 and A6, while typical acceleration-time and ΔV -time plots for the system level tests are shown in Figures A7 and A8. For comparison, the analytical curves are represented as dashed lines in Figures A5 - A8.

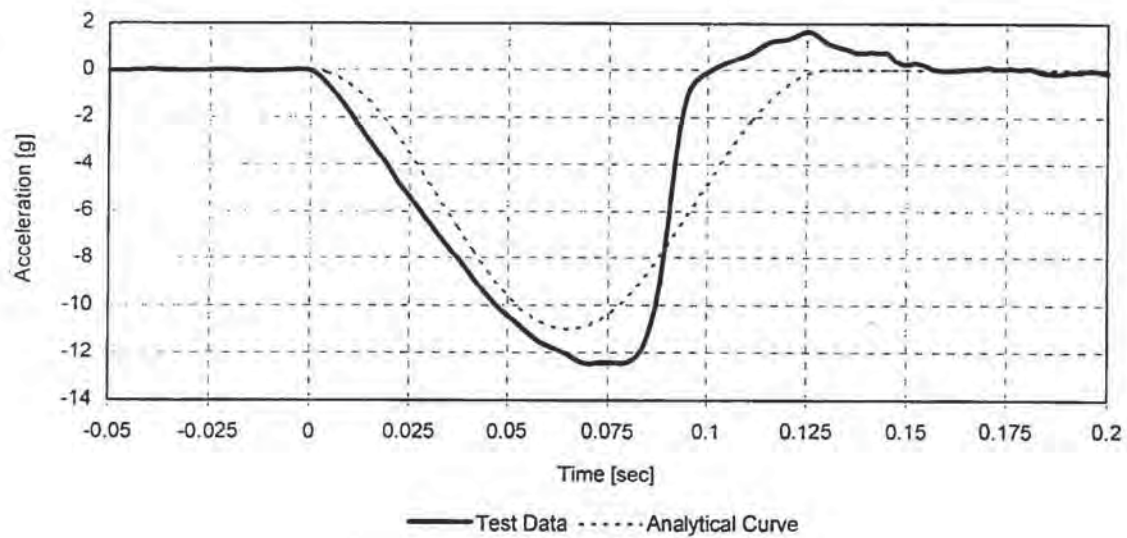


Figure A5. Acceleration-time curve for component-level tests

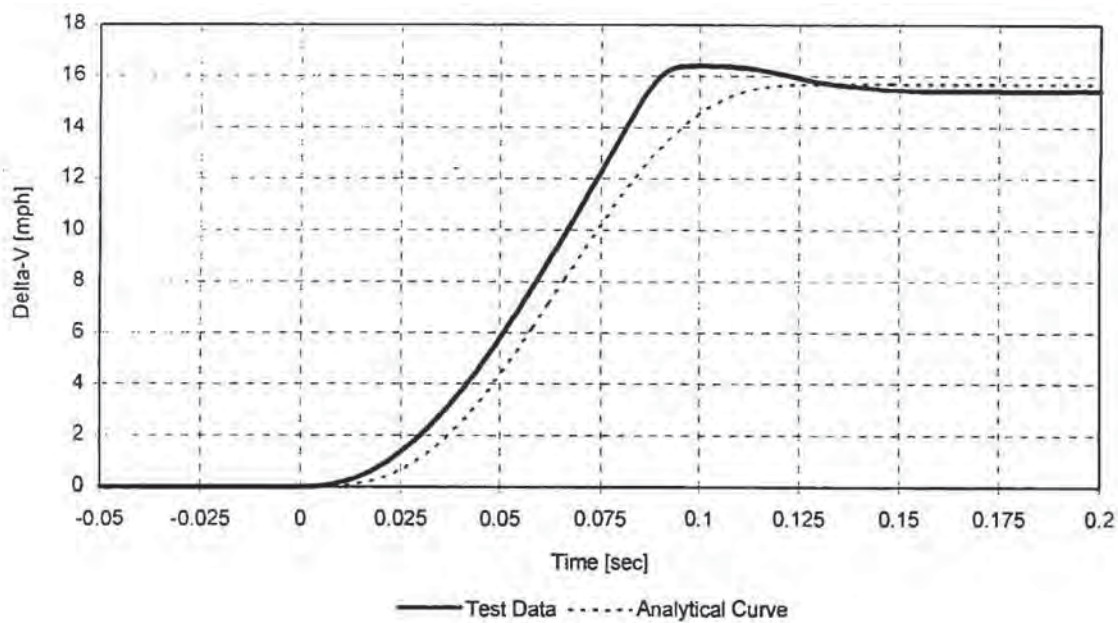


Figure A6. ΔV -time curve for component-level tests

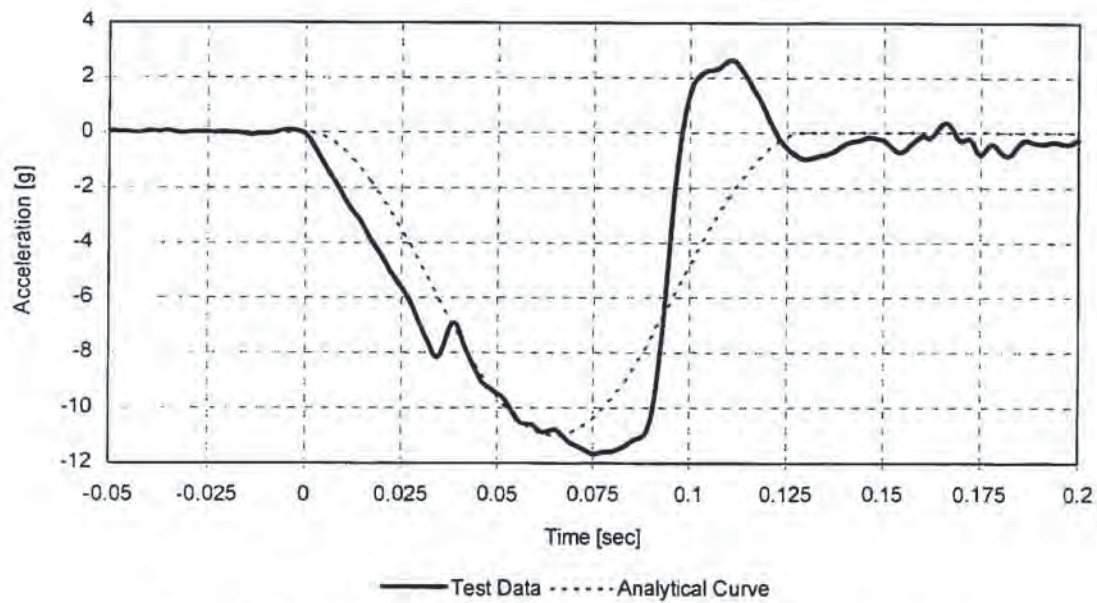


Figure A7. Typical acceleration-time curve for system-level tests

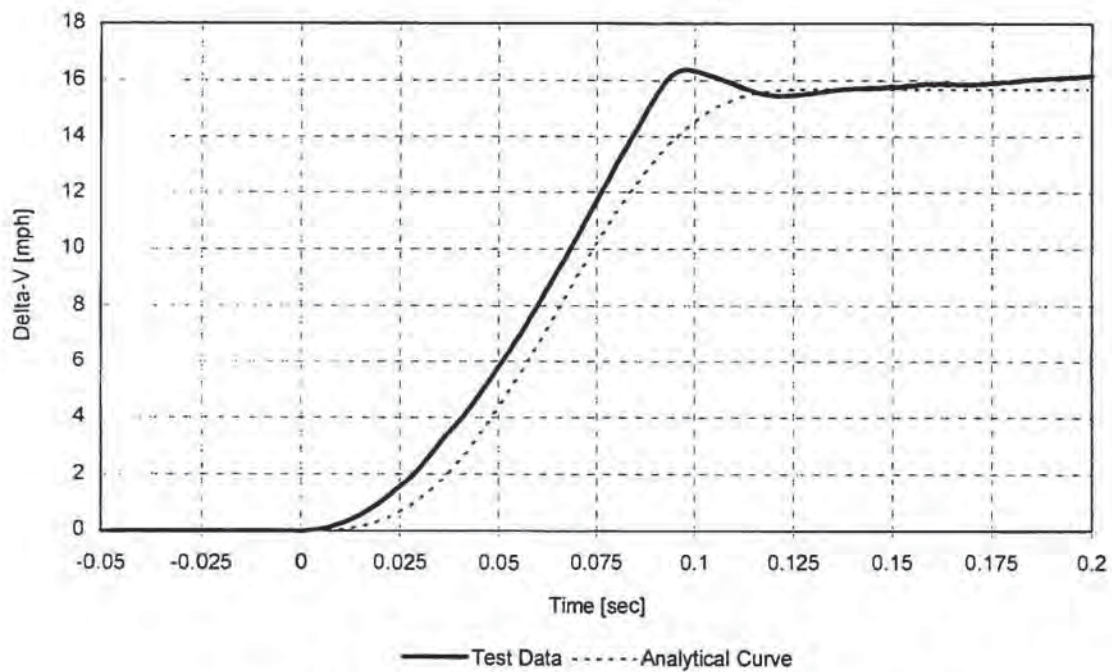


Figure A8. Typical ΔV -time curve for system-level tests

The effects of dummy dynamics on the sled pulse can be seen when comparing the acceleration-time curves of the component-level and system-level tests. The most significant effect is evident after the peak deceleration level has been reached. In the system-level tests, two test dummies were used, in contrast to just one for the component-level tests. The use of two test dummies resulted in higher loads applied to the sled platform through the restraint systems during the deceleration of the test dummy mass. This is seen in the system-level acceleration-time curve, appearing as a more rapidly applied positive acceleration occurring between approximately 100 milliseconds and 120 milliseconds. The effect of the low restitution honeycomb is also evident in the fairly rapid fall-off from the peak deceleration in both cases. In the acceleration-time curve for the system-level test, a “blip” attributed to a buckling characteristic of the honeycomb material, is seen as the pulse is rising to its peak value. This “blip” had no effect on the occupant kinematics and has very little effect on the resulting ΔV -time curve.

As mentioned previously, sled facilities may not be capable of exactly matching the analytical acceleration-time curve described in Section A3.1. Typical results from the sled testing conducted for this report indicate a deceleration pulse duration of approximately 100 milliseconds, compared to the 130 millisecond duration specified by the analytical curve. This is primarily a result of the characteristics of the honeycomb material. It is this kind of facility-specific consideration that creates the dilemma for specifying appropriate sled fixture pulse shapes. As outlined in Section A2, pulse shapes for testing purposes are specified in a variety of ways. For the purposes of the development of heavy truck restraint system testing, it is recommended to approximate a vehicle-specific crash pulse, if it is available. If a specific pulse is not known, a pulse approximating that specified in Section A3.1 should be used. Specifically, the pulse should result in a minimum ΔV of 15.5 mph, occurring within a duration of no greater than 130 milliseconds.