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Design Considerations for a Compatibility Test Procedure

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ABSTRACT

A major focus of the National Highway Traffic Safety Administration's (NHTSA) vehicle compatibility and aggressivity research program is the development of a laboratory test procedure to evaluate compatibility. This paper is written to explain the associated goals, issues, and design considerations and to review the preliminary results from this ongoing research program. One of NHTSA's activities supporting the development of a test procedure involves investigating the use of an mobile deformable barrier (MDB) into vehicle test to evaluate both the self-protection (crashworthiness) and the partner-protection (compatibility) of the subject vehicle. For this development, the MDB is intended to represent the median or expected crash partner. This representiveness includes such vehicle characteristics as weight, size, and frontal stiffness. This paper presents distributions of vehicle measurements based on 1996 fleet registration data. While there is still considerable work to be done to develop meaningful aggressivity metrics that relate to real-world crash performance, this paper summarizes NHTSA's work to date in this area.

INTRODUCTION

For several years, NHTSA has been conducting a vehicle compatibility research program to study the problems, trends, and evolving issues in vehicle-to-vehicle crashes. Much of this research has been statistical in nature, trying to define the nature and extent of the compatibility problem within the US automotive fleet. This research, conducted by NHTSA and many others, has led to a growing interest in the development of test procedures to evaluate the compatibility of individual vehicles. In fact, the major aim of the International Harmonised Research Activity (IHRA) on compatibility has been to develop internationally agreed test procedures designed to improve compatibility of vehicle structures in front-to-front and front–to-side impacts[1].

Within the IHRA compatibility working group, a number of possible candidate test procedures have been identified for a frontal test. These include a full frontal barrier test with load cells, with or without a thin (150 mm) deformable element; an offset deformable barrier (ODB) test with load cells; and an overload test using the ODB to evaluate the passenger compartment integrity; a test using barrier elements to explore shear (e.g., the progressive deformable barrier test being developed by the French[2]); and a moving deformable barrier (MDB) test with load cells behind the deformable element.

While NHTSA has been studying each of the identified test procedures, the focus of the developmental activity has been on the full frontal barrier test with load cells and on the MDB test. This paper updates NHTSA's previously reported efforts[3] evaluating the use of a load cell MDB for use in a potential compatibility test. The use of a load cell MDB allows a test procedure to account for the mass of the vehicle, which will affect the change in velocity for the struck vehicle and therefore the severity of the collision. It is expected that a compatibility test will provide a self protection challenge for smaller vehicles, while for larger vehicles, the challenge will be not to "overload" the measured forces on the MDB face. It has not been shown that the forces measured on an MDB or rigid barrier face have any correlation to vehicle compatibility; however, this is an area of active research which seems to have some potential[4]. While this work is continuing, there are still the many questions regarding how a MDB should be designed for use in a potential compatibility test. Any compatibility test is intended to evaluate a vehicles' performance in vehicle-to-vehicle crashes. Federal motor vehicle safety Standard (FMVSS) 214 testing evaluates a vehicles' vulnerability to side crashes. Here the MDB is designed to be the aggressor. In contrast, an aggressivity test would require a more vulnerable MDB to evaluate the force and acceleration environment in a frontal-frontal crash. Both aggressivity and vulnerability could be simultaneously evaluated by developing an MDB to represent an average vehicle or the most likely collision partner. Here the vehicle under test must protect its occupants while providing an acceptable crash environment for the MDB. Regardless of the test objectives, proper MDB design requires some understanding of vehicle characteristics within the U.S. fleet. This paper will analyze available data on the US fleet and develop distributions of vehicle characteristics that are relevant to the design of an MDB.

DATA SOURCES

This analysis utilizes the R.L Polk Company's National Vehicle Population Profile (NVPP) to determine the composition of the US fleet based on annual registrations. The registration data are analyzed by grouping corporate twins and siblings into car groups that span vehicle design years[5]. These car groups were developed using changes in the vehicle wheelbase to identify which model years can be grouped together. This technique is generally, but not completely consistent with the significant vehicle design changes reported in NHTSA's New Car Assessment Program (NCAP) and compliance programs. The registration data extracted from Polk NVPP are used to weight and distribute vehicle characteristics obtained from NHTSA's test programs and other data sources. The test data is primarily from the frontal NCAP program, but where available static vehicle measurements from side NCAP, FMVSS 208, FMVSS 214, and FMVSS 301 compliance programs are also used. Additional vehicle measurements are collected in a vehicle parameter database[6] that are not collected in the NHTSA's test programs. This database has a wealth of vehicle measurements, but is limited mostly to passenger cars. The vehicle parameter database can be readily linked to NHTSA test databases.

The correlation between NVPP registration data and the car group codes was last developed for 1996. Car group codes were identified for 93.4% of the 1996 registrations (160,572,388). The 1996 registrations were divided among 402 unique car groups, including both passenger cars and LTV's. The car group coding system developed in Reference 4 also provides the capability to decode vehicle identification numbers (VIN) into the same car group codes. There are 609 frontal NCAP tests with valid 17 digit VIN's that correspond to 275 unique car group codes. Additionally there are 1,236 full scale vehicle crash tests with NHTSA standard pre and post test vehicle measurements available. Correlating the NCAP test data with the 1996 registration data, accounts for approximately 85% of all 1996 registrations. Not all measurements exist for all tests. The fleet coverage for a specific vehicle characteristic will depend upon which tests have valid measurements. Additionally, there are numerous car groups that have multiple corresponding NCAP tests. The results of each NCAP test will be distributed among the registrations for the car group.

EVALUATION OF DESIGN FACTORS

STIFFNESS – One of the principle concerns with the design of an MDB is selecting the appropriate stiffness to use for the honeycomb of the barrier face. The frontal NCAP tests provide force deflection data that can be used to correlate the vehicle's crush with the force measured on the load cell barrier. Reference 3 presents averages, by vehicle category for all of the force-deflection profiles measured in the frontal NCAP program. It is desired to update these averages by weighting the test results according to the corresponding fleet registrations. These measurements are shown in Figure 1. Here the force measured on the load cell barrier is plotted against the displacement measured at the B pillar or the left rear seat, depending upon available sensor data. The data for each of the tests was truncated from time zero until the time of maximum displacement. The force deflection profile was resampled in 1 mm increments, so that multiple tests could be averaged. Since different vehicles have different levels of crush, the right axis is used to plot the percent of registrations, for each vehicle category, that were averaged at each deflection interval. Generally, deflections above 600 mm average the results of a varying number of NCAP tests and their corresponding fleet registrations.

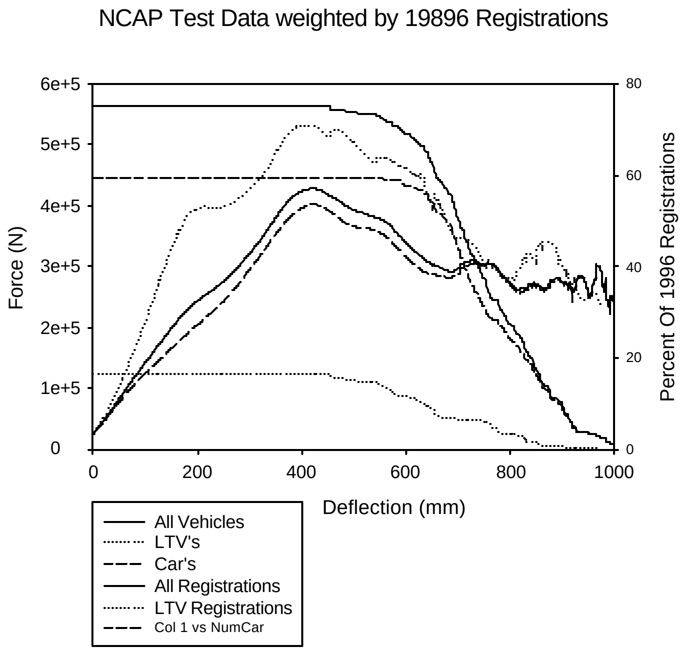

Figure 1: Force Deflection profiles

The NCAP force-deflection data under represents the LTV's, as a percentage of the fleet data. The LTV data represent only 20% of the "All Vehicles" force-deflection data. In 1996, LTV's represented 31% registrations in NVPP. Thus the force-deflection profile for "All Vehicles" significantly under represents the contributions due to LTV's.

A similar analysis was conducted for the average height of force. Here, the height of each load cell is used to compute the average height of force (AHOF) for each time step during the crash for each NCAP test.

$$HOF(t) = \frac{\sum_{1}^{36} Fi \times Hi}{\sum_{1}^{36} Fi}$$

The height of force is then averaged, using the force(t) data as a weighting function. The weighting is intended to insure that the AHOF reflects the height at which the load was transferred to the barrier.

$$AHOF = \frac{\sum_{0}^{t} HOF(t) \times F(t)}{\sum_{0}^{t} F(t)} \qquad t = time\,step$$

The AHOF for each NCAP tested was weighted using the registration data and is shown in figure 2. The median AHOF was 473 mm for cars and 534 mm for trucks. Loadcell barrier testing with the FMVSS 214 barrier produced an AHOF of 506 mm as indicated by the vertical line in figure 2.

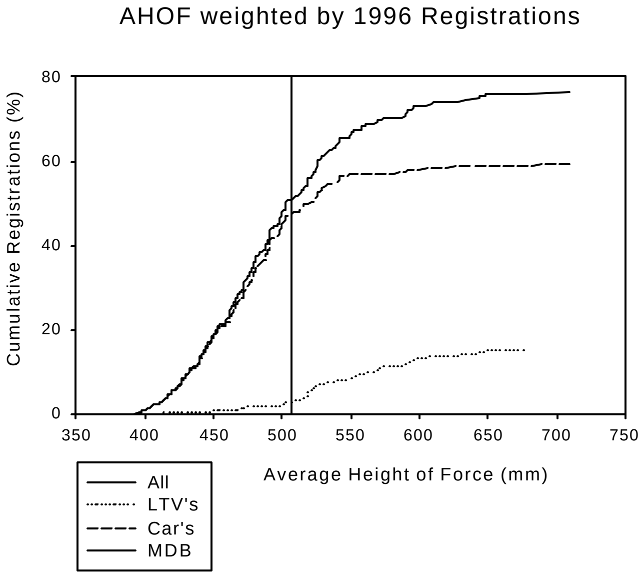

Figure 2: Average Height of Force

One additional measure of interest, particularly in side impact crashes, is the initial stiffness of the force deflection profiles. Visual examination of Figure 1 shows a strong variation in the initial slope of the force deflection profile between cars and LTVs, from 0 to about 400 mm of deflection. To provide a numerical measure of the initial slope, each force deflection profile was linear fit with a straight line that was constrained to start within the first 200 mm and have an R^2 value > 0.95. The slope of the longest straight line, greater than 75 mm in length, that met these criteria was selected as the initial slope for the force deflection curve. The slope measurements, distributed by 1996 registrations, are shown in Figure 3. The vertical line indicates the initial slope of 214 barrier measured from loadcell barrier testing.

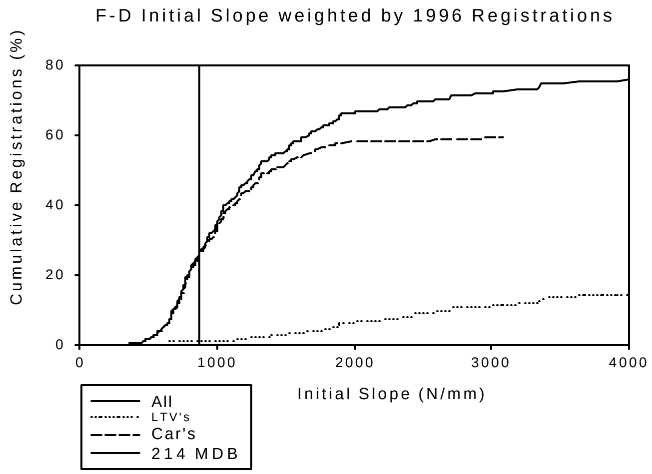

Figure 3: Force Deflection Slope measurements

The median slope for the cars tested is around 1040 N/mm, while for LTV's the median is around 2200 N/mm, or about twice as steep. Several of the older LTV models had extremely steep initial slopes.

WEIGHT – Vehicle weight is one of the most commonly measured vehicle parameters, yet it is generally difficult to find consistent measures for vehicle weight. Polk NVPP reports curb weights for passenger vehicles, but does not report curb weights for LTV's. Additionally, the weights that Polk reports are the base weight for the model and may not reflect the average weight of the vehicles in the fleet. NHTSA test databases record the weight of the vehicle as tested, but this weight includes the weight of dummies, ballast, and stoddard solution. A vehicle's test weight can be 100 to 200 kg heavier than the reported curb weight. This can be clearly seen from Figure 4, which shows curb weight as reported by Polk NVPP and the test weights reported in NHTSA testing. NVPP data has a median car curb weight of 1330 kg while the test data for cars had a median weight of 1494 kg, or an average increase of 164 kg between the NVPP reported curb weights and the NCAP test weight. The vertical line represents the weight of the current FMVSS 214 MDB.

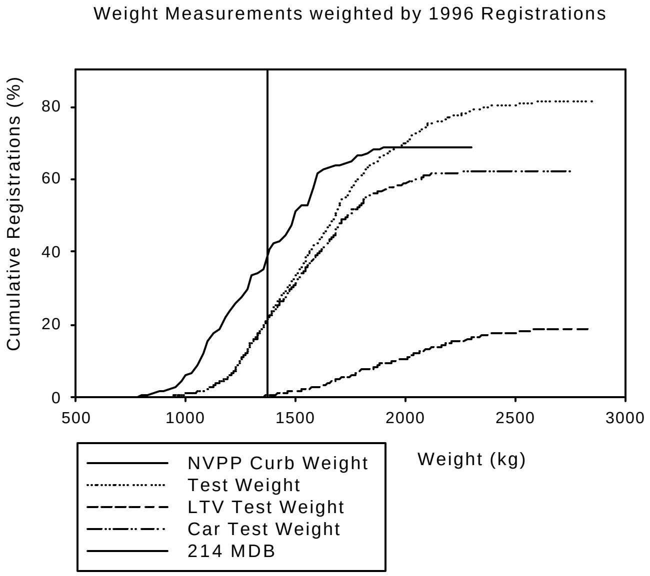

Figure 4: Weight Measurements

While the car test weights are always greater than the curb weight, there is no consistent relationship between them. LTV's represents 23 percent of the test weight distribution, which does not reflect the 31 percent LTV registrations for 1996.

WIDTH – The vehicle width is readily applicable to the design of an MDB. Figure 5 compares the overall vehicle width measured in NCAP testing against the vehicle widths reported in the vehicle parameter database. The vertical line indicates the width of the FMVSS 214 honeycomb face. It is interesting to see that the specifications average about 50 mm wider than was reported in the NHTSA test programs. No explanation was readily apparent for this discrepancy.

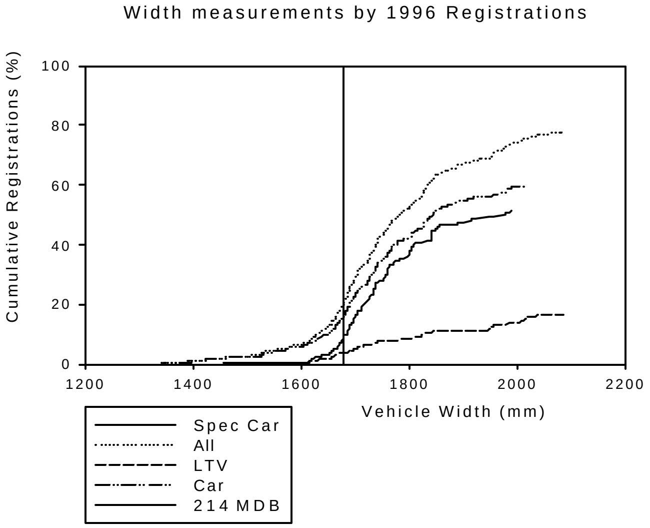

Figure 5: Width Measurements

LENGTH – For a pure frontal crash, the overall vehicle length is not a significant design parameter, however if an oblique or offset test condition is chosen, then the wheelbase can play a significant role. Additionally, the NCAP test procedure includes measurements of vehicle front to the front of the engine and the vehicle front to the firewall. These measures may be useful in determining an appropriate crush depth for the honeycomb face. Figure 6 shows these length measurements for the 1996 fleet as measured in the NCAP test program. The front of engine and firewall measurements are shown for all vehicles only.

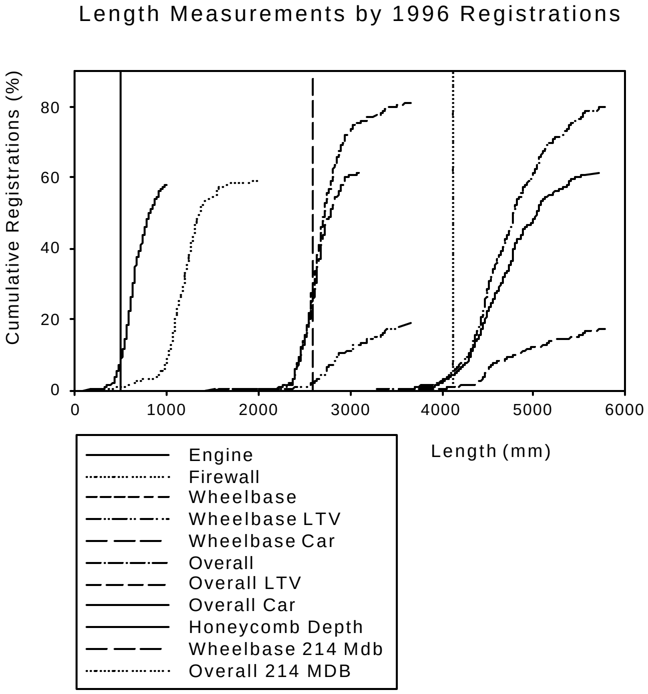

Figure 6: Length Measurements

The three vertical lines in Figure 6 represent measurements from the existing FMVSS 214 MDB. From left to right these are, the length of the honeycomb face, the wheelbase, and the overall length. The wheelbase of the MDB is near the 50%'tile for the car measurements. The honeycomb length is considerably shorter than the typical vehicle front to engine length. This indicates that the MDB may not have sufficient crush depth to represent a typical crash partner.

HEIGHT – Unfortunately, NHTSA's test programs include almost no height measurements. The only data available for height measurements comes from the vehicle parameter database, which is essentially limited to cars. The measurements of interest are the minimum height of the bumper, the height of the cowl or windshield to hood interface, and the minimum rocker panel height. These measurements are plotted in Figure 7. The vertical lines represent the bumper height and the maximum height of the honeycomb face.

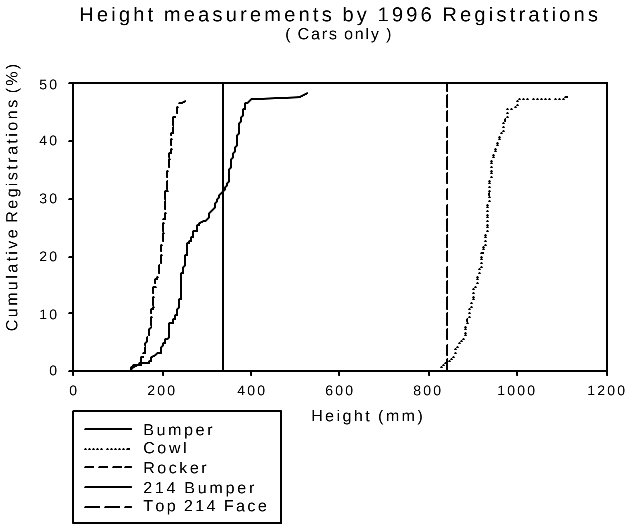

Figure 7: Height Measurements

CONCLUSION

This paper presented a methodology for using vehicle measurements, primarily from the NCAP testing program, to estimate collected fleetwide distributions of vehicle characteristics. These distributions can be used to aid in the development of a MDB for compatibility testing. The optimum vehicle characteristics for an MDB depend upon the measurements, criteria and intent of a compatibility test. Regardless of whether a vulnerability, aggressivity, or combined compatibility test is being developed, these fleet distributions can help in the development of an MDB to represent the existing fleet. It might also be interesting to generate similar distributions based on new vehicle sales rather than registrations. This might provide better predictions of changing fleet characteristics. While there is still considerable work to be done in the development of a meaningful compatibility test, these design charts can provide some insights into the appropriate ranges for many design parameters.

REFERENCES

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ADDITIONAL SOURCES

See http://www-nrd.nhtsa.dot.gov/departments/nrd-11/aggressivity/ag.html for current information on NHTSA's compatibility research program.