EVALUATION OF DEVICES TO MEASURE THE INJURY MITIGATION PROPERTIES OF STEERING SYSTEMS

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ABSTRACT

Recent research at the National Highway Traffic Safety Administration has focused on how to improve the injury mitigation properties of steering assemblies. In a paper at last year's IRCOBI Conference, we described the magnitude of the total "harm" caused by steering assemblies and summarized the results of a model analysis to define injury mitigation properties. This paper presents the next phase of the research, which deals with selecting a test device and test procedure for evaluating design alternatives to reduce injury.

The approach for evaluating test devices is presented. Test devices are selected, and the results of initial tests are presented. Improvements in analytical models to allow simulation of the test devices are described. The research presented forms the basis for selecting test devices for the evaluation of steering assemblies.

INTRODUCTION

The evaluation of countermeasures for enhanced crash protection, requires a series of research and development steps which include the following:

1. A preliminary evaluation of alternative concepts to mitigate the injuries arising from collisions between the specific parts of the human body and the vehicle components which contribute significantly to the total "harm" occurring in the vehicle fleet.

2. The development of a test surrogate and associated test methods, instrumentation, and injury scales to measure the injury mitigation potential of possible countermeasures.

3. The use of the test surrogate for the evaluation of countermeasures, and assessments of benefits.

An earlier paper (Reference 1) discussed the application of modeling to assist in accomplishing the preliminary assessments of concepts, as defined by step 1, above. Reference 1 applied the concept of "harm" and the use of models in evaluating alternative countermeasures for the steering assemblies. That paper proposed improved properties of the steering system and estimated benefits of those improvements based on computer modeling.

The purpose of the present paper is to summarize the progress toward the development of a test surrogate to evaluate steering system improvements. The research reported here is a continuation of the work on steering assemblies reported in Reference 1.

INJURY MEASUREMENT PRIORITIES FOR A TEST SURROGATE

In order to specify the injury measurement requirements for a test device, it is useful to examine accident data to determine the frequencies and severities of injuries by body region which occur in the vehicle fleet. The concept of "harm" introduced in References 2 and 3, and applied in Reference 1, provides a basis for examining injury frequency and severity.

The total fleetwide harm is defined as the sum of the most serious injuries suffered by all crash victims, with each injury weighted according to severity. This total fleetwide harm may be partitioned by crash direction, occupant position, body region, etc. The partitioning of total harm permits insights into the consequence of injury to each body region, accounting for both frequency and severity. However, the definition of appropriate weighting factors is still the subject of continued research.

For the purposes of this paper, injury severity is based upon the Abbreviated Injury Scale (AIS) described in Reference 4. The AIS scale rates injuries from 1 (minor) to 6 (fatal) according to threat to life. No consideration of disability is included in the AIS scale. The scaling factors for each AIS level are shown in Table I. Scaling factors for each injury level are suggested in Reference 1, based upon the relative cost of injuries as reported in Reference 5. The components of the societal losses are medical costs, productivity losses, and "other" expenses which include insurance and legal costs. No attempt is made to include the human costs of physical or mental impairment, diminished quality of life, pain, and grief. These human losses are not measurable in totally economic terms.

The purely economic costs of impairment are suggested in Reference 6, but are not included in this paper. An attempt to develop scaling factors for the noneconomic, human costs of impairment is the subject of Reference 7. An illustrative application of these factors to assess the distribution of impairment losses is contained in Reference 8. Recognizing the limitations of the weighting factors, harm is still a useful concept in evaluating priorities and goals for safety improvements. Application of the harm concept to setting goals for occupant protection is discussed in Reference 9.

The National Accident Sampling System (NASS) file provides the basis for evaluating the frequency of injuries of various severities. The NASS file is representative of police reported accidents in the United States. Therefore, the application of harm weighting factors to all the injured occupants in this file should produce an estimate of fleetwide harm which is representative of the national experience in police reported accidents in the United States. The NASS file contains information on accident severity, crash modes, vehicle data including extent of damage, and occupant data including injury locations and severities. The combined 1979-1985 NASS file contains more than 65,000 cases of crashes involving vehicles of all types. The NASS file for 1985 is summarized in Reference 10.

Let us examine the harm distribution for the most serious injury to passenger car drivers in frontal crashes reported in the 1979 through 1985 NASS file.

The cumulative harm for drivers in frontal collisions is shown as a function of crash speed in Figure 1. This figure shows that in frontal crashes the head and face are the leading causes of harm in crash severities up to 15 mph delta V. Above 15 mph, the head, chest, and abdomen harm increase sharply. At 25 mph, the chest harm again increases sharply, and by 30 mph, exceeds the head harm.

Figure 2 shows the percentage of cumulative harm for the chest, abdomen, and face as a function of crash speed. The figure shows that a large fraction of the facial harm occurs at speeds below 20 mph. The fraction of the chest and abdominal harm which occurs at 30 mph is about the same as the fraction of facial harm which occurs at 20 mph.

The expected effect of Federal Motor Vehicle Safety Standards is to reduce the total fleetwide harm. An examination of those standards which are intended to limit steering system harm is useful in projecting future changes in harm distribution.

In the United States, the safety of steering systems is directly regulated by two safety standards. Standard No. 203, "Impact Protection for the Driver from the Steering Control System," prescribes a steering system component test involving an impact with a body block at 15 mph. The force measured at the base of the steering column is limited to 2,500 pounds. Standard No. 204, "Steering Control Rearward Displacement," prescribes a 30 mph vehicle crash test in which the horizontal dynamic intrusion of the steering system is limited to 5 inches.

A third safety standard, Standard No. 208, "Occupant Crash Protection," scheduled for full implementation in 1989 requires a 30 mph crash test with anthropomorphic dummies. This standard sets limits on the head, chest, and femur measures in frontal impacts. For passenger cars, the standard will require, by 1989, that all passenger cars provide the driver and right front passenger automatic protection. For light trucks and vans, a modification to the standard has been proposed which would require, by 1989, the 30 mph crash test for dynamic testing of manual belts, but would not require automatic protection.

It may be anticipated that the introduction of automatic protection in passenger cars will reduce the magnitude and distribution of harm shown in Figures 1 and 2. The degree of change will depend on the effectiveness of the various technologies offered. For example, the facial harm would be expected to be lower in a passenger vehicle fleet equipped with air bags, than in an equivalent fleet equipped with a less effective facial mitigation technology. Similarly for light trucks, the proposed requirement for occupant protection in a 30 mph crash test may stimulate additional steering system technologies to reduce head injury. In view of expected improvements in the safety of the vehicle fleet, it will be necessary to adjust the harm analysis to reflect the benefits from safety initiatives as new data become available.

At present, none of the standards directly regulate facial and abdominal injury. As discussed in Reference 1, different steering system safety technologies produce different benefits to the various body areas. An objective of this research is to be able to measure steering system induced injuries to various body areas so that improvements can be evaluated.

The measurement of injury mitigation potential for the face, head, chest, and abdomen requires not only a test surrogate, but also injury criteria to be used in interpreting the test results. Worldwide biomechanics research findings provide much of the basis for injury criteria.

Several research programs currently underway are producing additional data on the injuries caused by the steering system. The primary data come from cadaver tests which study chest, abdominal, and facial injuries induced by a generic steering system. This test data is augmented by computer reconstruction of selected crashes which involve injuries of interest.

The strategy for surrogate development and selection is to evaluate candidate test devices for measuring the priority injury modes using procedures which simulate cadaver tests which have been reported in the literature. The crash severity range of interest is defined by past accident experience, and by anticipated changes which might influence that experience.

SELECTION OF CANDIDATE TEST DEVICES

A program to improve test devices to evaluate steering systems should logically start with an evaluation of the performance of existing test devices. The test device used in Standard No. 203 is a body block which impacts the steering wheel at 15 mph. The test criteria is a limit of the force (2,500 pounds maximum) measured on a load cell at the end of the steering column. The test device used in Standard No. 208 is the anthropomorphic dummy. Recently, this standard was amended to introduce an improved dummy--the Hybrid III. The test criteria for this device include chest deflection, in addition to the traditional measurements of head and chest acceleration and femur loads.

The choice between a body component test device and a complete dummy involves trades between the simplicity and lower cost of the component test device and the need for testing the entire vehicle, which requires a complete dummy. Both approaches have roles in assessing safety improvements; and, therefore, both are included in the evaluation program.

The Hybrid III dummy offers a promising choice as a surrogate for steering system evaluation. The device is being evaluated both as a systems test device, and as a component test device. In the latter case, only part of the dummy is used. For example, a relatively simple modification to Standard No. 203 might be to replace the body block test device with an instrumented Hybrid III chest.

Extensive research and development has been undertaken worldwide to develop test devices for measuring facial injury potential of steering assemblies. TRRL has developed a procedure using aluminum hexcell honeycomb material which has been used to develop a wheel designed to mitigate facial injury (Reference 11). Volvo has sponsored the development of a Hybrid III headform fitted with a matrix of piezoelectric transducers to measure facial contact loads (Reference 12). The Dept of Transport, Canada, has developed a frangible facial insert to limit facial injury (Reference 13). Daimler-Benz has conducted research using load sensing Fuji pressure sensitive film (Reference 14). The first three of these existing devices are included in the evaluation program. The fourth may be included later if reliable calibration data can be developed.

All these evaluations can be greatly assisted by models. Models offer several significant capabilities. First, they permit "what if" studies which indicate sensitivities of parameters to change. Second, they allow insight and understanding into differences between component tests and systems tests. Third, they permit analysis to be performed more economically and quickly than performing full-scale tests for every condition.

BASELINE TESTS FOR SURROGATE DEVELOPMENTS

The testing for surrogates is separated into two parts--facial test development, and thorax/abdomen test development. The facial test development program evaluates the four different facial test devices listed earlier. At this time, no test data is available from this program. The thorax/abdomen test development program has initiated sled testing to evaluate the performance of the Hybrid III dummy. Preliminary test results are included in this paper.

The facial injury test devices are evaluated using procedures similar to those used by Nyquist and others (Reference 15). In these tests, the face is impacted at speeds ranging from 10 to 26 km/hr by a device resembling an unyielding steering rim. The program for test device evaluation will replicate the Nyquist procedure, but will use a Hybrid III dummy as the test subject. All three of the candidate facial injury test devices have been adapted so that they can be mounted on the Hybrid III in place of the standard head. Therefore, it is possible to expose each of the test devices to impact conditions which closely simulate the cadaver tests reported in the literature. This type of testing will permit a direct comparison of the measurements made by the test devices and the injuries received by the cadavers.

The thorax/abdomen development sled test program included Hybrid III dummies and cadavers. The tests employed a Chevrolet Citation body on the sled. The baseline tests used a generic steering column designed to crush at a nearly constant force of 750 pounds The Citation steering wheel was modified to permit the inclusion of a 5 axis load cell between the wheel and column. This change was made in a way that alterations to the mass and deflection properties of the steering wheel were very small. The tests were conducted at sled delta V's of 15, 21, and 25 mph.

Summaries of the test conditions and other measurements are included in Reference 16. Time history traces for selected measurements at two test speeds are summarized in Figures 3 and 4.

Additional base line testing will include the test device specified in Standard No. 203 and the Hybrid III thorax used like the 203 test device. In addition, tests of a Hybrid III dummy equipped with an abdominal insert are being conducted. Results of these tests are not yet available.

SELECTION AND DEVELOPMENT OF MODELS

The requirements for models to assist in surrogate development are different from those for preliminary evaluation of countermeasures. In the latter case, the modeling of the countermeasure was essential, while the modeling of the human could be crude. However, for surrogate development, the modeling of the human must be more precise. The PADS model used in Reference 1 provides a detailed model of the steering assembly, but uses a simple three mass model for the occupant. In order to apply a better occupant model the CVS model was selected. The CVS model typically uses a fifteen mass occupant which is permitted to move in all three dimensions. The model is documented in Reference 17. Validation of the model is included in References 17 and 18. Typical applications are shown in References 19 and 20.

The model validation documented above was for a Part 572 dummy. The first task to improve the model for this application is to develop a validated data set for the Hybrid III dummy. This has been done and is reported in Reference 21. The model is now being used to understand differences between complete dummy tests and dummy component tests. In addition, the model is being validated for the sled tests reported earlier. It will eventually be used to reconstruct accidents in a similar manner to those reported in Reference 20.

DISCUSSION OF RESULTS

The test results to date are limited to comparisons between the Hybrid III dummy and cadavers for steering system impacts at speeds of 15, 20, and 25 mph.

The results of baseline testing indicate that the Hybrid III dummy loads the steering column in a way which is generally similar to the cadaver. This can be seen by comparing time history of the normal force measured by a load cell located between the steering column and the wheel, shown in Figures 3a and 3b. At the lower speed, shown in Figure 3a, the peak force is slightly lower for the dummy than for the cadaver. At the higher speed, shown in Figure 3b, the peak force is in good agreement.

The moment measurements from the load cell, shown in Figures 4a and 4b, also exhibit similarities. However, there is a greater difference in the moment loading than in the normal force loading. At lower speed, moment data from only one cadaver was available, and that data showed a much lower peak moment. At the higher speed, the dummy moment loading was generally within the corridor, but with a higher peak.

Although these preliminary test results show similarities between the column loadings, additional research is required to assess the contact injuries produced by the steering wheel to the face, chest and abdomen. The planned research program is designed to address these questions.

The characteristics of the Hybrid III dummy have been modeled for the CVS crash victim simulator model, and this data set is now available to the safety community.

TABLE I. HARM FACTORS

AIS VALUE	HARM SCALE FACTOR
6	264.9
5	232.5
4	56.7
3	9.2
2	3.0
1	0.7

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Figure 1 Cumulative Harm
By Body Region versus Velocity Change
(Drivers in Frontals)

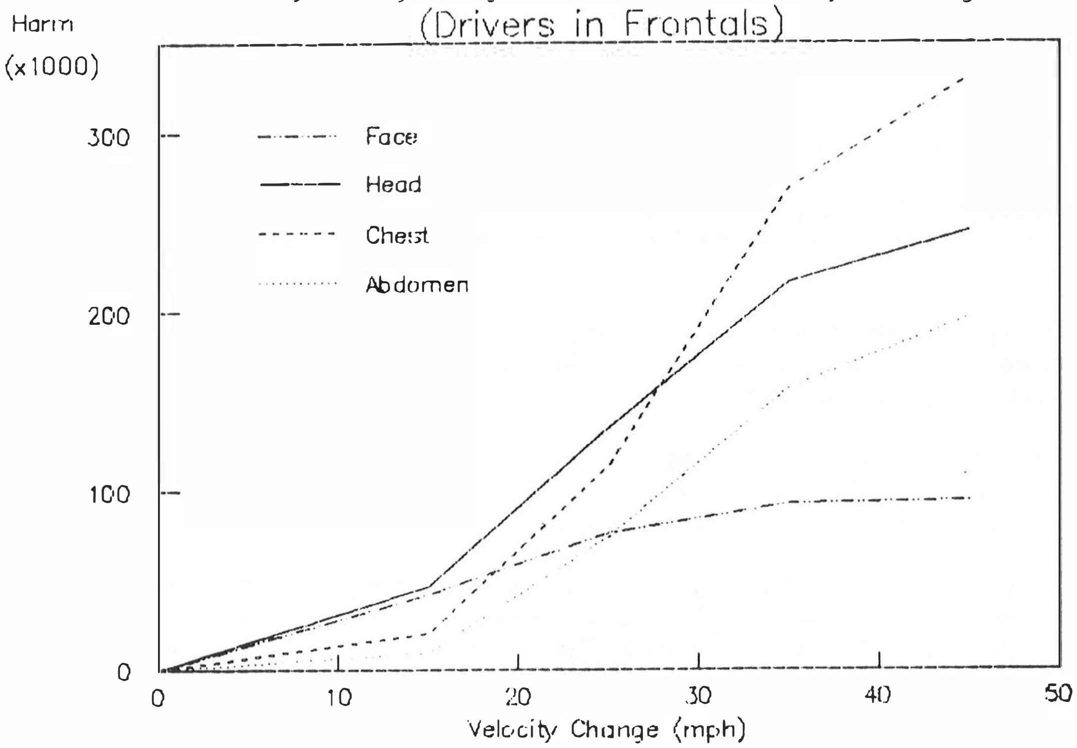
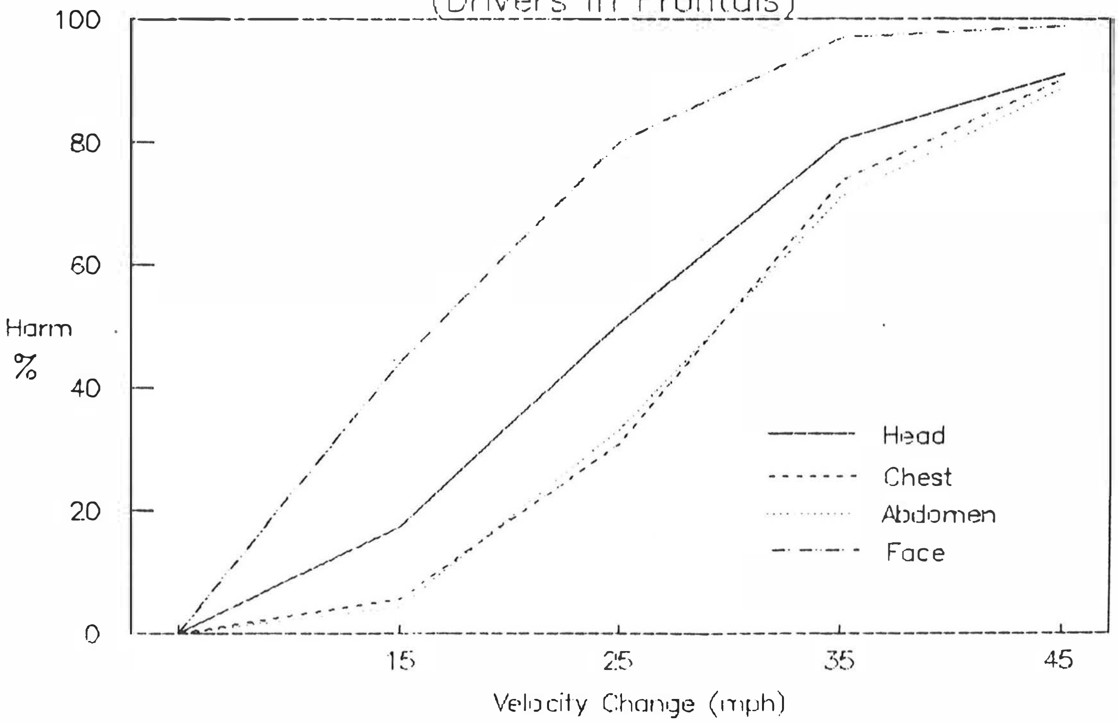


Figure 2 Percent Cumulative Harm
By Body Region versus Velocity Change
(Drivers in Frontals)



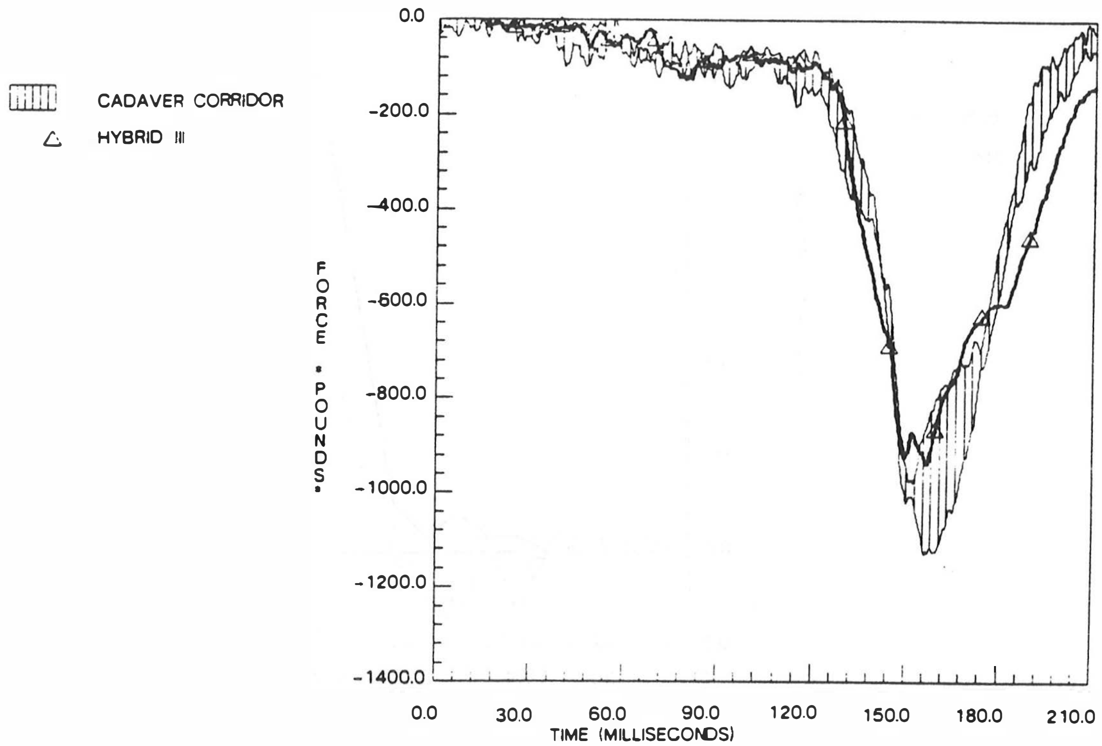


Figure 3a. Steering Column Force Measurements at 15 MPH

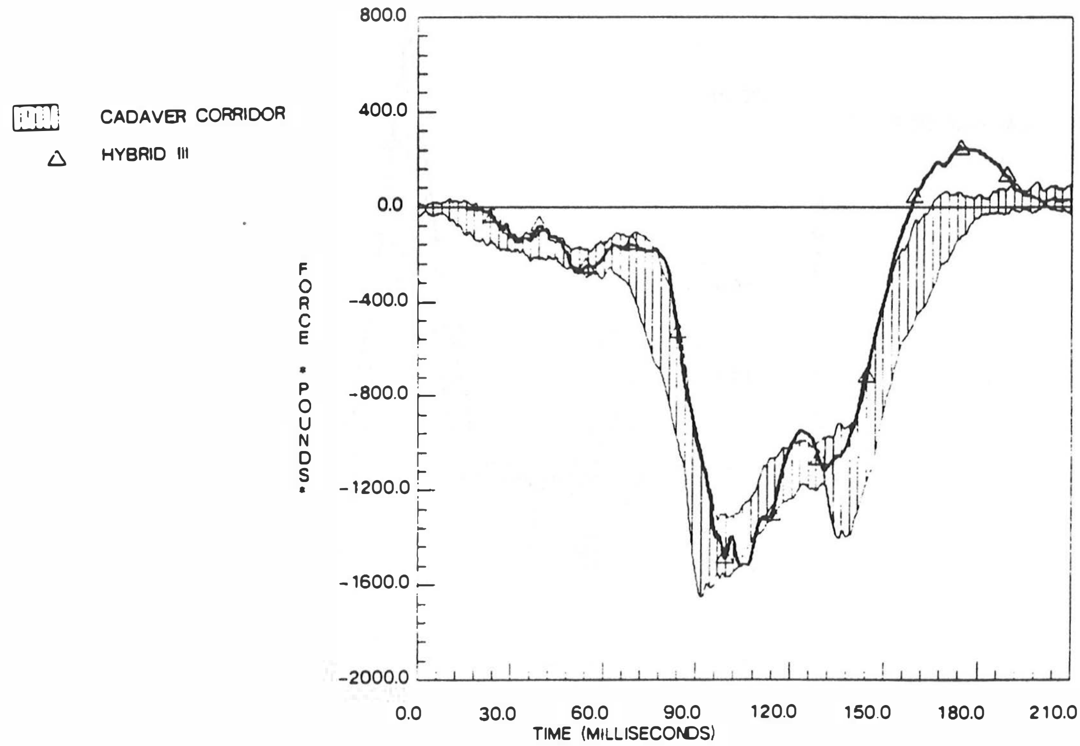


Figure 3b. Steering Column Force Measurements at 25 MPH

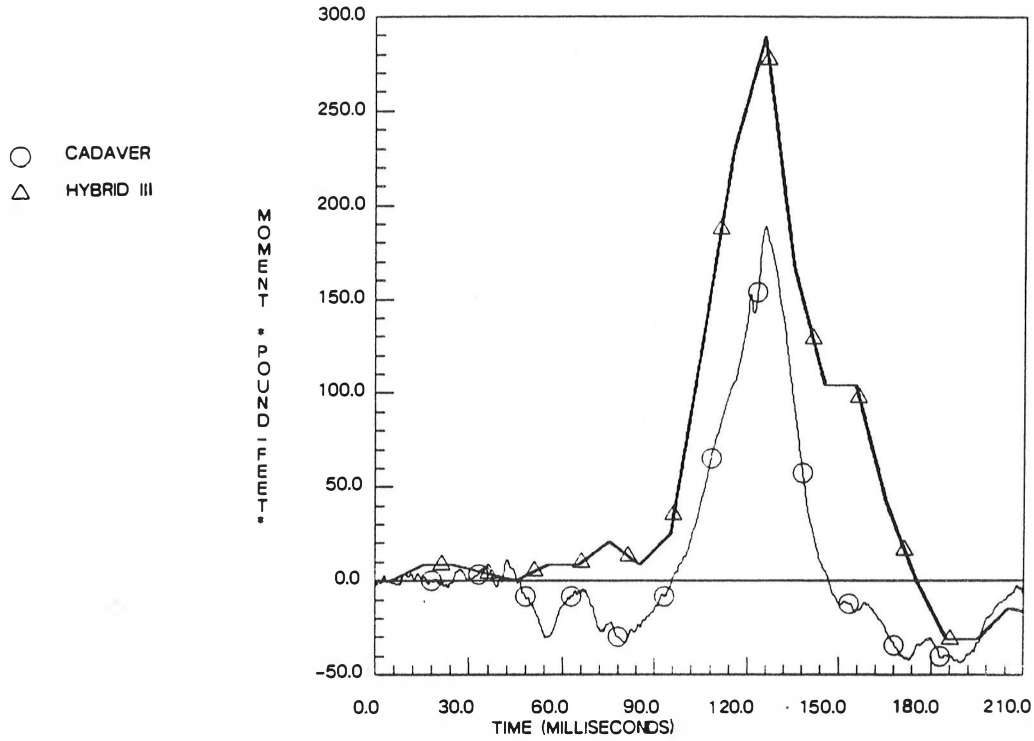


Figure 4a. Steering Column Moment Measurements at 15 MPH

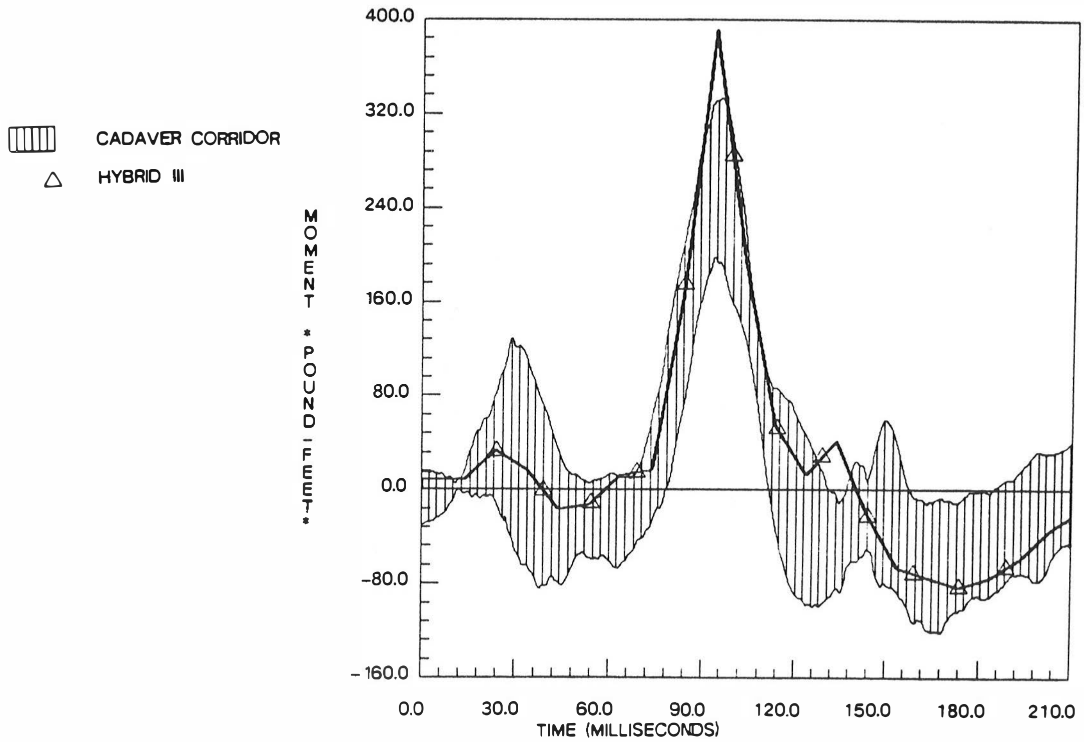


Figure 4b. Steering Column Moment Measurements at 25 MPH