THE GEORGE WASHINGTON UNIVERSITY – VIRGINIA CAMPUS
SCHOOL OF ENGINEERING AND APPLIED SCIENCE
FHWA/NHTSA NATIONAL CRASH ANALYSIS CENTER

Develop Improved Roof Crush Test Procedure

Proposed Research Plan and Milestones
Submitted by K. Digges – June 12, 2001

Work Statement Tasks

1. **Define the state-of-the-art in rollover crash safety research** (literature review). During the period 1988-92 NHTSA sponsored an advisory group on vehicle rollover. The group contained members from industry, government and research institutions. The group was chaired by K. Digges until July 1989 and subsequently by Jim Hackney. The group surveyed the existing literature and research in rollover and identified research to address rollover stability testing. Roof crush testing was not considered. However, the literature compiled will form the basis for this study. In addition, this study will survey the published literature on rollover research since 1992. It will survey NHTSA research and rulemaking activity in rollover, including the basis for the new consumer information standard. A report will be published that summarizes the relevant literature and identifies needed research. Milestones – Complete during 1st Quarter.

2. **Identify and quantify opportunities for reducing casualties from roof injuries in rollover crashes** (literature review and NASS data analysis). Past NHTSA research has indicated that the most harmful rollovers to the vehicle structure are those in which the vehicle completes more than 180 degrees of rotation in the air and lands on the opposite side a-pillar. Data analysis will be conducted to verify this assumption. In particular, the new analysis will examine the relationship between the damage to the vehicle structure and the injury to the occupants. Representative cases will be selected from the files for computer modeling to better understand the injury mechanisms. The magnitude of the casualties that could be attributed to contact with the vehicle's roof or upper structure will be determined. Milestones – Complete During 2nd Quarter

3. **Rollover crash tests for roof crush. (**vehicle testing and vehicle modeling). This task will initiate dynamic rollover/roof crush testing of one or more selected vehicle models. The vehicle model selection criteria will include: (1) the availability of existing FEM models of the vehicle structure, and (2) the rollover frequency of the vehicle in service. The test vehicles will be instrumented to measure strain and deformation at critical locations in the vehicle roof support structure. The tests will not only provide data for modeling the roof and support structure, but also information on the structural deformation during realistic conditions associated with rollovers. The tests will give an indication differences in structural performance for different rollover conditions. Four different test modes will be evaluated. The first test mode is a drop of an entire vehicle on its roof. In this test, the drop

height and the pitch and roll angles will be specified in order to realistically load the roof and supporting structure. The surface on which the vehicle is dropped may be inclined to partially simulate the frictional forces from vehicle rotation during ground contact. Alternatively, a pedestal may be used to simulate localized loading. A second test mode will apply a dynamic impact to the vehicle roof using a pendulum device. The weigh and velocity of the pendulum will be sufficient to simulate the roof loading during a rollover crash. This test method has been developed and is being applied to personnel carrying military trucks by the Australian Ministry of Defense. With modifications, it may be applicable to passenger vehicles. The third type of test is the controlled rollover test. In this test, the vehicle is suspended from a moving vehicle and dropped on its roof from a specified height and at a specified angle. The Australian Ministry of Defense has developed such a test capability and has conducted vehicle rollover tests for research purposes. The fourth type of test is a modification of the FMVSS 216 static crush test. The test modification would involve changing the direction of loading. NHTSA R&D staff have requested that any improved roof crush test be related to the FMVSS 216 test and that modifications to 216 should be examined. This part of the test project will address NHTSA's concerns. Instrumentation will be included on the test vehicles, as needed, to assist in developing and validation the FEM models of the roof and support structures. Existing FEM models of the tested vehicles will be modified as needed to produce results that simulate the tests. Milestones – Drop tests and static tests to be conducted during the first year. FEM models validated by drop testing will be completed during the first year. Pendulum tests and full vehicle controlled rollover tests to be conducted during the second year.

4. **Rollover crash attributes related to roof crush.** (vehicle modeling). This task will develop and exercise a finite element model of a representative vehicle structure that is capable of addressing the structural issues associated with a realistic roof crush test. The finite element model will permit direct comparisons of different test protocols. In particular, it will permit comparison of a proposed protocol with the existing test requirement of FMVSS 216. It will also permit an assessment of variations of FMVSS 216, a requirement that has been requested by NHTSA officials. The model will also permit the assessment of structural issues. The structural issues to be addressed are as follows:
    1. What is the critical vehicle orientation at roof impact that causes the highest amount of roof crush?
    2. What is the effect of broken side windows and windshield on the critical vehicle orientation and the extent of roof crush?
    3. What is the effect of variations in the vehicle's vertical velocity on the extent of roof crush?
    4. What is the effect of variations in the vehicle's angular and horizontal velocity on the extent of roof crush?
    5. What differences in extent of roof crush exist between static roof loading (FMVSS 216), variations in FMVSS 216, vertical drop dynamic loading at various angles and drop heights, and dynamic loading with lateral and angular velocity (as exists in an actual rollover)?
    6. How do differences in roof crush resistance affect the severity of the vehicle rollover crash in terms of vehicle acceleration and number of quarter turns?

The task will require the refinement of an existing FEM model and its validation for the roof loading anticipated by the study. Initially, the model will be validated for FMVSS 216 type loading and vertical drop test loading. Subsequently, it will be validated for dynamic loading. . Existing tests will be used to validate the model where practical. Additional tests conducted in Task 3 will be used to validate the dynamic load conditions and to measure parameters not available in the 216 tests. The model will be applied as soon as possible to answer the questions specified above. Reports will be published at the end of the 2nd year that summarize the model validation and its applications.

Milestones -

Validated model for static test , drop test, and answers to questions 1 and 2 - 1st year.

Validated model for dynamic tests and answers to questions 3 and 6 - 2nd year.

5. **Rollover crash attributes related to injury from roof contact** (data analysis and vehicle/occupant modeling) This task will be devoted to computer modeling of occupant motion during rollovers. Both restrained and unrestrained occupants will be examined. Initially the model will be validated using data and films from rollover tests. The model will then be applied to study occupant kinematics during rollover. The modeling will initially involve reconstructing real world cases to better understand the injury mechanisms. It will than progress to modeling of typical rollover cases to better understand the pre conditions to the cause the occupant to be most vulnerable to injury from roof crush. Modeling will compare the occupant loading with and without roof crush. A report and associated papers will be published that summarize the results of the data analysis and modeling. Questions to be addressed are as follows:
   1. For restrained and unrestrained occupants, how do the variables of occupant position, occupant size/headroom, vehicle tripping acceleration pulse, vehicle angular velocity, and vehicle vertical velocity affect the vulnerability of occupants to injuries from roof contact?
   2. For the most critical conditions identified in a, above, what is the effect of roof crush on the occupant loading?
   3. For restrained occupants, assess the effects of lap belt pre-tensioning on occupant loading from roof contact.
   4. For restrained and unrestrained occupants, assess the effects of padding and inflatable devices on occupant loading from roof contact.

   Milestones – Complete During 2nd Year

6. **Occupant position in critical rollover conditions.** (vehicle and occupant modeling and analysis) This task will conduct vehicle and occupant modeling of rollover crashes using roof crush conditions determined by the finite element model. The analysis will assess the consequence of roof crush on the occupant under pre-impact conditions that are typical of rollover crashes. Based on the combined simulation of vehicle motion, occupant motion and roof crush, a range of critical conditions that result in maximum occupant loading will be established. Milestones – Recommend critical conditions for occupant loading - 3rd Year

7. **Postulate critical test conditions – roof deformation; occupant position; criteria for rating test results.** (vehicle testing, vehicle modeling, vehicle/occupant modeling, and analysis) This task will use all previous analysis and document the results of the program. It will recommend an improved roof crush test and test criteria. The task will then conduct tests of selected vehicles to validate the results. It will recommend a test program to validate the recommendations and to assess the performance of the vehicle fleet. The recommended test program will be initiated and conducted to the extent that funds are available. Milestones – Final Report – 3rd year

Research Approach

The research will be conducted by the National Crash Analysis Center in the Engineering Dept.of The George Washington University. The research will be conducted in cooperation with the NHTSA, the Canadian Dept. of Transport, the Australian Ministry of Transport, Monash University, and the Australian Ministry of Defense.