TECHNICAL ASSESSMENT PAPER:

RELATIONSHIP BETWEEN ROLLOVER AND VEHICLE FACTORS

prepared
by

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1.0 FOREWORD

The activities documented in this report were initiated in response to two petitions for rulemaking requesting the development of a standard for rollover stability. They were submitted to the National Highway Traffic Safety Administration (NHTSA) over the past five years. The first, received by the agency in September 1986, was submitted by Senator (then Congressman) Timothy E. Wirth, and the second, received in June 1988, was submitted by the Consumers Union of United States, Inc. (CU). Although the agency denied the Wirth petition (Reference 1), which asked the agency to propose a specific rollover stability standard, NHTSA in its April 1988 denial (Appendix A) indicated that it intended to conduct additional testing and analysis to investigate the problem of rollover of light duty vehicles and that those efforts might lead to rulemaking. The CU petition (Reference 2), which asked that NHTSA investigate the rollover problem and then propose appropriate rulemaking, was granted in a September 1, 1988 letter (Appendix B), based upon the commitment made in the Wirth denial to investigate the rollover issue.

1.1 INTRODUCTION-GENERAL

Rollover accidents occur for many reasons. As with any accident, all three components of the driver/vehicle/environment system play a part in the development of the situation that results in a crash. However, there are extremes wherein a factor or factors related to one of the parts of the system is predominant in the causation of the accident. In the case of the driver, take the "extreme" example of a driver falling asleep at the wheel; for the environment, consider an unexpected patch of ice on an otherwise clear roadway resulting in a skid; and for the vehicle, a vehicle which has a such a low level of rollover stability that a simple, but severe, steering input by the driver as part of an accident avoidance maneuver results in the vehicle's rolling over.

The vast majority of crashes are caused by the interaction of factors from all three parts of the driver/vehicle/environment system. This rulemaking program attempts to accurately define and measure a vehicle performance factor(s) that is influential in the causation of rollover accidents - to the degree that a regulation based on that factor can significantly reduce the number and/or consequences of rollover crashes.

The goal of this rulemaking program is to determine the feasibility of developing a viable and appropriate standard or standards related to vehicle rollover stability that would reduce the likelihood of rollovers and/or to reduce the casualties associated with vehicle rollover crashes. In order to achieve that goal, a number of research and analysis tasks were planned and conducted. The purpose of these research and analysis tasks was to develop a measure of a vehicle's rollover stability that can be used to predict the vehicle's likelihood of rolling over given involvement in a crash. This document summarizes those efforts and results (which only comprise one aspect of the potential vehicle rulemaking) and discusses the adequacy of the results to accurately predict the rollover accident involvement rate of vehicles. The various alternatives for vehicle stability rulemaking action, and the

implications of the research and analysis results on those alternatives, are then discussed. Also addressed are additional testing, analysis and evaluation activities being undertaken by the agency to improve its understanding of rollover accident causation.

1.2 THE ROLLOVER ACCIDENT PROBLEM

This project addresses the crash avoidance aspects of rollover accidents that involve light duty vehicles, which includes passenger cars, and light trucks and vans (LTV's). This latter group includes compact and full-size pickup trucks, mini and full-size passenger and cargo vans, and sport utility vehicles (SUV's). SUV's are passenger vehicles with special features (usually four-wheel-drive) that allow for off-road operation. It should be noted that in the agency's Consumer Information Regulation (49 CFR 575.105) "Utility Vehicles", utility vehicles are defined as "multipurpose passenger vehicles (other than those which are passenger car derivatives) which have a wheelbase of 110 inches or less and special features for occasional off-road operation." Of the SUV's on the market today three, the Toyota Land-Cruiser with a wheelbase of 112.2 inches, the Lamborghini LM002 with a wheelbase of 122.4 inches and the Chevrolet/GMC Suburban with a wheelbase of 129.5 inches, do not fall in both categories.

Rollover crashes are of particular interest since rollover accidents are the most dangerous collision type for all classes of light vehicles, measured by either fatalities or incapacitating injuries per involved occupant. In terms of fatalities per registered vehicle, rollovers are second only to frontal crashes in their level of severity. These results are reported in a 1986 report documenting analyses conducted by NHTSA's National Center for Statistics and Analysis (Reference 3). These high injury/fatality rates are even more alarming given the fact that rollovers are by far the least frequent crash mode, as measured by accident involvements per registered vehicle. The National Accident Sampling System (NASS) datafile for 1989 estimates 137,600 rollover accidents involving passenger cars. Of these, 124,800 are single-vehicle rollovers, and the vast majority of these, 114,800, occur off the roadway. For LTV's, there are 75,600 rollovers, 65,800 single-vehicle rollovers, of which, 57,200 occur off road. Based on NASS data, nearly 90 percent of rollovers occur in single-vehicle accidents. Various accident data studies have indicated that the vehicle is out of control (skidding sideways or spinning) prior to overturning in from 50 percent to 80 percent of all rollovers.

The rollover problem is generally more serious for the LTV, and in particular, the SUV "portion" of the light vehicle group. State accident data (North Carolina for 1984 and 1985) indicate that although the involvement rate (involvements per registered vehicle) for LTV's in all types of collisions is only 68 percent that of passenger cars, their involvement rate in accidents involving rollover is 127 percent that of passenger cars. Rollover accidents are particularly dangerous for the occupants of SUV's, with their incapacitating injury rate being 28 percent higher than that for all light vehicles combined. This occurs even with similar seat belt usage, as shown in an agency regulatory evaluation on "Rear Lap/Shoulder Belts," where seat belt usage rate in accidents of pickups was estimated to be 70 percent of

passenger cars, but "on/off road" vehicles were estimated to have usage rates "equivalent" to passenger cars (actual rate was 95 percent).

In terms of rollover fatal accidents, 1989 Fatal Accident Reporting System (FARS) data indicate that LTV's have fatalities per registered vehicle rates 104 [94.5 versus 46.3 fatalities per million RV] percent higher than passenger cars, with small pickup trucks and SUV's having the highest comparative rates- 259 [based on 119.8 fatalities per million RV] percent and 254 [based on 117.5 fatalities per million RV] percent that of passenger cars respectively. However, since there are many more passenger cars the LTV's on our nations highways, approximately two-thirds of all rollovers involve passenger cars. Based on 1989 FARS data, 5682 fatalities occurred in passenger car rollovers and 3862 fatalities occurred in LTV rollovers.

Further discussion of the nature and magnitude of the rollover problem of light duty vehicles and of the prior analyses of accident data is found in the "Technical Evaluation of Rulemaking Petition" (for Senator Wirth's petition on rollover propensity-Reference 4) and in a discussion of the petition in Section 2.1.2.

1.3 PREVIOUS ANALYSIS OF FACTORS RELATED TO ROLLOVER CRASH INVOLVEMENT

The following is a basic review of accident data analyses performed by both the agency and others prior to the efforts reported in this document. This summary presents what has been studied to better quantify the relationship between vehicle, driver and environmental factors and rollover accident involvement.

1.3.1 Analyses Conducted Prior to the Submission of the Wirth Rollover Propensity Petition

Several researchers have reported correlations between certain vehicle parameters and various measures of rollover accident involvement. Some of these are discussed in Reference 4. Two vehicle parameters that were shown to have significant correlations with the rate of rollovers in single vehicle accidents were:

1. rollover stability factor, and

2. critical sliding velocity.

Both the rollover stability factor, which is one-half the vehicle's track width divided by the vehicle's center of gravity height, (h_g), and the critical sliding velocity, which is a measure calculated from various vehicle dimensions and mass and inertial properties, will be discussed later in this section and in Section 4.

Various accident condition variables have been shown to exhibit a relationship with rollover rates. These include pre-crash stability (skidding or spinning), vehicle pre-crash condition (skid sideways or spin) and skid type (rear wheel lateral or four wheel lateral).

Various driver- and environment-related accident variables also seem to influence the likelihood of rollover. These include driver age, alcohol involvement, driver error, rural vs. urban roadway, day vs. night, the roadway speed limit, the rollover's occurring on or off the roadway, and accidents occurring where the roadway was straight or curved.

Of all these factors, the one which exhibited the greatest correlation with rollover accident involvement is rollover stability factor. The rollover stability factor's correlation "makes sense" since it has an obvious physical relationship to the dynamics of a rollover accident (this is discussed in detail in Section 4).

Other factors which are very important in determining a vehicle's rollover stability (measured or calculated) and its rollover propensity are those related to the vehicle type or class. This is particularly true of LTV's. LTV's have functional characteristics that are inherently different from passenger cars and that contribute to an inherently lower level of rollover stability. Since these same characteristics of LTV's are, to some extent, vehicle characteristics basic to the use for which these vehicles are designed, potential for improvement in their fundamental rollover stability may be limited. This view was noted in the agency's denial of the rulemaking petition from Senator Wirth (Appendix A). In responding to that petition the agency stated that a regulatory requirement based on the rollover stability factor alone, given the then limited understanding of the overall rollover accident causation issue, was not reasonable or practicable and might be in conflict with certain statutory considerations.

Before proceeding, one feature of a previous study should be noted. In a 1974 paper (Reference 5), I. S. Jones argued that a vehicle which has a relatively low rate of rollover per single vehicle accident might have a relatively high overall rate of rollover accident involvement, when measured per vehicle mile travelled (VMT), or per registered vehicle, because of a high rate of single vehicle accidents per VMT or registered vehicle. Jones argued that this could be particularly confounding to an analysis of vehicle rollover stability when comparing vehicles with significantly different handling characteristics; the reasoning being that vehicle handling characteristics influence a vehicle's involvement in single vehicle accidents and since most rollovers occur in single vehicle accidents, the influence of those handling differences could confound an analysis that examines the correlation between rollover involvement and vehicle rollover stability measures. Based on this, Jones reasons that by using rollovers per single vehicle accident as the accident rate measure, the confounding influence of other vehicle factors, unrelated to vehicle rollover stability, would be significantly reduced. This is also reasonable noting that the vast majority of rollovers occur in single vehicle accidents and as such, the occurrence of the single vehicle accident can be viewed as the opportunity for, and therefore, an exposure measure of, a rollover accident.