

## TRENDS IN AUTOMOBILE SAFETY: ANALYSES OF RECENT NCAP FRONT CRASH TESTS

This article discusses some findings about automobile safety in frontal crashes. As is known, the NHTSA as part of their ‘New Car Assessment Program’ (NCAP) with the stated intent of helping customers select vehicles that are ‘safer’ according to NHTSA’s ranking of ‘more stars’. This rating system was revised some years ago for automobiles of model years 2011 and later ([http://www.safercar.gov/staticfiles/safetytech/st\\_landing\\_ca.htm](http://www.safercar.gov/staticfiles/safetytech/st_landing_ca.htm)). One of the interesting aspects of the new NCAP is that NHTSA publishes an ‘overall score’ for the vehicle’s crashworthiness by combining the scores from frontal crash, side impacts and rollovers. Other significant changes in the NCAP are the addition of a test dummy representing small occupants, the inclusion of new injury-related parameters and significantly raised thresholds for achieving the highest (five stars) rating. Since wide publicity is given to NCAP scores and all vehicle manufacturers try to achieve the highest possible ratings for their new product, these ratings serve as mandates in vehicle design.

***NCAP Tests for Frontal Crashes:*** The test configuration for this mode is 35 miles per hour impact of the vehicle into a fixed rigid barrier. This simulates crashes with fixed and rigid objects on the road and also represents full frontal crash of the car with another identical car. In these tests, the driver is represented by an anthropomorphic test device (ATD) simulating a fiftieth percentile male whereas the front passenger ATD simulates a fifth percentile female. The measured parameters are the responses of head, chest, femurs as well as the forces and moments on the neck. These measurements are used to calculate ‘relative risk’ scores which are then translated into separate ‘stars’ for the driver and the passenger. According to NHTSA, the following relationship exists between the ratings (‘stars’) and the risk of injury in frontal crashes.



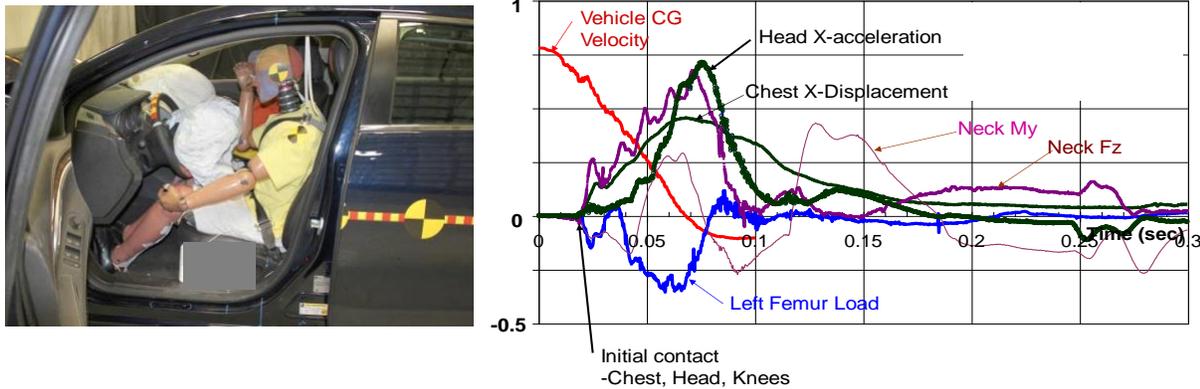
★★★★★	= 10% or less chance of serious injury
★★★★	= 11% to 20% chance of serious injury
★★★	= 21% to 35% chance of serious injury
★★	= 36% to 45% chance of serious injury
★	= 46% or greater chance of serious injury

### ANALYSIS OF NHTSA’S TEST DATA

#### **Background:**

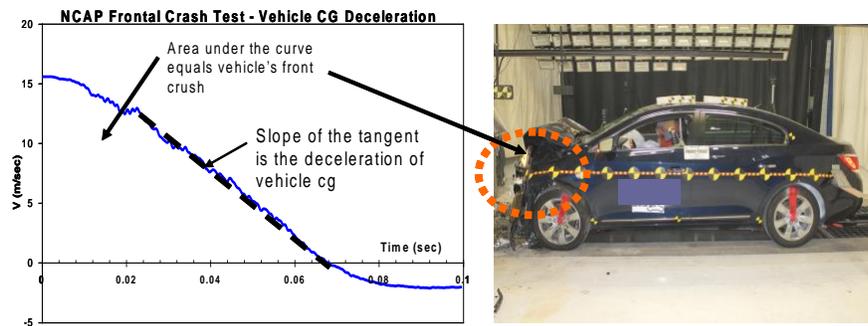
The figures below show a driver ATD in a test as well as its response parameters. All the responses have been normalized (with different normalization factors as described in NCAP test procedures) so that they can be compared in one plot.

Front NCAP Crash Test – Time history of Vehicle & Driver ATD Response



Several observations can be made from the above plots. The ‘time to zero’ for vehicle CG occurs at approximately 70 milliseconds in this test, followed by a rebound. The initial contacts of the driver ATD body segments (femurs, chest and head) occur close together (~20 milliseconds). The maximum chest displacement (in x-direction) and the maximum head acceleration (the x-component) occur in the 70 -80 millisecond timeframe. For the neck bending moment  $M_y$  (extension or flexion) and neck force  $F_z$  (tension or compression), both the positive and the negative maxima are used in the computation and it is therefore important to consider the occupants’ motion during both the loading and the rebound phases.

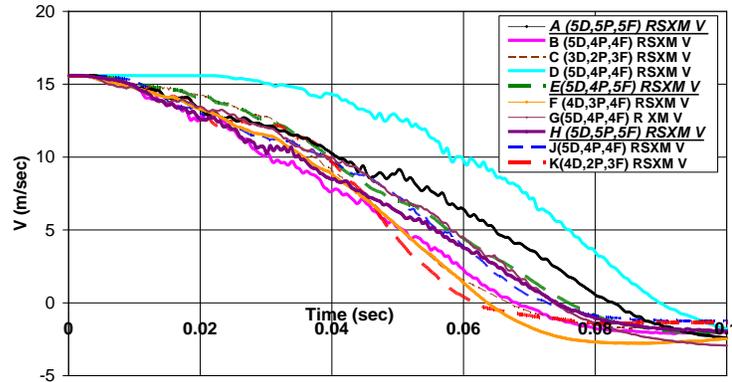
The exterior structure of the vehicle crushes to dissipate a portion of the crash-induced kinetic energy and thereby improves the protection for properly restrained occupants. All other factors remain constant, the larger the area under the curve, the more the deformation of the front end.



**Vehicle Structure Performance:**

Shown below are some plots of velocity-versus-time measured near the vehicles’ CG from tests of different vehicles. The legends associated with each curve designate the tested vehicle by a letter (e.g. ‘C’) and also show its NCAP score, e.g. the first two characters are the number of stars for the driver (‘3D’ means three stars for the driver), the next two are the number of stars for the passenger and the last two show combined frontal test score (‘3F’ means NHTSA’s combined rating of three stars for the vehicle’s driver and passenger in frontal crash).

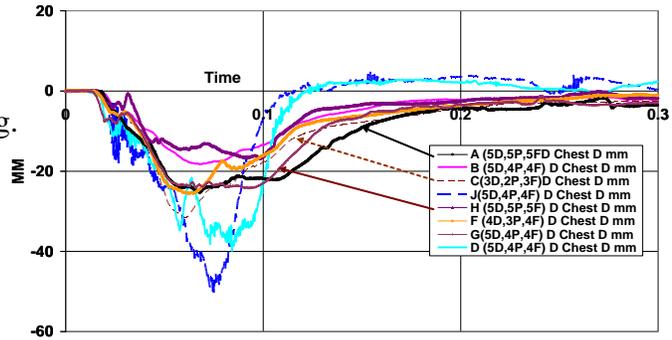
**NCAP Data for 2011 & 2012 Vehicles -  
Analysis of Frontal Velocity-vs-Time History**



**Chest Compression:**

The chest displacement of the ATD is a function of its impact velocity, the force-displacement-time properties of the seatbelts and the shape, size and deployment dynamics of the driver airbag. To reduce the chest x-displacement, it is necessary that will all safety-related components e.g. seatbelts, airbag, knee bolsters, seats, etc., be optimized as an ‘integrated system’. The plot below shows chest x-displacements of driver

**NCAP Data for 2011 & 2012 Vehicles - Analysis of  
Driver Chest X Displacement (mm)**



ATD from several crash tests. In calculating the NCAP score, the measured chest displacement is compared to a reference value (63 mm for the driver, 52 mm for the passenger).

Similar results are observed for measured chest displacements of passenger ATD (not shown here). Since this ATD represents a fifth percentile female for which a ‘base’ value published by NHTSA (52 mm) is lower than that for the driver, it is obvious that the passenger ATD has relatively larger influence on the vehicle’s NCAP ratings. Some of the shown vehicles (C, D, J) with high values of chest compression therefore have a relatively large ‘relative risk’ and lower star ratings.

**Neck Injury Parameters:**

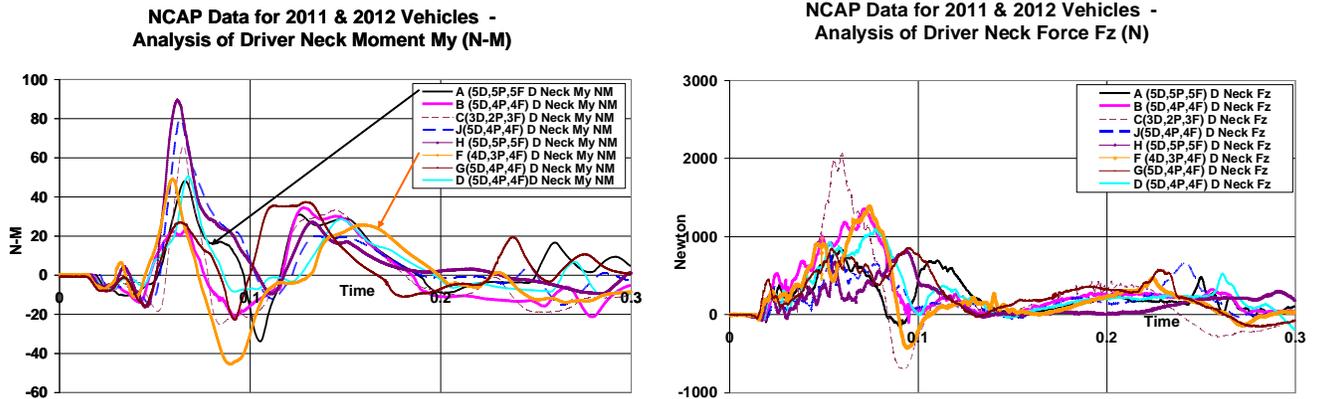
The NHTSA defines [1] a parameter  $N_{ij}$  which combines the possible modes of neck loading - tension or compression combined with either flexion or extension (forward or rearward bending):

$$N_{ij} = F_z / F_{critical} + M_y / M_{critical}$$

The values for  $F_{critical}$  and  $M_{critical}$  are defined differently for the two ATDs. The neck injury probability calculation is based on comparing  $N_{ij}$  and the tension/compression to ‘base’ values.



Measured responses from several tests are shown below for the driver ATD. The first figure below is plot of the moments ( $M_y$ ) whereas the second figure shows the neck forces ( $F_z$ ). The peak values of the bending moment and of the tension/compression forces may occur at different instants in the same vehicle. It should be mentioned that all of the vehicles shown in the plot except 'C' and 'F' achieved 5-star rating for the driver.



Similar data are observed for passenger ATD in these tests. The reference values for neck injury probability are relatively lower for the fifth percentile female and their measured neck forces and moments have a relatively larger contribution to the relative risk computations for the passenger-side ATD and to the NCAP rating.

**COMMENTS:** The changes in the NCAP test and measurement procedures described above have led to several improvements in automobile designs. The development of more efficient structures along with the optimization of safety systems in the vehicle are both necessary for higher 'star' ratings. Possibilities also exist for utilizing pre-crash systems [2] and pre-tightening the seatbelts to further improve performance in frontal crashes.

**References**

1. Eppinger et al, "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems – II", [http://www.nhtsa.gov/ DOT/ NHTSA/NRD/Multimedia/PDFs/Crashworthiness/Air%20Bags/rev\\_criteria.pdf](http://www.nhtsa.gov/ DOT/ NHTSA/NRD/Multimedia/PDFs/Crashworthiness/Air%20Bags/rev_criteria.pdf)
2. Verma and Goertz, "Evaluation of Pre-Crash Safety Systems Effectiveness", SAE Paper 2010-01-1042.