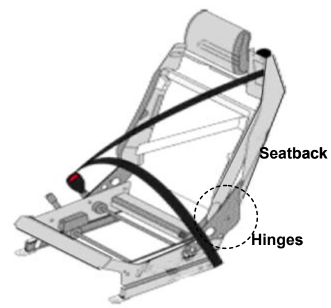
AUTOMOBILE SEAT STRUCTURES AND OCCUPANTS' SAFETY IN REAR CRASHES

The structural properties of an automobile's seats and seatbacks are important factors in investigating injuries to a vehicle's occupants involved in rear crashes. It is sometimes stated that such injuries occur when seatsbacks deform excessively, resulting in the person's impact with injurious parts of the vehicle or with another occupant. It is also claimed by some that a stronger structure for seats & seatbacks would reduce or prevent these injuries. This article discusses the merits of such 'stronger' structures in preventing injuries in rear crashes.

STRUCTURAL MECHANICS OF SEATS



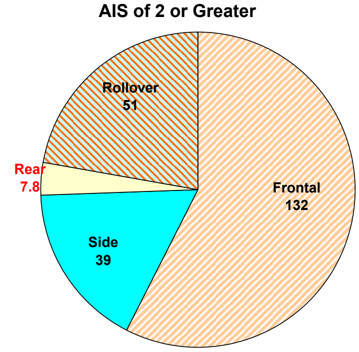
When a vehicle is hit in the rear by another vehicle, the relative motion between the person in the seat and the seat/seatback causes dynamic loading on the seat structure, leading to deformations of the seat & seatback consisting of:

- *Compression of the padding on seat/ seatback*
- *Deformation of seatback structure*
- *Deformation of the seat bottom structure*
- *Deformation of recliner mechanism*
- *Deformation of the vehicle floor and resulting motion of seat and seatback*

THE LAW: There are no US laws requiring dynamic tests of seats or seatbacks in high speed rear crashes. However, there are quasi-static test requirements (FMVSS 207 and FMVSS 210) for structural strength of seats and their attachments to the floor. Another regulation (FMVSS 202a) governs the design of headrests. In addition, Insurance Institute for Highway Safety conducts tests simulating low speed rear crashes and rates the vehicles in four different categories of performance.

STATISTICS: The average annual number of occupants that suffer injuries of AIS 2 or greater, in various modes of impact, was estimated from the NASS-CDS database for the years 1996-2007 (see *Verma & Goertz, "Evaluation of Pre-Crash Sensing and Restraint Systems Effectiveness"*, SAE Paper 2010-01-1042) and is shown here. It is observed that rear impacts are associated with comparatively fewer injuries than the other crash modes.

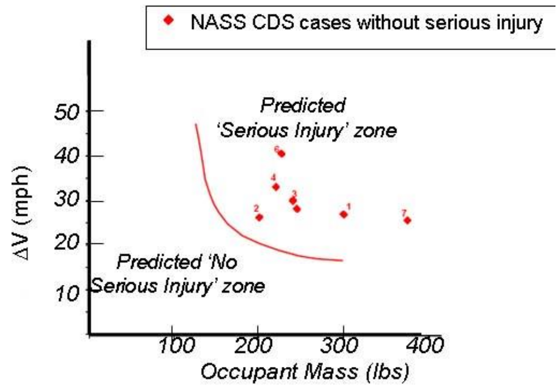
NASS CDS 1996-2007 Weighted Estimates - Average Annual Number of Occupants (in 10^3) with Maximum AIS of 2 or Greater



Past Research:

Simple relationships between the ΔV (change in velocity of the vehicle) and injury parameters have been proposed to explain the complex phenomena of injury causation in rear crashes. For example, Saczalski *et al* (*SAE paper 2003-01-2205)* concluded that 'stiff' seatbacks provide equal or better protection than 'yielding' seatbacks and defined 'serious injury zone' and 'no serious injury zone' based on the mass of the occupant.

In a subsequent publication, Viano *et al (SAE paper 2007-01-0708)* presented data contradicting the validity of the above findings. Other papers have analyzed the effect of variables such as seatback recline angle (see Edwards et al, *"Front Seat Injuries in Rear Impacts: Analysis of Seatback Incline Variable in NASS-CDS"*, SAE paper 2009-01-1200).



SEAT AND SEATBACK DESIGNS:

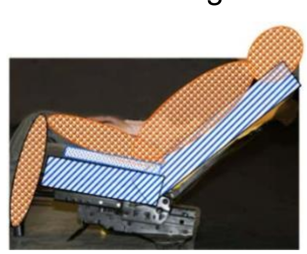
Seats are one of the most important factors in determining the comfort experienced by a vehicle's occupants. Physical designs of seats and seatbacks vary widely among various automobiles. The general design practice is to provide adequate structure in the seat and the seatback to support the expected operational loads while meeting other constraints of aesthetic, comfort and performance criteria by cushions, armrests and adjuster mechanisms. The photograph here shows the structural components of a modern seatback.

Crash Loads Applied to Seats: In a rear crash, the loading on a seatback consists principally of the seat occupant's mass multiplied by the vehicle's forward acceleration. In other crash modes (e.g. frontal and oblique crashes), seatbelt forces also need to be considered since they may be a significant part of the loading on the seat and the seatback. If there are multiple occupants in a vehicle, then one or more of these occupants may load the seatback in front of them when their vehicle is involved in frontal or offset crashes.

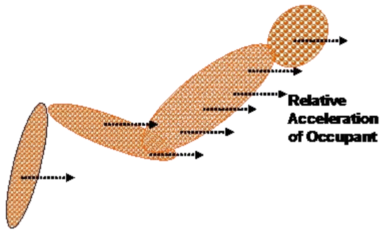
RELATIONSHIP BETWEEN SEATBACK STRUCTURE AND OCCUPANT INJURIES:

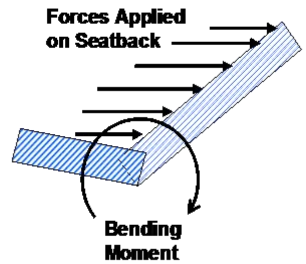
Simplified Structural Analysis: The role of seatback structure as a factor in occupant injuries is examined below. In order to compare different strengths of these structures without other confounding factors, only purely rear crashes are considered. However, the conclusions also apply to other angles of rear impacts.

A diagram of a seat with an occupant is shown here. When the subject vehicle is hit in the rear by another faster vehicle, the magnitude and the distribution of

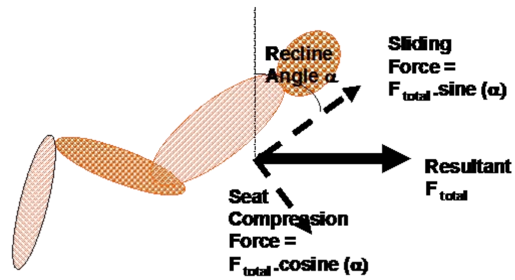


dynamic loadings on the seat structure depend on factors such as the relative and angle of the seat and the seatback, the occupant's mass, the impact speed, etc..





Thus, the loading pattern in a purely rear impact will be a rearward loading on the seatback as well as a bending moment.



The resultant force on the occupant may be visualized as one force component tending to slide the occupant upward along the seat and a second component as shown causing compression of the seat. The magnitude and the direction of the excursion of the occupant is the resultant from all the applied forces. The dynamic friction between the seat / seatback and the occupant is the principal component resisting the upward sliding motion. The contact area between the occupant and the seat/ seatback is one of the main factors influencing the dynamic friction. The larger the seatback recline angle from the vertical, the larger the force tending to slide the occupant (upward and rearward) out of the seat and the smaller the force causing seat compression.

- If the contact forces between the occupant and the seat/seatback are sufficiently large, injuries may result from these forces on the occupant's body.
- If there is a large amount of occupant's excursion from the seat, it may result in contacts with various parts of the vehicle, e.g. roof structure, pillars, rear seats, etc. The magnitude of any injuries from such contacts will be dependent on the structural property of the contacted component, the relative speed of impact of the body segments and their injury thresholds.
- For a properly positioned occupant on the seat, a 'softer' seat/seatback structure will provide a larger contact area with the occupant's body because of the resulting compression of the seatback, leading to a relatively smaller (as compared to the case below) 'sliding excursion' out of the seat and a larger 'compression' into the seat.
- Conversely, a 'stiffer' seat/seatback structure will likely lead to more 'sliding excursion (as compared to the case above)' out of the seat and smaller 'compression excursion'.

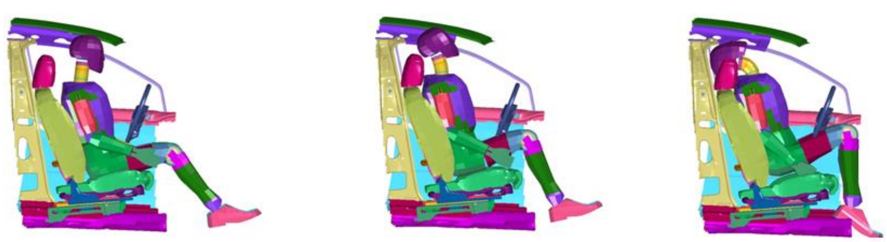
For occupants that are not properly positioned on the seat (such as seated sideways, leaning out of seat, fully reclined position, etc.) at the moment of impact, the structural properties of the seat / seatback are not properly utilized.

Detailed Structural Analysis: Evaluation of seat design concepts for occupants' protection can be conducted by techniques such as finite element simulations of the vehicle and its occupants in a crash. Results from such a study of a mid-sized sedan, impacted in the rear with Delta-V of 15 mph, is shown below.

The representation of the vehicle and the seat were obtained from design drawings of a current sedan and studies were conducted for two different sizes of occupants – one with the occupants simulated as 50th percentile male ATD ('anthropomorphic test device' or dummy) and the other with 95th percentile male ATD.

In these studies, the seatback was made completely rigid under applied loading, representing the upper limit of a 'stronger seat'. Results from this finite element simulation of rear crash confirm the earlier observations from the simplified structural model. When the seat / seatback structures have been made completely rigid, the 'seat compression' is eliminated but a larger amount of 'sliding excursion' of the occupant occurs, leading to multiple possible contacts between the occupant and the vehicle's interior, such as head-to-roof, neck-to-headrest, head-to-headrest, etc.

Seat, Seatback and Vehicle Structure : Finite Element Model of Rear Crash



Driver 50th percentile ATD, Rigid Seat, Rear Impact

Since a rigid seatback does not dissipate any of the kinetic energy of the crash, all of this energy is dissipated by the impact of the occupant's body segments with the seat structure and with other components in the vehicle's interior. Thus, injuries are likely from the high contact forces on the body segments as well as from significant rotational motions of the head and the neck.

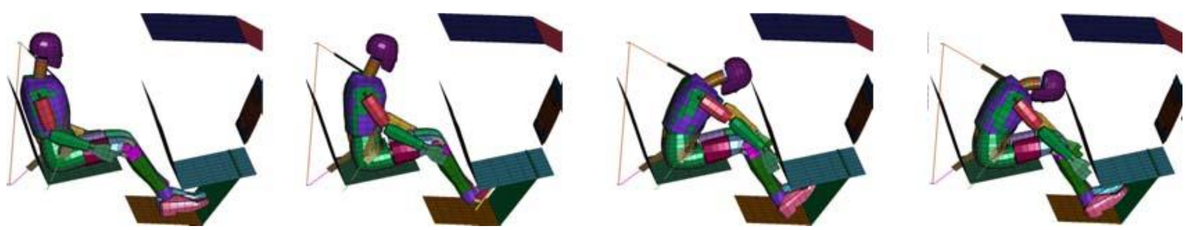
A study of the impact dynamics of a 95th percentile ATD in the same vehicle (shown below) was also conducted and qualitatively identical conclusions regarding 'stiffer' seats and seatbacks were reached.

Driver 95th percentile ATD, Rigid Seat, Rear Impact

These studies make it obvious that stiffening or strengthening of the seat and seatback structures in these cases does not result in reducing or eliminating the likelihood of injuries. Similar conclusions are reached for other amounts of partial stiffening.

OTHER FACTORS IN DESIGN OF SEATS/ SEATBACKS : Safety of Rear Seat Occupants in Frontal Crashes

In the case when an occupant is present in the rear seat and the vehicle is involved in a frontal crash, the rear occupant's impact will be with the back of the front seat and thus, its design needs to take this into account. Studies were conducted for a mid-sized sedan in a 30-mph frontal crash with a 50^{th} percentile male ATD in the rear seat, restrained by a three-point seatbelt with pyrotechnic pretensioners. The front seat was positioned as it would be as the driver (of the size of 50^{th} percentile male ATD) would have set. The results are shown below.



The resulting dynamics of the properly restrained rear seat occupant shows the impacts between the rear occupant's body segments and the back of the front seat. The calculated results for injury parameters showed that, other factors being equal, a stiffer structure in the front seatback is likely to produce higher injury levels for the rear seat occupant(s).

SUMMARY: Structural designs of automobiles' seat and seatback are based on multiple requirements including those of occupants' safety in crashes. It is necessary to conduct detailed evaluation of the vehicle's and its occupants' dynamics and of the structural behavior in order to assess the likely factors affecting the injury outcome in a specific crash, since each crash is unique in terms of the magnitude and the time-history of events,