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Effective Head Restraint Systems Based on Integrated Structure and Barrier Analysis

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Abstract: *Head restraints is one of the most automotive safety feature integrated into the top of each seat to limit the rearward movement of the occupant's head, in a collision to prevent or mitigate whiplash or injury in the cervical vertebrae. Integrated head restraint refers to a head restraint formed by the upper part of the seat back, or a head restraint in which the height is adjusted and it cannot be detached from the seat . it should not be detached from the vehicle structure except by the use of tools in a mandatory circumstances. Based on a certain type car, the finite element model for the car was enhanced in such a way that the space occupied by the hybrid III dummy and safety-belt restraint system was just 50 %. The basic principle of the dynamic explicit non-linear FEM, an equation describing the rear-end crash process and finite element discretization was proved in barrier test. Then the rear-end crash was simulated and analyzed, by Solving the responses of integrated structure deformation, and the time curve of acceleration and energy absorption during the whole crash process , as well as the response of dummy and the performance indicators including head, chest, thigh etc.. The effective energy absorption effect of the main energy-absorption components, and driving safety during the rear-end crash process were analyzed and verified successfully. A more comprehensive evaluation of the car during the rear-end crash process was achieved side impact dummy.*

Keywords:*Head restraint, whiplash, occupant protection, rear impact, dummy.*

I. INTRODUCTION

Reducing the relative velocity between the occupants and the vehicle interior to reduce the risk of injury to the occupant during a collision is a basic requirement of automatic safety. According to Newton's Laws ,change in an occupant's velocity requires a force to be applied to the occupant. The Safety engineers are analyzing the maximum force applied to the driver or passenger without injury and adjustment with certain Standards (ex. FMVSS 208 -Frontal, 214-side) for occupant protection.The most familiar safety restraint features required by federal standard are safety belts and supplemental air bag restraint systems.Other non-regulated restraint systems include energy- absorbing E-A (or collapsible) steering column and E-A knee bolsters which are measured using Hybrid III or SID.The Potential injury indices includes peak pelvic acceleration and TTI (Thoracic Trauma Index)Modern vehicles offer passenger protection systems with a high level of protection in all known types of crash tests. The trend is toward increasingly complex safety systems driven by the desire to attain the best ratings for worst-case scenarios with maximum demands on safety criteria. Improvements can be attained in laboratory situations, but the degree to which this helps vehicle occupants in a real world accident might be unclear.

II. EFFECTIVE RESTRAINT SYSTEM

The Essential to know the required stopping distance Can be considerwith the tolerance level of 60 g's in chest with Optimum or minimum stopping distance with a square wave (uniform) deceleration pulse, a.k.a. Equivalent Square Wave (ESW) is6-in from 30 mph and 24-in stopping distance from 60 mph in a Half-sine deceleration pulse requires (more realistic) and 9.7 in for 30 mph and 37.7 for 60 mph .Larger distances are required to stop from high velocities at sub-injury levels .In a 30-mph barrier collision, a typical full-size car can haveup to 28 in of front-end crush about 15 in between the occupant and the interior6 in deformation of the interior compartment with a total of about 49 inches. For surviving high speed crashes the essential to use the frontend crush and available distance between the occupant and the interior are accomplished when a restraint is used. The air bag, energy absorbing steering column and safety belts are all restraint systems that slow the occupant shortly after the vehicle starts to decelerate. Part of the distance is lost in a harness by slack and belt stretch. The distance between the driver and the steering wheel is lost in the case of the energy-absorbing column restraint, and the distance of the front-end crush and occupant space traversed during the sensing and deployment time for the air bag are lost. However, the remaining useful distance does increase the survival velocity appreciably.TheStudiesbased on the vehicle response and the occupant response are classified as;

- The primary impact
- The secondary impact

The primary impact:Between the vehicle front-end structure and the fixed barrier are major portion of the crash energy is absorbed by structural deformation that produces a crash pulse transmitted to the occupant compartment. The compartment intrusion is largely affected by the extent of the vehicle front-end deformation, influenced by vehicle design parameters such as the strength of the structural members, the available package space, the stack-up of non-crushable power-train components, the vehicle mass, and the test speed.

The secondary impact: Between the occupant and the restraint system and/or the vehicle interior. Occupant responses are measured by parameters such as the HIC, chest g's, chest deflection, and femur loads. The Affected by the vehicle crash pulse, the extent of the intrusion and the intrusion rate into the occupant compartment, the restraint system, the vehicle interior profile/ stiffness, and the dummy construction/ instrumentation.

III. INTEGRATED STRUCTURAL AND OCCUPANT SIMULATION

In Traditional design methodology , the full vehicle crash testing to determine responses of an occupant, restrained or unrestrained contacting vehicle interiors with or without compartment intrusion.Integrated structural and occupant simulation modeling offers several potential advantages over the traditional full-vehicle crash testing.

Some Advantages:

- Early design guidance
- Shorter vehicle design
- Development time
- Optimization of structural and package efficiency,
- Evaluation of design alternatives and reduced prototype test requirements

Fmvss 208 – Frontal Collision

Vehicles impacting a fixed barrier either perpendicular or at a 30 degree angle at a speed of 30 mph must provide protection for the front-seated Hybrid III dummy occupants as follows:

- Head Injury Criterion (HIC) - The resultant acceleration at the center of gravity of the dummy head must be such that the expression.
- Chest Injury (CLIP) - The resultant acceleration at the center of gravity of the dummy chest shall not exceed 60 g's, except for the intervals whose cumulative duration is not more than 3 ms.
- Femur Loads - The compressive force transmitted axially through each dummy upper leg shall not exceed 2,250 lbs.
- Chest Deflection - The chest deflection shall not exceed 76.2 mm

IV. BARRIER TEST

Instruments provide vehicle acceleration/deceleration data experienced in the passenger compartment.Two, tri-axial accelerometers are mounted to the rocker panels at the base of the B-pillar for such measurements. For frontal barrier or rear impacts, longitudinal component of acceleration from underneath the B-pillar, located in an un-deformed area of the vehicle occupant compartment. The deceleration-time history is a superposition of a spectrum of frequencies representing the instrumentation noises, elastic-plastic vibrations, structural collapse, and engine/accessories interactions as they impact one another.

A. Barrier Test- Output

Against a rigid concrete barrier, a 50th percentile male driver (unbelted) with a Steering assembly airbag. Dummies instrumented with triaxial accelerometers at the centers of gravities of the head and chest, and load cells at the femur. Recorded data processed according to SAE J211 specification. The filtered data are then analyzed for calculating injury performance numbers assessing dummy performance in compliance with FMVSS 208.

Figure 1. Mid-sized vehicle crash against a full rigid barrier

TheForce required to change a velocity is proportional to acceleration. Complicating factors such as relative motion for whiplash injury are not considered. The parameter that causes injury, "force", is measured with a force transducer. Assuming that rigid body dynamics apply, understanding that the human body is not a rigid body.

B. Vehicle Response

In the case where a vehicle crashes into a rigid fixed barrier, less stopping distance is required than in braking. The vehicle loses all of its kinetic energy in a fraction of a second through front-end structural deformations. The amount of deformation is equal to the stopping distance of the vehicle. Since the stopping distance of a vehicle in the barrier crash is normally short, a much higher force is generated at the barrier interface. The vehicle stopping distance (or dynamic crush) in barrier tests largely depends on crash pulses. The dynamic crush can be determined by double integration of the vehicle crash pulse with known initial impact velocity.

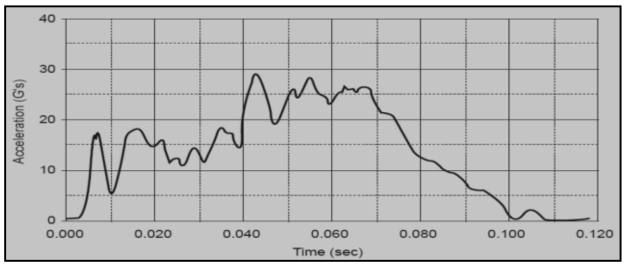

Figure 2. Vehicle deceleration versus displacement

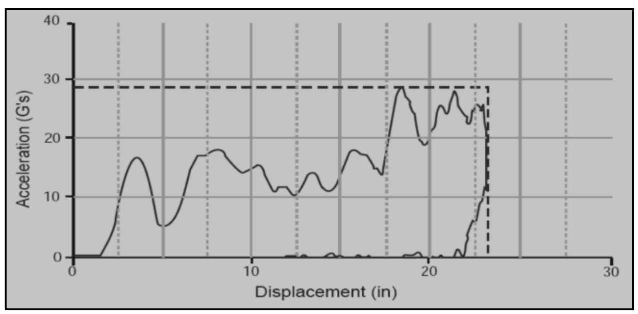

Figure 3. Vehicle deceleration versus displacement

V. VELOCITY-TIME HISTORIES/ VEHICLE AND OCCUPANT

The efficient utilization of the vehicle available package space in front-end structure, which depends on the pulse waveform efficiency, is of vital importance. Square wave is an idealized pulse that is used in many crash-related analyses Acceleration of the vehicle and/or the occupant is directly related to the slope of the velocity-time curve at any time t.The difference, at any time t, between the occupant and the vehicle velocity time curves represents the relative velocity (D v) between them; *and* the displacement of the vehicle and occupant over the ground is represented by the area under their respective velocity-time curves with respect to the time axis, and the relative displacement of the occupant with respect to the vehicle is the area between their respective velocity-time curves.

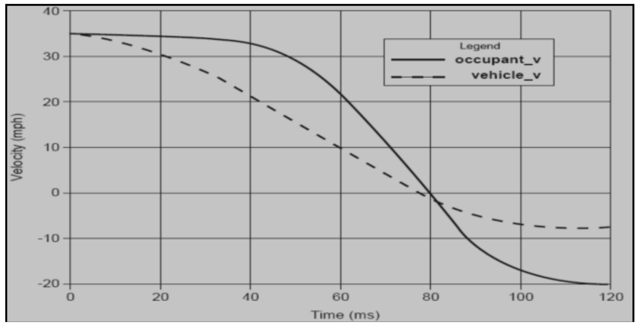

Figure 4. Velocity-time histories/ vehicle and occupant

VI. VELOCITY PROFILES

The shaded area under the velocity curve represents the 24 in of vehicle crush, which is equal to the distance the vehicle travels over the ground Velocity-time diagram of braking.

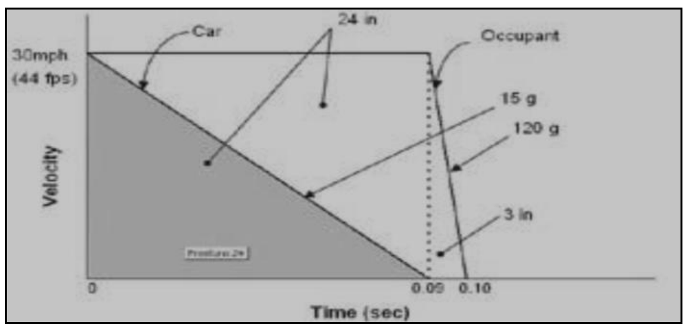

Figure 5. Velocity-time diagram of crashing vehicle

VI. FRONTAL IMPACT ANALYSIS

A frontal crash is a two-impact event

- ***Primary Impact***
- ***Secondary Impact***

Primary Impact: The Vehicle strikes a barrier, causing the front-end to crush. Kinetic energy of the vehicle is expended in deforming the vehicle's front structure. The design of the front-end, rear, or side to crumple in a collision and absorb crash energy is called crash energy management or crashworthiness.

Secondary Impact :The second (secondary) impact occurs when the occupant continues to move forward as a free-flight mass and strikes the vehicle interior or interacts with or loads the restraint system. Some of the kinetic energy is expended in deforming the vehicle interior or the restraint system, and in compressing the occupant's torso. Remaining kinetic energy is dissipated as the occupant decelerates with the vehicle The kinetic energy dissipated during the second impact is a function of the occupant's mass and of the differential velocity of the occupant to the interior.

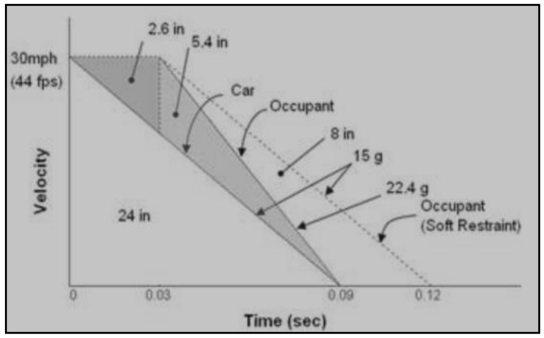

Figure 6. Velocity-time diagram of crashing vehicle and restrained driver

VI. ENERGY ABSORBING MATERIALS

The Energy-absorbing (EA) materials on the interior, and devices such as EA steering columns, belts and air bags provide two important synergistic benefits.

- First, these enhance "ride-down" for the occupant within the vehicle compartment.
- Second, these absorb some of the energy of the second impact

The EA materials can be designed through selection of appropriate characteristics to crush at forces below human tolerance levels. EA materials absorb energy while being crushed, and because of this crush, the occupant's differential velocity with the interior in the second impact is reduced over a longer period of time than that from impacting with a rigid surface. This produces lower deceleration forces on the occupant.

VII. SIDE IMPACT ANALYSIS

The Velocity profiles obtained by the numerical integration of accelerometer data taken from the following locations:

- Center of gravity (CG) of the moving deformable barrier (MDB)
- Non-impacted left-hand rocker of the target vehicle
- Door inner panel at the armrest
- Side Impact Dummy (SID) pelvis
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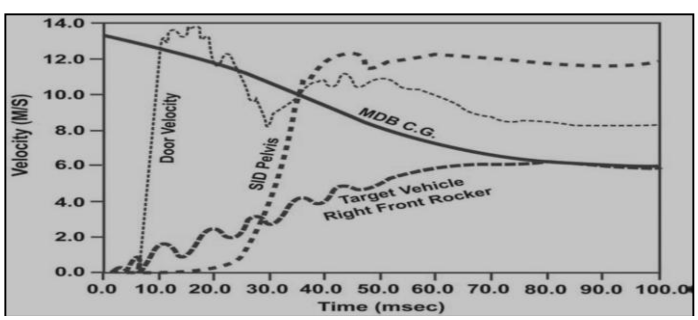

Figure 7. Typical velocity profile in side impact

A. Side Impact -Fbd

The forces acting on the door are: FMDB is the punch-through force of the MDB acting on the door Fstructure is the body side structural resistance of the target vehicle that resists door intrusion.. Force is the integral of the door support frame reaction pressures acting on the door peripheral areas and is shown as one-half of its concentrated load in two parts F_{dummy} is the door-to-dummy interaction force, also is the reaction force acting on the dummy.

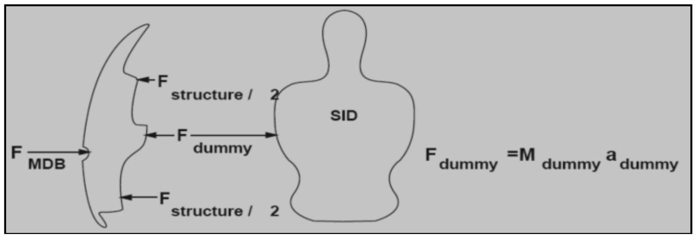

Figure 8. Door and SID "free-body" diagrams

B. Side Impact -Observations

From Newton's Second law, following observations were made Decreasing the MDB punch-through force (*FMDB) would decrease the force* acting on the dummy (F_{dummy} *ummy)* .Decreasing the rate of change in the linear momentum of the door by making the door lighter or decreasing the door intrusion velocity would decrease the force acting on the dummy. Increasing the struck vehicle body side structural resistance (Fstructure) *would* also decrease the force acting on the dummy.

C. Countermeasures For Limiting The Force On The Dummy During Side Impact

Reducing the door intrusion velocity (and hence, its rate of change in linear momentum) via structural upgrading of the body side. Reduces the severity of subsequent momentum exchange between the door and the dummy. Limiting the peak forces acting on the dummy (*Fdummy).*Use a foam cushion with a nearly constant force-crush characteristic or a deployable side airbag. Reduces the MDB punch-through force (FMDB) while also making the door inner sheet metal and trim more compliant for occupant cushioning, thereby further reducing Fdummy. Optimizing the specific stiffness by maximizing the structural stiffness/unit material usage of the vehicle body side structure via efficient structural design and use of an airbag or foam cushion in an optimum combination of the first two strategies.

VIII. STRUCTURAL UPGRADING

The crash event between the MDB and the target vehicle is shortened. MDB slows at a faster rate while the struck vehicle rigid body motion speeds up at a higher rate. The door intrusion and intrusion velocity are reduced. The dummy pelvis, hit by a slower intruding door, is subjected to a milder acceleration as evident by the slope the dummy pelvis velocity curve. The structural upgrade weight penalty to achieve this effect is enormous. The weight penalty is estimated at more than 18 kg (40 lbs) for a 2-door compact vehicle. TRL has shown that certain structural upgrading of the vehicle body side structure could lead to an undesirable intrusion profile of B-pillar/door by tilting inboard at the "waistline" and concentrating the impact load on the occupant in the thorax region. A more desirable crush pattern for the B-pillar/door is to remain upright during side impact for a more evenly distributed impact loading on the occupant.

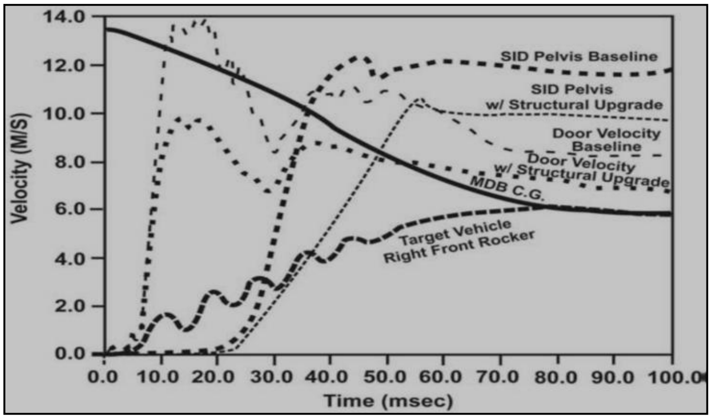

Figure 9. Effects of a hypothetical structural upgrade

IX. EFFECTS OF CUSHIONING

A stiff linear spring constant (K1), increases in direct proportion to the panel deflection (δ) as the dummy leans heavily against the door during side impact. The force (Fdummy) acting on the dummy pelvis, which is equal to K1δ causes the pelvis acceleration (in the Mpelvisapelvis term) to exceed the limits. Initially, when the dummy is hit by the intruding door and as the reaction force (Fdummy) begins to rise, but is less than Fconstant, the stiff spring K1 will deflect up to δ1 until $F_{dummy} = F_{constant}$. At this point onward, the load-limiting spring will begin to crush (δ) at a constant force (Fconstant). The dummy pelvis, subjected to an appropriate level of this constant reaction force from the door, will accelerate at a constant level without exceeding the requirement as long as the cushion does not bottom out.

X. DISCUSSIONS

The crush duration between the MDB and the target vehicle will remain unchanged from the baseline Door velocity profile will remain unchanged. Deploying load-limiting foam cushion contacts the dummy pelvis early in the crash event and accelerates it away from the intruding door sooner than that of the baseline. Consequently, the dummy pelvis will experience a milder acceleration as evidenced from the slope of its velocity history. Strategy is to use a deploying door trim with the load-limiting foam cushion behind it to quickly push the stationary SID away from the intruding door steel at a controlled rate.

Restrained Occupant Models :Two models of chest deceleration to study simulation of a restrained occupant and vehicle front-end dynamics

- A trilinear segment approximation to the chest deceleration
- A sine-wave approximation

The models are used to calculate the required stopping distance by knowing the available vehicle interior space, the required vehicle crush distance and the average vehicle deceleration can then be calculated the occupant velocity is assumed to be constant, the occupant is in a free flight since “belt slack”.

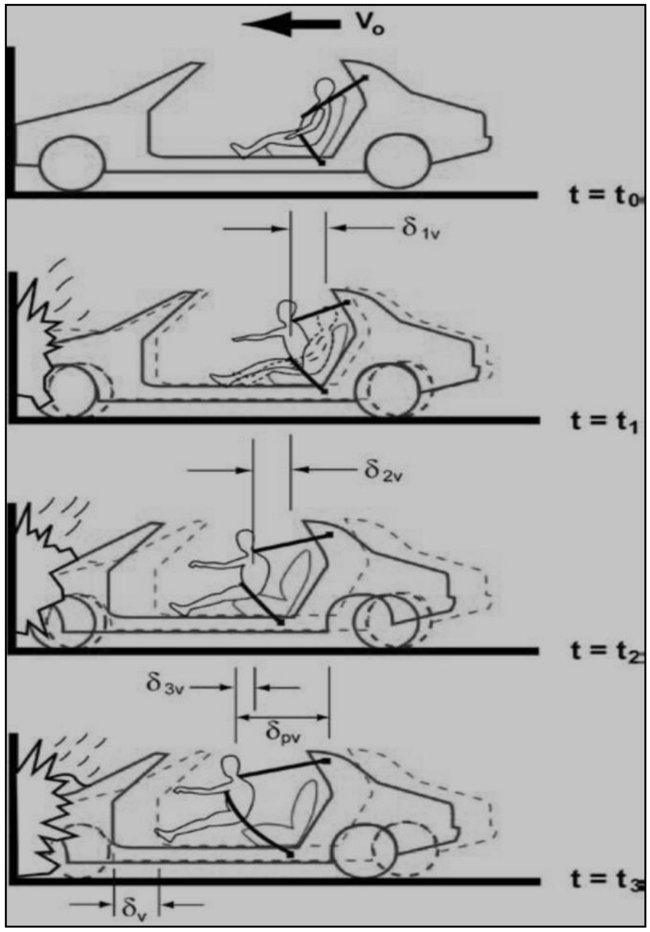

Figure 10. Idealized model

XI. CONCLUSIONS AND FUTURE ENHANCEMENTS

Modern vehicles offer passenger protection systems with a high level of protection in all known types of crash tests. The trend is toward increasingly complex safety systems driven by the desire to attain the best ratings for worst-case scenarios with maximum demands on safety criteria. Improvements can be attained in laboratory situations, but the degree to which this helps vehicle occupants in a real world accident might be unclear. For Mercedes-Benz, real-life safety therefore does not only mean a continuous improvement of occupant protection in laboratory tests, but rather a broad consideration of the possible spectrum of real world accident scenarios. Based on a holistic approach of active and passive safety, the true potential for further improving occupant protection in passenger car accidents can be realized by: · Preventive occupant protection in the pre-crash phase · Covering the individual needs of the occupants in the crash phase. · Optimizing the chain of emergency response in the post-crash phase. With PRE-SAFE, Mercedes-Benz has developed an initial system for preventive occupant protection. Other applications are in the development phase. Other components of the real life safety strategy under development are individual safety and care-safe. This is a mechanism whereby the occupant is in contact with the vehicle interior before the vehicle velocity approaches zero. Helps in a possible reduction of occupant loads since the second collision occurs at a lesser relative velocity than that would have occurred when the vehicle is completely stationary. It is then possible that the second collision velocity may be equal to or greater than the initial impact velocity.

The second collision velocity varies as the square root of the ratio, if ESW deceleration assumed for the vehicle .A more detailed ride-down analysis possible for other vehicle deceleration profiles.

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