

MODULAR DOOR SYSTEM FOR SIDE IMPACT SAFETY OF MOTOR VEHICLES

John Townsend, Michael Kaczmar

Joalto Design Inc., Southfield MI 48034, USA

Mohamed El-Sayed

Kettering University, Flint MI 48504, USA

Paper: 479

ABSTRACT

Side impact collision is one of the toughest safety challenges facing the Auto Industry today. Over thirteen thousand deaths, due to side impact, occurred during 1998 in the United States alone. The main difficulty in designing for side impact collisions is the limited crumple zone between the impacting vehicle and the impacted occupant.

This paper presents a proprietary side impact protective door system within the space between the outer skin of a car door and the occupant, which will be as efficient as those already standard in frontal impact. The main objective for introducing the side impact structural system is to maximize energy absorption and minimize injury to the occupant.

The developed structural side impact door system acts as a Primary Structure, to be assembled as a truly modular entity. This primary structure is also packaging modular in the sense that it acts as a carrier for the door latch, window regulator and hinges.

A variation in safety and structural performance of the developed door system can be achieved by integrating the structural modular door with the vehicle body, using a patented integration system known as Door And Chassis-frame Integration Technology (DACIT). Unlike the traditional doors, that are just suspended weights, the modular door is truly structural and therefore adds strength to the vehicle body. When DACIT is used with the door system the vehicle door becomes part of the overall vehicle structure.

The design and development of the side impact modular door system for different size vehicles with and without DACIT will be discussed. In addition, the five stars rating achieved during several side impact crash tests simulating Sport Utility Vehicles hitting mid-size vehicles, equipped with the developed modular door system, will be presented.

INTRODUCTION

With the ongoing development of lighter, fuel-efficient cars that are subjected to ever increasing safety requirements, the automotive engineer must strive to meet all the structural requirements of what has typically been thought of as conflicting criteria. Enabling a vehicle to be safe and fuel-efficient often

demands the structural engineer to compromise between weight savings and crashworthiness. These demands, combined with the recent sharp increase in the amount of Light Truck Vehicles (LTV's) on North American roadways, has brought the matter of vehicle incompatibility and the crashworthiness of smaller vehicles to the attention of the automotive consumer.

At the 1998 International Enhancement of the Safety of Vehicles (ESV) Conference, numerous papers from leading experts in the field of vehicle crashworthiness were presented [1]. Three different parameters of side impact were argued to be the most crucial contributor. Firstly, there was the belief that vehicle mass is the most important aspect that needs to be addressed. Others believed that geometry, i.e. variance in main vehicle structure heights, was the most critical design issue. Finally, a third contingent argued that the variable stiffness between full-framed and unit-body type vehicle structures should be considered the most influential factor in developing compatible vehicles. While all arguments were based on test data and analysis, the vast difference of opinion indicated that the solution to incompatibility could not be reduced to one factor alone. After further investigation, it was apparent that since no single variable was the dominant cause, a safety system that worked to improve vehicle compatibility in terms of stiffness and geometry would be a valuable vehicle component.

In this paper we discuss the Joalto proprietary side impact protective door systems introduced within the space between the outer skin of a car door and the occupant, which will be as efficient as those already standard in frontal impact. The main objective for introducing the side impact structural system is to maximize energy absorption and minimize injury to the occupant.

JOALTO MODULAR DOOR TECHNOLOGY

To address several automotive safety issues, Joalto Design Inc. has developed a structurally modular door technology with several attributes. The patented modular door technology [2], combines light weight, reduced cost, structural stiffness, durability and packaging modularity in a set of space frame door modules. The developed structural door modules act as Primary Structures, to be assembled

as truly modular entities. Each primary structure is packaging modular in the sense that it acts as a carrier for the door latch, window regulator and hinges. The most important attribute of the developed modular door technology, however, is the side impact safety performance.

The Joalto door technology has been developed based on the Cruciform Side Intrusion Beam (XSIB), [3], which incorporates the side intrusion beam and the primary door structure as one element Figure 1.

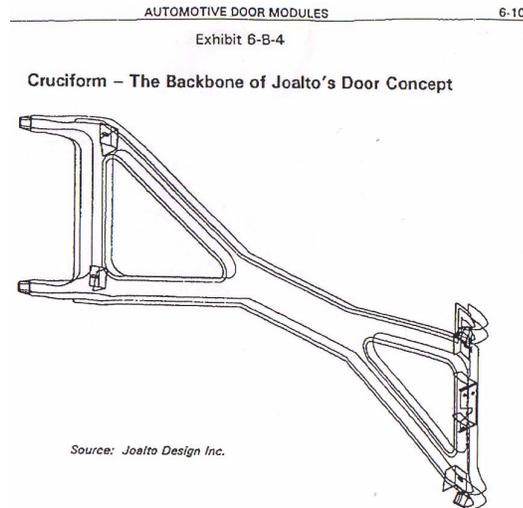


Figure 1.

Cruciform Side Intrusion Beam (XSIB).

The XSIB equipped door design is intended to resist deformation into the passenger compartment using geometry that provides protection to a larger range of impact heights. In comparison, standard tubular side intrusion beams leave the occupant vulnerable to impacting vehicle encroachment above and below it’s smaller cross-section.

A variation in safety and structural performance of the developed door system can be achieved by integrating the structural modular door with the vehicle body, using a patented integration system known as Door And Chassis-frame Integration Technology (DACIT), [4]. The reintegration is intended to distribute the impact energy throughout most of the vehicle sides and further reduce the localized door deformation.

Unlike the traditional doors that are just suspended weights, the modular door is truly structural and therefore adds strength to the vehicle body. When DACIT is used with the door system the vehicle door becomes part of the overall vehicle structure.

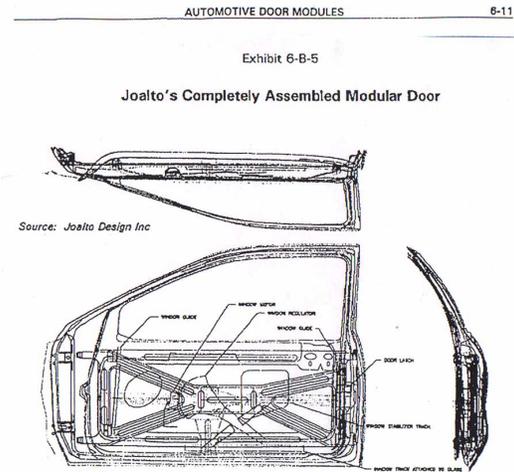


Figure 2.

Jualto’s assembled modular door.

The developed Joalto modular door system can be produced through different manufacturing options and materials. Figure 2, shows a stamped steel module while Figures 3-5, show different assembly options for hydro-formed tubes.

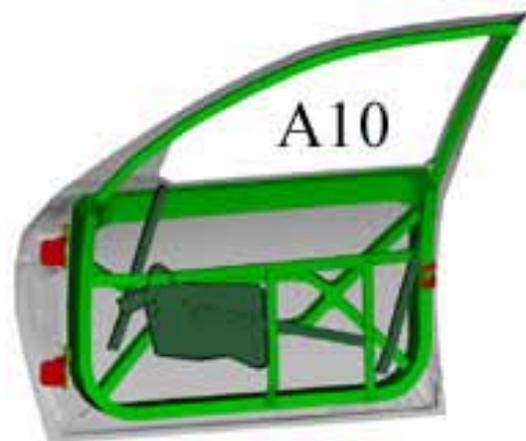


Figure 3.

Hydro-formed modular door and frame.

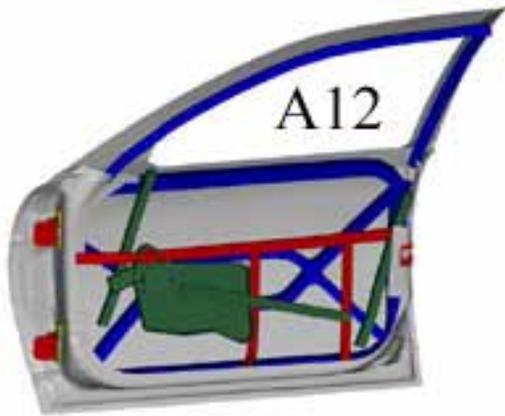


Figure 4.
Modular door with separate secondary beam.

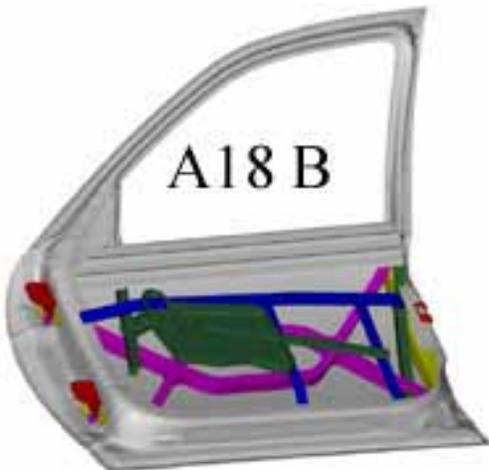


Figure 5.
Modular door with separate frame.

In a recent independent study for modular doors technology, it was concluded that the Joalto door module while being the least in manufacturing cost: “provides the opportunity for performance improvements with regards to crash performance (side impact), vehicle driving performance (increasing the stiffness of the entire car body), as well as to the durability of the door itself. Furthermore, heavy and load introducing

components, for example, window regulators can be supported better by a frame structure than by a panel.

This design aims at separating the door outer panel from the load carrying structure. In general, this increases the styling design flexibility, both regarding shapes and material types” [5].

SIDE IMPACT TESTS

To demonstrate the crash performance of the Joalto door systems, a set of side impact tests were designed to reflect the current fleet of vehicles on North American roads. The developed Joalto side impact tests resembled a collision from an average sport utility vehicle into a midsize sedan door. The goal of these tests was to simulate side impact with a sport utility vehicle in terms of bumper height.

In order to test the door structure in a side impact, without actually testing the crashworthiness of the entire vehicle, a test apparatus was developed where midsize sedan doors, seats and seatbelts can be interchanged on a reusable, test bed in Figure 6.

The crash apparatus was developed to allow reuse of the attachments such as the hinge face (A-pillar) and the rocker panel. These parts were made of reinforced steel plate in order to be able to sustain impact from multiple tests. A fabricated B-pillar that replicated the bending moment of the production piece was used in place of an actual pillar. The B-pillar was made to be deformable and replaceable so that it would deform like a production model and not be too rigid to allow deformation of the door.

The target door and bumper were placed such that the FMVSS-214 specified 27° angle of impact was achieved. Instead of creating the specified hex-cell movable deformable barrier (MDB), a production light truck bumper was used. The bullet apparatus consisted of a bumper assembly from a popular late model pickup. The stock bumper was trimmed to clear the A-pillar of the target vehicle in order to minimize the role of the A-pillar in dissipating the energy of the collision. The stock bumper brackets were replicated in structure and welded to generic frame rails that, like the B-pillar, matched the same bending moment as the production units for the first 12 inches of the striking vehicle frame.

The average LTV bumper height was found to be 24 inches from ground level, and this value was used for the test. Additionally, the average weight of these vehicles was computed to be approximately 4000 lbs. It was intended to use both this bumper height and bullet mass in replacement of the FMVSS-214 specified parameters. However, the facility in which these crash tests were performed could not generate the increased level of impact energy that the increased weight required. Therefore, the weight

remained at 3027 lbs., and for the test its incoming speed was 30.2 mph. Since baseline doors were tested, any performance difference between the stock, unmodified doors and the prototype door systems would be evident, regardless of weight

Four three-axis load cells were placed behind the frame rails of the bumper apparatus, two on each rail. In order to capture any moment in the frame rails one load cell was placed above and one below each frame rail. Accelerometers were placed in 5 locations on the door, one at each corner of the inside panel and one at the center of the cruciform. One accelerometer was placed on the B-pillar, aft of the striker latch. A BioSID test dummy was used to measure the occupant loads in this crash situation.

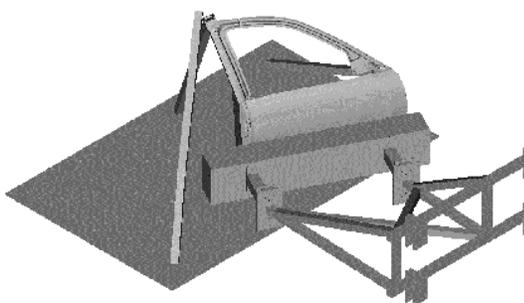


Figure 6.
Crash Test Rig.

Since the crash tests performed used a new apparatus and the geometry was somewhat different from the crash facilities regular tests. Several preliminary impacts at lower speeds were carried out. The actual crash data used for analysis consisted of four tests. The first two tests were carried out using the production sedan doors, one without the BioSID, and the second with the BioSID. The data from the non-dummy equipped baseline test was used to prove consistency of results between impacts. The third test featured the cruciform side intrusion beam and was carried out with a BioSID dummy positioned and belted into the production sedan seat. The final test used a cruciform beam that structurally reintegrated the door with the vehicle body using DACIT.

RESULTS AND CONCLUSIONS

After filtering the raw data, several measurements were used to rate the performance of the doors. The Thoracic Trauma Index (TTI), Pelvic Acceleration, Head Injury Criteria (HIC), maximum

door deformation and maximum bumper loads were compared between the baseline and modified doors and, where applicable, to the threshold standards for the FMVSS-214 tests as shown in Table 1. Finally the unofficial “star” ratings were compared.

Maximum door deformation in test 247 was decreased by 2.4 inches over the baseline doors. Test 249, which uses the cruciform beam utilizing DACIT, showed a reduction of 3.6 inches. Additionally, the final displacement of the Joalto doors were 3.0 and 4.6 inches less than that of the production sedan doors respectively.

Table 1.

Comparative Crash Results

	Standard Sedan Door R0098247	Joalto Cruciform Door R0098248	Joalto Cruciform Door w/ DACIT R0098249
TTI (g's)	76.46	52.70	61.37
Pelvic Acceleration (g's)	49.41	46.80	49.97
Head Injury Criteria (HIC)	87.29	61.69	88.09
Mid-door Displacement (in)	-18.0	-15.6	-14.4
Mid-door Displacement (in) @ 150 ms	-17.28	-14.28	-12.72
Top Front (lbf)	12040	13132	17324
Bottom Front (lbf)	8884	4633	5306
Top Rear (lbf)	3673	4765	4690
Bottom Rear (lbf)	4412	4290	5485

Figure 7, summarizes mid-door deformation. The mid-door deformation at 150 ms represents the final position of the center of the inner door panel on the production door, and the location of the upper-center component in the cruciform beams. The differences in the maximum deformation and the final deformation illustrate the elastic deformation or “spring-back” in the door beams. This indicates that the prototype beams need to be modified such that there is more plastic deformation.

The Joalto XSIB showed a reduction in the Thoracic Trauma Index (TTI). This was decreased by 32% in test 248 and 19.8% in test 249. This increased the subjective “star” ratings from a 3 star to a 5 star. This means that compared to the production baseline door, the Joalto Cruciform door showed a marked increase in the level of side impact protection. One of the goals set before the test was to show that

structural reintegration of the door would be the most beneficial side impact protection system. Test results indicate that the beam was too rigid and therefore raised the acceleration levels as a result of the reduction in intrusion. The level of spring-back that occurred in this test supports this conclusion. With fine-tuning of the beam, this can be eliminated.

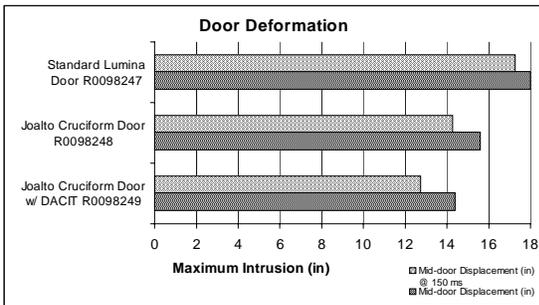


Figure 7.

Door Deformation and Spring-back.

Compared to the baseline, production door, the BioSID dummy showed a lower pelvic acceleration in the Joalto Cruciform Door (248). The pelvic accelerations were reduced by 5.3% with the 248 beam but increased slightly when the beam was structurally reintegrated with the body. This is attributed to a localized beam failure that occurred in near the hip point of the test dummy. The failure occurred near a pie-cut and welded section of the beam. This reflects the way the prototype beams were fabricated. This feature and fabrication method would not occur in a production environment and therefore in a production beam this material anomaly would not exist.

Analysis of the peak bumper loads in each of the tests showed that the Joalto door distributed the impact load across a broader area than the production door, thereby creating a lower localized intrusion into the occupant cabin.

After inspection of the parts used in the impact tests, visual conclusions could be made as well. A closer look at the deformation of the seatbacks as a result of door intrusion showed that the seat used in the production door impact test was bent inward at a much greater angle than the seat used in the Joalto door beam (248) test. This trend continued through test 249.

The seat back accelerometers showed that the seat back in test 247 was deformed 32.4 in., 6 in. less deformation occurred in test 248, 18 in less in test

249. This indicates that the door intrusion near the B-pillar and seatback area was significantly less.

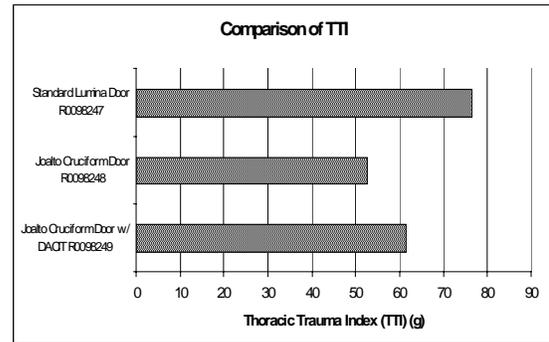


Figure 8.

TTI Comparison.

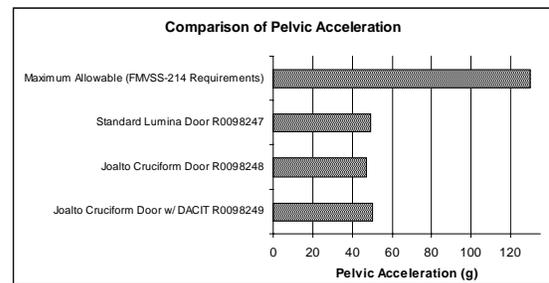


Figure 9.

Pelvic Acceleration Comparison.

The deformation of the bumper in the 248 test was markedly greater than that used in the 247 test. The bumper was folded in the center showing a larger fork effect and was flattened in a greater amount. This indicates that the door and B-pillar system was able to withstand a higher impact energy threshold and energy dissipation was directed back into the impacting vehicle.

The overall results of this test show that the Joalto Design Cruciform side intrusion beams have potential for increased passenger safety, not only in disparate situations like a LTV-midsize sedan impact, but in impacts between vehicles in the same class. With additional development, the safety benefits can be maximized, and if used in conjunction with other systems, the occupant protection potential can be fully realized.

REFERENCES

1. Disparity of Vehicle Size in Side Impact Accidents, NHSTA International Conference, Windsor, Canada, June 1998.
2. Vehicle Closure Panel Having An Intrusion Beam as Primary Structure, Patent Number 6196619, March 2001.
3. Improvements in Sliding Automobile Door, Patent Number 5524960, June 1996.
4. Integrated Motor Vehicle Door and Chassis, Patent Number 5908216, June 1999.
5. Automotive Door Modules, ITB Group Ltd., September 2000.