

THE EFFECT OF OCCUPANT PROTECTION BY CONTROLLING AIRBAG AND SEATBELT

Teru Iyota

Toshihiro Ishikawa

Mazda Motor Corporation

Japan

Paper No.198

ABSTRACT

Recent research revealed that greater proportion of heavier male occupants and lighter female occupants sustain serious injuries in frontal crash. The cause is thought that the frontal occupant restraint systems are designed to minimize the injury risk for 50th percentile occupant only, and its characteristics are not adjustable. In this study, vent hole area of the airbag and load limiter force of the seat belt were controlled according to occupant sizes, and the effect of occupant protection for different occupant sizes were evaluated.

MADYMO 3D was used in this analysis, and evaluation was performed not only in the 5th, 50th, and 95th percentile occupant size dummies, but also in the various physiques occupant size dummies. The various physiques occupant size dummies were created using the physique scaling application of MADYMO.

As a result, all size of occupant dummies, from 5th to 95th percentile occupant dummies were evaluated, and injury severity of those occupant dummies were described.

INTRODUCTION

Recently, injury risks of occupants have decreased by wearing seat belts and equipping airbags, and these restraint systems have been improved to decrease injury risks moreover. Figure 1 shows results of accident analyses in the United States, which were investigated by NHTSA. Number of lives saved by seat belts and airbags are increasing every year. In 2000, seat belts saved 11889 lives and airbags saved 1584 lives.

And it is known that the control of characteristics of the airbag and the seat belt according to impact severity is effective to reduce the occupant injury risks. Vehicles with such restraint systems are beginning to prevail throughout the

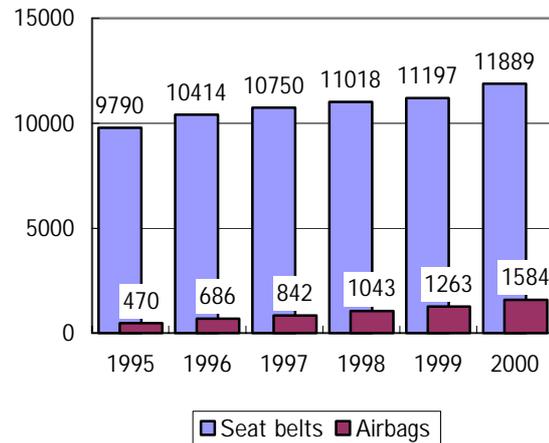


Figure 1. Number of lives saved by wearing seat belts and equipping airbags

world.

On the other hand, analyses of Phase 4 and 5 of the Co-operative Crash Injury Study (CCIS) reported that heavier male drivers and lighter female drivers tend to sustain more serious injuries than average male drivers.

Results of frontal crash tests, with 5th percentile female dummies and 50th percentile male dummies conducted by NHTSA, show that the injury risks of the 5th percentile dummies are different from those of the 50th percentile dummies.

Therefore, researches to reduce injury risks for all occupants with various physiques by controlling restraint systems have been conducted recently.

In this study, characteristics of an airbag and a seat belt are controlled according to occupant physiques, and the effects are evaluated with various occupant physiques. Objectives of this study are as follows.

- The characteristics of an airbag and a seat belt, which minimize the injury risks for three typical occupant physique dummies (5th percentile female dummy, 50th percentile male dummy and 95th percentile male dummy), are found and the injury reduction effects are clarified.

- These characteristics are applied to various physique dummies between 5th percentile female dummy and 95th percentile male dummy, and the differences in the injury risks are clarified.

METHODS

Simulation Model

MADYMO simulation was used in this study. Typical small car layout was used for this simulation, with belted driver in 56km/h (35mile/h) full frontal crash against a rigid barrier.

Specifically, the model was made as follows.

- Airbag volume: 45 liters
- Inflator output: 160kPa
- Seat belt: with pre-tensioner and load limiting retractor (LLR)

The following dummy models are used.

- 5th percentile female Hybrid III dummy
- 50th percentile male Hybrid III dummy
- 95th percentile male Hybrid III dummy
- Scalable Hybrid III dummy model

These dummy models are packaged in MADYMO.

Seating positions for each dummy model is as follows.

- 5th percentile dummy: Foremost pos.
- 50th percentile dummy: Middle pos.
- 95th percentile dummy: Rearmost pos.
- Scaled dummies: According to the physiques, seating position changes between foremost position and rearmost position.

Characteristics of airbag and seat belt control

In this study, controlled objects according to the occupant physiques were characteristics of airbag and seat belt, which are most popular occupant restrain systems. The airbag characteristics are mainly determined by inflator characteristics and vent hole area. The seat belt characteristics are mainly determined by characteristics of pre-tensioner and LLR. In this study, the vent hole area and the LLR characteristic were chosen as the controlled objects to simplify this study. Figure 2 shows the controlled characteristics of the vent hole area and the

LLR load used in this study. The vent hole area has two stages and they are switched with elapse of time. The LLR load also has two stages and they are switched by extending length of the seat belt. For 5th percentile female dummy, only the lower load level is used.

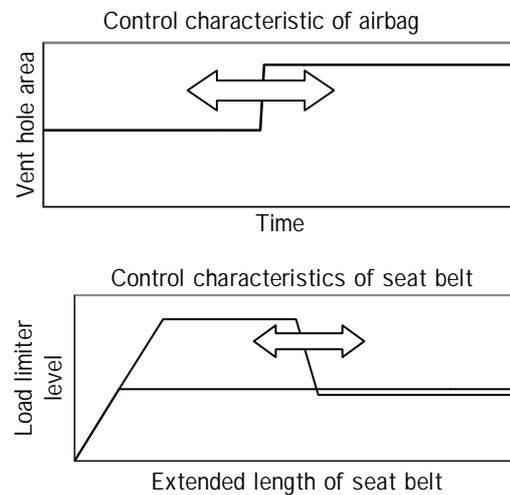


Figure 2. Control characteristics of airbag and seat belt

Evaluation procedure

Examinations are conducted by comparison of injury values and restrain system characteristics, in case of conventional “base system” and “control system.”

In the “base system,” the vent hole area and the LLR load have single characteristic, which are determined to minimize the injury values for 50th percentile male dummy.

In the “control system,” the vent hole area and the LLR load are controlled according to occupant physiques. Those control characteristics are determined by MADYMIZER, mathematical programming algorithm in MADYMO. The design variables are vent hole, which includes two different areas and three changing times, and LLR, which includes two different loads and two changing lengths. In this optimization, the rating formula of US-NCAP shown below is used as the objective function.

$$P_{COMB} = P_{HEAD} + P_{CHEST} - (P_{HEAD} \times P_{CHEST})$$

$$P_{HEAD} = \frac{1}{1 + \exp(5.02 - 0.00351 \times HIC36)}$$

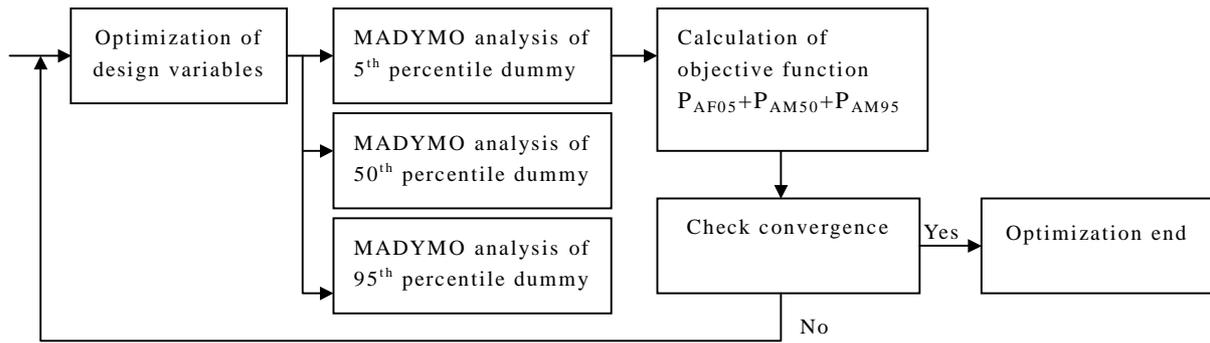


Figure 3. Optimization flow chart for three occupant physiques

$$P_{CHEST} = \frac{1}{1 + \exp(5.55 - 0.0693 \times CHEST\ G)}$$

An optimized flow, as shown in figure 3, is used to derive the specifications, which can minimize the injury values for three occupant physiques (5th percentile female dummy, 50th percentile male dummy and 95th percentile male dummy) simultaneously. The injury values of three physiques are compared between base system and control system. Moreover, some occupant models with middle physiques between 5th percentile dummy and 50th percentile dummy, between 50th percentile dummy and 95th percentile dummy are created using MADYSCALE in MADYMO,

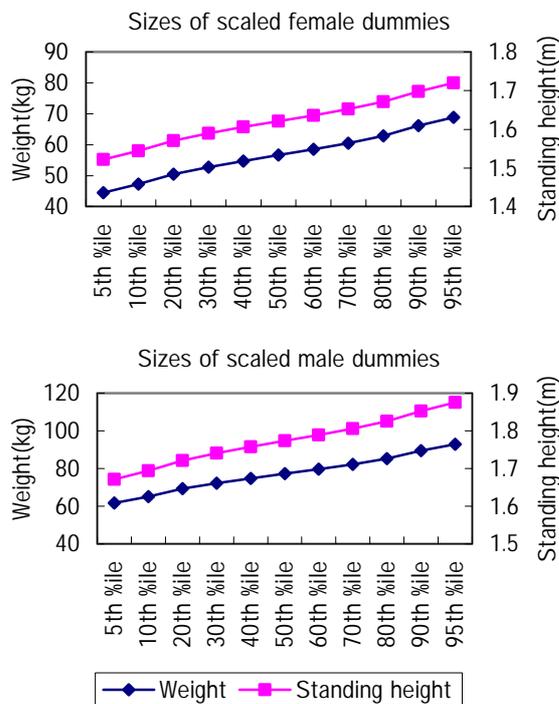


Figure 4. Sizes of scaled dummies

to evaluate injury value difference by physiques. Female models and male models for every 10th percentile are created as the middle physiques as shown in figure 4. The injury values, when applying three specifications derived by the optimization flow to these dummies, are calculated, and those results are compared.

RESULTS

Effect of injury risk reduction by the airbag and the seat belt control

The injury values in the “base system” HIC, chest G’s and P_{comb} (US-NCAP injury index) of the three typical occupant physiques (5th percentile female, 50th percentile male and 95th percentile male) in the “base system” are shown in figure 5. Each injury value is normalized with the injury value of 50th percentile male. The chest G’s and P_{comb} of 5th percentile female and the HIC, chest G’s and P_{comb} of 95th percentile male are higher than those of 50th percentile male. Especially, the HIC of 95th percentile male

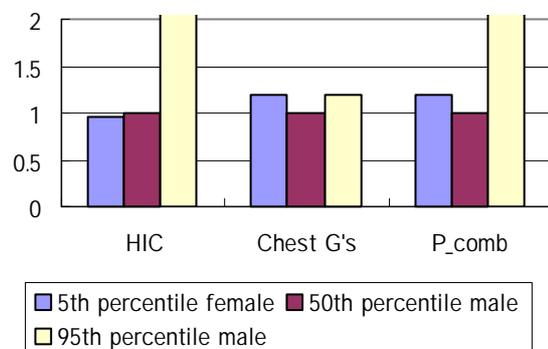


Figure 5. Comparison of injury values in the “base system”

is much higher.

Optimized specifications for three occupant physiques Figure 6 shows the control characteristics of the optimized vent hole area and LLR load. In the vent hole characteristics, the switch timing of the vent hole area, from small to large, delays in the order of dummy size, 5th percentile female, 50th percentile male and 95th percentile male. In the LLR characteristic, for 5th percentile female, only lower load is used. For 50th and 95th percentile male, the load is controlled from high to low, and the extending seat belt length, at the load change, for 95th percentile male is longer than that for 50th percentile male.

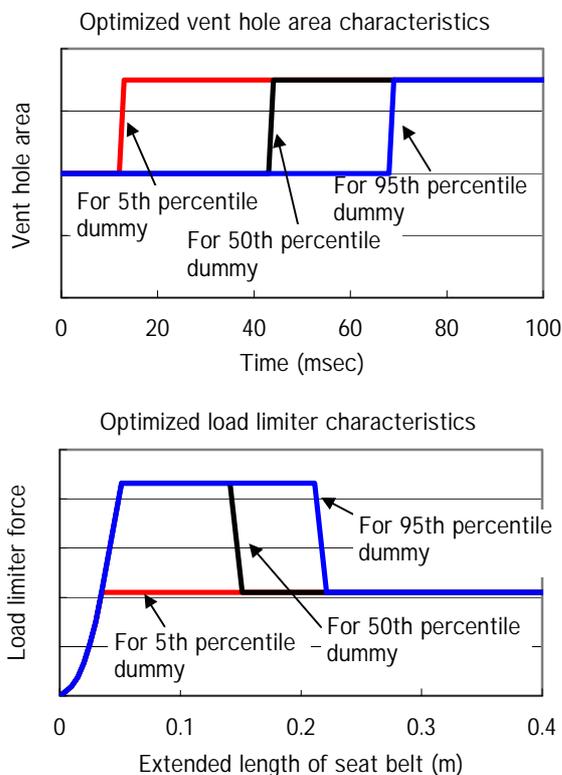


Figure 6. Control characteristics of the optimized vent hole area and the LLR

The injury values in the “control system” Figure 7 shows the injury values (HIC, chest G’s, and P_{comb}) when the optimized specifications are applied to each dummy. Each injury value is normalized with the injury value of 50th percentile male. All of the injury values of 5th percentile dummy are almost the same as those of 50th percentile male. Although

the HIC of 95th percentile male is higher than that of 50th percentile male, the difference in the control system is smaller than that in the base system.

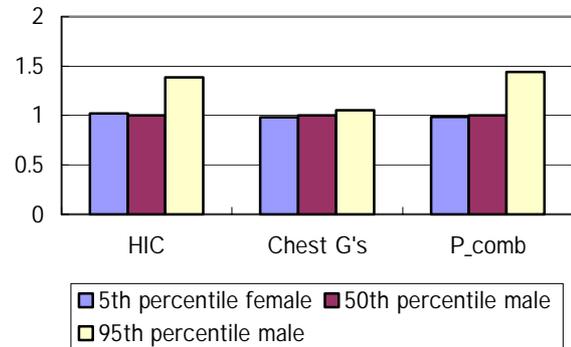


Figure 7. Comparison of the injury values in the “control system”

Figure 8 shows the comparison of injury values between the base system and the control system. Each value is normalized with the injury value in the base system. All injury values are lower than those in the base system except the chest G’s of 50th percentile male.

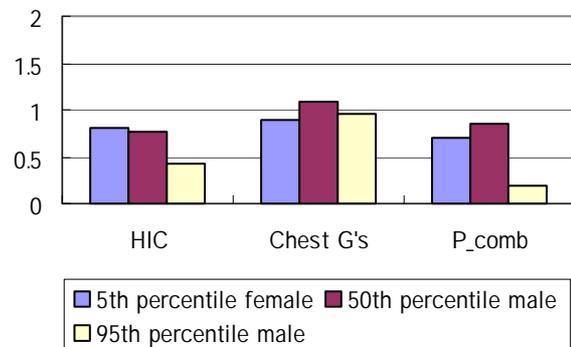


Figure 8. Comparison of the injury values in the “base system” and the “control system”

Evaluation of various occupant physiques

The P_{comb} is calculated by applying the three optimized specifications (for 5th percentile female, 50th percentile male and 95th percentile male) to various occupant physiques, which are made by MADYSCALE, is shown in figure 9. The dummy weight is indicated on the horizontal axis as an index of occupant

physique. In case of the specification for 5th percentile female, if the occupant physique is enlarged from the 5th percentile male, the P_{comb} is almost equivalent until approximately 60kg. However the P_{comb} increase rapidly over 60kg.

In case of the specification for 50th percentile male, if the occupant physique becomes smaller than the 50th percentile male, the P_{comb} increase gradually. If the occupant physique becomes larger, the P_{comb} increase rapidly from around 85kg and over.

In case of the specification for 95th percentile male, if the occupant physique becomes smaller, the P_{comb} increase gradually.

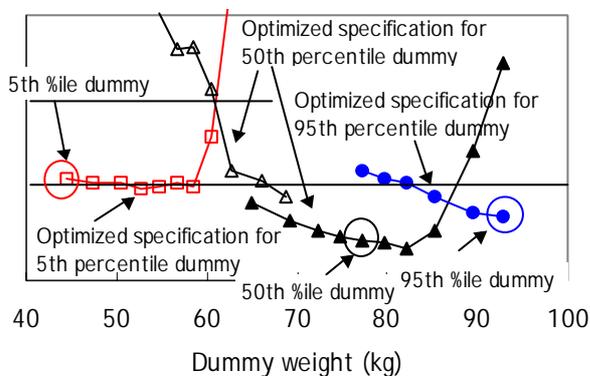


Figure 9. P_{comb} for various dummy sizes when applying three optimized specifications

DISCUSSION

Effect of injury risk reduction by airbag and seat belt control

Injury values in the “base system”

In the base system, it is considered why chest G's of 5th percentile female and HIC

and chest G's of 95th percentile male get worse than those of 50th percentile male.

Figure 10 shows behaviors of 5th percentile female, 50th percentile male and 95th percentile male when each dummy moves to foremost position. The 50th percentile male deforms the airbag sufficiently, and moves just in front of the steering wheel. On the other hand, the 5th percentile female deforms the airbag only a little. The 95th percentile male deforms the airbag completely and the head strikes the steering wheel. Therefore, though the kinetic energy of 50th percentile male seems to be absorbed by the airbag and seat belt efficiently, the kinetic energies of the others do not seem to be absorbed adequately.

Figure 11 shows time histories of the head and chest accelerations of 5th percentile female, 50th percentile male and 95th percentile male. The chest acceleration of 5th percentile female peaks at about 45msec and the peak value is higher than that of 50th percentile male. This is thought that the LLR load mainly determines the value at that time. Because the LLR load in the base system is the same for each dummy and the mass of 5th percentile female is smaller than that of 50th percentile male. This is the reason why the chest G's of 5th percentile female is higher than that of 50th percentile male.

The head acceleration of 95th percentile male increases rapidly at about 80msec because of the contact between the head and the steering wheel. This is thought that since the mass of 95th percentile male is larger than that of 50th percentile male, the restraint forces by the seat belt and the airbag are too low. Therefore, the forward moving distance of the 95th percentile dummy becomes larger and the head

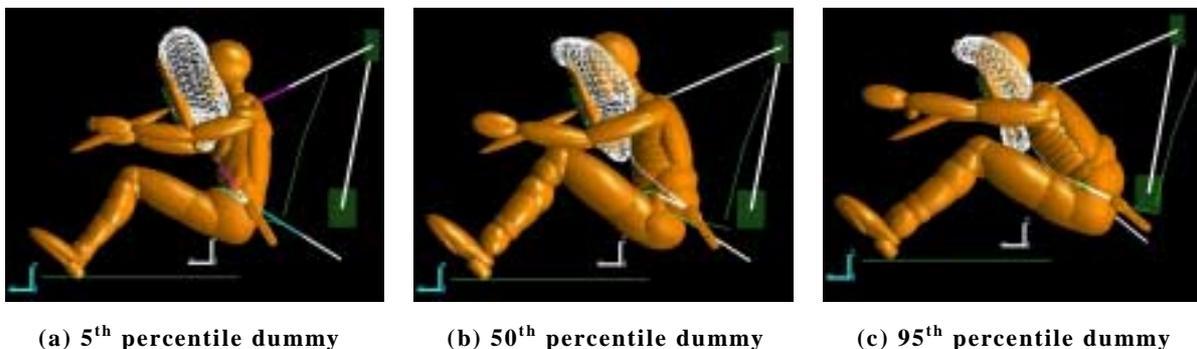


Figure 10. Behaviors of 5th percentile female dummy, 50th percentile male dummy and 95th percentile male dummy move to foremost position

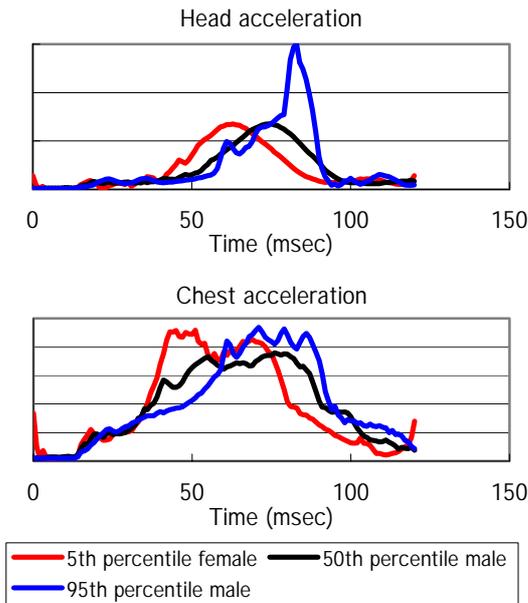


Figure 11. Head and chest acceleration in the base system

impacts against the steering wheel. It is necessary that the value after the contact against the steering wheel is to be treated as a reference value, because the steering shaft is treated as a rigid body in this simulation model.

Injury values in the “control system” Reasons why the injury values of 5th percentile female and 95th percentile male in the control system are reduced, compared with those for the base system are considered.

Figure 12 shows time histories of the head and chest accelerations, the airbag internal pressures and the shoulder belt loads of 5th percentile female in the base system and the control system. It is confirmed that the head and chest accelerations in the control system is reduced because of the reduction of the airbag internal pressure by the expansion of vent hole area and the reduction of the shoulder belt load by the use of the lower load of the LLR.

Figure 13 shows the behaviors of 5th percentile female in the control system when the dummy moves to foremost position. The dummy deforms the airbag enough and moves until just in front of the steering wheel. The kinetic energy of the dummy seems to be absorbed by the airbag and seat belt efficiently.

Figure 14 shows time histories of the head and chest accelerations, the airbag internal pressures and the shoulder belt loads of

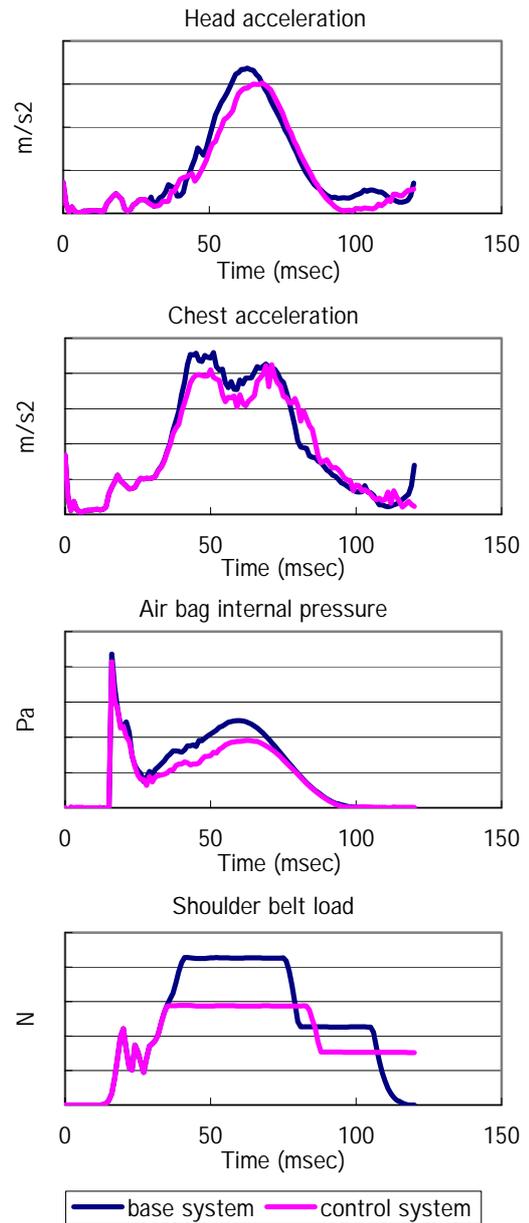


Figure 12. Head and chest accelerations, airbag internal pressure and shoulder belt load of 5th percentile female dummy

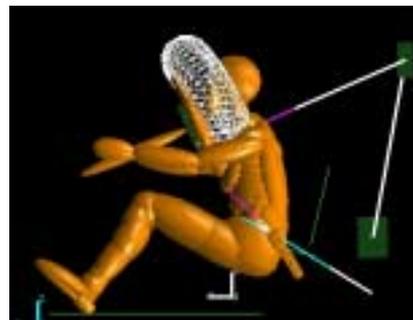


Figure 13. Behavior of 5th percentile female dummy moves to foremost position

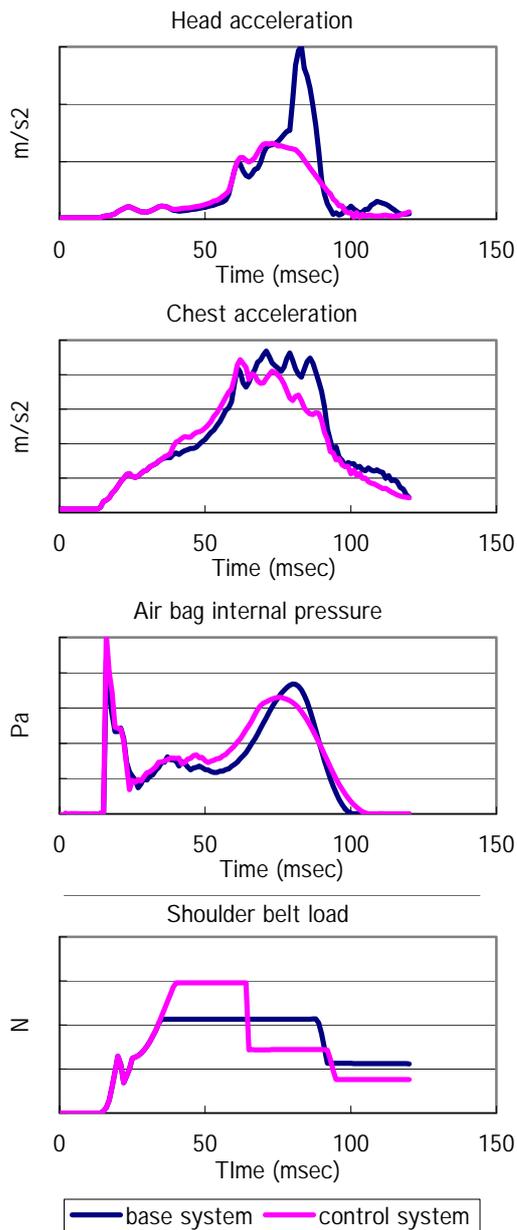


Figure 14. Head and chest acceleration, air bag internal pressure and shoulder belt load of 95th percentile male dummy

95th percentile male in the base system and the control system.

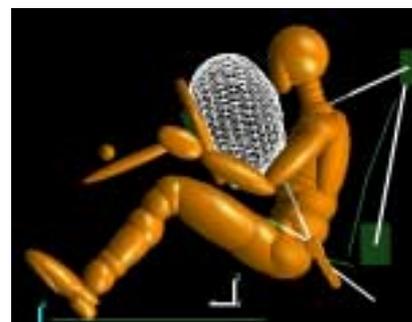
The airbag internal pressure between about 40msec and 70msec in the control system is higher than that in the base system because of the reduction of the vent hole area. Also, the shoulder belt load until about 60msec in the control system is higher than that in the base system because of using the higher load of the LLR.

Therefore the forward movement of the dummy becomes shorter, so the contact between the head and the steering wheel

does not occur.

Then, it is considered why the HIC of 95th percentile male in the control system is still larger than that of 50th percentile dummy.

Figure 15 shows the behavior of 50th percentile male and 95th percentile male at 45msec when the airbag deploys fully. There are some spaces between the 95th percentile male and the airbag, because the seat position for 95th percentile male is rearmost position. Therefore, it is considered that delayed restraint force of the airbag is one of the reasons for worth HIC than 50th percentile male.



(a) 50th percentile male



(b) 95th percentile male

Figure 15. Behavior of dummies when air bag deploys fully

Evaluation for various dummy sizes

The changes of the injury risks for various occupant physiques are discussed. From figure 9, the P_{comb} when applying the specification for 5th percentile female dummy and the specification for 50th percentile male dummy to 70th percentile female dummy is much higher than that of 5th percentile female dummy and 50th percentile male dummy respectively. In addition, 70th percentile female dummy is about 60kg physique.

Figure 16 shows time histories of head and chest accelerations, airbag internal pressures and shoulder belt loads of 70th percentile female dummy when 5th percentile male dummy and 50th percentile male dummy specifications are applied.

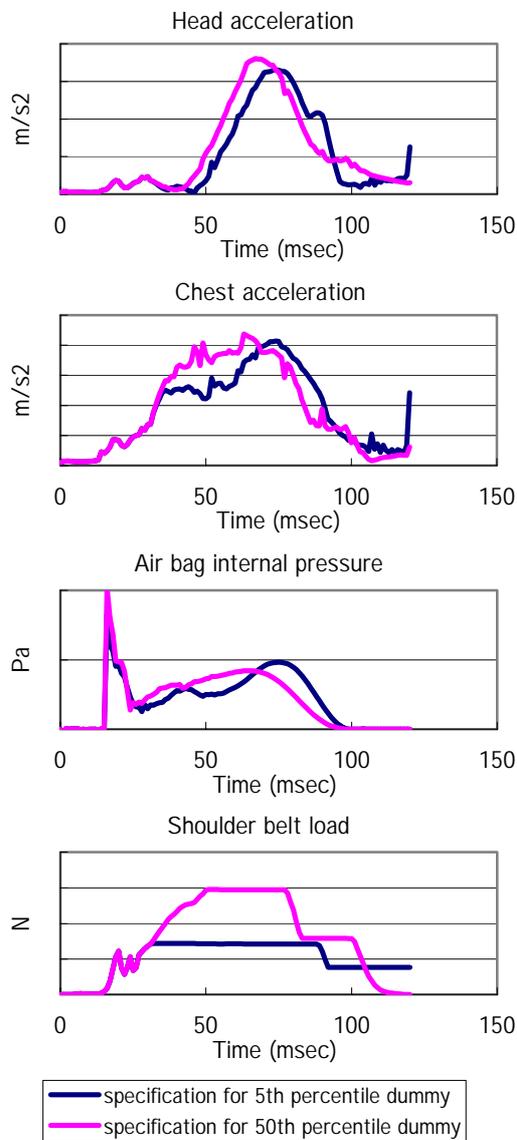


Figure 16. Head and chest acceleration, air bag internal pressure and shoulder belt load of 70th percentile female dummy

In case of the 5th percentile female specification, the forward movement of the dummy increases because the shoulder belt load is too low and finally the dummy impacts against the steering wheel (see Fig. 17). This phenomenon causes the increase of the injury values.

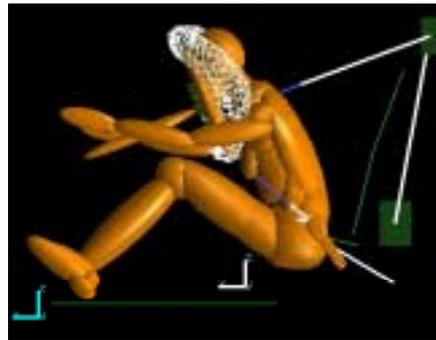


Figure 17. Behavior of 70th percentile female dummy moves to foremost position in 5th percentile female specification (at 85msec)

The P_{comb} increases sharply around 60kg because the contact between the dummy and the steering wheel begins to occur at that weight.

In case of the 50th percentile male specification, the injury values seem to get worse because the shoulder belt load is too high.

Reasons of the changes of the injury values between 50th percentile male and 95th percentile male are considered to be the same as above.

In this way, the evaluation for various occupant physiques is useful to determine where the three specifications should be switched. Two switching points at the dummy weight are identified in order to minimize the injury values for all physiques of occupants in Fig.18. One is the intersection point on the line of P_{comb} of the specification for 5th percentile

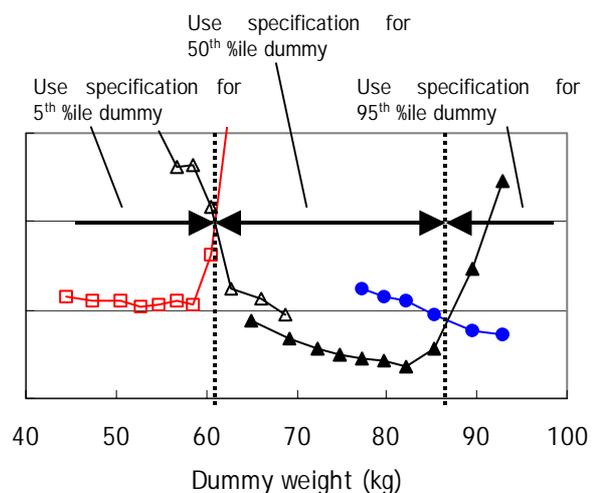


Figure 18. P_{comb} for various dummy sizes when applying three optimized characteristic

female and the line for 50th percentile male. The other is the intersection point on the line of the specification for 50th percentile male and the line of that for 95th percentile male.

The P_{comb} around the switching point from the specification for 5th percentile female to that for 50th percentile male, about 60kg, gets worse sharply as shown in figure 18.

As mentioned before, contact between the dummy and the steering wheel or excessive restraint force by the airbag and seat belt increases the P_{comb} . To prevent this sharp increase, it is considered effective to strengthen the specification for 5th percentile female or to weaken that for 50th percentile male.

Figure 19 shows the results of the modified specifications. Though the P_{comb} of 5th percentile female in the modified specification is a little higher, the P_{comb} around about 60kg decrease. As a whole the specifications after the modification seem to be better than those before the modification. It is confirmed that the evaluation by the dummy models with various physiques is effective to consider the system which reduces the injury risks for all occupant physiques.

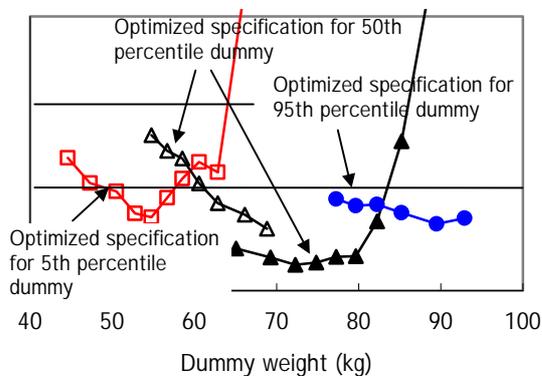


Figure 19. P_{comb} for various dummy sizes when applying three optimized characteristic

It is necessary to detect the physiques of the occupants precisely in order to control the airbag and seat belt according to the occupant physique. Such sensing system has been studied recently. In the development of such sensing systems, the evaluation by the dummy models with various physiques is necessary to determine the switching physiques and to evaluate the influence of the sensor threshold and so on.

CONCLUSIONS

The effect of injury reduction

If the characteristics of airbag and seat belt, which are set for the average physique, are applied to smaller occupants, the restraint force is too strong and the injury values get worse. If they are applied to larger occupants, a contact between the occupant and the steering wheel occurs because of the lack of the restraint force and the injury values get worse.

The expansion of the airbag vent hole area and the reduction of the LLR load can reduce the HIC and chest G's of 5th percentile female, because the airbag internal pressure and the shoulder belt load decrease.

The reduction of the vent hole area and the increase of the LLR load can reduce those of 95th percentile dummy because the airbag internal pressure and the shoulder belt load increase. However there is a limit in reduction of HIC of 95th percentile dummy because the restraint by the airbag delays due to the seating position.

The evaluation of various occupant physiques

When the optimized specifications for a single physique is applied to other physiques, the amount of forward movements increases as the mass of the upper part of the body increases. When an occupant impacts against the steering wheel, the injury values increase sharply.

On the other hand, the peak accelerations of the head and chest increase when the mass of the upper part of the body decreases due to the relative increase of the restraint force.

In order to minimize the injury values for all physiques of occupants, the evaluation of middle physiques is effective to determine the physiques at which the specifications should be switched and to derive the system specifications which can reduce the injury values around switching points.

REFERENCES

NHTSA, DOT HS 809 327 Traffic safety facts 2000 occupant protection

McCarthy, M.G., Chinn, B.P., *The effect of occupant characteristics on injury risk and the development of active-adaptive restraint system*, ESV 2001 Paper 314

Summers, L., Hollowell, W.T., Prasad, A., *Analysis of occupant protection provided to 50th percentile male dummies sitting mid-track and 5th percentile female dummies sitting full-forward in crash tests of paired vehicle with redesigned air bag system*, ESV 2001 Paper 338

Clute, G., *Potentials of adaptive load limitation presentation and system validation of the adaptive load limiter*, ESV 2001 Paper 194

Holdring, P.N., Chinn, B.P., Happian-Smith, J., *An evaluation of the benefits of active restraint system in frontal impacts through computer modeling and dynamic testing*, ESV 2001 Paper 328