SINGLE STAGE DRIVER AIRBAG MODULE DEVELOPMENT FOR OUT-OF-POSITION

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ABSTRACT

A driver airbag module has been developed with single stage inflator in an attempt to determine the 05th% ATD measured dummy injury response ("MDIR") in out-of-position scenarios (two NHTSA positions). Through computer simulations, dynamic MDIRs for in-position 05th%ile and 50th%ile dummies were evaluated as well.

It typically takes many design iterations to finalize a driver side module configuration to meet FMVSS208 regulatory conditions. Some typical parameters are tear seam cover design, cushion folding pattern and inflator output. In this paper, a Taguchi design of experiments was used to evaluate the influence of module design parameters. A MDIR comparison between a proposed new driver airbag module with a single stage inflator and a baseline module with a dual stage inflator was made not only for out-of-position tests, but also in-position crash simulations.

Currently in the US market, a majority of driver airbag modules use dual stage inflators to meet the injury assessment reference value ("IARV") criteria set by federal regulation. This driver airbag module with single stage inflator will give car manufacturers an option to eliminate the seat track position sensor and to reduce the number of wire harnesses which are required to connect the dual stage inflator. An additional benefit would be a simplified airbag control unit involving both algorithm and hardware. This simplification should be accomplished while providing comparable MDIR for both in-position and out-of-position scenarios over a baseline module with a dual stage inflator.
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INTRODUCTION

The driver side airbag has played a significant role in saving the lives of occupants behind the steering wheel during a crash event [1]. However, there is a potential injury risk by the airbag when the occupant is located close to the airbag module [2]. One example of this is due to improper seating such as forced seating change by emergency braking called out-of-position ("OOP"). In an effort to provide more effective occupant protection and mitigate airbag induced injury, many different technologies have been developed. These technologies include cover tear seam design, cushion folding pattern [4, 7] and inflator output tailoring.

The advanced airbag rule made by the National Highway Traffic Safety Administration (NHTSA), in part [3], provides procedures and IARV guidelines to conduct low risk deployment ("LRD") airbag tests with a 05th%ile female dummy as well as the dynamic MDIR requirements.

To investigate the effects of module parameters and to find a combination that can reduce the risk of airbag induced injury, either a Design of Experiments ("DOE") [5] or an optimization tool can be used. As it is well known, a DOE full factorial method could increase the number of tests resulting in unwanted additional cost and a development timing increase. In addition, there is a need to secure a robust margin for the ATD MDIR in case of testing set-up change and/or variation [6]. Therefore, a Taguchi design was chosen because it is effective in reducing testing, and the variability caused by outside noise factors, while evaluating the influence of module parameters.

An active venting technology (TRW developed Self Adaptive Venting, "SAVe", US patent # 6773030 and 7954850) was incorporated in the Taguchi DOE to give MDIR margin for the OOP test conditions while retaining dynamic MDIR for the in-position, high speed crash modes.

Pendulum testing was used to evaluate the stiffness of each driver airbag module and to help correlate the component level simulation model. Later, this validated component model was inserted into the system level sled model to compare the indicated MDIR.

The new driver airbag module with single stage inflator showed MDIR levels below FMVSS 208 maximum IARVs for OOP tests. Simulation showed an equivalent and/or comparable dynamic MDIR over a dual stage baseline module for all size adult occupants (05th%ile and 50th%ile), belted or unbelted.

OOP TESTS WITH A BASELINE DUAL STAGE MODULE

Baseline dual stage module has a bag folding of multiple horizontal pleats. Bag diameter was 711mm (28") and the discrete vent size was 2×18mm. The cover tear seam pattern was "Y" type. (Figure 10) See the table 1 below for the module configuration. The baseline dual stage inflator was a hybrid type technology with a peak pressure of 215kPa for high output and 145kPa for low output. (Figure 1)

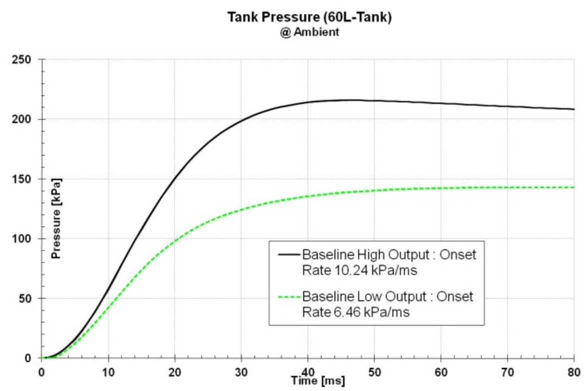


Figure 1. Inflator Pressure Curves from Baseline Module.

Table 1.
Baseline Bag Parameters

	Bag Diameter	Tether Size (3H/9H)	Discrete Vent Size	Adaptive Vent
Baseline	711mm	254mm/254mm	2×18mm	without

A test series evaluating the two positions specified by NHTSA was conducted with the baseline dual stage module. Low inflator output with 150ms delay between 1st stage and 2nd stage was used for all tests. These 2 regulated positions are called "Position #1 - Chin on Module position" and "Position #2 - Chin on Rim position". Two tests were conducted on each position to see the data variability as well as average MDIR. Figure 2 identifies the MDIRs from the tests for position 1. The major challenge to pass the OOP requirements is to reduce the initial punch-out force from the early airbag deployment. Neck tension variance was 20% of NHTSA's FMVSS208 regulatory value.

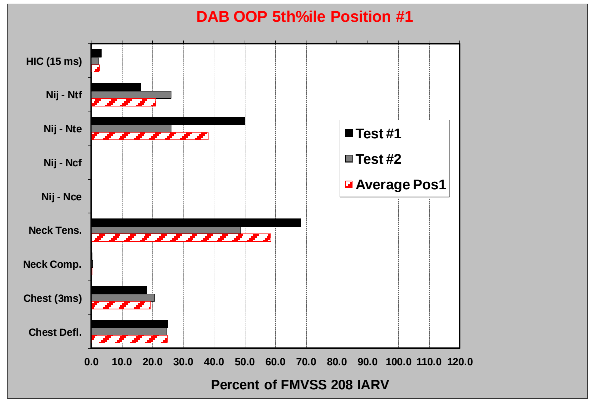


Figure 2. OOP Baseline MDIRs for NHTSA Position 2.

Two data points were obtained for "Chin on Rim" position test with the 05th percentile female dummy and Figure 3 shows the MDIRs from the test. This NHTSA regulated position usually puts the dummy's chest as close as possible to the steering wheel. This close proximity results in not only relatively high chest deflection, but also relatively getting high neck MDIRs due to airbag deployment under the chin. As shown in Figure 3 below, all MDIRs were within the regulation limits. 81% of chest deflection was the highest MDIR. Again, the neck tension force had 20% variation.

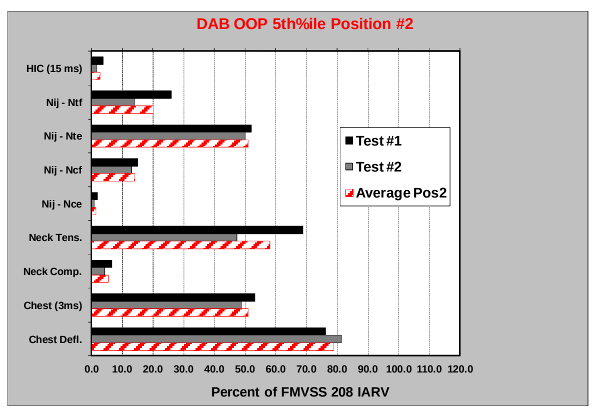


Figure 3. OOP Baseline MDIRs for NHTSA Position 2.

DESIGN CONSIDERATIONS FOR SINGLE STAGE MODULE

A self adaptive vent("SAVe") was designed in the rear panel. One end of the tether from adaptive vent technology was attached to the guide panel to cover the vents and the other end was attached to the rear panel (Figure 4). If the airbag fully deploys, the adaptive tether tightens, creating tension in the tether and pulling adaptive vent closed. The travel distance of adaptive tether to cover vents is 95mm. If the airbag deployment is obstructed, (i.e. by an OOP occupant) the tether does not tighten and the vents stay open. Thus, a portion of the gas is venting through adaptive vent (Figure 5).

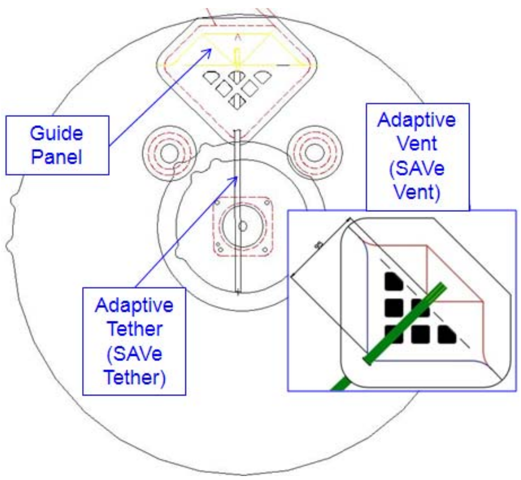
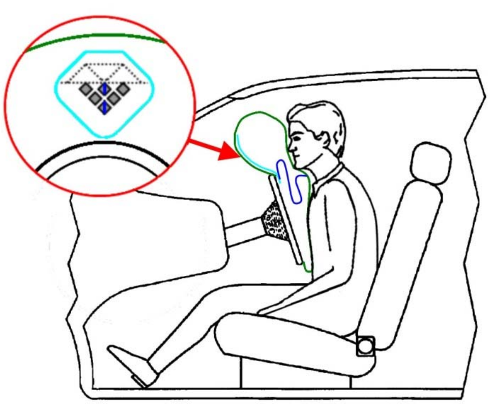


Figure 4. Self Adaptive Venting Schematic Diagram.



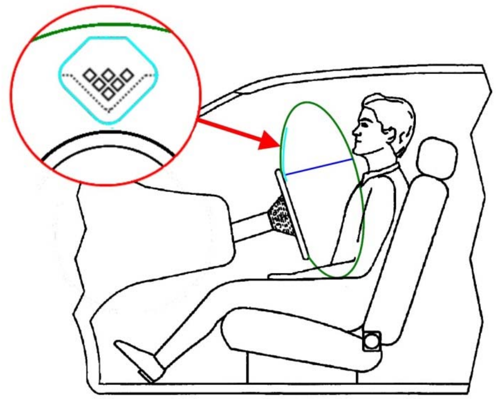
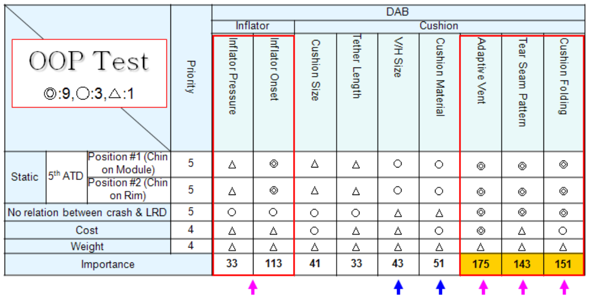


Figure 5. Self Adaptive Venting Working Mechanism.

Like stated above, adaptive vents have two main objectives. The first is being to remain open when an occupant is obstructing the deployment. The second is being to close and seal when the occupant is un-obstructed. Controlling these two functions begins with the tear stitch. It must be strong enough to keep the adaptive vent open during the assembly and folding process, and to tear during the lowest deployment conditions (i.e. a cold, low output deployment). A unique tear stitch design and thread combination provide that balance with minimal variation.

Another feature that drives the vent functionality is the tether length. It needs to be long enough to keep the vent open as long as possible to vent the gas in an out-of-position condition while being short enough to close and seal the vent for a normally seated condition. A series of static inflations helps determine a length that fulfills both requirements. But to help minimize the effect of variations in the length, a tether attachment location is found that has later contact with a normally seated occupant. This location is generally near the center of the bag, but may be need to be biased to the 12 o'clock position.

A Critical-to-Satisfaction (CTS) translation was used to identify critical functional factors influencing both dynamic crash MDIR and OOP MDIR. Four design parameters including adaptive vent design, inflator output, cover tear seam design and bag folding were identified to separate main parameters affecting OOP MDIR, while minimizing the influence on dynamic MDIR (Figure 6).



OOP Test ◎:9,○:3,△:1			Priority	DAB Inflator: Inflator Pressure	DAB Inflator: Inflator Onset	DAB Cushion: Cushion Size	DAB Cushion: Tether Length	DAB Cushion: V/H Size	DAB Cushion: Cushion Material	DAB Cushion: Adaptive Vent	DAB Cushion: Tear Seam Pattern	DAB Cushion: Cushion Folding
Static	5th ATD	Position #1 (Chin on Module)	5	△	◎	△	△	○	○	◎	◎	◎
		Position #2 (Chin on Rim)	5	△	◎	△	△	○	○	◎	◎	◎
No relation between crash & LRD			5	○	○	○	○	△	△	◎	◎	◎
Cost			4	△	△	○	△	△	○	◎	△	○
Weight			4	△	△	△	△	△	△	△	△	△
Importance				33	113	41	33	43	51	175	143	151

Figure 6. CTS Translation Chart.

Figure 7 below shows the "P-Diagram" explaining the Taguchi DOE set-up to find a module configuration to meet FMVSS208 OOP requirements.

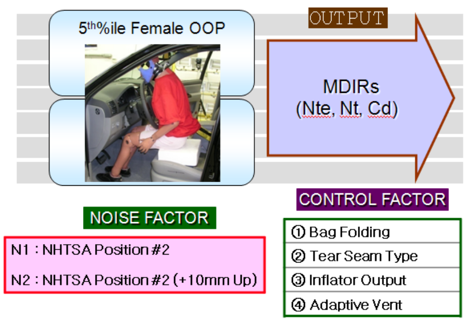


Figure 7. P-Diagram Set-up for OOP Tests.

From the baseline dual stage module OOP test series, NHTSA position 2 was chosen as the worst case dummy position based on higher MDIRs and airbag deployment variation. In addition to this, another dummy position was introduced. The head was raised by 10mm along vehicle z-axis to simulate test set-up variation. These two dummy positions were regarded as noise factors.

Neck tension ("Nt"), Nte and chest deflection("Cd") were chosen as output monitoring factors because these 3 MDIRs showed the highest values in the baseline tests.

Four different control factors from Critical-to-Satisfaction (CTS) translation were chosen to find a module configuration which would decrease the nominal MDIRs, while suppressing variation.

Figure 8 below shows two outputs of TRW DI10 pyrotechnic single stage inflator ballistic curve comparisons with baseline dual stage hybrid inflator. Star(intended to have radially deploying bag, TRW US patent # 6726615, 7090248 and 6086089) and tuck/roll were used for bag folding method as a control factor. (Figure 9) "I" type and "Y" type were used for cover tear seam pattern (Figure 10). Adaptive vent was also considered as a control factor.

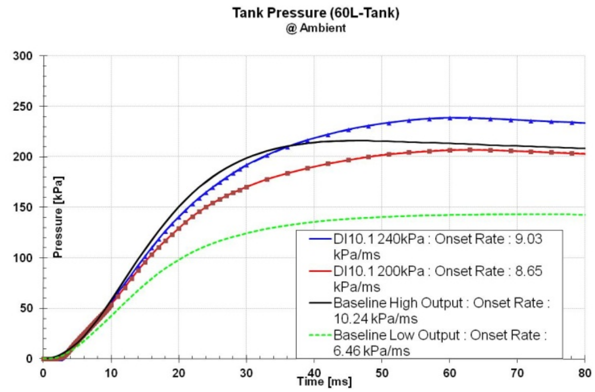


Figure 8. Control Factor: Inflator output.

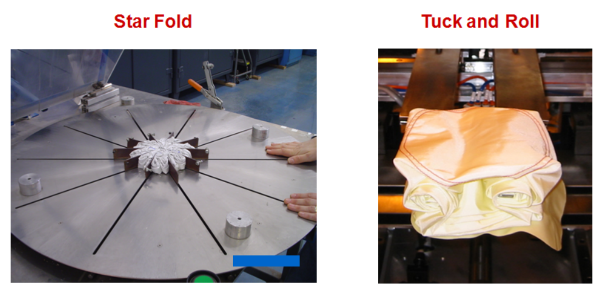


Figure 9. Control Factor: Bag Folding Method.

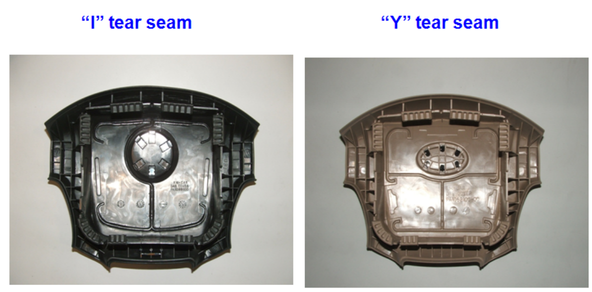


Figure 10. Control Factor: Tear Seam Design Pattern.

DOE ANALYSIS

Table 2 identifies the module configurations and test matrix for Taguchi method. The total number of tests would be 16 for each ATD position with the full factorial DOE method, but only 8 were tested with Taguchi method which reduced significant number of tests. The bag diameter and tether size were carried over from the baseline bag, but the discrete vent hole was changed to 2×30mm. The corresponding test results are shown in Figure 11 ~ Figure 13. Like explained in P-Diagram set-up, two data points were obtained for NHTSA position 2 (1^{st} and 2^{nd} in Figures) and one data point obtained for offset head location by 10mm (3^{rd} in Figures). Since M5~M8 module showed consistently lower neck tension and Nij responses, star folding was chosen. The next focus was to minimize chest deflection with lower response variations.

Table 2.
Module Configurations for DOE

	Design/Control Factor			
	Bag Fold	Inflator	Tear Seam	Adaptive Vent
M1	T/R	200	Y	W/O
M2	T/R	240	Y	With
M3	T/R	240	I	W/O
M4	T/R	200	I	With
M5	Star	200	I	W/O
M6	Star	240	I	With
M7	Star	240	Y	W/O
M8	Star	200	Y	With

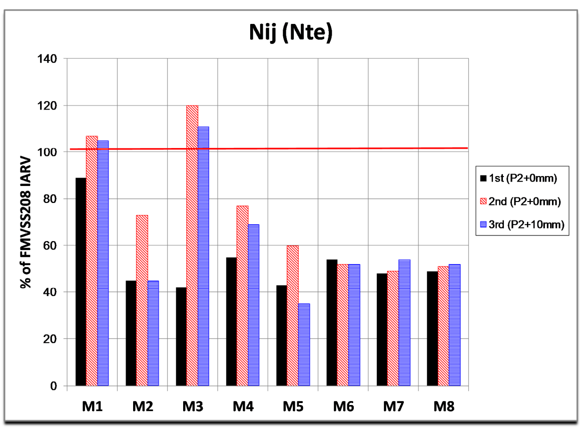


Figure 11. DOE Test Results (Nte).

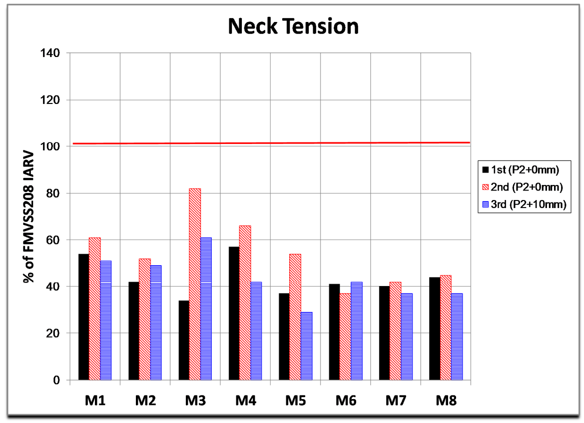


Figure 12. DOE Test Results (Neck Tension).

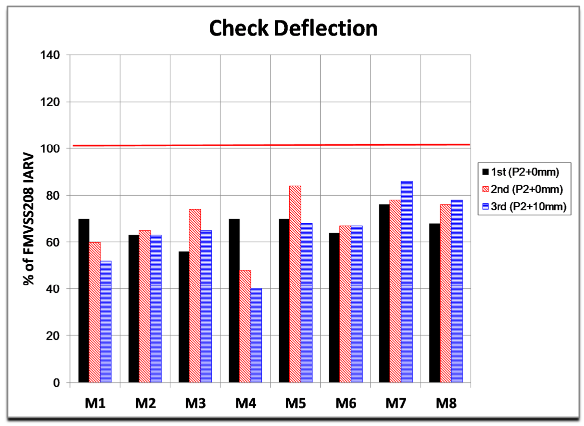


Figure 13. DOE Test Results (Chest Deflection).

Using the Taguchi method, signal to noise ratio (S/N ratio) and mean values were analyzed to evaluate trends in module parameters. Star folding and self adaptive vent were found to reduce Nij mean value while maintaining minimal response variations. (Figure 14 and 15) For chest compression, "I" tear seam pattern along with 200kPa inflator output showed lower injury values. (Figure 16 and 17)

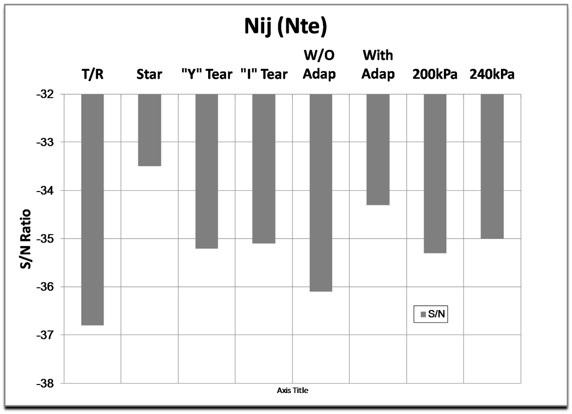


Figure 14. Robust Taguchi Analysis (Nte: S/N).

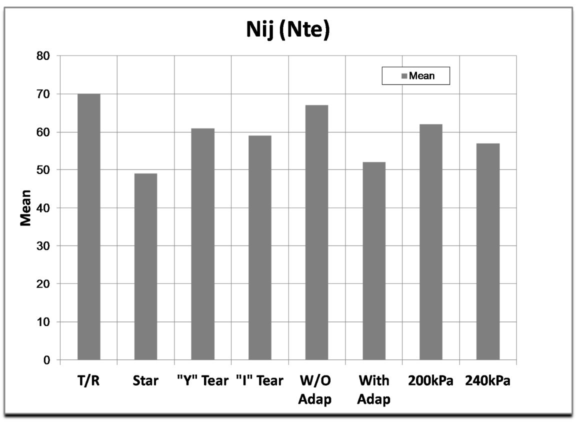


Figure 15. Robust Taguchi Analysis (Nte: Mean).

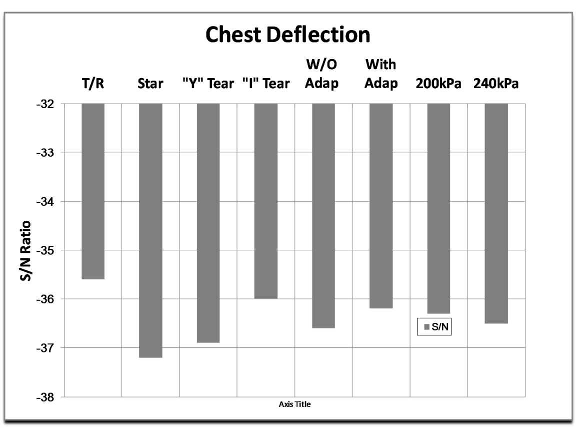


Figure 16. Robust Taguchi Analysis (Chest deflection: S/N).

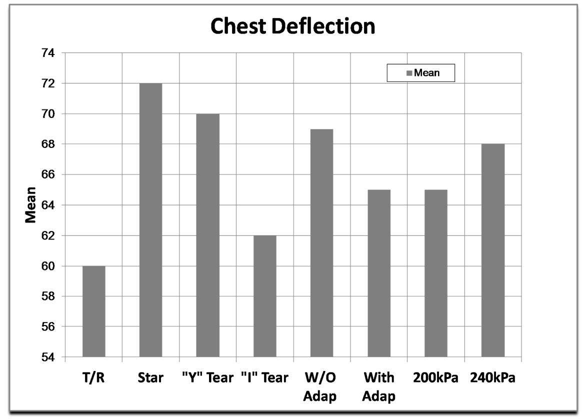


Figure 17. Robust Taguchi Analysis (Chest deflection: Mean).

Based on the DOE analysis and Taguchi robust design, star folding, Self adaptive vent, "I" tear seam and 200kPa inflator were chosen. However, 240kPa inflator was still considered as second solution in case of the necessity of more inflator output to attain desired dynamic MDIR (Table 3). Again, the bag diameter and tether size were the same as the baseline bag, except 2×30mm discrete vent.

Table 3.
Suggested Module Configurations

	Bag Folding	Inflator (DI10)	Tear Seam	Adaptive Vent
Suggestion 1	Star	200kPa	I	with
Suggestion 2	Star	240kPa	I	with

OOP CONFIRMATION TESTS

OOP confirmation tests were performed to evaluate MDIR of suggested modules. The testing environment (steering wheel, steering column position and angle, seat and dummy position) was exactly same as what was tested in the baseline OOP. Figure 18 and Figure 19 show MDIR percentage of FMVSS208 limits for each NHTSA position. Both modules showed lower MDIRs, along with less variation over the baseline dual stage module for neck tension and chest deflection. The highest percentage of MDIR from the suggested modules is below 70% of FMVSS208 limit. As shown Figure 20 through 25, airbags were consistently deployed behind the steering wheel. This reduced not only the MDIR, but also data variations from the repeated tests.

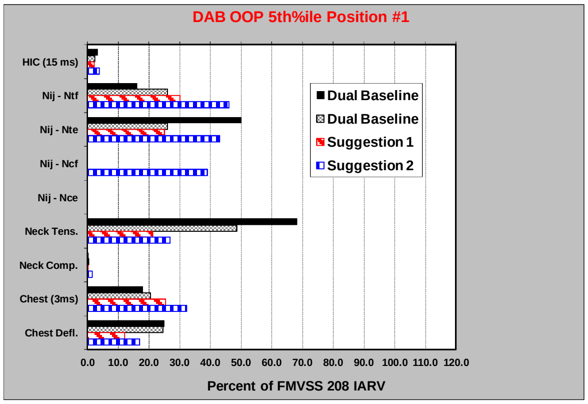


Figure 18. NHTSA Position 1 Confirmation OOP Test.

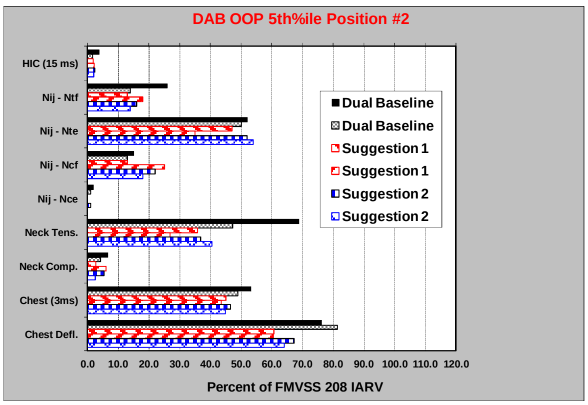


Figure 19. NHTSA Position 2 Confirmation OOP Test.

Figure 20. Confirmation OOP Test for NHTSA Position 1 at 15ms(Suggestion 1).

Figure 21. Confirmation OOP Test for NHTSA Position 1 at 15ms(Suggestion 2).

Figure 22. Confirmation OOP Test for NHTSA Position 2 at 15ms(Test 1 with Suggestion 1).

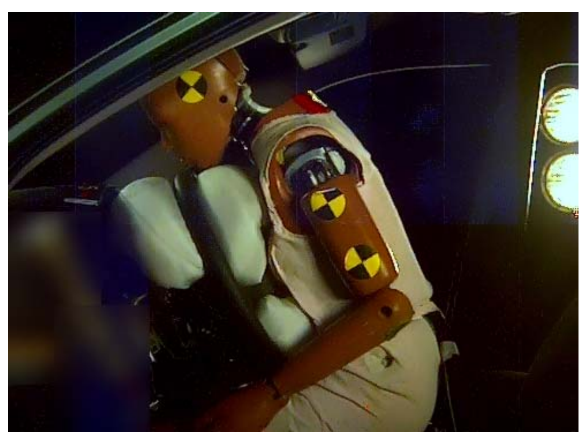


Figure 23. Confirmation OOP Test for NHTSA Position 2 at 15ms(Test 2 with Suggestion 1).

Figure 24. Confirmation OOP Test for NHTSA Position 2 at 15ms(Test 1 with Suggestion 2).

Figure 25. Confirmation OOP Test for NHTSA Position 2 at 15ms(Test 2 with Suggestion 2).

PENDULUM TESTS

A pendulum test series was completed to compare bag stiffness between baseline dual stage and proposed single stage modules. These were the same modules used in confirmation OOP testing. Figure 26 and 27 below show pendulum acceleration versus angle displacement curve for each inflator output. The -0.5 degree angle represents bag bottoming out and pendulum strike through. The suggested single stage modules showed earlier restraint force than baseline dual stage low output due to higher initial acceleration values. On the contrary, they showed slower loading along with higher peak acceleration than baseline dual stage high output. These characteristics are similar to inflator ballistic curves. (Figure 8) This pendulum data was used to correlate a component level airbag simulation model (MADYMO). The correlated model was used in a system level sled model to compare MDIR.

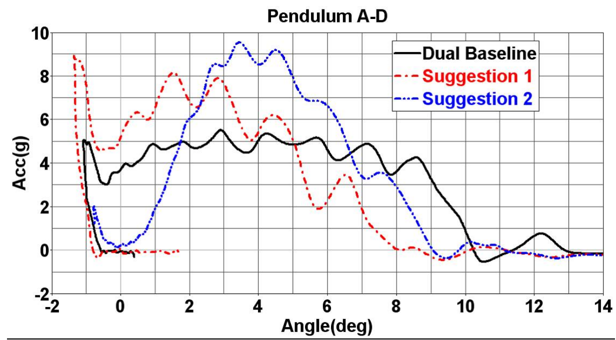


Figure 26. Pendulum Comparison (High Output for Baseline) : 90˚ Initial Angle.

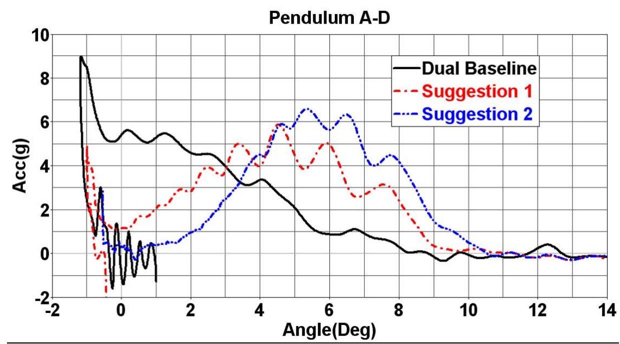


Figure 27. Pendulum Comparison (Low Output for Baseline) : 70˚ Initial Angle.

DYNAMIC MDIR COMPARISON

MADYMO simulation was used to compare the MDIR between the baseline dual stage and the proposed single stage designs. The vehicle pulse for 40kph and 56kph were shown in Figure 28. The vehicle environment information is shown in Table 4 below.

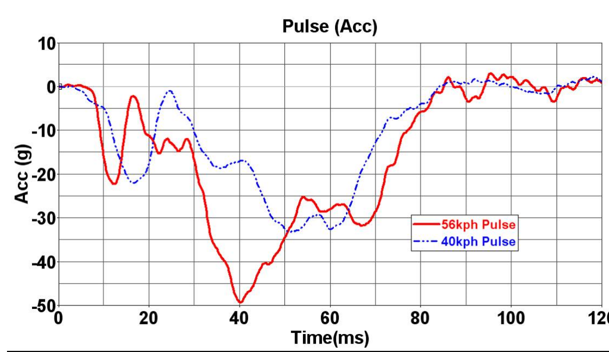


Figure 28. Dynamic Vehicle Crash Pulses.

Table 4.
Vehicle Environment Information

	Load Limiter	Belt Pretensioner	Airbag Fire Time	Speed
Belted	DLL	Retractor (14ms)	14ms	35mph
Unbelted	N/A	N/A	18ms	25mph

Four critical dynamic testing modes (40kph 50th%ile unbelted, 40kph 05th%ile unbelted, 56kph 50th%ile belted and 56kph 05th%ile belted) were evaluated (Figure 29). Low output was used for the baseline of 56kph 05th%ile belted and 40kph 05th%ile unbelted. High output was used for the remaining crash modes. MDIRs were compared in Figure 30~33. For both unbelted modes, the highest MDIRs were chest acceleration and chest deflection. The proposed single stage modules showed lower values than the baseline for these MDIRs. For the 56kph belted 05th%ile and 50th%ile ATD, suggestion 2 showed less performance on HIC, neck and chest response than suggestion 1. This is due to too much inflator gas from 240kPa peak output inflator. However, the overall MDIR with suggested single stage designs were comparable to the baseline dual stage for belted test conditions. This study was not focused on improving dynamic MDIR, but rather showing comparable MDIR to the baseline. Further, parameter tuning including vent size and steering column could help tune the system.

Figure 29. ATD Kinematics from Dynamic Simulations.

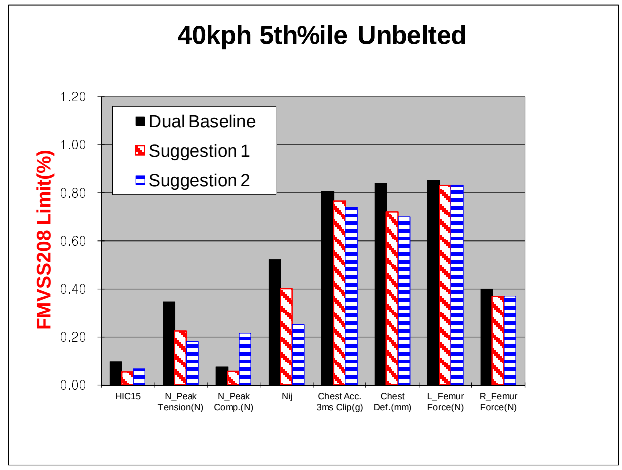


Figure 30. Dynamic MDIR Comparisons (40kph, 05th%ile Unbelted)

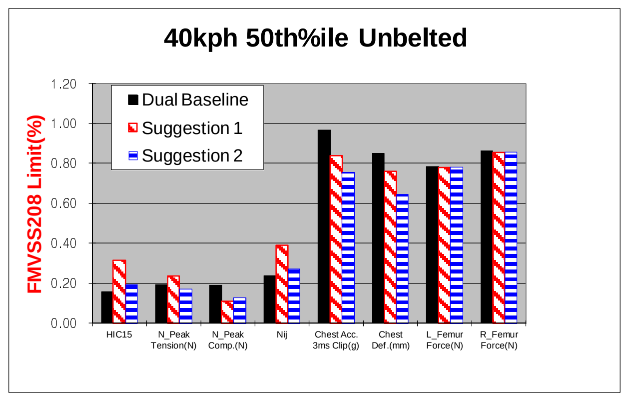


Figure 31. Dynamic MDIR Comparisons (40kph, 50th%ile Unbelted).

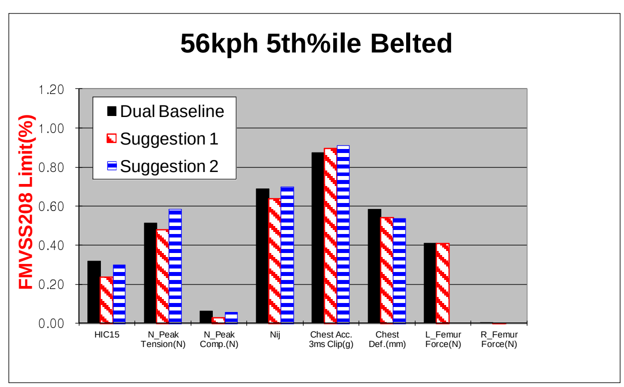


Figure 32. Dynamic MDIR Comparisons (56kph, 05th%ile Belted).

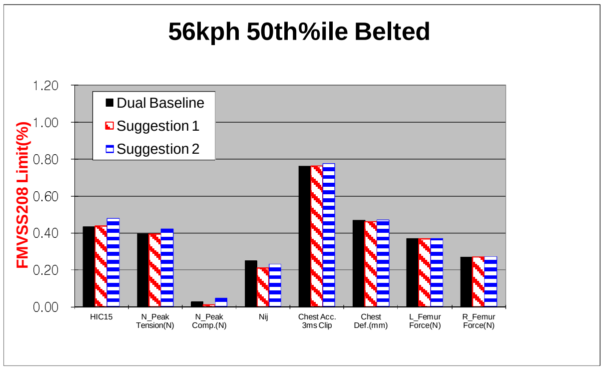


Figure 33. Dynamic MDIR Comparisons (56kph, 50th%ile Belted).

CONCLUSIONS

A baseline dual stage module showed MDIR variations on neck tension for NHTSA position 1 and 2.

Using the Taguchi method, signal to noise ratio (S/N ratio) and mean values were analyzed to determine robust single stage airbag module configurations. Star folding and self adaptive vent were found to reduce Nte mean value while maintaining minimal response variations. "I" tear seam pattern was chosen for chest compression. Two single stage module designs were suggested and showed lower MDIRs, along with less variation over the baseline dual stage module for neck tension and chest deflection through confirmation tests. Repeated confirmation tests showed the bag deployed consistently behind the wheel. The deployment variations with the baseline module were addressed with suggested modules.

A pendulum testing showed that the characteristics of suggested single stage designs were in the middle between the dual stage low output and high output in terms of early restraining force and bag stiffness. These characteristics were similar to inflator ballistic curves.

Comparable MDIR with the proposed module design with a single stage inflator was demonstrated for both unbelted and belted in-position critical crash modes through MADYMO simulations.

Suggested driver airbag module (Star folding, Self adaptive vent, "I" tear seam) with single stage inflator will give car manufacturers an option of a simpler and lighter module solution, along with simpler airbag deployment logic over dual stage designs. Suggested designs were based on the vehicle environments studied. Different solutions from the same development methodology could be applied for other vehicle environments.

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