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ABSTRACT

The development of the Advanced Restraint System has lead to an innovative way in which we evaluate the systems effect on the occupant. This paper presents some initial investigation into the driver airbag system that consists of an inflator, cushion fold, tear seam pattern, and offset of the airbag cover to steering wheel rim plane. An initial DOE is reviewed to establish significant parameters and to identify equations for further investigation.

INTRODUCTION

This paper focuses on the latest NHTSA developments for Advanced Air Bag Regulation that, according to NHTSA, improves occupant benefits and risk reduction. On January 6, 1997, NHTSA published an NPRM (62 FR 807) to temporarily amend Standard No. 208 to help reduce the fatalities and injuries that current air bags are causing in relatively low speed crashes. NHTSA's proposal would permit or facilitate an approximate 20 to 35 percent average depowering of current air bags. NHTSA has proposed in the SNPRM May 5th, 2000, test methods to meet specified injury criteria performance limits when the driver air bag is deployed in the presence of an out-of-position 5th percentile adult female dummy. NHTSA identified two positions that tend to be "worst case" in terms of injury criteria. In the first of these positions, the dummy's chin is on the air bag module (S26.2); in the other, the dummy's chin is on the upper rim of the steering wheel (S26.3).

When the dummy's chin is on the upper rim of the steering wheel the chest cavity comes into close proximity to the airbag module cover. This produces direct contact on the torso region where evaluation of the Viscous Criteria (V*C), Chest G's, and Chest Deflection can be assessed.

PARAMETER STUDY

A DOE was developed to evaluate the significant parameters of the driver airbag system that consists of an inflator, cushion fold, tear seam pattern, and offset of the airbag cover to steering wheel rim plane. To achieve the best test consistency, the inflator and airbag fold/cushion were maintained as a unit using production intent manufacturing procedures. The inflator and cushion fold are evaluated together as a soft pack for the testing with the dummy's chin on the upper rim of the steering wheel (S26.3). The main interaction with the chest is caused by the inflator gas pressure and the tear seam strength. These factors also had a very direct control on the direction of expansion of the airbag during a deployment.

A two-level full factorial design with three variables was conducted with replication. This required relatively few runs per factor and allowed a fuller exploration to indicate major trends for further experimentation. This is an important step in that it allows for the addition of other fractional designs to be used as building blocks to solve the more complex model that may develop.

Test levels for each run are shown in Table 1 in the design matrix. This matrix does not represent the random order. Each run must be randomized by order to validate the ANOVA results. By replicating runs, the variation of a single observation (standard deviation) can be calculated for each effect. This assumes that error (variation) is IIDN$\mathbf{(0,\sigma^2)}$[1].

1. Independently and identically distributed in a normal distribution with mean zero and variance σ^2.

Table 1. DOE run levels for each variable.

Test	Offset	TearSeam	Inflator
1	-1	-1	1
2	-1	-1	1
3	-1	1	1
4	-1	1	1
5	1	-1	1
6	1	-1	1
7	1	1	1
8	1	1	1
9	-1	-1	-1
10	-1	-1	-1
11	-1	1	-1
12	-1	1	-1
13	1	-1	-1
14	1	-1	-1
15	1	1	-1
16	1	1	-1

The complete design is evaluated using a statistical software program. The standard ANOVA is used after defining the factorial design. ONLY THE SIGNIFICANT TERMS ARE SHOWN.

Analysis of Variance for VC (coded units)

Source	DF	P
Main Effects	3	0.000
2-Way Interactions	3	0.037

Term	Coef	P
Constant	0.46275	0.000
TearSeam	0.28012	0.000
Inflator	0.14212	0.001
TearSeam*Inflator	0.09550	0.008

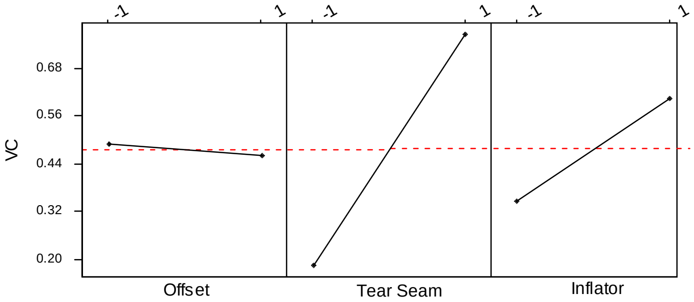

Figure 1. Main Effects Plot for VC

All of the main effects are significant except for the offset as shown in Fig. 1. This was briefly described in Horsch et. al. (1990) with the use of different inflators. Horsch et. al. changed the inflator and modified the same module while offsetting the distance between the wheel plane and test dummy. In the testing conducted for this paper, the modules are not identical resulting in different combinations being evaluated. The difference in space between the module and steering wheel plane (Offset) is not statistically significant. The deployment path of the airbag can be checked against the film observations. This will be further evaluated with different factorial designs.

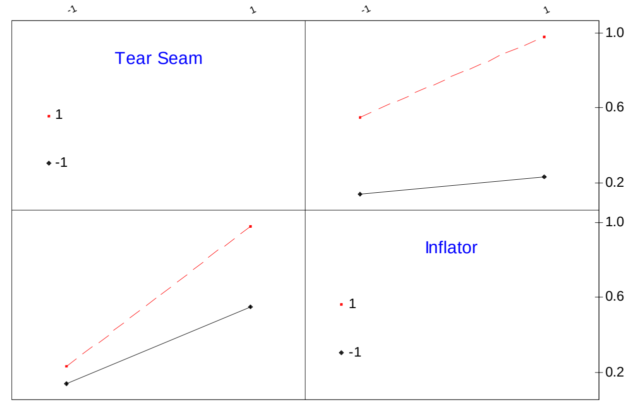

Figure 2. Interaction Plot (LS means) for VC

The effects of the TearSeam and Inflator cannot be interpreted separately because of the 2 way interaction of the TearSeam + Inflator shown in Fig. 2. This interaction will complicate the modeling but may lead to more identification of dependency on specific design parameters.

The Normal Probability Plot of the effects is shown in Fig. 3. If a normal probability plot is constructed for the data drawn from a single normal distribution, the data will fall approximately along a straight line. If all the data in a sample population comes from the same distribution with the exception of a few data points, the normal plot will show these exceptions as points off a line that passes through the aligned points. The variance of the effect values should be equal meaning that all the insignificant effect estimates should fall on a straight line on the plot centered near zero. Factor B, C, BC are significant from Fig. 3. Reviewing the effect and coefficients to build the model:

$$Y(VC)= .463 + .280B + .142C + .095BC \qquad (1)$$

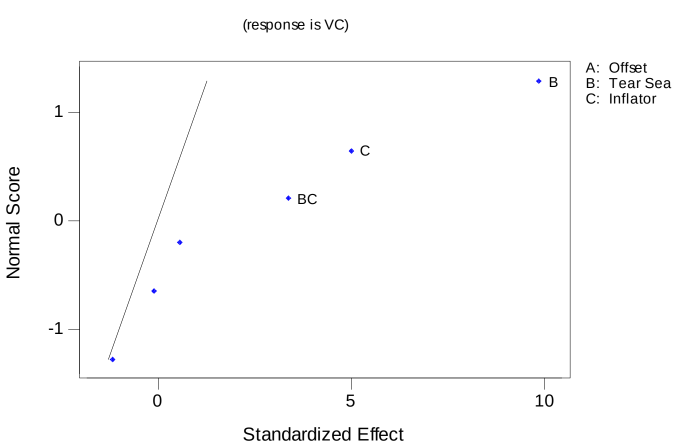

Figure 3. Normal Probability Plot of the Standardized Effects

EMPERICAL MODEL

The mechanism underlying a system may be too complicated to allow an exact model to be postulated from theory. In such circumstances an empirical model may be used to evaluate a response of interest. The degree of complexity that should be incorporated in the model can seldom be guessed with certainty *a priori*. To evaluate the airbag parameters the constant term and the independent constant coefficients for the model need to be generated. This will take the form of:

$$Y(VC)= x_nB_n + y_nC_n + x_ny_nB_nC_n \quad (2)$$

Where x_n, y_n, x_ny_n are the individual components' constant coefficients.

B_n, C_n, B_nC_n are the individual components under investigation for each variable.

Ex: B-Variable (Tear Seam)

B_1 = U Tear Seam
B_2 = H Tear Seam
B_3 = 2/3 Tear Seam
B_4 = X Tear Seam

It is desirable to determine each variable's n^{th} contribution to the total system. In this way the variables constituents can be used to evaluate the response value. Further identification of an appropriate test to verify the characteristics, i.e. inflator proportional to mass flow test, can be developed. To determine the coefficients, the DOE analysis is run as subset of each variable being investigated. The constant term will provide for a good estimate of the +/- variable levels.

The DOE results in the following:

Offset: A-term

[-1 level]	[+1 level]
$Z_1 = 0.463$	$Z_2 = 0.466$

This term demonstrates that the Offset is not a contributory in this study and is very close to the constant term in Eq. 1, Y(VC) model generated by the DOE.

TearSeam: B-Term

[-1 level]	[+1 level]
$X_1 = 0.0915$	$X_2 = 0.3715$

Inflator: C-Term

[-1 level]	[+1 level]
$Y_1 = 0.1600$	$Y_1 = 0.3025$

Using equations 1 and 2 with the known constant values, the cross product interaction BC can be determined.

Coefficients:

$X_1Y_1 = -0.0880$

$X_1Y_2 = -0.1525$

$X_2Y_1 = -0.0610$

$X_2Y_2 = -0.3660$

Notice that the Y2 factor has a higher level than the Y1 factor and recall that the Y factor is related to the inflator level. This is shown in the interaction of the tear seam + inflator demonstrated in Fig. 2.

By inspection of the (+/-) levels for each variable, the B_+ contributes significantly more than the B_- level. Whereas the inflator variable C appears to be more linear in response. This may potentially be the scalar range of the characteristic in question rather than the ultimate range of the variable. It was the intention of the test to distribute the variable as far apart in value as possible so that further testing at center points could be done.

DIAGNOSTIC CHECKING

Analysis conducted to scrutinize the model and confirming its ability to predict the original data can be carried out by looking at the residuals. Inadequacies in the proposed model should be looked for by critical examination of the crude data. The model predicts a very good response in the lower levels but tends to spread into a larger trace as shown in the plot of the residuals, Fig. 4.

According to Anscombe and Tukey (1963), this data suggests a funnel shape or curvilinear tendency when plotting the residual compared to the fit. One attempt to find a suitable transformation is to make an analysis for various transformations choosing the one that shows no evidence of the transformable interaction. Box and Hunter (1964) suggest the use of a power series.

$$\mathbf{Y = y^{\alpha}}$$

where α is a constant of the power series determined by using the equation

$$\mathbf{y^{\alpha} = (y^{\alpha} - 1) / (\alpha y_n^{\alpha-1})}$$

y_n..is the geometric mean obtained by averaging log y and taking the antilog of the results.

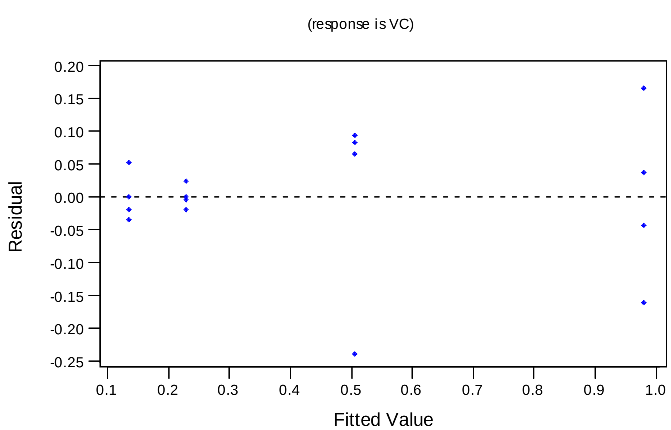

Figure 4. Residuals Versus the Fitted Values

The transformation is evaluated using alpha values from 1.5 to .33 choosing the point at which the residual sum of the squares from the fitted model is minimized. This range of alpha allows the use of known transformation such as Poisson or binomial. These can range from the reciprocal (α=2), considered a strong transformation to a more mild transformation of the square root (α=.5). The extent of the curvature that a transformation produces over a given range is considered its "strength". Fig. 5 and Fig. 6 demonstrate the residual fits of alpha .5 and .33 respectively.

Analysis of Variance for VC (coded units)
Alpha = .5

Source	DF	P
Main Effects	3	0.000
2-Way Interactions	3	0.074

Term	Coef	P
Constant	0.64360	0.000
TearSeam	0.22212	0.000
Inflator	0.08985	0.000
TearSeam*Inflator	0.003369	0.019

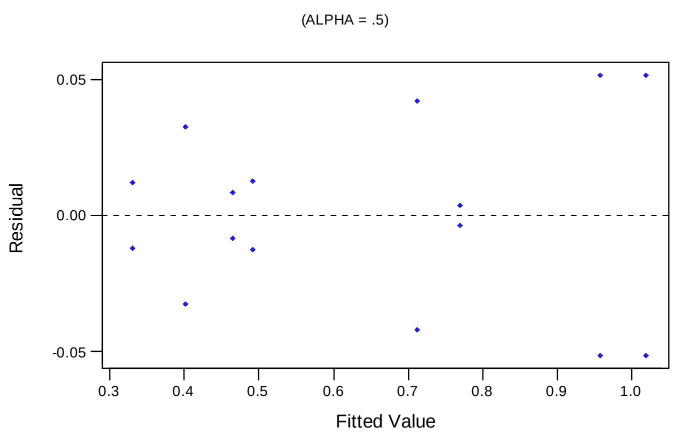

Figure 5. Residuals Versus the Fitted Values for Alpha=.50.

Analysis of Variance for VC (coded units)
Alpha = .33

Source	DF	P
Main Effects	3	0.000
2-Way Interactions	3	0.016

Term	Coef	P
Constant	0.73538	0.000
TearSeam	0.17079	0.000
Inflator	0.06793	0.000
TearSeam*Inflator	0.01781	0.065

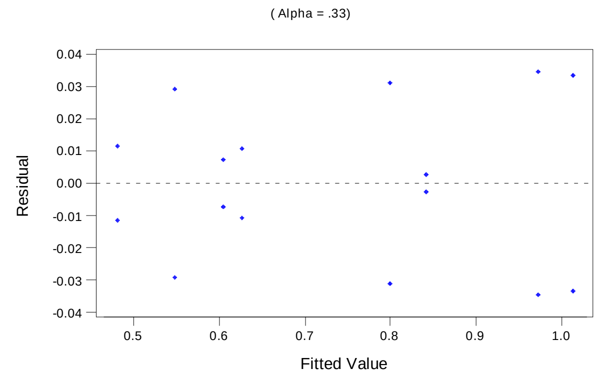

Figure 6. Residuals Versus the Fitted Values for Alpha=.33.

The minimum value of $\mathbf{y^{\alpha} = (y^{\alpha} - 1) / (\alpha y_n^{\alpha-1})}$ is around alpha = .28. The analysis conducted around .28 using the V*C response data follows.

Analysis of Variance for VC (coded units)
Alpha = .28

Source	DF	P
Main Effects	3	0.000
2-Way Interactions	3	0.201

Term	Coef	P
Constant	0.76721	0.000
TearSeam	0.15197	0.000
Inflator	0.06016	0.000
TearSeam*Inflator	0.01368	0.098

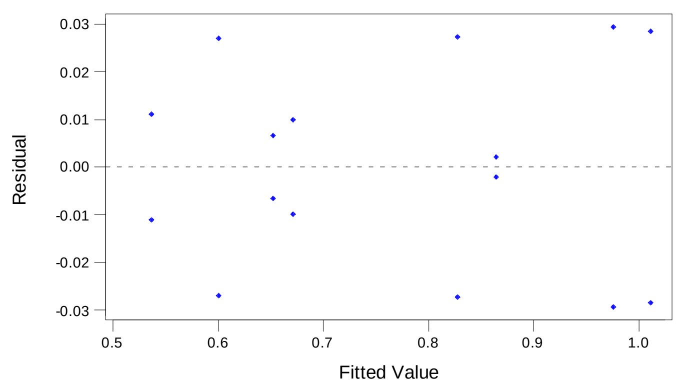

Figure 7. Residuals Versus the Fitted Values for Alpha=.28.

The residuals look very consistent with the power series, $\mathbf{Y = y^{.28}}$ providing for a better model assumption and removes the interaction term BC. Comparison of Fig. 3 to Fig. 8 shows the transformation effectiveness to removal the curvature.

The model takes on the form of

$$\{Y(VC)\}^{.28} = x_n B_n + y_n C_n$$

Where n is the negative (-1) or positive (1) level of the components B & C. Repeating the similar analysis conducted earlier the coefficients are:

TearSeam: B-Term

[-1 level]	[+1 level]
$X_1 = 0.6152$	$X_2 = 0.919$

Inflator: C-Term

[-1 level]	[+1 level]
$Y_1 = 0.707$	$Y_1 = 0.827$

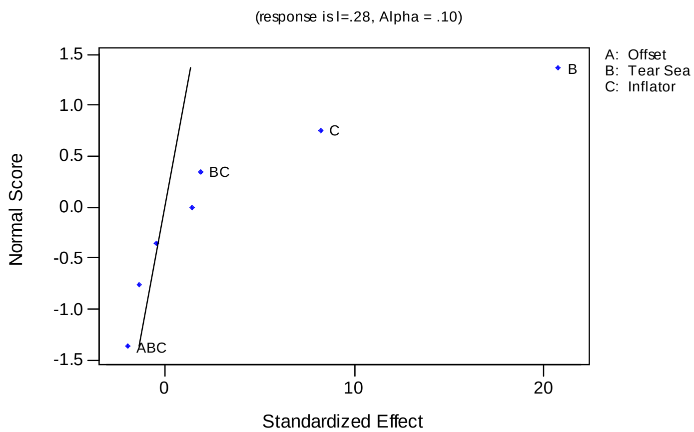

Figure 8. Normal Probability Plot of the Standardized Effects Values for Alpha=.33

CONCLUSION

An initial DOE was reviewed that examined several parameters of the driver airbag system. From the analysis some parameters where considered significant and a empirical linear model was used to predict the response of V*C. The model was complicated with an interaction between the TearSeam and Inflator levels. The two-way interaction was reduced to coefficients of interaction for each level. Solving four linear equations and using the values settings from the DOE accomplished this. A power series transformation ($Y=\mathbf{y}^{\alpha}$) reduces the dependency of a two-way interaction. This provided the best fit of the data, which tended to be curvilinear in nature.

Future testing will be conducted to estimate the bag fold and inflator level and determine a characteristic of these factors on the model. V*C is only one variable that must be looked at during an OOP testing, the other are HIC, NIJ, Upper and Lower neck moments etc. which need to be investigated and entered into a model as factors. The end results will be an empirical model that closely predicts OOP test results. This modal can be used to discriminate variable's parameters in designing airbag modules.

ACKNOWLEDGMENTS

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CONTACT

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

Term:
ANOVA – Analysis of Variance