AN INTEGRATED SYSTEM FOR TRANSPORT AIRCRAFT CABIN INTERIOR DESIGN AND CERTIFICATION BY ANALYSIS

A Dissertation by

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DEDICATION

To my wife Lekshmi and

my constant companion Scruffy

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ABSTRACT

Every cabin configuration, in all types of aircraft (Transport, General Aviation and Rotorcraft), need to be certified as per the existing Code of Federal Regulation governing that particular type of aircraft. The current practice used to comply with Federal Aviation Regulations (FAR's) related to aircraft seats and cabin interiors is to conduct full-scale system sled tests. This approach can be expensive and the test results are sensitive to changes in test conditions, such as the sled pulse, dummy calibration, seat belt elongation, etc., resulting in scatter in the results. With the development of the more robust codes for the analytical tools, it should be possible to successfully capture the test conditions by one of these tools and to obtain results which compare favorably with the actual tests results.

For Part 25 category of transport aircrafts, 14CFR 25.562 states: "Each seat type design which approved for crew or passenger occupancy during takeoff and landing must successfully complete dynamic tests or be demonstrated by rational analysis based on dynamic tests of a similar type seat, in accordance with each of the following emergency landing conditions" and then the conditions are stated.

When these federal regulations were enacted, the ability of analytical tools was limited and there did not exist enough data to show that certification could be performed using analysis. The objectives of this research are to identify the conditions under which a Part 25 type aircraft could be certified by analysis for compliance with the 14 CFR 25.562 regulation, and also to identify the validation criteria when using analytical tools.

The validation criteria for the analytical model have been developed based on the scatter that is seen in actual testing. The underlying premise is that the analytical modeling of the testing should be allowed to predict the injury criteria within the same band of scatter as the actual tests. The study develops a validated model and this model is shown to be robust in predicting the protection/injury criteria that the tested configurations offer. Using these validated models, a full factorial design of experiment (DOE) analysis was performed to determine the effect the factors have on the dynamic response of the seat-dummy-restraint-cabin systems. In this study, the factors chosen were the seat cushion type, thickness of the cushion and the rigidity of the seat for the 14 CFR 25.562 Test -1 condition (up test) and the studied response was the resulting lumbar load. For 14 CFR 25.562 Test -2 condition (down test), the studied factors were the seat set back distance, seat belt type, type of bulkhead and the coefficient of friction of the impact surface, while the studied response was the resulting Head injury criteria (HIC) based on the impact of the dummy head with the frontal structure.

Guidelines were developed in this study pertaining to the circumstance under which analytical tools could be considered as a valid replacement for the certification testing. Based on the sensitivity study, a new integrated analytical system methodology has been developed that would help the aerospace cabin interior designers in developing crashworthy cabin interiors. A graphical user interface was developed which would help the cabin interior designers to optimize their design by selecting component that would help in minimizing the injury criteria studied. This would reduce the time it takes to design these configurations and would reduce the cost of certification while improving the safety of the flying public.

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LIST OF ABBREVIATIONS / NOMENCLATURE

FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
CFR	Code of Federal Regulation
HIC	Head Injury Criteria
ATD	Anthropomorphic Test Dummy
DOE	Design of Experiments
RSM	Response Surface Methodology
SD	Standard Deviation
ANOVA	Analysis of Variance
DE	Differential Evolution
GA	Genetic Algorithms
EA	Evolutionary Algorithms
ES	Evolutionary Strategies

CHAPTER 1

INTRODUCTION

1.1 Motivation

Full-scale sled tests, which are currently used to develop aircraft interior furnishings, often require several test articles to be destroyed in order to develop an engineering solution and to demonstrate the compliance with the Head Injury Criteria (*HIC*) for a design. The *HIC* compliance poses a significant problem for the airlines and the manufacturers of the jet transports, due to high costs and schedule overruns during the development and certification of aircraft seats. In addition to compliance of HIC, when designing seats, it is important to reduce the lumbar load and keep it below the threshold limit. The test for compliance for any seat involves destroying a seat in the process while ensuring that the lumbar load is below the threshold limit. This dissertation deals with the efforts to find suitable means to certify aircraft interior by analysis and to develop tools for helping aircraft interior designers to select components that would reduce the injury criteria. Even though the regulations allow for certification by analysis they do not specify the validation criteria or in the cases where they do the analytical model needed to replicate the dynamic test are subject to a higher degree of reliability than the actual dynamic sled test.

1.2 Background

With the advent of flight and airplanes, it was assumed by many, including the pilots, that airplane accidents were a part of operating these machines. It was during World War I that pioneering work on crashworthiness was done. In 1917 Hugh

DeHaven, a young American cadet, was involved in an air crash in which all the other three cadets were killed. The reason for his surviving the accident was that his was the only cockpit to remain more or less intact. Based on this insight he considered the concept of designing the airplanes for crash survival [1].

The manufacturers of aircraft interior paid scant attention to crashworthiness of the different interior fittings, their main concerns were weight, space optimization and comfort. In 1984 the General Aviation Safety Panel was constituted to address safety issues for general aviation aircraft. The recommendations put forward by this committee formed the basis for the Federal Aviation Regulations (FARs) Parts 23, 25 and 27 for general aviation, transport aircraft, and rotorcraft [2-4].

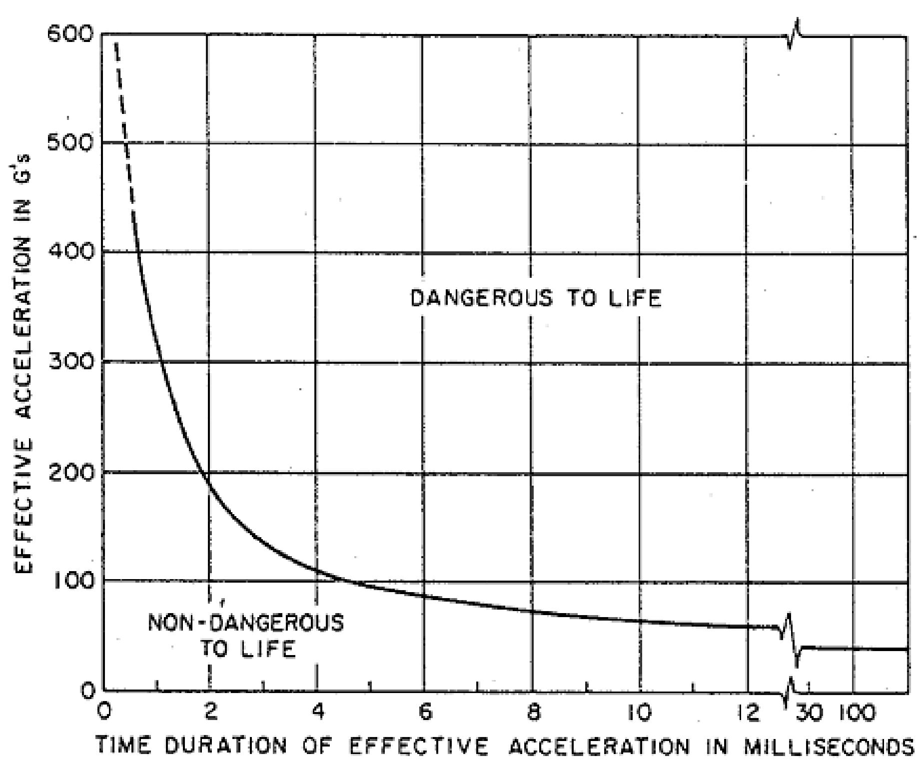

Figure 1 Wayne State Tolerance Curve [5]

The compliance with the Head Injury Criteria (HIC) specified in 14 CFR 23.562 [2] and CFR 25.562 [3] poses a significant problem for many segments of the aerospace industry. The airlines and the manufacturers of jet transports have experienced high costs and significant schedule overruns during the development and certification of 16G seats because of the difficulties encountered in meeting this requirement.

This injury criterion was evolved from the Wayne State Tolerance Curve shown in Figure 1. Gadd [6] defined the Severity Index (SI) that is based on raising the time integral of head acceleration in G's to the power of 2.5, after observing this to be the slope of the line which closely fit the Wayne State data when it was plotted using a log-log scale. He also proposed the injury threshold of 1000. This Severity Index was used in the first injury standard used by the National Highway Traffic Safety Administration (NHTSA) in March of 1971 [7]. Versace [8] subsequently advocated the use of an "effective acceleration" which he defined as { $\frac{1}{t}\int a^{2.5}\,dt$ } where *t* and *a* respectively represent the time interval and resultant head acceleration. As a result of certain objections to the Severity Index, the NHTSA rescinded its use and the SI was superseded by the Head Injury Criterion *HIC* [9]. The head injury criteria, *HIC,* was subsequently defined by Gurdjian [10, 11] as shown in equation (1)

$$\mathrm{HIC} = \left[(t_2 - t_1) \left\{ \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t)\,dt \right\}^{2.5} \right]_{max} \qquad (1)$$

where, a(t) - resultant acceleration of the head center of gravity in G's,

t_1 - initial integration time, expressed in seconds,

t_2 - final integration time, expressed in seconds.

This maximization is performed by identifying the time interval, $t_2 - t_1$, which results in the largest functional value. This criterion was adapted from the Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The definition contained in the aerospace regulations currently differs from the one originally listed in FMVSS No. 208. Generally, a maximum window size of 36 ms is used in the automotive industry, while in aerospace applications, the *HIC* is evaluated over the period when the head of the Anthropomorphic Test Dummies (ATD) [12] is in contact with the aircraft interior. Injury is defined as any *HIC* value exceeding 1000s. The *HIC* was subsequently recommended as one of the injury criteria by the General Aviation Safety Panel (GASP) [13] to be considered in the design and certification of aircraft seats and restraint systems.

For the most part, two kinds of problems have been encountered in the certification of 16G airline seats. The first, referred to as the front-row *HIC* problem, occurs for seats located directly behind bulkheads or cabin class dividers. These structures are typically both stiff and strong and therefore produce very high *HIC* values during head impacts.

Industry has addressed this problem using a number of approaches with mixed results. These approaches range from requesting an exemption to the rule to removing one row of seats from the aircraft. Technology-based solutions include the development of articulated seats and "y-belt" restraint systems. None of these solutions have been judged to be entirely satisfactory by the airlines, airframe manufacturers, or the FAA. Articulated seats are expensive and heavy and are also objectionable to the airlines because of the maintenance problems posed in supporting a nonstandard piece of equipment. The use of y-belts also creates a similar maintenance problem as well as generating concern about the safety of applying large restraint system forces to soft abdominal tissues. Finally, removing a row of seats from a transport aircraft creates a significant economic burden to airlines that have learned how to consistently generate high passenger load factors.

Manufacturers of airline seats have also encountered similar problems in satisfying the *HIC* requirement for an occupant who is seated behind another seat. The industry refers to this as the row-to-row *HIC* problem. It has proven to be a difficult certification requirement due to the wide variety of in-flight entertainment systems that are built into airline seats. These systems typically include video displays and telephone hand-sets which result in a large number of head impact locations which must be evaluated in addition to other sites produced by arms and tray tables. An effective component test is needed that can be used to quickly identify the critical head impact condition given the large number of possibilities. Currently, the only rigorous way to identify the critical condition is to conduct several full-scale seat tests. This approach is expensive since at least one seat test article is consumed during each test.

Business jets represent another important segment of the general aviation market. These aircrafts are certified under both 14 CFR Parts 23 & 25 depending on the design's gross weight and other factors. The interior designs of business aircraft contain passenger amenities that are intended to provide both comfort and functionality appropriate for executive travel. These furnishings, in addition to track and swivel chairs, include drop-down tray tables, cabinets, galley and lavatory equipment, as well as side-facing divans. Typical general aviation configurations contain many possible head impact sites, which make it very difficult to establish the critical head impact test condition. Component test devices represent very attractive engineering tools that could be used in solving these problems. These aircrafts are generally equipped with shoulder harnesses that present the same problems for the design of a component head impact test device as described above for small general aviation aircraft.

The *HIC* problem is also challenging to interior designers of general aviation aircraft. Their problem, however, is somewhat different from the airline problem described above. The smaller general aviation aircraft are certified to 14 CFR Part 23 that requires the shoulder harnesses be installed in these aircrafts. Since one of the purposes of the shoulder harnesses is to mitigate the head injury risk during an accident, it is obvious that their effect on the dynamics of the problem must be reflected in the design of any component head impact test device.

Addressing the *HIC* problem requires careful study and quantification of the restraint system performance, ATD motion, seat cushion, seat legs, seat pitch, and energy absorbing characteristics of the interior structures. Traditionally, sled testing of the ATD-seat-restraint-interior structure, such as the bulkhead test shown in Figure 2., has been used to test for the injury criteria of the occupants.

The lumbar load injury criterion is generally critical for the vertical test conditions of 14 CFR 25.562(b)(1). Full-scale dynamic seat testing, per 14 CFR 25.562(b)(1), requires a specific minimum velocity of 35ft/s, minimum acceleration of 14G, and maximum rise time 0.08seconds. These requirements are also required by Technical Standard Order (TSO) C127a [14].

A spring-mass model to predict an occupant response during ejection seat testing and to address the spinal injury was developed by Stech and Payne [15]. This model represented the biodynamic properties of the human body and suggested a spinal injury mechanism that is especially sensitive to the spring force in the spinal column. This injury mechanism has become known as the Dynamic Response Index (DRI) and is currently used by the Department of Defense as a criterion with which to evaluate the performance of ejection seats [16]. While the DRI measure is appropriate for the relatively stiff ejection seats installed in military aircraft, its application to civil aircraft seats has produced unrealistic results [17]. Subsequent research, at the FAA Civil Aerospace Medical Institute (CAMI), led to the development of the 1500-lb spinal injury criterion contained in 14 CFR 25.562 and TSO-C127a. The spinal injury criterion was developed using a modified 49 CFR Part 572, subpart B anthropomorphic dummy, which continues to be used in dynamic seat tests. The dummy modifications are described in SAE International Aerospace Standard (AS) 8049 Rev(A) [18]. The 1500-lb load limit corresponds to a DRI of about 19. Data for the military population at that time indicate that the probability of detectable spinal injury at DRI = 18 is about 5 percent and about 20 percent at a DRI of 22. Thus, a DRI of 19 corresponds to a probability of spinal injury of about 9 percent.

The problem with certifying a seat for lumbar load becomes an issue when the seat needs to be re-certified. This required when the seat cushion is replaced after years of use. Many a times it is not possible to get the exact same seat cushion and if a different seat cushion is used then the current methodology is to recertify the whole seat with the new seat cushion which is a costly and time consuming process.

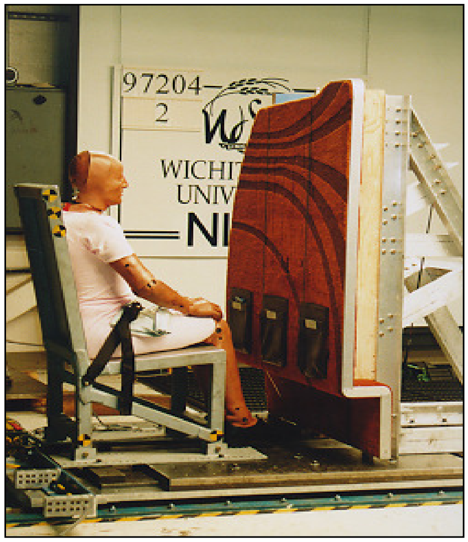

Figure 2. Full-scale sled testing of the ATD-seat-restraint-interior structure under Test – 2 (down test) conditions

This sled testing procedure has proven to be extremely costly and time consuming. For each test, the test article, namely the seat, is destroyed, while the main purpose of the test is not the evaluation of the dynamic response of the seat but the impact response and energy-absorbing capabilities of the interior structure. It is not uncommon that an airframe manufacturer has several different types of seats in a particular aircraft. These seats, in their early development stage, are costly and several test articles could be destroyed for evaluating one design. Furthermore, the sled testing of the ATD-seat-restraint-interior structure is a complicated procedure requiring a large flow time. These factors have motivated the seat manufacturers, airframe manufacturers, the FAA, test labs, as well as research providers to purse alternative methods of certification. With the advent of more robust analytical codes, the FAA has acknowledged that there exists a real possibility of certifying by analysis. FAA is funding research in this regard to develop a set of parameter which would specify as to what constitutes a valid model

1.3 Literature Review

Very little work has been done regarding understanding the scatter of data due to the inherent variations in the full-scale sled testing procedure. Even though it has been have acknowledged by many of the researchers that there exists variation in the full-scale sled test procedure, most of the research to date has been to see if analytical tools can be used to replicate the kinematics, injury criteria, and parameters obtained from the sled test without studying the variation in the experiment itself.

AC 20 -146 [19] issued by FAA, mostly based on the work done by the Civil Aero medical Institute (CAMI), has shown very little evidence as to why certain limits have been specified under which a model is considered to valid. No evidence has been provided to show why the upper and lower limits specified define the actual test.

Olivares [20, 21] has shown that under controlled conditions analytical model can be considered valid representation of test. But even in this study no attention was given to looking at what constitutes the validation criteria. It should be noted, however, that the use of modeling for this purpose is itself a complex (and contentious) issue.

Committee No. 60 of the American Society of Mechanical Engineers is currently working toward developing international standards governing the correctness and credibility of all modeling and simulation activities [22]. When completed, currently bandied about terms such as model "validation" will at last be subject to strict protocols [23, 24].

Collier et al (2002) [25] states that Analysis tools have and will continue to play an essential role in structural certification and goes on to suggests a way to improve reliability of analysis tools so that eventually the aerospace industry will be able to reduce specific architecture testing which accounts for 25–30% of product costs. This paper did not focus on the evaluation of analysis methods, but rather on how to increase confidence in the predictions made with any given analysis method and the software that implements it.

Yang *et al.* (1994) [26] conducted the feasibility study of using the gradient based numerical optimization technique to optimize a simplified vehicle front horn problem by integrating Pro/ENGINEER, PDA/PATRAN3, RADIOSS in the optimization algorithm. Both single- and multiple-objective formulations were used in the study and an improved design was achieved. They concluded that the crashworthiness optimization using the gradient-based approach is feasible but requires good quality of the finite element mesh during the design iterations.

Yang and Tho *et al.* (1999) [27] integrated an explicit crash code (FCRASH) and commercial available optimization package (iSIGHT) to solve a front rail crashworthiness optimization problem using three approaches: gradient-based, design of experiment/penalty/gradient-based, and design of experiment/penalty/ response surfaces. They found that the crash functions are very noisy and used 5% step size to compute the sensitivity using the finite difference method.

Etman *et al.* (1996) [28] adopted the sequential approximate optimization technique to deal with the noisy objective and constraint functions, as well as the high computational costs of the numerical analysis. In this work, the linear model functions are built based upon the responses calculated for a multipoint experimental design in a restricted design space. The linear programming is used to solve the optimization problem within the search subregion. In each iteration, the optimal solution obtained from previous iteration is used as the starting point of the approximate optimization.

Johnson *et al.* (1996) [29] demonstrated the use of regression and Kriging metamodels for surface estimation in multidimensional optimality analysis for linear programming. The methodology was demonstrated using a small example problem, a three source-four destination transportation problem and a multiperiod manufacturing problem. It was shown that these metamodels provide remarkably accurate predictions of the optimal objective function value.

Schramm and Thomas (1998) [30] attempted to use the sequential polynomial regression for crashworthiness design optimization problems. The quadratic polynomial is employed to construct the crash objective and constraint response surface functions globally. In their implementation, only a subset of the polynomial coefficients is computed depending on the number of design points and number of analyses in each of the design iteration.

Kurtaran *et al.* (2002) [31] applied the successive response surface approximation to solve the crashworthiness design optimization problems. In this approach, the sizes of the successive subregions are highly influential on the accuracy of the approximations to be constructed. In general, the smaller the size of the subregion, the better the accuracy of the approximation. A schemed is adopted to determine the size of the subregions in their work.

Sobieski *et al.* (2000) [32] employed the response surface methodology to optimize the vehicle weight under the constraints of NVH (noise, vibration and harshness) and crash requirements. They reported a very significant reduction in elapsed computing time for such a large-scale multidisciplinary design optimization (MDO) problem (from 9 months to 1 day) through the efficient use of shared memory multiprocessor systems.

Kodiyalam *et al.* (2001) [33] extended Sobieski's previous work to increase the computational complexity by addressing multiple safety impact scenarios including frontal crash, offset crash, side impact and roof crush, in addition to the NVH discipline. The MDO problem was solved using multiple approximation models, sensitivity based approximation model for NVH responses and Kriging metamodels for the crash responses.

Miura *et al.* [34] attempted to combine the response surface methodology and numerical optimization technique in a commercial optimization, iSIGHT (Engineous Software), to improve the crash performance of a knee impact problem.

Craig *et al.* (2005) [35] employed a screening method based on the response surface methodology (linear) to select a reduce subset of design variables in the optimization process for the knee impact and frontal impact problems.

Lanzi *et al*. (2005) [36] used the response surface methodology constructed by radial basis functions and coupled with genetic algorithm to optimize the shape of composite absorbers with elliptical cross-sections under the impact requirements.

1.4 Scope and Objectives of This Dissertation

The purpose of this study is to quantify the variations that exist in the full-scale sled tests at one particular facility which has been approved by the Federal Aviation

Administration to certify cabin interiors. Once the variations have been quantified, based on the current regulations for Part 25 type aircraft, analytical tool will be used to simulate the sled test. The mathematical model so developed will be shown to be robust enough to predict the various criteria which are monitored during a full-scale sled. The deviation from the test, if any, are shown the scatter band offered by the experimental process itself.

Using these validated models, the two test conditions mentioned in the regulation will be studied to identify some of the key parameter using a design of experiment model. This would generate a design space where the parameter's influence on the injury criteria studied can be mapped by using a response surface methodology. The surface so obtained will be used for developing a tool for helping aircraft interior designers to come up with designs which are safe for the flying public while keeping the cost and time needed for such a development to a minimum.

This dissertation starts by stating the conditions that are stated in the regulations for testing and certifying transport aircraft interiors and seats. The report then goes on to show the scatter in the sled test data and tries to statistically quantify the scatter in the sled test data. Once the scatter had been established analytical model were developed which validated against the sled tests. The versatility of the model were shown by using the validated model to predict the injury criteria under actual full-scale sled test conditions. A design experiments model is used to understand the effect of a few critical parameters that were studied and to generate a response surface of the design space. Using the response surface a toll was developed that would help aircraft cabin interiors to design components that are crashworthy without the need of multiple tests.

CHAPTER 2

FEDERAL AVIATION REGULATION FOR CRASHWORTHINESS RELATED TO SEAT AND CABIN INTERIOR CERTIFICATION

Federal Aviation Administration has put in various regulations to ensure the safety of flying public. Based on the type of aircraft the regulations have been crafted so that natures of operation of these aircrafts are taken into consideration while enacting the regulation. The main classifications of the type of aircrafts are

- Part 23 Type of Aircraft – General Aviation type of aircraft
- Part 25 Type of Aircraft – Transport type of aircraft
- Part 27 Type of Aircraft – Rotorcraft

2.1 FAR 25.562

14 CFR 25.562 specify two types to ensure that the cabin interior and seat would provide a safe environment during emergency landing and take off conditions. In order to ensure that the seta provide enough protection occupant the FAR's state that every seat configuration will be subject to dynamic test as per the following conditions:

2.1.1 <u>FAR 25.562 Test -1 Configuration</u>

An anthropomorphic test dummy ATD specified in 49 CFR Part 572 Subpart B will serve as an occupant and each seat will be subject to a change in downward vertical velocity (Δ v) of not less than 35 feet per second, with the airplane's longitudinal axis canted downward 30 degrees with respect to the horizontal plane and with the wings level. Peak floor deceleration must occur in not more than 0.08 seconds after impact and must reach a minimum of 14g. The setup is shown in Figure 3.

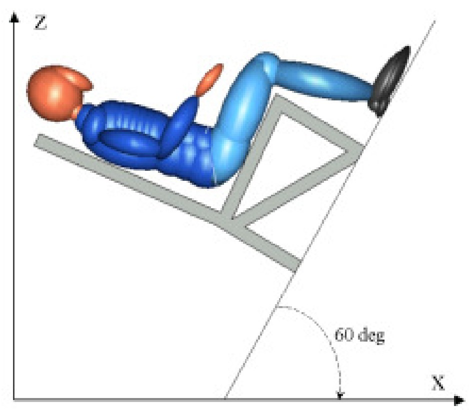

Figure 3. Part 25.562 Test -1 Configuration

2.1.2 Part 25.562 Test -2 Configuration

As per the regulation every seat configuration must be subject to dynamic full-scale sled test. The test condition state that a change in forward longitudinal velocity (Δ v) of not less than 44 feet per second, with the airplane's longitudinal axis horizontal and yawed 10 degrees either right or left, whichever would cause the greatest likelihood of the upper torso restraint system (where installed) moving off the occupant's shoulder, and with the wings level. Peak floor deceleration must occur in not more than 0.09 seconds after impact and must reach a minimum of 16g. Where floor rails or floor fittings are used to attach the seating devices to the test fixture, the rails or fittings must be misaligned with respect to the adjacent set of rails or fittings by at least 10 degrees vertically (i.e., out of Parallel) with one rolled 10 degrees. The top view of the test setup showing the 10° yaw is shown in Figure 4.

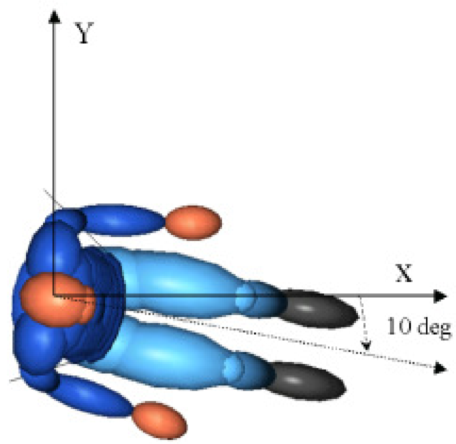

Figure 4 Part 25.562 Test – 2 Configuration

Computer analysis may be used to substantiate a seat system design that is subjected to the certification requirements of FAR Part 25.562 after it has been correlated to the validation acceptance criteria specified below. The computer model is considered validated if reasonable agreement between analysis and test data can be shown. The validation must be performed on a baseline seat design or cabin interior design that has demonstrated compliance, by test, to 14 CFR 25.562 test conditions.

Once validated, the model may then be utilized for certification purposes under the conditions specified further in this chapter.

The general validation acceptance criteria includes, but is not limited to, the following:

- The model must be validated against dynamic tests.
- The model should be utilized for conditions that are similar to the model validation conditions. Similarity should exist between the current seat analysis

and the test and analysis used to validate the analysis model, including loading conditions, seat type, and worst-case conditions.

- The general occupant trajectory, verified by time history plots, should correlate against test data.

In addition to the general validation criteria above, the applicant may need to validate the model to some or all of the application specific criteria

2.2 General Validation Criteria

The model is considered validated and may be used as means of demonstrating compliance if the validation acceptance criteria specified in this section have been demonstrated. The criteria will allow for some subjective interpretation as long as the basis of such interpretation is consistent with good engineering judgment. Such interpretation shall also be commensurate with the basis of the regulation, and the level of correlation required of the applicant shall not be imposed to tolerances beyond that observed in a dynamic test. The validation acceptance criteria are as follows:

1. The model must be reasonably validated against a dynamic test.
2. The model can be utilized for substantiation under similar conditions that the model was validated against.

In addition to the general validation criteria above, the model has to correlate to the following application specific criteria:

2.2.1 Structural Response

The computer model, used for structural certification, may be validated by correlating the following structural performance criteria to dynamic test.

2.3 Internal Loads

Internal loads such as floor reaction loads are a required means to show correlation. Reasonable agreement between the peak resultant floor reaction load obtained in the analysis and test data should not exceed 10%.

2.4 Structural Deformation

Reasonable agreement should be obtained between the mode of structural deformation obtained by analysis and test data for members that are critical to the overall performance or structural integrity of the seat or seating system. Validation may be established by visual comparisons or by over-laying space (xy, yz or zx) plots obtained from the analysis to photometric data obtained from dynamic tests.

2.5 Restraint System

Compliance with shoulder harness load is defined in FAR Part 25.562(c)(6). Validation of the restraint system may be obtained by correlating the analysis belt load force-time history to test data.

The phase and maximum value force-time history profile should correlate within 10% of dynamic test data. This would ensure that in the analysis, the energy from the occupant as a result from inertia forces are transferred appropriately to the seat and vice versa.

Additional parameters such as belt pay-out or permanent elongation of the seat belt may be correlated if similar measurements were recorded during dynamic full-scale sled test event.

2.5.1 Injury Criteria

Validation of the injury criteria may be obtained by correlating the analysis time history plots to test data. In general, the level of deviation in the injury criteria between analysis and test data should not within the variation experienced for the particular kind of test. If no previous test for the similar configuration was performed, then the deviation between the analysis and test should be within ± 10%.

2.6 Spine Load

Compliance with spine load is defined in FAR Part 25.562(c)(7). The maximum allowable limit is 1,500 pounds. The phase and maximum value force-time history profile for spine load obtained in the analysis should be correlated to the dynamic test.

2.7 Discrepancies

Failure to satisfy all validation criteria does not automatically preclude the model from being validated. The applicant and the FAA ACO engineer should evaluate if the deviations will have a detrimental impact on the model to sufficiently predict the crash scenario, and to determine if deviations from the validation criteria are acceptable.

In addition, the applicant may present evidence to show that the deviation is within the inherent reliability and statistical accuracy of the test results. Discrepancies between results obtained from analysis and test data should be quantified.

CHAPTER 3

STUDY TO ESTABLISH THE STATISTICAL VARATION IN FULL-SCALE SYSTEM SLED TESTING

3.1 Standard Deviation

It was important to measure the variability of the sled test as an average, mean, only indicates the central score and where the most frequent score are. It tells very little about the data, scores that are not at the center of the distribution. Thus in order to study the variation of the data, not only is the mean value important the measure of variability is also critical. The ideal way to understand the scatter of data points in a sample is to measure its mean and sample standard deviation. Formulated by Galton in the late 1860s,[37] the standard deviation remains the most common measure of statistical dispersion, measuring how widely spread the values in a data set are. If many data points are close to the mean, then the standard deviation is small; if many data points are far from the mean, then the standard deviation is large. If all data values are equal, then the standard deviation is zero. A useful property of standard deviation is that, unlike variance, it is expressed in the same units as the data. Standard deviation of the sample is measure as shown in equation (2)

$$S_x = \sqrt{\frac{\sum (X - \overline{X})^2}{N - 1}} \tag{2}$$

where S_x is the standard deviation of the sample

X is the individual scores

$\overline{X}$ is the mean of the sample

N is the count

3.2 Test for Normality

Many data analysis methods (t test, ANOVA, regression) depend on the assumption that data were sampled from a Gaussian distribution. The best way to evaluate how far your data are from Gaussian is to look at a graph and see if the distribution deviates grossly from a bell-shaped normal distribution. There are potential problems when trying to determine the normality using this method. These potential problems are:

- Small samples almost always pass a normality test. Normality tests have little power to tell whether or not a small sample of data comes from a Gaussian distribution.
- With large samples, minor deviations from normality may be flagged as statistically significant, even though small deviations from a normal distribution won't affect the results of a t test or ANOVA.
- Decisions about when to use parametric vs. nonparametric tests should usually be made to cover an entire series of analyses. It is rarely appropriate to make the decision based on a normality test of one data set.

It is usually a mistake to test every data set for normality, and use the result to decide between parametric and nonparametric statistical tests. But normality tests can help in understanding the data, especially when similar results are seen in many experiments. There are numerous tests for deciding if a set of data is normally distributed or not. In this study Shapiro – Wilk W test for normality has been used.

3.2.1 Shapiro – Wilk W Test for Normality

As a test for the normality of complete samples, the W statistic from Shapiro – Wilk test [38] has several good features namely, that it may be used as a test of the composite hypothesis, that is very simple to compute once the table of linear coefficients is available and that the test is quite sensitive against a wide range of alternatives even for small samples ($n < 20$). The statistic is responsive to the nature of the overall configuration of the sample as compared with the configuration of expected values of normal order statistics.

A drawback of the W test is that for large sample sizes it may prove awkward to tabulate or approximate the necessary values of the multipliers in the numerator of the statistic. Also, it may be difficult for large sample sizes to determine percentage points of its distribution.

The W test had its inception in the framework of probability plotting. The formal use of the (one-dimensional) test statistic as a methodological tool in evaluating the normality of a sample is visualized as a supplement to normal probability plotting and not as a substitute for it.

The object of the W test is to provide an index or test statistic to evaluate the supposed normality of a complete sample. The statistic has been shown to be an effective measure of normality even for small samples against a wide spectrum of non-normal alternatives. The W statistic is scale and origin invariant and hence supplies a test of the composite null hypothesis of normality.

To compute the value of W, given a complete random sample of size n, x_1, $x_2,\ldots,x_n$, one proceeds as follows

i. Order the observations to obtain an ordered sample $y_1 \leq y_2 \leq \ldots \leq y_n$.

ii. Compute: $S^2 = \sum_1^n (y_i - \bar{y})^2 = \sum_1^n (x_i - \bar{x})^2$ (3)

iii. a. If n is even, $n = 2k$, compute

$$b = \sum_{i=1}^{k} a_{n-i+1}(y_{n-i+1} - y_i), \tag{4}$$

where the values of a_{n-i+1}, are given in the table in Appendix A.

b. If n is odd, $n = 2k + 1$, the computation is just as in (iii) (a), since $a_{k+1} = 0$ when $n = 2k + 1$. Thus one finds

$$b = a_n(y_n - y_1) + \ldots + a_{k+2}(y_{k+2} - y_k), \tag{5}$$

where the value of y_{k+1}, the sample median, does not enter the computation of b.

iv. Compute: $W = b^2 / S^2$ (6)

v. 1, 2, 5, 10, 50, 90, 95, 98 and 99 % points of the distribution of W are given in the Table in Appendix B. Small values of W are significant, i.e. indicate non-normality.

3.3 Standard Deviation and Normal Distribution

An observation is rarely more than a few standard deviations away from the mean. Chebyshev's inequality entails the following bounds for all distributions for which the standard deviation is defined.

- At least 50% of the values are within $\sqrt{2}$ standard deviations from the mean.
- At least 75% of the values are within 2 standard deviations from the mean.
- At least 89% of the values are within 3 standard deviations from the mean.
- At least 94% of the values are within 4 standard deviations from the mean.
- At least 96% of the values are within 5 standard deviations from the mean.
- At least 97% of the values are within 6 standard deviations from the mean.
- At least 98% of the values are within 7 standard deviations from the mean.

And in general:

- At least $(1 - 1/k2) \times 100\%$ of the values are within k standard deviations from the mean.

Dark blue, shown in Figure 5, is less than one standard deviation from the mean. For the normal distribution, this accounts for 68.27 % of the set; while two standard deviations from the mean (medium and dark blue) account for 95.45%; three standard deviations (light, medium, and dark blue) account for 99.73%; and four standard deviations accounts for 99.994%. The two points of the curve which are one standard deviation from the mean are also the inflection points [39].

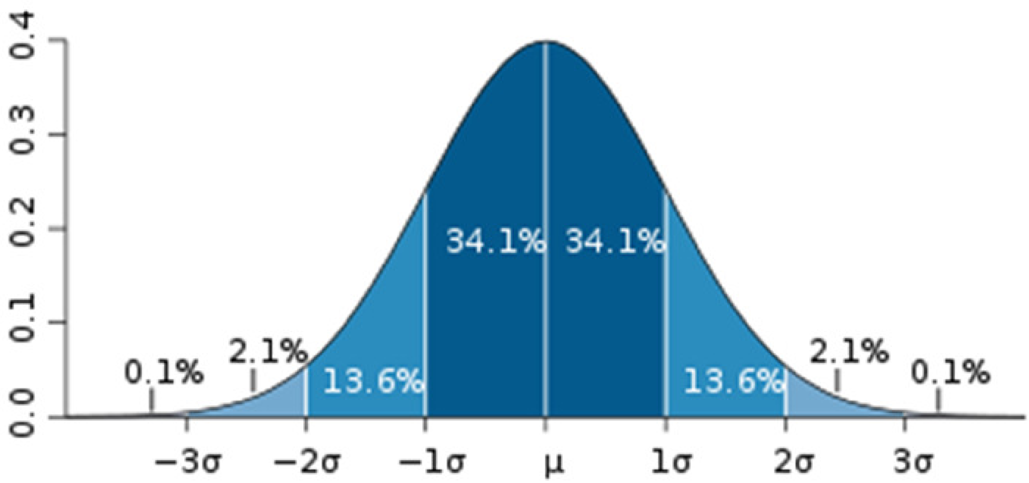

Figure 5 Satndard Deviation Diagram

The central limit theorem says that the distribution of a sum of many independent, identically distributed random variables tends towards the normal distribution. If a data distribution is approximately normal then about 68% of the values are within 1 standard deviation of the mean, about 95% of the values are within two standard deviations and about 99.7% lie within 3 standard deviations. This is known as the 68-95-99.7 rule, or the empirical rule.

For various values of z, the percentage of values expected to lie in the symmetric confidence interval $(-z\sigma, z\sigma)$ are as shown in Table 1.

The advantage of using standard deviation is the closest we come to computing the average of deviations. The standard deviation allows us to gauge the extent to which the scores are consistently close to each other and, correspondingly, the degree to which they are accurately summarized by the mean. If the standard deviation is relatively large, then we know that a relatively large portion of the scores are relatively far away from the mean. It also indicates how much the scores below the mean deviates from it and how much the scores are spread around the mean. If we were to assume that the lumbar data scatter follows a normal distribution then, +2SD and -2SD are useful. Figure 6 shows the -2SD and +2SD on the normal distribution graph.

TABLE 1

SYMMETRIC CONFIDENCE INTERVAL

zσ	**Percentage**
1σ	68.27%
1.645σ	90%
1.960σ	95%
2σ	95.450%
2.576σ	99%
3σ	99.7300%
3.2906σ	99.9%
4σ	99.993666%
5σ	99.99994267%
6σ	99.9999998027%
7σ	99.9999999997440%

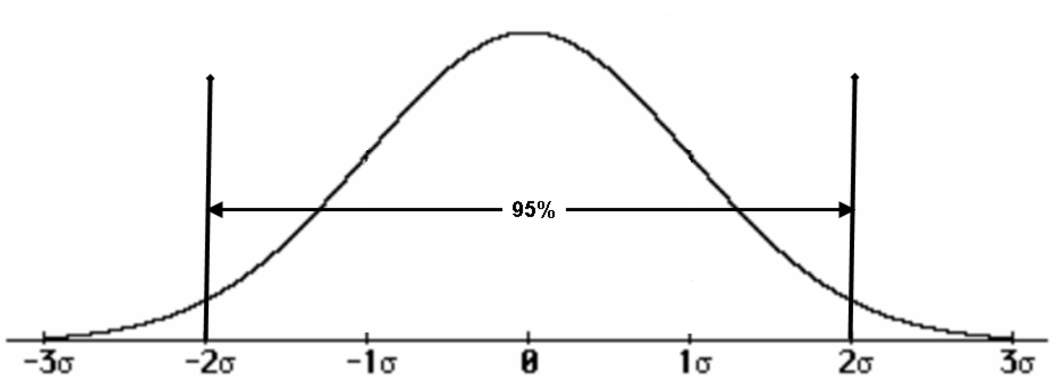

Figure 6 -2SD and +2SD marked on the normally distributed curve

3.4 Part 25.562 Test-1 Using a Rigid Iron Seat

Four tests, using two ATDs in each test, performed over a month was used as the sample population for studying the variations inherent in a sled test. A Test-1 condition sled test with rigid iron seat has the least number of variables, with the variables being sled pulse, instrumentation (calibration) of the ATD, position of the ATD and the property of the restraint system.

In order to determine the inherent variation in the sled test for a Test-1 condition, a statistical analysis of the data was conducted. In Test-1 condition the lumbar load of the ATD is measured and this has a threshold of 1500lbs above which is considered to cause severe injury.

3.4.1 Data Analysis for Test – 1 Configuration

The data from the full scale test is given in Table 2. It may be noticed that even though the regulation, FAR Part 25.562, specifies 14G as the peak sled pulse in almost all the cases this has been over shot. This is common occurrence in the various tests that are conducted at FAA approved test facility that use steel strap for decelerating the sled. The regulation only specifies that the minimum deceleration should be 14G and the rise time should be 0.08 seconds. This results in frequent overruns of the sled pulse resulting in the test articles being subjected to a higher deceleration than that specified under the regulations. The lumbar load at 14G is calculated from the data from the sled test by assuming that the pulse acceleration and lumbar load are directly proportional and hence a linear interpolation is performed to obtain the lumbar load at 14G. This approximation is permitted as per the FAA.

TABLE 2

LUMBAR LOAD DATA FROM THE FULL SCALE SLED TEST

No.	Left-Side Seat	Right-Side Seat	Left Lumbar Load (lbs)	Right Lumber Load (lbs)	Max. Accel. (G)
1	Bare Iron Seat	Bare Iron Seat	1170	1110	15.14
2	Bare Iron Seat	Bare Iron Seat	1306	1360	15.47
3	Bare Iron Seat	Bare Iron Seat	862	740	14.57
4	Bare Iron Seat	Bare Iron Seat	1085	849	14.44

The lumbar load measured at various acceleration pulses are scaled down to 14G and the lumbar load is then calculated. Table 3 lists the lumbar load for 14G

TABLE 3

LUMBAR LOAD AT 14G

Test #	ATD Location	Lumbar Load @ 14 G (lbs)	Mean	Standard Deviation
1	Left (Rigid Iron Seat)	1081.90	992	185.23
1	Right (Rigid Iron Seat)	1026.42		
2	Left (Rigid Iron Seat)	1181.90		
2	Right (Rigid Iron Seat)	1230.77		
3	Left (Rigid Iron Seat)	828.28		
3	Right (Rigid Iron Seat)	711.05		
4	Left (Rigid Iron Seat)	1051.94		
4	Right (Rigid Iron Seat)	823.13		

On performing a test for normality of the above data revealed the W value was calculated as 0.934, which is larger than the tabulated 50% point, which was 0.932. This revealed that the data was normally distributed.

It may be noticed that even in tests in which the same sled pulse was used, and with the ATD seated side-by-side as shown in Figure 7, the lumbar load differed greatly. This, pseudo normalized data, was used as the sample data for studying the inherent variations in conducting a sled test with a rigid iron seat. The standard deviation of the data was calculated, as shown in TABLE 3, and thereby the overall variation of the data from the mean was established.

Figure 7 Two ATDs placed Side-by-Side

It was observed that once the lumbar loads were normalized to 14G, then the mean lumbar load was 922 and the standard deviation was 185.23. Applying the Chebyshev's inequality principle, 95% of the scatter in lumbar load data can be included when using a ±2SD to the mean. This is then applied to each test to see what the range of scatter would be for that test. This standard deviation was also used to calculate the variation for each test as shown in Table 4.

TABLE 4

THE RANGE OVER WHICH LUMBAR LOAD IS LIKELY TO BE FOUND

No.	Left-Side Seat	Right-Side Seat	Left Lumbar Load	Right Lumbar Load	Max. Accel.	+2SD	Mean	-2SD
1	Bare Iron Seat	Bare Iron Seat	1170	1110	15.14	1510.47	1140	769.53
2	Bare Iron Seat	Bare Iron Seat	1306	1360	15.47	1703.47	1333	962.53
21	Bare Iron Seat	Bare Iron Seat	862	740	14.57	1171.47	801	430.53
39	Bare Iron Seat	Bare Iron Seat	1085	849	14.44	1337.47	967	596.53

3.5 Part 25.562 Test – 2 Using a Rigid Iron Seat and Aluminum Sheet As A Bulkhead

Seven test were conducted at NIAR impact dynamics lab for Test – 2 configuration in which the seat setback distance was 34 inches , as defined in Figure 8 Test – 2 Setup, and the bulkhead used was 0.63 inch thick 6061 Aluminum Sheet. The seat restraint used for all the tests was polyester seat belt. These test were conducted over the years from 1996-2002. These tests represent a condition in which the number variables are minimal, as far as test -2 configuration is concerned. The variations due to the use of honeycomb panels which is typically seen in aircraft for use as bulkhead is eliminated by using these aluminum sheets as the deformation of the aluminum will be consistent and so too will the coefficient of friction that the aluminum offers.

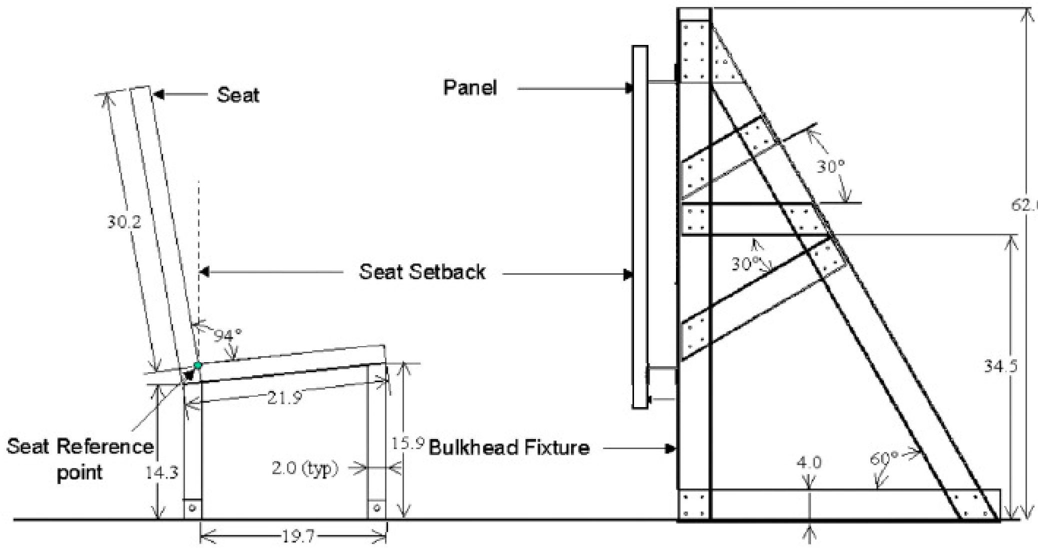

Figure 8 Test – 2 Setup

3.5.1 <u>Data Analysis for Test – 2 Configuration</u>

Data from the full-scale sled tested under Test – 2 configuration, as shown in Figure 9, is tabulated in Table 5. The sled pulse for each of these tests varies considerably and the so does the other parameters like exact position of the ATD, batch from which the aluminum sheet were used etc. The head injury criteria (*HIC*) has been calculated for all the test and this calculated only during the duration of head contact with the bulkhead.

TABLE 5

HIC VALUE FROM FULL-SCALE SLED TESTS

No.	Seat Setback Distance	Type of Bulkhead	Average Head CG Acceleration	HIC
2	34	Aluminum	47.4	586
3	34	Aluminum	49.6	549
4	34	Aluminum	49.5	716
5	34	Aluminum	48.4	694
6	34	Aluminum	50.1	653
7	34	Aluminum	47.6	421

Before any further analysis was done on the data a test of normality was performed to see if the data conforms to a normal distribution. Using Shapiro – Wilk test the W value was calculated as 0.932, which is greater than the tabulated 50% point, which is 0.928

Now that the data has been found to normally distributed, further analysis of the data can be performed. The first step is to find out the standard deviation of the data so that the 2SD limit can established within which the 95% of scatter in the data would encompassed. This upper and lower bound would also help during model validation, as any value within this limit should be considered as valid representation of the test. Table 6 shows the standard deviation and of the data.

TABLE 6

STANDARD DEVIATION OF THE DATA FOR TEST – 2 CONFIGURATION

No.	Seat Setback Distance	Type of Bulkhead	Average Head CG Acceleration	HIC	Mean	SD
1	34	Aluminum	47.4	586	603.17	109.43
2	34	Aluminum	49.6	549		
3	34	Aluminum	49.5	716		
4	34	Aluminum	48.4	694		
5	34	Aluminum	50.1	653		
6	34	Aluminum	47.6	421		

The mean HIC for the set of data was 603 and the standard deviation was 109.43. The range of HIC data, as can been seen, is from 716 to 421 for the similar inputs to the experiment. Based on this the validation range can be set at ±2SD from the mean as this encompass 95% of the data obtained from the full-scale sled test. This range has been shown in Table 7.

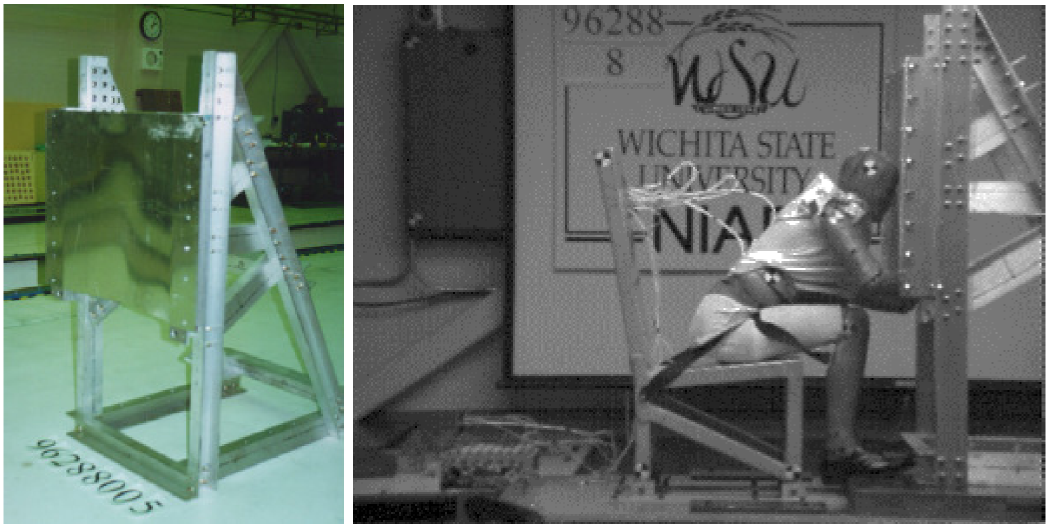

Figure 9 Test – 2 Aluminum bulkhead and sled test

TABLE 7

THE SCATTER BAND FOR WHICH 95% OF DATA IS ENCOMPASSED

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Seat Setback Distance</th><th rowspan="2">Type of Bulkhead</th><th rowspan="2">HIC</th><th colspan="3">Validation Range for HIC</th></tr>
<tr><th>-2SD</th><th>Mean</th><th>+2SD</th></tr>
<tr><td>1</td><td>34</td><td>Aluminum</td><td>586</td><td rowspan="6">384</td><td rowspan="6">603</td><td rowspan="6">822</td></tr>
<tr><td>2</td><td>34</td><td>Aluminum</td><td>549</td></tr>
<tr><td>3</td><td>34</td><td>Aluminum</td><td>716</td></tr>
<tr><td>4</td><td>34</td><td>Aluminum</td><td>694</td></tr>
<tr><td>5</td><td>34</td><td>Aluminum</td><td>653</td></tr>
<tr><td>6</td><td>34</td><td>Aluminum</td><td>421</td></tr>
</table>

CHAPTER 4

MODEL VALIDATION

4.1 Validation Model for Test - 1 Configuration

For validating the Test – 1 configuration, a mathematical model was build to using MADYMO[40]. The model would be validated against the mean lumbar load valued. The idea being that when an idealized 14G pulse is used and if the model is validated against the mean value, then when using the validated model to predict the lumbar load for the 4 tests conducted, changing the idealized pulse used with the actual sled pulse for those tests should result in lumbar loads within the permissible range. The load deflection property of the stiff iron seat is as shown in Figure 10. It can been seen that the seat is extremely stiff and the advantage of using such a stiff seat is that all the effect of the deceleration are transferred to occupant/ATD. This would result in evaluating the worst case criteria where no energy is absorbed by any component of the seat .

The seatbelt properties where determine dynamically testing the seatbelt material. The materials used in seatbelt have been rate sensitive and hence the testing of such material is performed at pre-determined test speed. The load deflection property of the seatbelt is normally supplied by the seatbelt manufacturer. The Figure 10 shows a sample polyester seatbelt property used for these test.

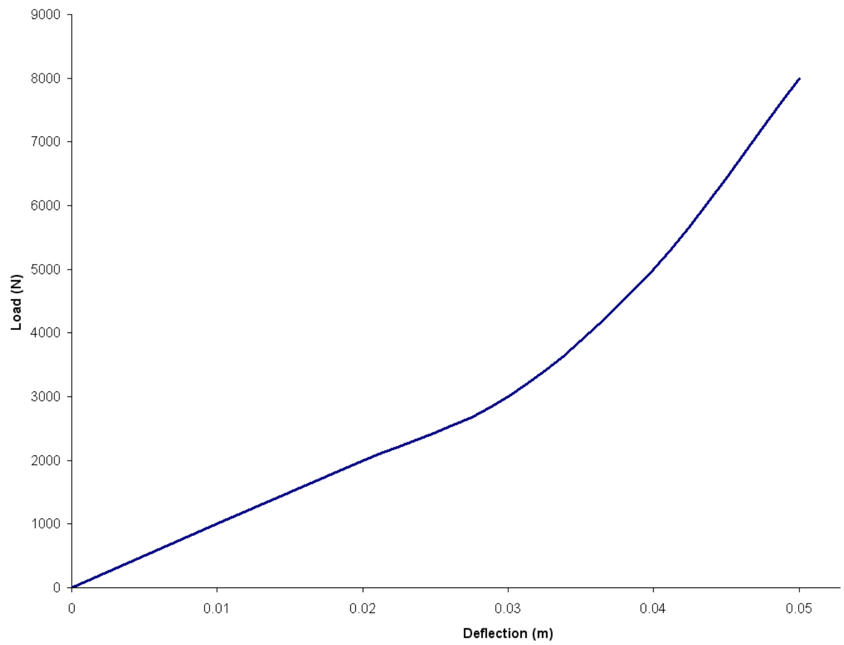

Figure 10 Iron Seat Load – Deflection properties

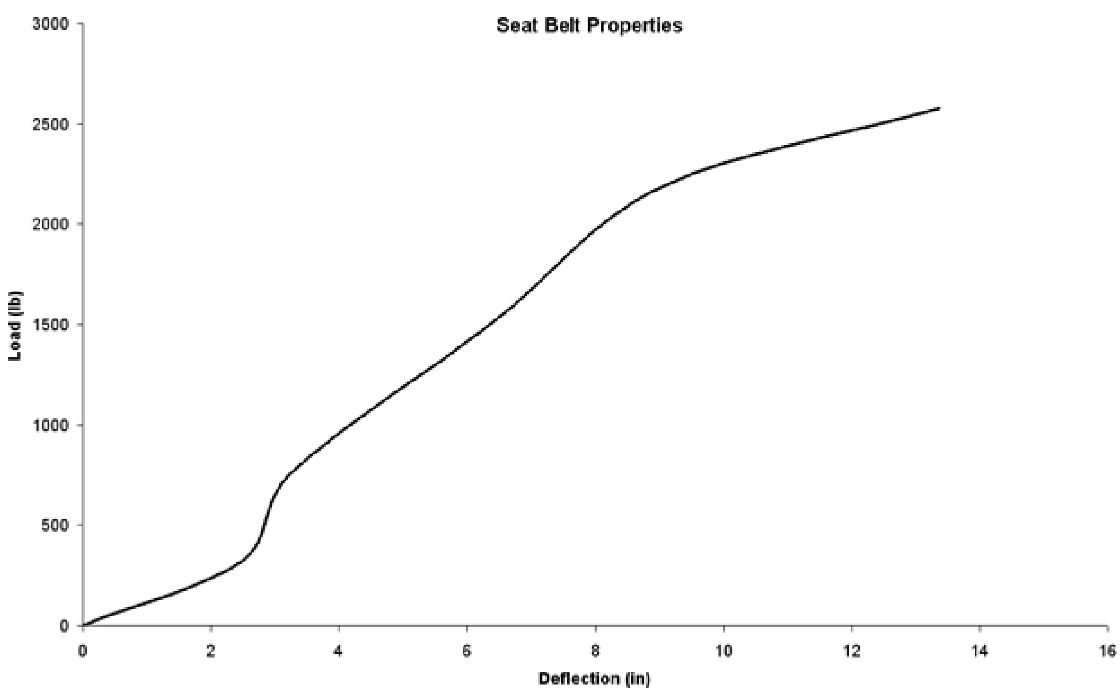

Figure 11 Set belt properties for Polyester seatbelt

4.1.1 Mathematical Model with Rigid Iron Seat

The model for validating against the mean was built by assuming idealized conditions. This included assuming the ATD was centered on the seat, there was no deflection of the seta, and the belt wrapped around the ATD had equal lengths on either side of the ATD. Figure 12 Model for Validation under Ideal Conditions shows the model that was build in MADYMO for validating against the mean lumbar load under idealized conditions. The seat belt and seat properties were as described earlier.

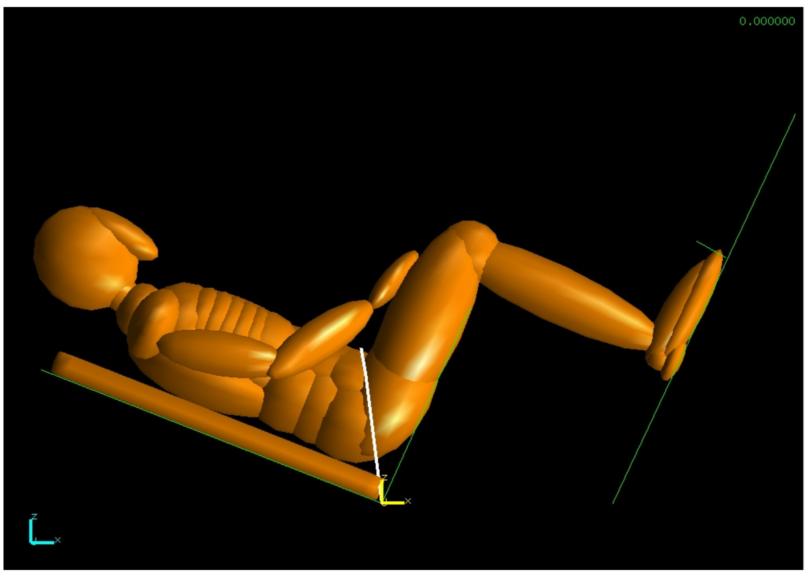

Figure 12 Model for Validation under Ideal Conditions

Since no lumbar load profile exist under the idealized sled pulse conditions, only the maximum lumbar load from the analysis was compared with mean lumbar load. The sled pulse used for this shown in Figure 13, which is the ideal sled pulse to be used for this configuration

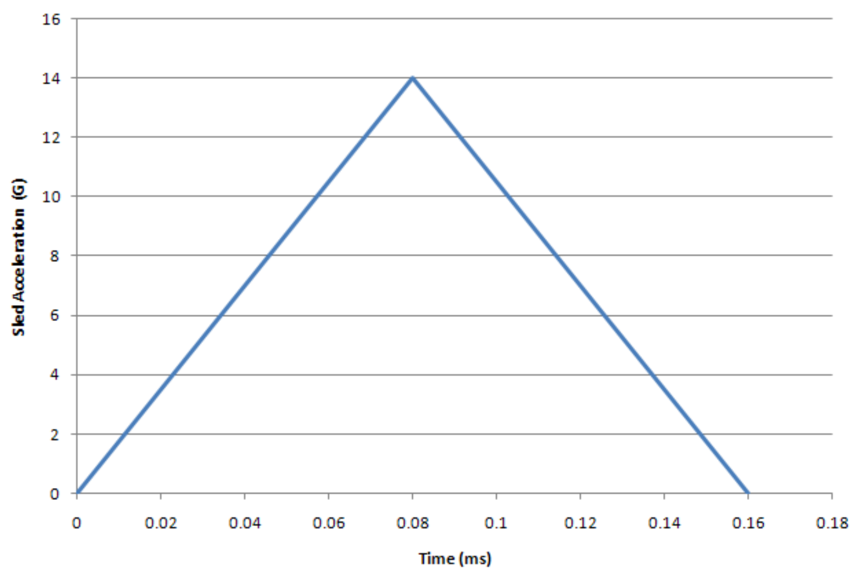

Figure 13. Ideal 14G Sled Pulse for Test – 1 Configurations

The results from the model thus build was validated so that maximum lumbar load from the analysis would compare well with the mean lumbar load measured for the 4 test (8 samples), 992lb. This model was considered as valid model for the Test – 1 configuration when using a rigid iron seat.

In order to study the robustness of this model, it was then used to predict the lumbar for the 4 test. For doing this the sled pulse from the test was applied to model instead of the idealized pulse and the lumbar load was measured. The sled varies from test to test and this would result in a different lumbar load. Since the exact position of the ATD was captured for each of the tests, the idealized location was used. Hence only one occupant was model during the building of the analytical model since modeling both occupant would result in the same lumbar load. Table 8 shows the measured lumbar load for the 4 test and the mean and the ±2SD limit for each of the test. The standard deviation used for this was calculated for the 4 tests.

TABLE 8

VARIATION OF THE LUMBAR LOAD ALLOWED FOR VALIDATION

No.	Left Lumbar Load	Right Lumber Load	Max. Accel.	+2SD	Mean	-2SD	Analysis
1	1170	1110	15.14	1510.47	**1140**	769.53	**1257**
2	1306	1360	15.47	1703.47	**1333**	962.53	**1325**
3	862	740	14.57	1171.47	**801**	430.53	**956**
4	1085	849	14.44	1337.47	**967**	596.53	**949**

It can be seen from the results that the lumbar road thus measured from the model compared very favorably with the sled test results. In fact on closer observation it is noticed that the predicted lumbar load closer to the mean for each of the test showing that model is able to predict the lumbar load with good accuracy.

The methodology shown here shows that once a validated model can be build it may be used for further prediction provided the parameters under which the model was validated remains the same.

4.1.2 Mathematical Model With Rigid Iron Seat And A 4" Thick DAX 26 Foam As Seat Cushion

Since the previous procedure is for the most basic type of validation, the question is whether this methodology would be true when more variables are introduced. The seat cushion places an important role in deciding the lumbar load of the occupant. Four test were conducted which involved the use of 4” thick DAX26 foam as seat cushion resulting in a sample population of 6.

TABLE 9

LUMBAR LOAD SCALED TO 14G FOR 4” DAX26 SEAT CUSHION

No.	Lumbar Load Scaled to 14G	Mean	SD
1	1693.17	1744.63	227.21
1	1636.58		
2	1925.12		
2	1924.16		
3	1926.23		
4	1362.51		

Table 9 shows the lumbar load scaled to 14Gs for the 4 test yielding in 6 sample data. The resulting mean and standard deviation has also been recorded in the table. For the current set of data the mean lumbar load was 1774.63lbs and the standard deviation was 227.21 lbs.

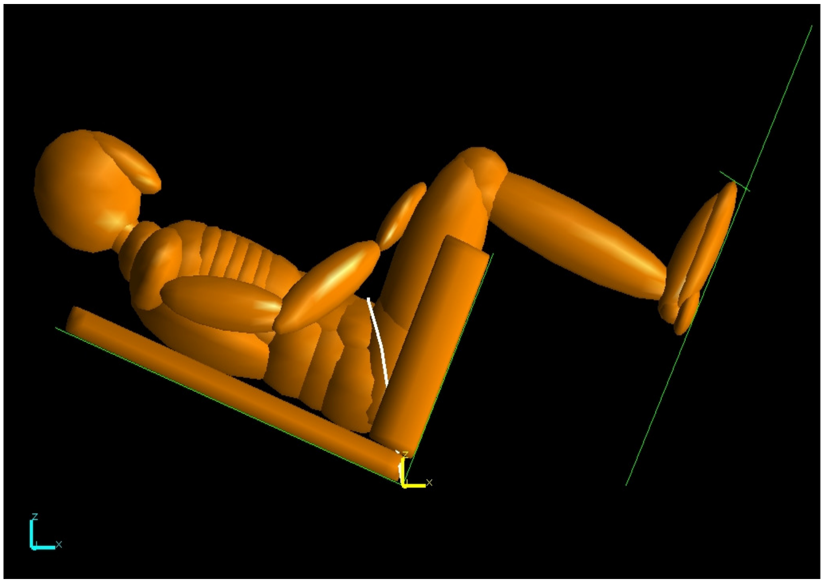

Figure 14. Model setup with 4” DAX26 foam

Figure 14 shows the model setup for the test 1 configuration in which a 4” DAX26 seat cushion foam was used on top of the rigid iron seat. The load deflection properties of the seat cushion (4”DAX26 foam) shown in Figure 15 have been incorporated in the model.

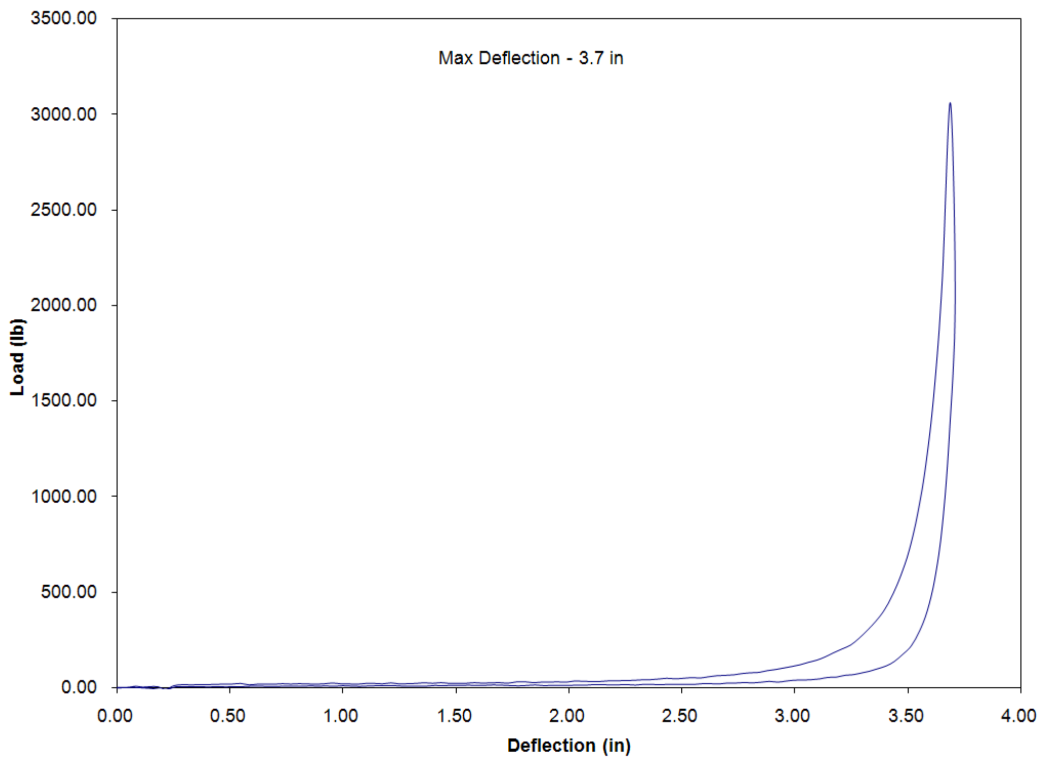

Figure 15. Load – Deflection Properties of a 4” DAX26 foam

The model was setup in such way that the 1G preload that happens when the ATD sits on the seat cushion was included in the model. This resulted in a better fidelity model. The idealized 14G sled pulse was applied to the model and the model was correlated against the mean lumbar load obtained from the test. Once the model was suitably correlated against the mean lumbar load, the valid model was used in the prediction of the lumbar load individual test cases.

Based on mean and standard deviation that was obtained for the set of data, the permissible spread or scatter which would encompass 95% of the scatter has been calculated and ±2SD limit on the mean was set and these results have been tabulated in Table 10. For test 3 the seat cushion used on the left seat and for test 4 the seat cushion used on the right seat was not a DAX 26 foam.

TABLE 10

COMPARISON OF LUMBAR SPREAD AT 2SD FOR 4" DAX26 AND ANALYSIS

No	Left Lumbar Load (lb)	Right Lumbar Load (lb)	Sled Accel. (G)	+2SD	Mean (lb)	-2SD	Lumbar Load – Analysis
1	1825	1764	15.09	2209.32	1794.5	1379.68	1894.26
2	1998	1997	14.53	2412.32	1997.5	1582.68	2026.1
3	1406*	1962	14.26	2376.82	1962	1547.18	2082.37
4	1381	1382*	14.19	1795.82	1381	966.18	1472.2

- Different Seat cushion is used

Based on the result obtained from the validated model it is safe to conclude that it is possible to build a robust analytical model which can be used for predicting the lumbar load. The important step in deciding the validation criteria is to determine the inherent variation in the test procedure and allow at very least the same amount of variation or band for the analytical model prediction.

4.2 Validation Model for Test - 2 Configuration

An analytical model will be set up to validate the setup where a rigid iron seat at 34"seat setback distance and 0.63 inch thick 6061 aluminum sheet was used as bulkhead was used. The Test – 2 configuration in which the test were conducted had varying sled pulse, but for the validation process an idealized 16G sled pulse, shown in Figure 16, will be used. The model will be validated against the mean HIC calculated, shown in Table 11, for this condition will be used.

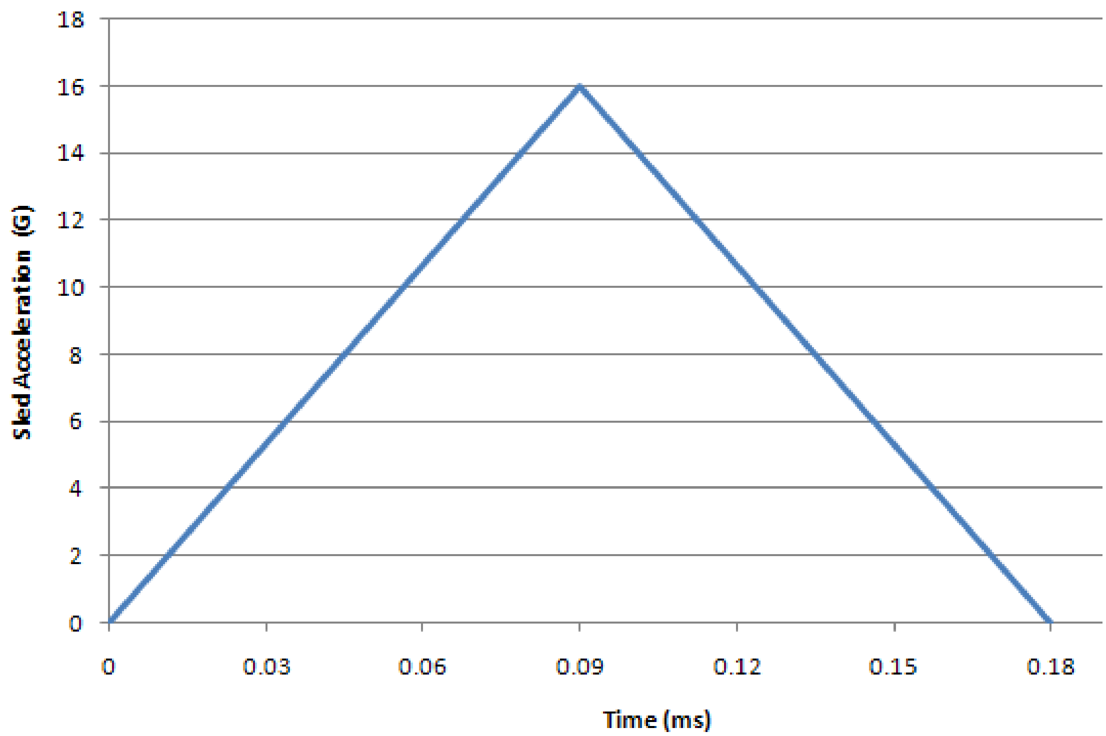

Figure 16. 16G Sled Pulse for Test – 2 Configuration

4.2.1 Mathematical Model with Rigid Iron Seat with an Aluminum Bulkhead

The properties of the seatbelt and the rigid iron seat used in the model are as shown in Figure 11 Set belt properties for Polyester seatbelt and Figure 10. The bulkhead property for this model was based on a finite element model of the aluminum sheet. The material properties used were:

Density	= 2.7g/cc
Modulus of Elasticity	= 68.9GPa
Yield Strength	= 48.3MPa
Poission's Ratio	= 0.3

The model so developed is shown in Figure 17. The model was validated so the HIC calculated from the model would compare well with the calculated mean HIC. Since an idealized pulse is used and the HIC against which the model is being validated is only the mean of the test, the profile of the head CG acceleration could not be compared.

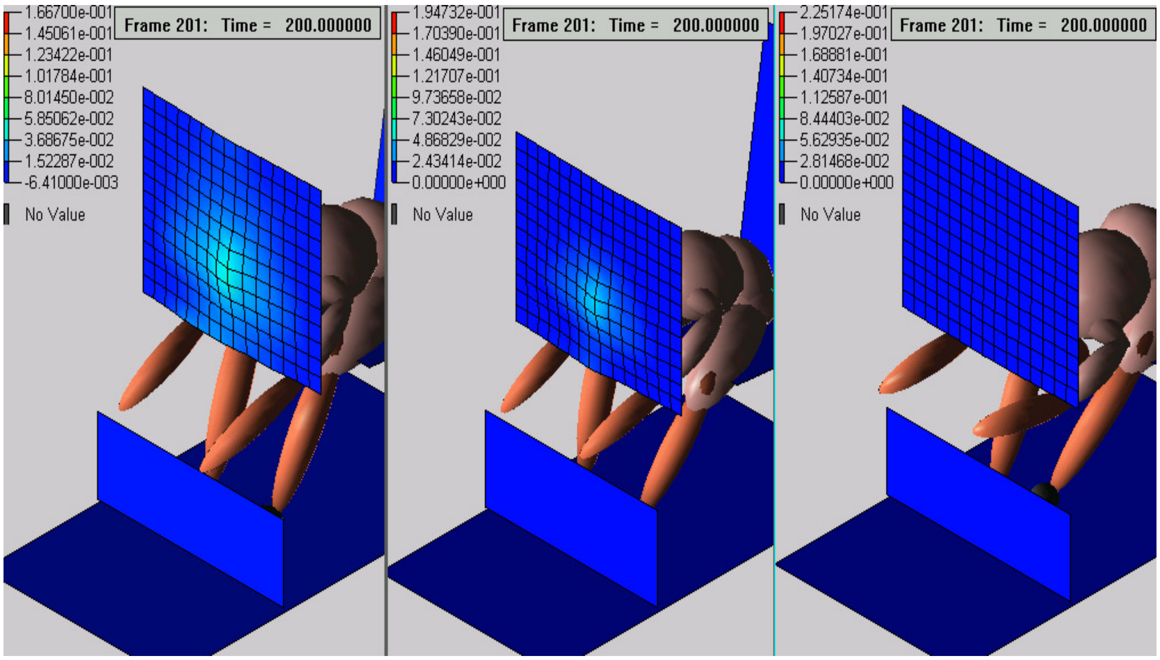

Figure 17. Validation of Test - 2 configuration under Idealized conditions

In order to test the robustness of the model and to test the methodology that is being employed, the validated model was used to predict the HIC when the sled pulse was changed to that observed during the test instead of idealized pulse which was used during the validation process.

It can be seen from the results, shown in Table 11, the HIC thus measured from the model compared very favorably with the sled test results. Furthermore the head CG resultant acceleration profile for test 6, shown in Figure 18, compares very favorably with the sled tests. The methodology shown here shows that once a validated model can be build it may be used for further prediction provided the parameters under which the model was validated remains the same.

TABLE 11

COMPARISON OF THE HIC SPREAD FROM TEST AND ANALYSIS

Full Scale Sled Test			**Validation Range**			**HIC from Analysis**
No	**Bulkhead**	**HIC**	**-2SD**	**Target**	**+2SD**	
2	Aluminum Sheet	586	367	**586**	805	**498**
3	Aluminum Sheet	549	330	**549**	768	**512**
4	Aluminum Sheet	716	497	**716**	935	**587**
5	Aluminum Sheet	694	475	**694**	913	**624**
6	Aluminum Sheet	653	434	**653**	872	**711**
7	Aluminum Sheet	421	202	**421**	640	**535**

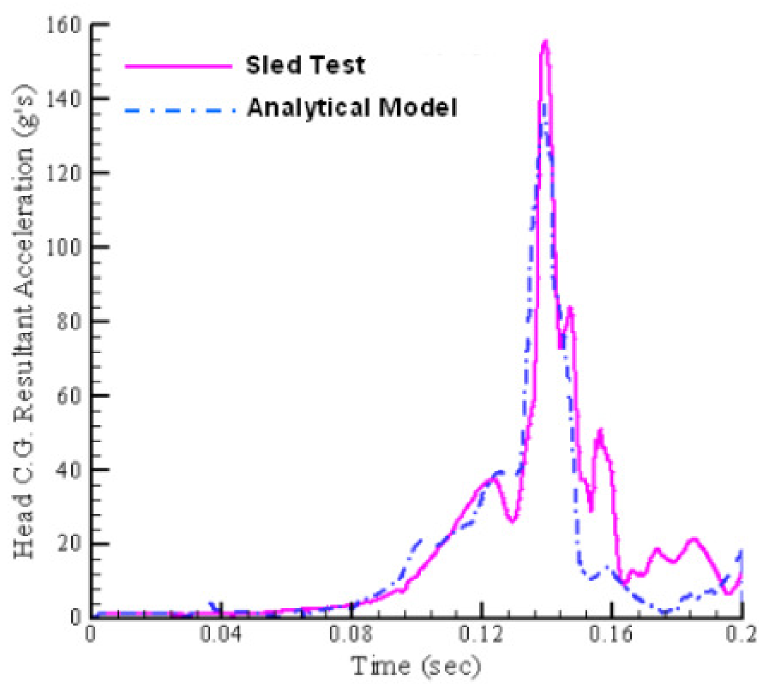

Figure 18. Head CG resultant acceleration comparison

4.2.2 Mathematical Model with Rigid Iron Seat with a Nomex Honeycomb Bulkhead

In order to show that the current methodology is effective under different set of conditions, a validated model was created for a test -2 configuration with a seat setback distance of 35” using a polyester belt and a Teklam N510E Epoxy/Nomex Honeycomb panel 1.0″ thick with fiberglass facing on both sides honeycomb bulkhead panel. The load – deflection properties of the bulkhead are measured by moving a bowling ball attached to the end of a linear actuator, as shown in Figure 19, and measuring the load deflection properties. The load deflection properties from performing such a test is shown in Figure 20.

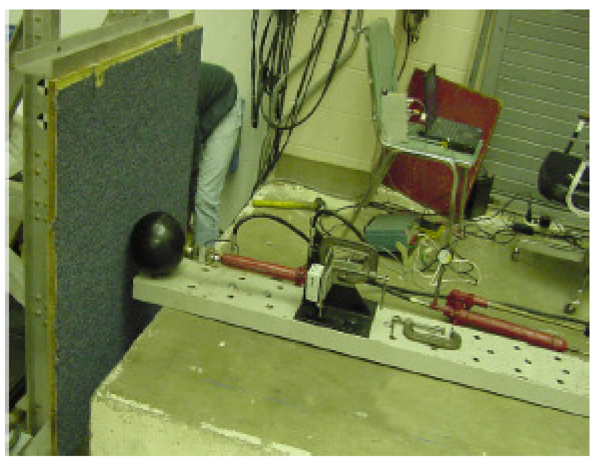

Figure 19. Test for determining the stiffness of composite bulkhead

The 3 test were conducted with Teklam N510E Epoxy/Nomex Honeycomb panel 1.0″ thick with fiberglass facing on both sides honeycomb bulkhead panel with a seatback distance of 35”. The mean and the standard deviation of the test were calculated and have been tabulated in Table 12.

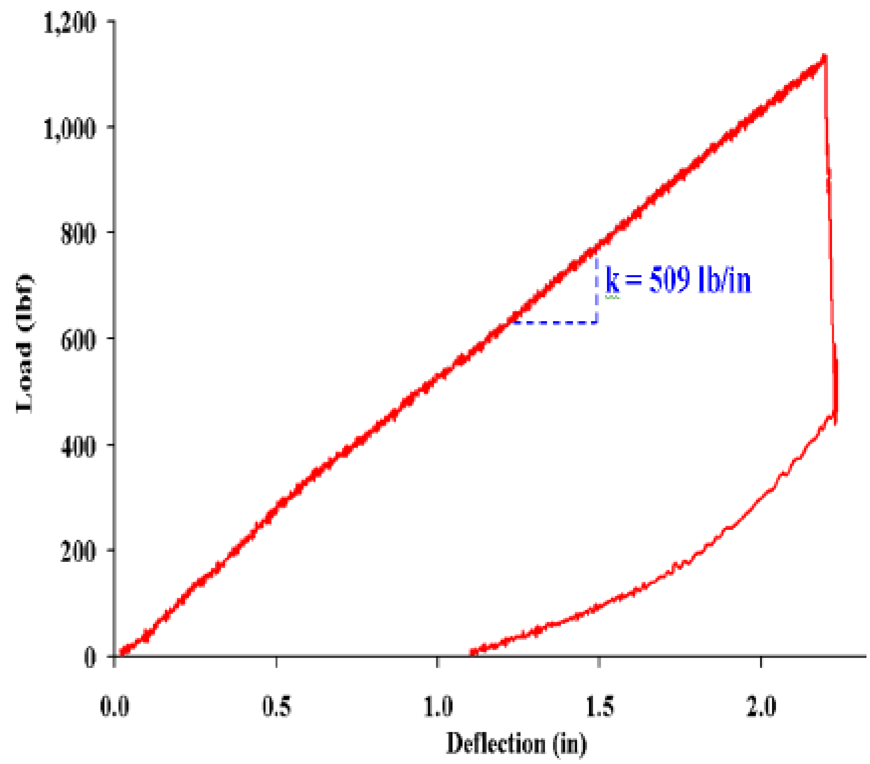

Figure 20. Load- Deflection properties of Nomex Honeycomb Bulkhead

TABLE 12

FULL SCALE SLED TEST RESULTS FOR NOMEX HONEYCOMB BULKHEAD

No	Sled Acceleration (g)	Seat Setback Distance (in)	Head Average Acceleration (g)	HIC	Mean	SD
1	16.0	35	57	617	718	89
2	15.6	35	53	754		
3	16.0	35	50	783		

The analytical model was setup so as to reflect the full-scale sled test configuration. The load deflection properties of the seat, seatbelt, and the bulkhead were incorporated into the model and an idealized 16G pulse was applied to model. The model was validated for the mean HIC of 718.

TABLE 13

COMPARISON OF THE HIC SPREAD FROM TEST AND ANALYSIS

No	Sled Acceleration (g)	Seat Setback Distance (in)	HIC	-2SD	Mean	+2SD	HIC from Analysis
1	16.0	35	617	439.68	617	794.32	662
2	15.6	35	754	576.68	754	931.32	806
3	16.0	35	783	605.68	783	960.32	701

The results from the analysis were compared with that from the full-scale sled test and they have shown compare favorably as seen in Table 13.

This helps in drawing the conclusion that once a model has been build to represent the most common scenario or mean then this model can be used for further studies in which the conditions under which they are validated doesn't change. Furthermore it is vital to understand the variation in the sled testing procedure for type test and allow that variation in the analytical models too.

AC 20-146 does not take into account the variability in test in a test facility and the variability is bound to increase when data is taken from different test centers. Assuming that across test center the position and the ATD and other test articles are exactly the same, the prime cause for variation is the nature of the sled pulse and the calibration of the ATD.

CHAPTER 5

DESIGN OF EXPERIMENTS AND RESPONSE SURFACE BASED OPTIMIZATION

5.1 Design of Experiments and Response Surface Plots

It is important to understand the various factors which could affect the HIC and lumbar load, the two prime injury indices when testing cabin interiors. Some of the factor can be intuitively understood and the designer uses their experience to design the interiors based on this. The idea of this study is to use surrogate-model based optimization that combines the Design of Experiments (DOE) and Response Surface Methodology (RSM) to explore the design space and construct approximate crash functions for solving crashworthiness design optimization problems. The RMS builds an algebraic function capturing the input-output relationship of a complex function based on a finite (hopefully small) number of sample pairs of an input and an output.

The RSM based optimization refers to the idea of speeding optimization processes by using the surrogate models for the objective and constraint functions. RSM is a statistical method for constructing smooth approximations to functions in a multi-dimensional space. Thus the local effect caused by the 'noisy' functions is alleviated and the method attempts to find a representation of the design response within a bounded design space. Based on the extraction of global information of these "efficient-to-compute" surrogate models (or so-called metamodels), designer can access the main effect and perform approximate optimization, multi-criteria trade-off analysis, robustness assessment, as well as robust design using alternative design formulations. The quality of

RSM is extremely crucial in those stages as poor RSM will be misleading, causing the optimization solution diverged and increasing the design cycle time.

Typically the surrogate model based optimization method involves the following procedures:

1. Choose an experimental design to sample the region of interest (of design space);
2. Perform analyses (or simulations) based upon the selected sample data;
3. Construct the surrogate model (or RSM, meta-model) to the observed sample data;
4. Perform approximate optimization to find the predicted optimal design;
5. Validate the predicted optimal design by conducting an analysis on the fine model (or true function);
6. Check for convergence (stop if within convergence tolerance);
7. Update surrogate model using new data points;
8. Iterate until convergence.

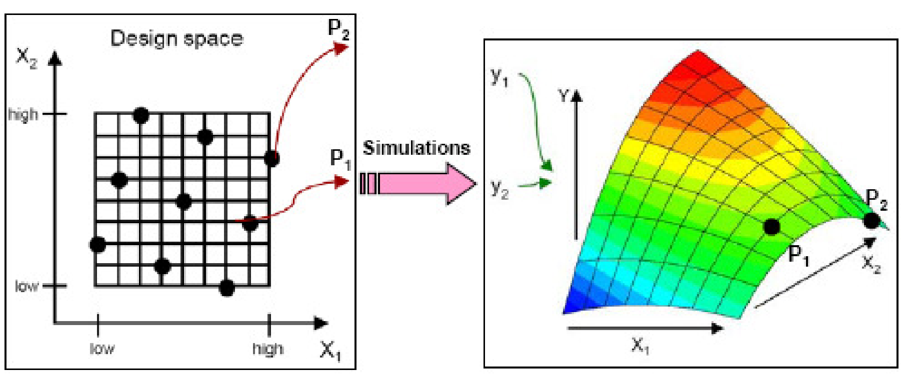

Figure 21. Schematic of DOE and RSM Based Computer Simulation

Figure 21 illustrates the procedures for Steps 1 to 3 [41]. The motivation of the method is to take advantage of the effectiveness of search algorithms used in the numerical optimization more efficiently using DOE generated data to construct surrogate models in an approximate optimization algorithm.

5.1.1 Design of Experiments for Test – 1

Before setting up a design of experiments model for understanding the effect of various parameters on the lumbar load, it is necessary to look at the critical factors affecting the lumbar load. Based on the testing experience it is noticed that some of the factors affecting the lumbar load are: type seat cushion, thickness of seat cushion, deformation of the seat, energy absorbing members in the load path etc.

TABLE 14

TREATMENTS AND LEVELS FOR TEST – 1 DOE

Treatment	Levels
Seat Cushion Type	DAX26
	DAX55
	CONFOR – Green
	CONFOR – Blue
Seat Cushion Thickness	0”
	1”
	4”
	6”
Seat Pan Deflection	0”
	0.5”
	1”

A full factorial run was setup for three parameters, called treatment, which were felt to be the most critical and the effect these treatments on the lumbar load, called the response, studied. Each of the treatments had different levels and these are shown in Table 14.

The DOE model was set up suing the Design Expert Software [42]. Based on the treatments and the levels a 48 run full factorial design was setup. The setup of the DOE is shown in Table 15 and has been sorted by Run.

TABLE 15

DOE SETUP OF TEST – 1 CONFIGURATION

Std	Run	Factor 1 A: Seat Cushion Type	Factor 2 B: Seat Pan Deflection	Factor 3 C: Seat Cushion Thickness	Response 1 Lumbar Load
34	1	DAX 55	1	4	
11	2	CONFOR - Blue	1	0	
44	3	CONFOR - Green	0.5	6	
28	4	CONFOR - Green	0	4	
15	5	CONFOR - Blue	0	1	
1	6	DAX 26	0	0	
26	40	DAX 55	0	4	
29	41	DAX 26	0.5	4	
47	42	CONFOR - Blue	1	6	
30	43	DAX 55	0.5	4	
4	44	CONFOR - Green	0	0	
38	45	DAX 55	0	6	
7	46	CONFOR - Blue	0.5	0	
45	47	DAX 26	1	6	
5	48	DAX 26	0.5	0	

Using the valid model developed earlier, the 48 runs involving various permutations of to treatments are analyzed and the lumbar load from these analyses was recorded. Table 16 shows the completed table for the DOE for test – 1 configuration. Having completed all the runs it necessary to evaluate the model for the effect each of these treatments had on the lumbar load and to find out if there was any significant interaction between the various treatments affecting the response. This was done by performing an analysis of variance (ANOVA). The ANOVA was performed using the Design Expert software which was used for setting up the DOE study.

TABLE 16

DOE FOR TEST – 1 CONFIGURATION WITH THE RESPONSES

Std	Run	Factor 1	Factor 2	Factor 3	Response 1
		A: Seat Cushion Type	B: Seat Pan Deflection	Seat Cushion Type	Lumbar Load
11	2	CONFOR - Blue	1	0	1201
44	3	CONFOR - Green	0.5	6	1301
28	4	CONFOR - Green	0	4	1103
15	5	CONFOR - Blue	0	1	1075
1	6	DAX 26	0	0	1001
37	7	DAX 26	0	6	1881
25	8	DAX 26	0	4	1703
14	9	DAX 55	0	1	1313
41	10	DAX 26	0.5	6	1948
6	11	DAX 55	0.5	0	1109
35	12	CONFOR - Blue	1	4	1351
21	13	DAX 26	1	1	1501
13	14	DAX 26	0	1	1301
24	15	CONFOR - Green	1	1	1199
40	16	CONFOR - Green	0	6	1287
46	17	DAX 55	1	6	2097
10	18	DAX 55	1	0	1201
32	19	CONFOR - Green	0.5	4	1187
23	20	CONFOR - Blue	1	1	1204
12	21	CONFOR - Green	1	0	1201
27	22	CONFOR - Blue	0	4	1198

TABLE 16 (continued)

Std	Run	Factor 1	Factor 2	Factor 3	Response 1
		A: Seat Cushion Type	B: Seat Pan Deflection	Seat Cushion Type	Lumbar Load
3	23	CONFOR - Blue	0	0	1001
43	24	CONFOR - Blue	0.5	6	1386
39	25	CONFOR - Blue	0	6	1338
19	26	CONFOR - Blue	0.5	1	1126
42	27	DAX 55	0.5	6	1999
33	28	DAX 26	1	4	1897
17	29	DAX 26	0.5	1	1398
36	30	CONFOR - Green	1	4	1303
20	31	CONFOR - Green	0.5	1	1049
48	32	CONFOR - Green	1	6	1359
16	33	CONFOR - Green	0	1	1010
9	34	DAX 26	1	0	1201
22	35	DAX 55	1	1	1533
31	36	CONFOR - Blue	0.5	4	1261
2	37	DAX 55	0	0	1001
8	38	CONFOR - Green	0.5	0	1109
18	39	DAX 55	0.5	1	1427
26	40	DAX 55	0	4	1790
29	41	DAX 26	0.5	4	1827
47	42	CONFOR - Blue	1	6	1404
30	43	DAX 55	0.5	4	1911
4	44	CONFOR - Green	0	0	1001
38	45	DAX 55	0	6	1946
7	46	CONFOR - Blue	0.5	0	1109
45	47	DAX 26	1	6	2039
5	48	DAX 26	0.5	0	1109

The evaluation was performed by using analysis of variance (ANOVA) and the various interactions were studied. The results from the ANOVA are shown in Table 17.

TABLE 17

ANOVA FOR TEST -1

ANOVA for Response Surface Reduced Cubic Model						
Analysis of variance table [Classical sum of squares - Type II]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5.25E+06	26	2.02E+05	247.551	< 0.0001	Significant
A-Seat Cushion	1.83E+06	3	6.11E+05	748.641	< 0.0001	Significant
B-Seat Pan Deformation	2.27E+05	1	2.27E+05	278.311	< 0.0001	Significant
C-Cushion Thickness	2.32E+06	1	2.32E+06	2838.590	< 0.0001	Significant
AB	3.23E+03	3	1.08E+03	1.320	0.2945	Not Significant
AC	7.14E+05	3	2.38E+05	291.500	< 0.0001	Significant
BC	7.27E+03	1	7.27E+03	8.904	0.0071	Not Significant
B^2	7.00E+01	1	7.00E+01	0.086	0.7724	Not Significant
C^2	4.31E+04	1	4.31E+04	52.855	< 0.0001	Significant
ABC	9.16E+02	3	3.05E+02	0.374	0.7726	Not Significant
AB^2	1.35E+03	3	4.51E+02	0.553	0.6520	Not Significant
AC^2	1.01E+05	3	3.37E+04	41.277	< 0.0001	Significant
B^2C	2.49E+01	1	2.49E+01	0.030	0.8631	Not Significant
BC^2	1.24E+03	1	1.24E+03	1.514	0.2322	Not Significant
C^3	4.11E+03	1	4.11E+03	5.038	0.0357	Significant
Residual	1.71E+04	21	8.16E+02			
Cor Total	5.27E+06	47				

With model F value of 247.5507903, the model is significant and there is only a 0.01% chance that the model F value this large could be due to noise. It is also noticed that only A, B, C, AC, BC, C^2, AC^2, AND C^3 are the significant model terms. In order to improve the model a model reduction is performed wherein the insignificant terms are removed. A reduced regression model is setup by ignoring the insignificant terms, AB, B^2, ABC, AB^2, B^2C and BC^2. The reduced regression model for test -1 was built and is shown in Table 18.

TABLE 18

REDUCED REGRESSION MODEL FOR TEST -1

ANOVA for Response Surface Reduced Cubic Model					
Analysis of variance table [Classical sum of squares - Type II]					
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F
Model	5246039.138	14	374717.0813	515.9071285	< 0.0001
A-Seat Cushion	1832964.083	3	610988.0278	841.2028559	< 0.0001
B-Seat Pan Deformation	227138	1	227138	312.7215683	< 0.0001
C-Cushion Thickness	2316655.869	1	2316655.869	3189.551095	< 0.0001
AC	713703.9203	3	237901.3068	327.5403929	< 0.0001
BC	7266.483516	1	7266.483516	10.00442956	0.0033
C^2	43136.8972	1	43136.8972	59.39049452	< 0.0001
AC^2	101061.901	3	33687.30033	46.38037401	< 0.0001
C^3	4111.983757	1	4111.983757	5.661342485	0.0233
Residual	23968.77849	33	726.3266209		
Cor Total	5270007.917	47			

5.2 Model Validation and Results

Model validation is performed by checking the normal plots and residual plots. The normal plotting of the residual does not show any abnormality or any evidence for outliers as shown in Figure 21 and Figure 22 respectively. The residual versus the predicted plots do not show any funnel shape as can be observed in Figure 23

The residual plots are shown in Figure 24 to Figure 26. From these plots it may be observed that they did not show any inequality in the variance.

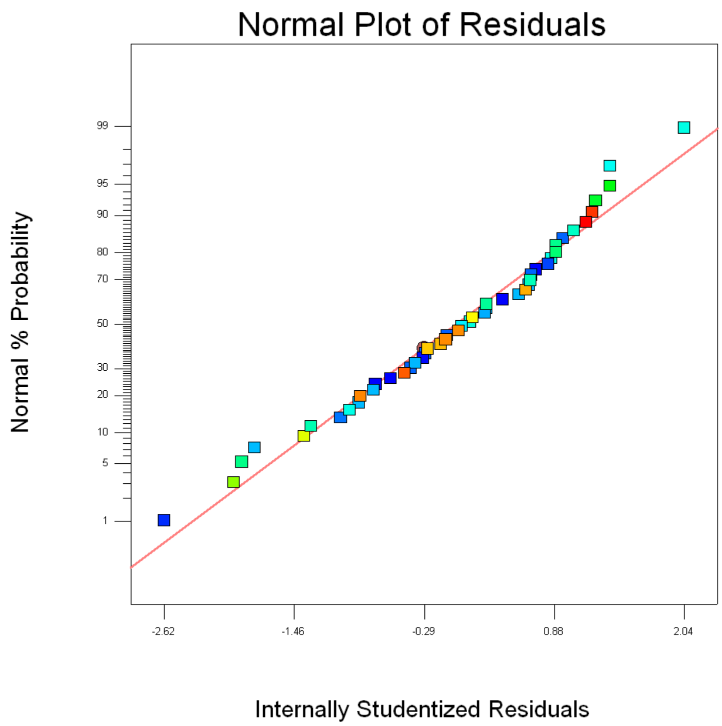

Figure 22. Normal Plot of Residuals

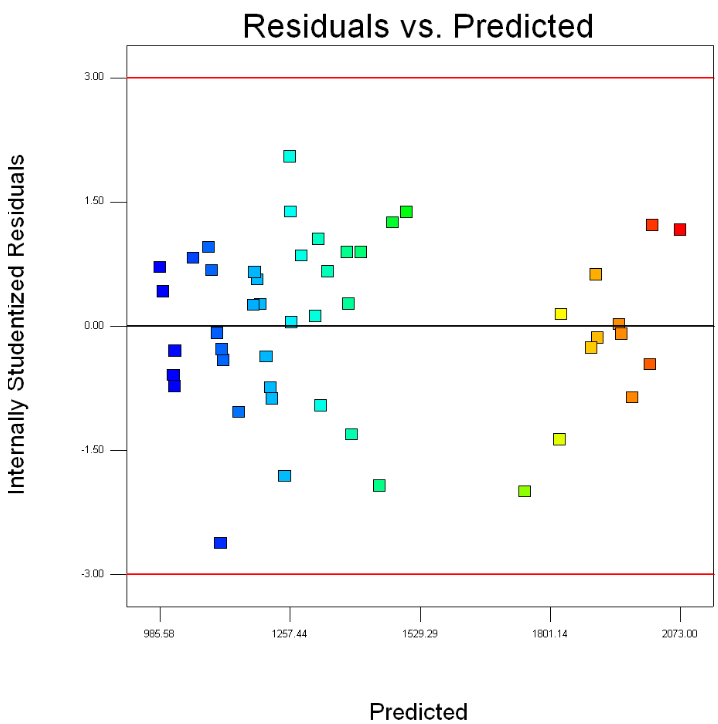

Figure 23. Plot of Residuals vs. Predicted values

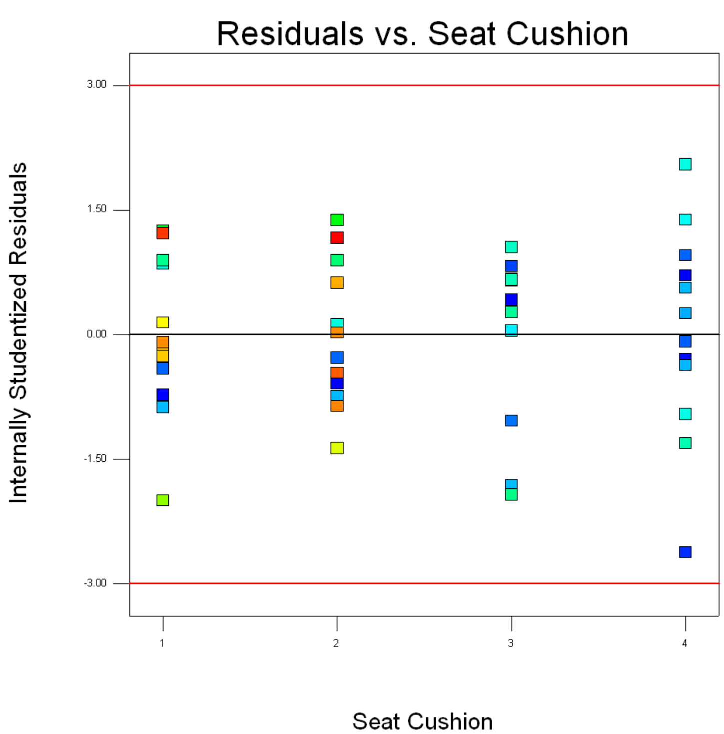

Figure 24. Plot of Residuals vs. Seat Cushion

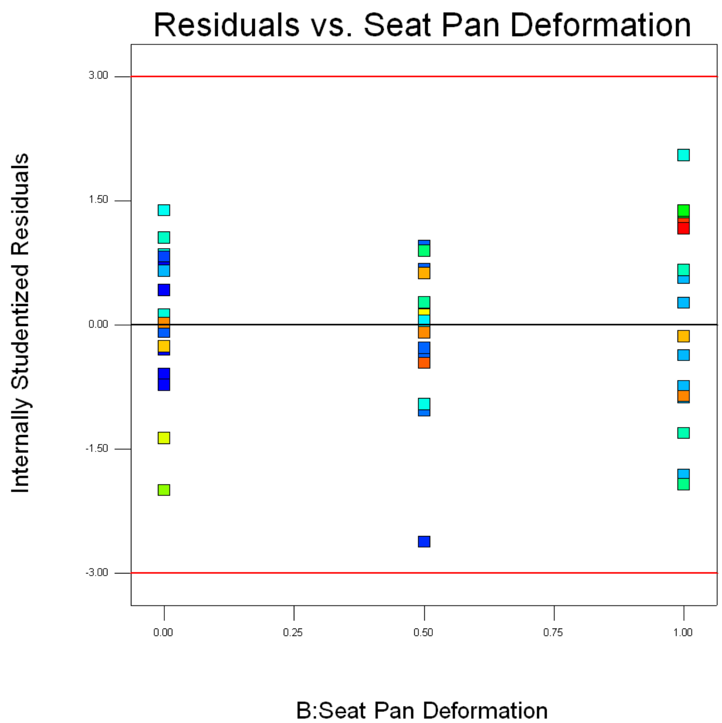

Figure 25. Plot of Residual vs. Deformation

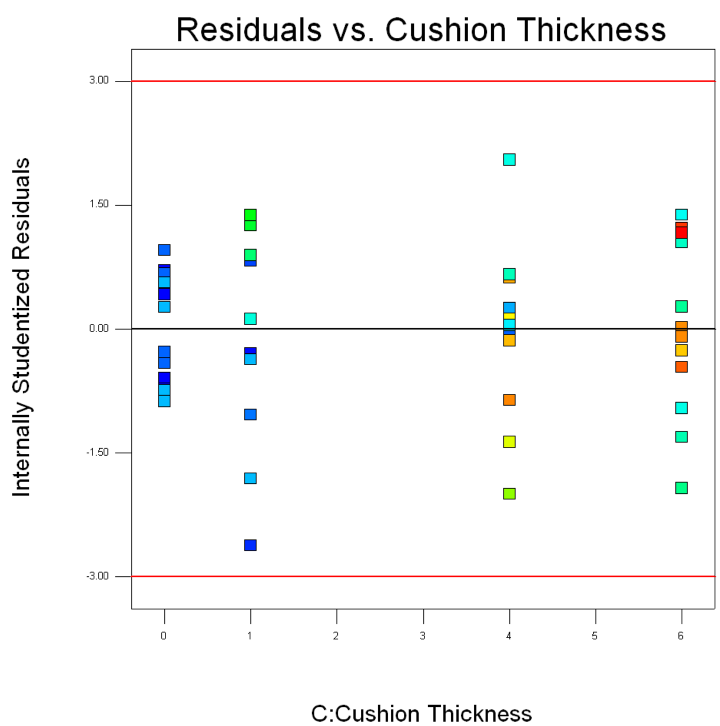

Figure 26. Plot of Residual vs. Cushion Thickness

5.3 Response Surface plots for Test – 1 DOE

Response surface plots were constructed for each of the seat cushion types. The purpose of building these response surfaces was to get their underlying equations of the surface fitted through the design point within the design space.

For a DAX26 seat cushion foam the response surface for the lumbar load have been plotted. Figure 27 shows the 2D contour plot of seat cushion thickness and seat pan deformation and the resulting lumbar load. The 3D response surface of the same is shown in Figure 28. The equation for the surface is:

$$\textit{Lumbar load} = 1016.76840 + 203.25275 * \textit{Seat Pan Deformation} + 298.29735 * \textit{Cushion Thickness} - 12.63736 * \textit{Seat Pan Deformation} * \textit{Cushion Thickness} - 35.61411 * \textit{Cushion Thickness}^2 + 1.67569 * \textit{Cushion Thickness}^3$$

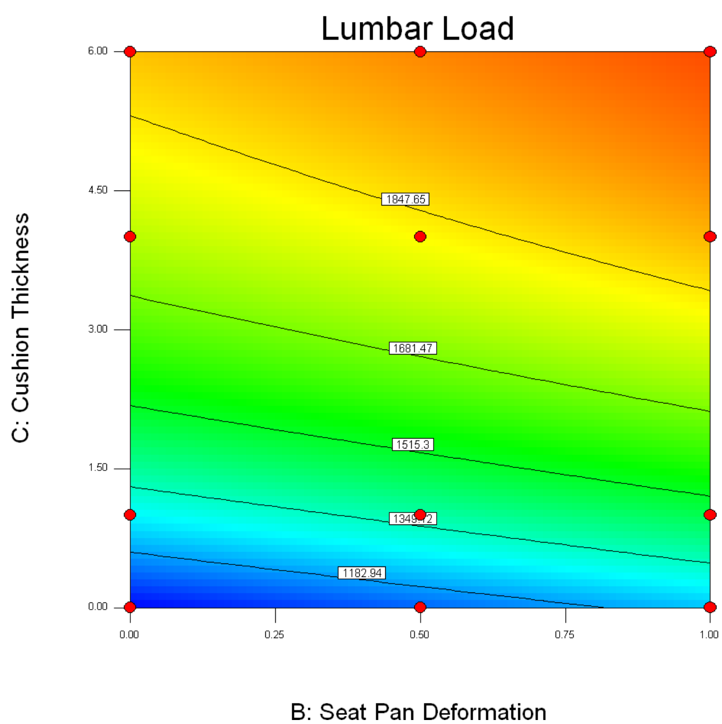

Figure 27.2D Contour Plot of Lumbar load for DAX26

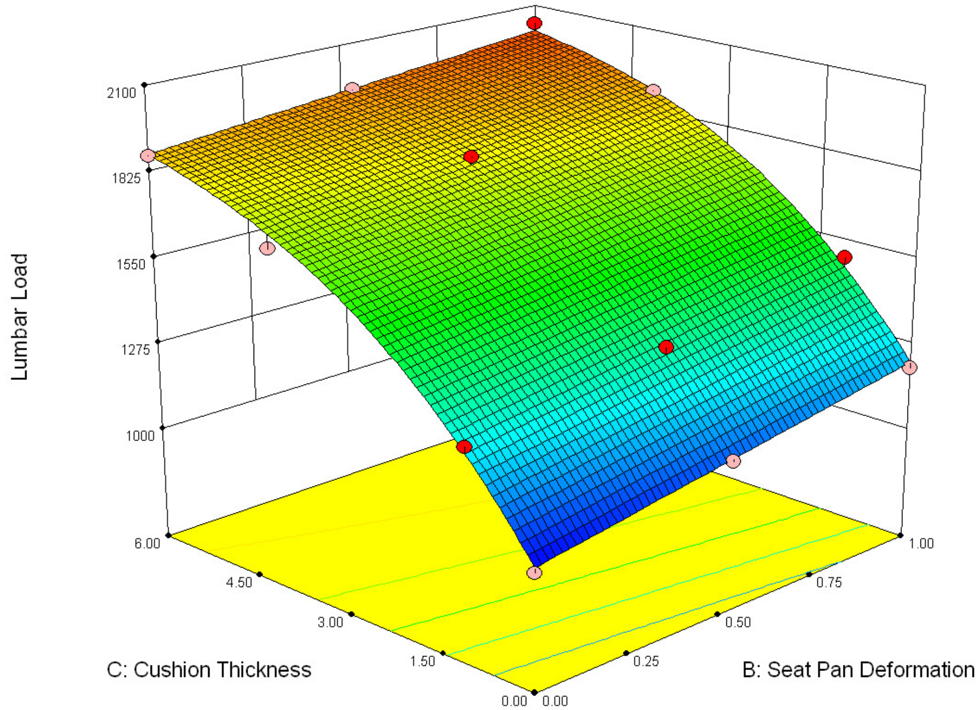

Figure 28. 3D Response surface plot of Lumbar load for DAX26

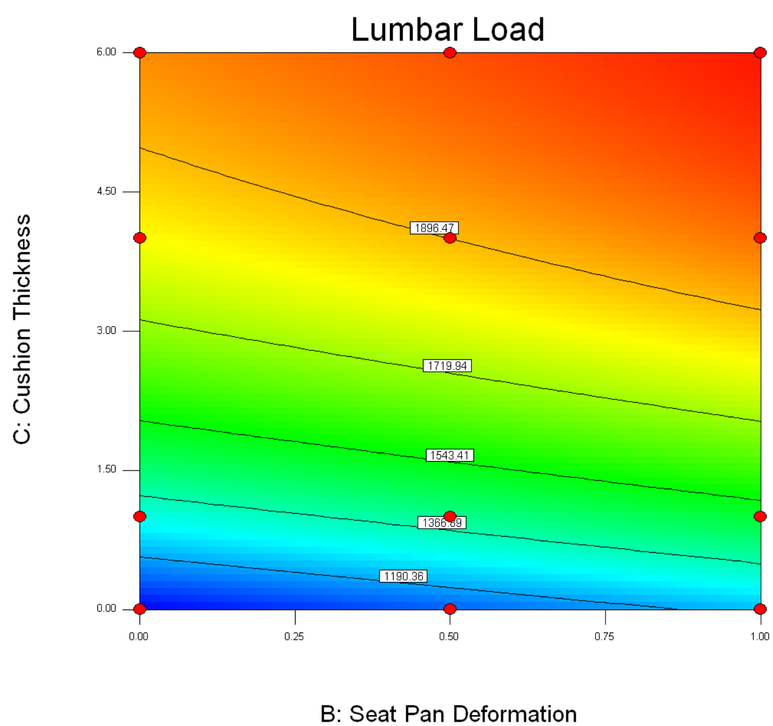

Figure 29. 2D Contour Plot of Lumbar load for DAX55

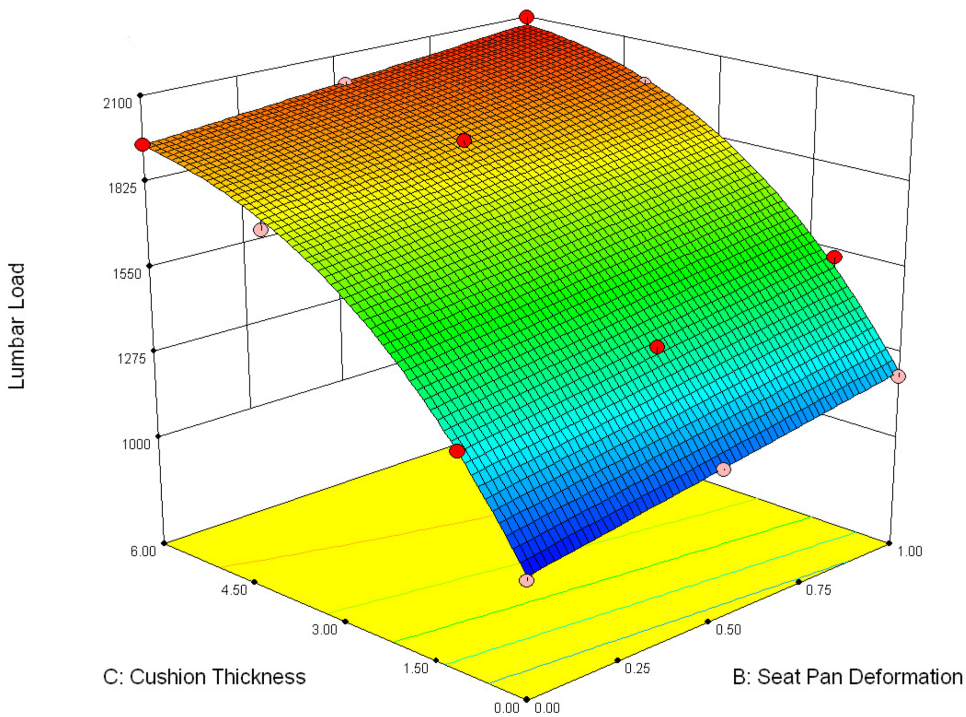

Figure 30. 3D Response surface plot of Lumbar load for DAX55

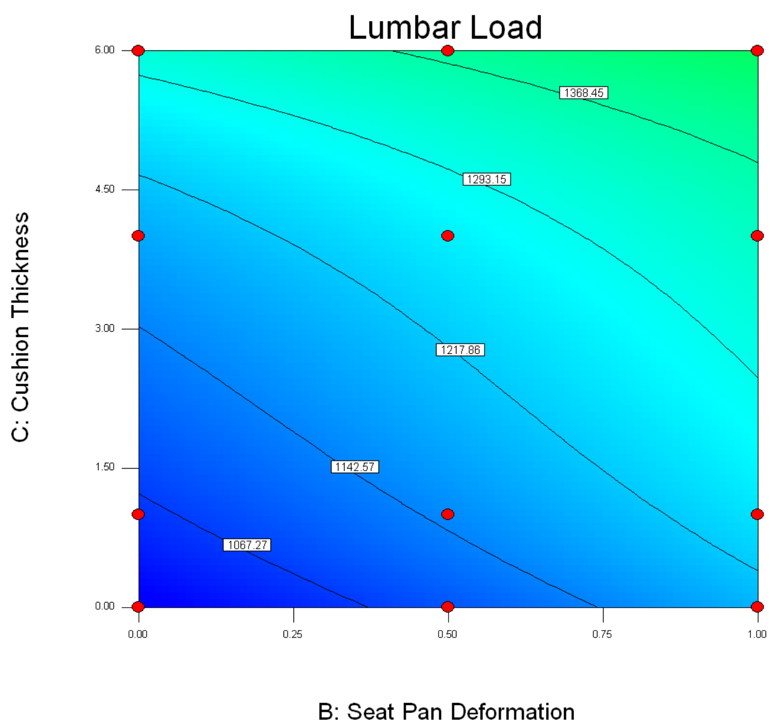

Figure 31. 2D Contour Plot of Lumbar load for CONFOR – Blue

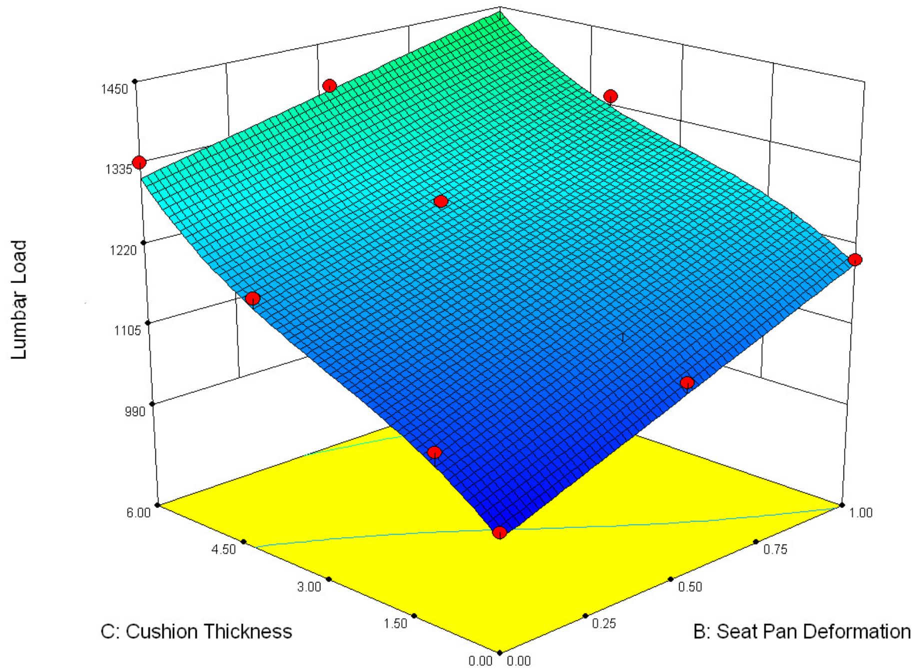

Figure 32. 3D Response surface plot of Lumbar load for CONFOR – Blue

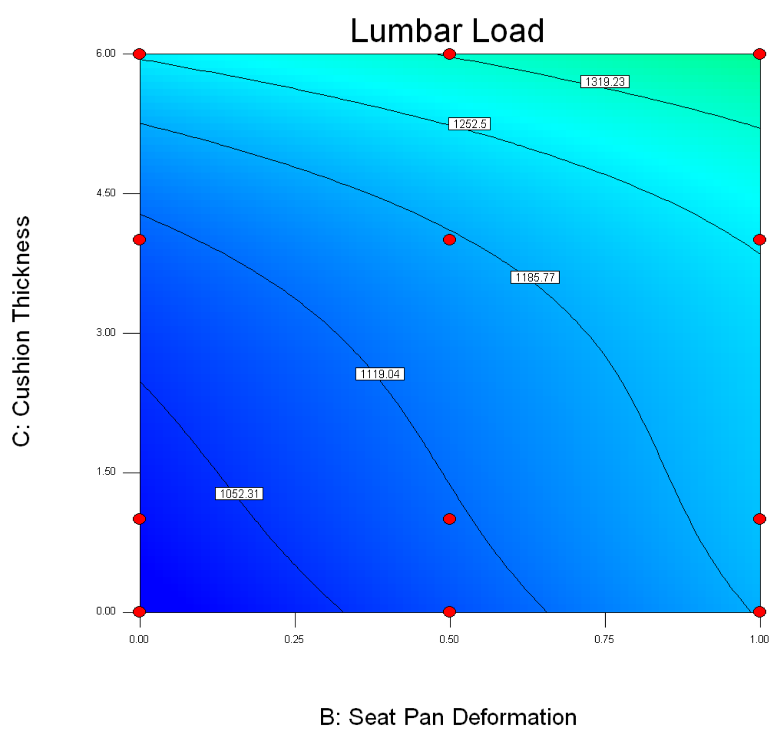

Figure 33. 2D Contour Plot of Lumbar load for CONFOR – Green

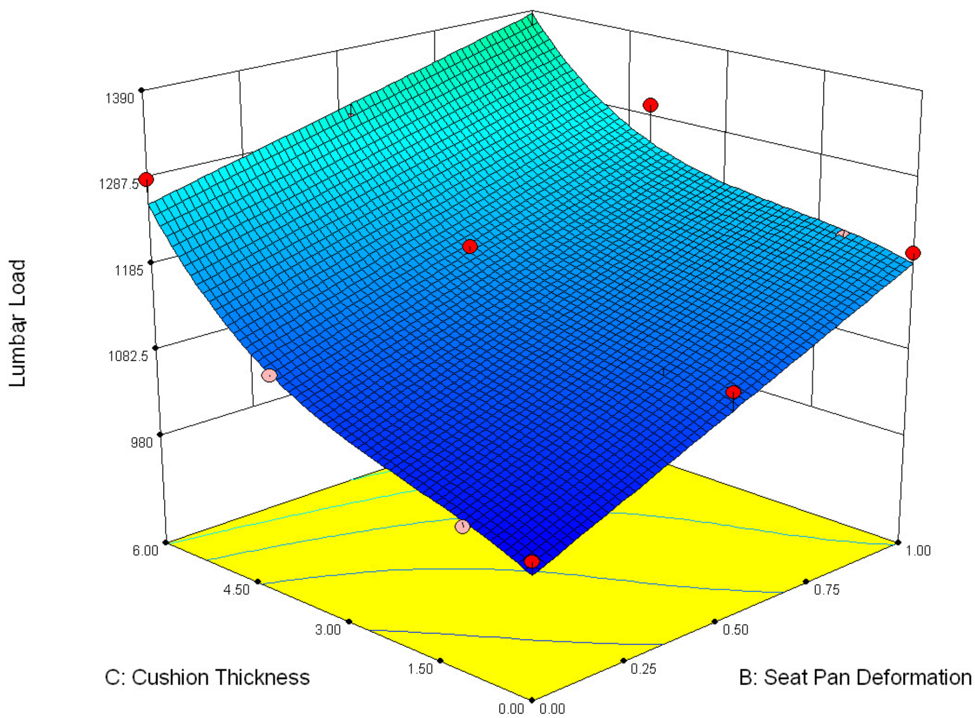

Figure 34. 3D Response surface plot of Lumbar load for CONFOR – Green

For the DAX 55 seat cushion, Figure 29 shows the 2D contour plot of seat cushion thickness and seat pan deformation and the resulting lumbar load. The 3D response surface of the same is shown in Figure 30. The equation for the response surface is:

$$\textit{Lumbar Load} = 1013.83055 + 203.25275 * \textit{Seat Pan Deformation} + 334.59302 * \textit{Cushion Thickness} - 12.63736 * \textit{Seat Pan Deformation} * \textit{Cushion Thickness} - 39.93803 * \textit{Cushion Thickness}^2 + 1.67569 * \textit{Cushion Thickness}^3$$

For the CONFOR - Blue seat cushion, Figure 31shows the 2D contour plot of seat cushion thickness and seat pan deformation and the resulting lumbar load. The 3D response surface of the same is shown in Figure 32. The equation for the response surface is:

*Lumbar Load = 991.98026 + 203.25275 * Seat Pan Deformation + 75.81289 * Cushion Thickness - 12.63736 * Seat Pan Deformation * Cushion Thickness - 13.68050 * Cushion Thickness^2 + 1.67569 * Cushion Thickness^3*

For the CONFOR - Green seat cushion, Figure 33 shows the 2D contour plot of seat cushion thickness and seat pan deformation and the resulting lumbar load. The 3D response surface of the same is shown in Figure 34. The equation for the response surface is:

*Lumbar Load = 985.58196 + 203.25275 * Seat Pan Deformation + 38.68813 * Cushion Thickness - 12.63736 * Seat Pan Deformation * Cushion Thickness - 8.92014 * Cushion Thickness^2 + 1.67569 * Cushion Thickness^3*

5.3.1 Design of Experiments for Test – 2

To understand the effect various parameters have on the HIC, it is necessary to look at the critical factors affecting the lumbar load. Based on previous testing experience some of the critical factors that affect HIC are seat setback distance, type of seatbelt, type of bulkhead, sled pulse, etc.

A full factorial run was setup with four parameters, called treatment, which were felt to be critical and the effect these treatments on HIC, called the response, studied. Each of the treatments had different levels and these are shown in Table 19. This is not an exhaustive list of critical parameter but just a sample of some of the parameter which were studied. These parameters have been shown to be critical in the past when full-scale sled were performed using bulkheads and restraint systems of various design.

TABLE 19

TREATMENT AND LEVELS FOR TEST – 2 DOE

Treatment	**Levels**
Type of Bulkhead	Aluminum Sheet
	Aluminum Honeycomb
	Nomex Honeycomb
Type of Seatbelt	Nylon
	Polyester
Seat Setback Distance	28”
	33”
	35”
	40”
Bulkhead Surface Friction	0.3
	0.6
	1

Based on the treatment and the levels a full factorial design yielded 72 runs for this DOE. The setup of the DOE model is shown in Table 20 and has been sorted by Run number. Only sample of the whole table for the DOES study is shown below. The run order was generated by Design Expert software which was used in this study for developing the DOE models. Since the response is not from experimental data the run order is not as critical as it would have been as there is no change or, if there is any, very little change that could occur when the analysis is repeated in a sequential order. Nevertheless the analyses were performed as per the run order in order to remove any bias that many occur.

TABLE 20

DOE SETUP OF TEST – 2 CONFIGURATION

		Factor 1	Factor 2	Factor 3	Factor 4	Response 1
Std	Run	A: Bulkhead type	B: Seat Belt	C: Seat Setback Distance	D: Bulkhead Surface Friction	HIC
63	1	Aluminum Honeycomb	Nylon	35	1	
22	2	Aluminum	Polyester	40	0.3	
65	3	Nomex Honeycomb	Polyester	35	1	
42	4	Aluminum Honeycomb	Polyester	35	0.6	
3	5	Aluminum Honeycomb	Nylon	28	0.3	
55	6	Aluminum	Nylon	33	1	
13	7	Aluminum	Nylon	35	0.3	
67	8	Aluminum	Nylon	40	1	
68	9	Nomex Honeycomb	Nylon	40	1	
54	10	Aluminum Honeycomb	Polyester	28	1	
11	65	Nomex Honeycomb	Polyester	33	0.3	
72	66	Aluminum Honeycomb	Polyester	40	1	
66	67	Aluminum Honeycomb	Polyester	35	1	
12	68	Aluminum Honeycomb	Polyester	33	0.3	
32	69	Nomex Honeycomb	Nylon	33	0.6	
34	70	Aluminum	Polyester	33	0.6	
37	71	Aluminum	Nylon	35	0.6	
50	72	Nomex Honeycomb	Nylon	28	1	

Using models that were validated before and after creating new validated models, the 72 runs involving various permutations of to treatments are analyzed and the HIC evaluated from these analyses was recorded. Table 21shows the completed table for the DOE for test – 2 configuration.

Once the DOE chart was completely filled in it was necessary to evaluate the model for the effect each of these treatments had on the HIC and to find out if there was any significant interaction between the various treatments affecting the response. This was done by performing an analysis of variance (ANOVA) on the set of data. The analysis was performed using the Design Expert software which was used for setting up the DOE study.

TABLE 21

DOE FOR TEST – 2 CONFIGURATION WITH THE RESPONSES

Std	Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1
		A: Bulkhead type	B: Seat Belt	C: Seat Setback Distance	D: Bulkhead Surface Friction	HIC
63	1	Aluminum Honeycomb	Nylon	35	1	1020
22	2	Aluminum	Polyester	40	0.3	0
65	3	Nomex Honeycomb	Polyester	35	1	544
42	4	Aluminum Honeycomb	Polyester	35	0.6	448
3	5	Aluminum Honeycomb	Nylon	28	0.3	1059
55	6	Aluminum	Nylon	33	1	913
13	7	Aluminum	Nylon	35	0.3	693
67	8	Aluminum	Nylon	40	1	431
68	9	Nomex Honeycomb	Nylon	40	1	419
54	10	Aluminum Honeycomb	Polyester	28	1	819
8	11	Nomex Honeycomb	Nylon	33	0.3	1433
46	12	Aluminum	Polyester	40	0.6	0
26	13	Nomex Honeycomb	Nylon	28	0.6	1811
23	14	Nomex Honeycomb	Polyester	40	0.3	0
35	15	Nomex Honeycomb	Polyester	33	0.6	601
41	16	Nomex Honeycomb	Polyester	35	0.6	427
38	17	Nomex Honeycomb	Nylon	35	0.6	1501
70	18	Aluminum	Polyester	40	1	0
48	19	Aluminum Honeycomb	Polyester	40	0.6	0
51	20	Aluminum Honeycomb	Nylon	28	1	1256
53	21	Nomex Honeycomb	Polyester	28	1	1346

TABLE 21 (continued)

Std	Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1
		A: Bulkhead type	B: Seat Belt	C: Seat Setback Distance	D: Bulkhead Surface Friction	HIC
2	22	Nomex Honeycomb	Nylon	28	0.3	1751
7	23	Aluminum	Nylon	33	0.3	782
43	24	Aluminum	Nylon	40	0.6	335
62	25	Nomex Honeycomb	Nylon	35	1	1585
5	26	Nomex Honeycomb	Polyester	28	0.3	1118
52	27	Aluminum	Polyester	28	1	1224
64	28	Aluminum	Polyester	35	1	512
44	29	Nomex Honeycomb	Nylon	40	0.6	398
18	30	Aluminum Honeycomb	Polyester	35	0.3	335
59	31	Nomex Honeycomb	Polyester	33	1	693
61	32	Aluminum	Nylon	35	1	913
15	33	Aluminum Honeycomb	Nylon	35	0.3	756
9	34	Aluminum Honeycomb	Nylon	33	0.3	943
19	35	Aluminum	Nylon	40	0.3	185
27	36	Aluminum Honeycomb	Nylon	28	0.6	1123
40	37	Aluminum	Polyester	35	0.6	363
28	38	Aluminum	Polyester	28	0.6	1099
58	39	Aluminum	Polyester	33	1	675
57	40	Aluminum Honeycomb	Nylon	33	1	1174
60	41	Aluminum Honeycomb	Polyester	33	1	604
29	42	Nomex Honeycomb	Polyester	28	0.6	1231
4	43	Aluminum	Polyester	28	0.3	1026
21	44	Aluminum Honeycomb	Nylon	40	0.3	582
30	45	Aluminum Honeycomb	Polyester	28	0.6	712

TABLE 21 (continued)

Std	Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1
		A: Bulkhead type	B: Seat Belt	C: Seat Setback Distance	D: Bulkhead Surface Friction	HIC
6	46	Aluminum Honeycomb	Polyester	28	0.3	662
71	47	Nomex Honeycomb	Polyester	40	1	0
24	48	Aluminum Honeycomb	Polyester	40	0.3	0
45	49	Aluminum Honeycomb	Nylon	40	0.6	601
31	50	Aluminum	Nylon	33	0.6	841
1	51	Aluminum	Nylon	28	0.3	1425
33	52	Aluminum Honeycomb	Nylon	33	0.6	1068
17	53	Nomex Honeycomb	Polyester	35	0.3	332
25	54	Aluminum	Nylon	28	0.6	1503
10	55	Aluminum	Polyester	33	0.3	440
20	56	Nomex Honeycomb	Nylon	40	0.3	257
39	57	Aluminum Honeycomb	Nylon	35	0.6	823
14	58	Nomex Honeycomb	Nylon	35	0.3	1343
16	59	Aluminum	Polyester	35	0.3	216
69	60	Aluminum Honeycomb	Nylon	40	1	627
47	61	Nomex Honeycomb	Polyester	40	0.6	0
49	62	Aluminum	Nylon	28	1	1617
36	63	Aluminum Honeycomb	Polyester	33	0.6	527
56	64	Nomex Honeycomb	Nylon	33	1	1611
11	65	Nomex Honeycomb	Polyester	33	0.3	549
72	66	Aluminum Honeycomb	Polyester	40	1	0

TABLE 21 (continued)

Std	Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1
		A: Bulkhead type	B: Seat Belt	C: Seat Setback Distance	D: Bulkhead Surface Friction	HIC
66	67	Aluminum Honeycomb	Polyester	35	1	557
12	68	Aluminum Honeycomb	Polyester	33	0.3	416
32	69	Nomex Honeycomb	Nylon	33	0.6	1521
34	70	Aluminum	Polyester	33	0.6	561
37	71	Aluminum	Nylon	35	0.6	811
50	72	Nomex Honeycomb	Nylon	28	1	1899

The results from the ANOVA are shown in Table 22. With model F value of 56.78, the model is significant and there is only a 0.01% chance that the model F value this large could be due to noise. It is also noticed that only A, B, C, D, AB, AC, C^2, AC^2, and BC^2 are the significant model terms. In order to improve the model a model reduction is performed wherein the insignificant terms are removed. A reduced regression model is setup by ignoring the insignificant terms, AD, BC, BD, CD, D^2, ABC, ABD, ACD, BCD, AD^2, BD^2, C^2D, CD^2, and C^3. The reduced regression model for test -2 was built and the ANOVA on the reduced regression model was performed and the results are shown in Table 23. Some of the terms which were considered not significant have been included for hierarchy correction.

TABLE 22

ANOVA ON TEST – 2 DOE MODEL

ANOVA for Response Surface Reduced Cubic Model						
Analysis of variance table [Classical sum of squares - Type II]						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.80E+07	32	5.64E+05	56.77612	< 0.0001	Significant
A-Bulkhead	1.01E+06	2	5.07E+05	51.08067	< 0.0001	Significant
B-Seat Belt	5.00E+06	1	5.00E+06	503.3203	< 0.0001	Significant
C-Seat Setback Distance	9.97E+06	1	9.97E+06	1003.864	< 0.0001	Significant
D-Bulkhead Surface Friction	3.55E+05	1	3.55E+05	35.7437	< 0.0001	Significant
AB	4.04E+05	2	2.02E+05	20.325	< 0.0001	Significant
AC	7.82E+05	2	3.91E+05	39.35904	< 0.0001	Significant
AD	1.79E+03	2	8.93E+02	0.08991	0.9142	Not significant
BC	2.28E+03	1	2.28E+03	0.229086	0.6349	Not significant
BD	2.83E+03	1	2.83E+03	0.285036	0.5964	Not significant
CD	1.59E+04	1	1.59E+04	1.598143	0.2137	Not significant
C^2	5.64E+04	1	5.64E+04	5.677048	0.0222	Significant
D^2	1.45E+03	1	1.45E+03	0.146202	0.7043	Not significant
ABC	5.21E+04	2	2.60E+04	2.620089	0.0856	Not significant
ABD	4.69E+02	2	2.35E+02	0.023622	0.9767	Not significant
ACD	1.89E+03	2	9.45E+02	0.095152	0.9094	Not significant
BCD	9.83E+03	1	9.83E+03	0.989309	0.3260	Not significant
AC^2	2.11E+05	2	1.06E+05	10.64013	0.0002	Significant
AD^2	1.02E+03	2	5.11E+02	0.051465	0.9499	Not significant
BC+	1.16E+05	1	1.16E+05	11.66991	0.0015	Significant
BD^2	2.28E+02	1	2.28E+02	0.022929	0.8804	Not significant
C^2D	2.02E+04	1	2.02E+04	2.037371	0.1614	Not significant
CD^2	1.32E+03	1	1.32E+03	0.13254	0.7178	Not significant
C^3	2.53E+04	1	2.53E+04	2.549494	0.1184	Not significant
Residual	3.87E+05	39	9.93E+03			
Cor Total	1.84E+07	71				

TABLE 23

REDUCED REGRESSION MODEL FOR TEST – 2

ANOVA for Response Surface Reduced Cubic Model					
Analysis of variance table [Classical sum of squares - Type II]					
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**
Model	17717413	13	1362877.934	110.2125128	< 0.0001
A-Bulkhead	1014803	2	507401.375	41.03227382	< 0.0001
B-Seat Belt	4999649	1	4999649.014	404.3090489	< 0.0001
C-Seat Setback Distance	9971721	1	9971720.721	806.3879903	< 0.0001
D-Bulkhead Surface Friction	355054.1	1	355054.0608	28.71232945	< 0.0001
AB	403790	2	201895.0139	16.3267423	< 0.0001
AC	781932.9	2	390966.4737	31.61647601	< 0.0001
BC	2275.586	1	2275.586336	0.184020947	0.6695
CD	15874.89	1	15874.89093	1.283762527	0.2619
C^2	56392.01	1	56392.01389	4.560280419	0.0370
BC^2	115921.1	1	115921.125	9.374250005	0.0033
Residual	717222.7	58	12365.90927		
Cor Total	18434636	71			

5.4 Model Validation and Results

Model validation is performed by checking the normal plots and residual plots. The normal plotting of the residual does not show any abnormality nor is there any evidence for outliers as shown in Figure 35 and Figure 36 respectively. The residual versus the predicted plots do not show any funnel shape as can be observed in Figure 36.

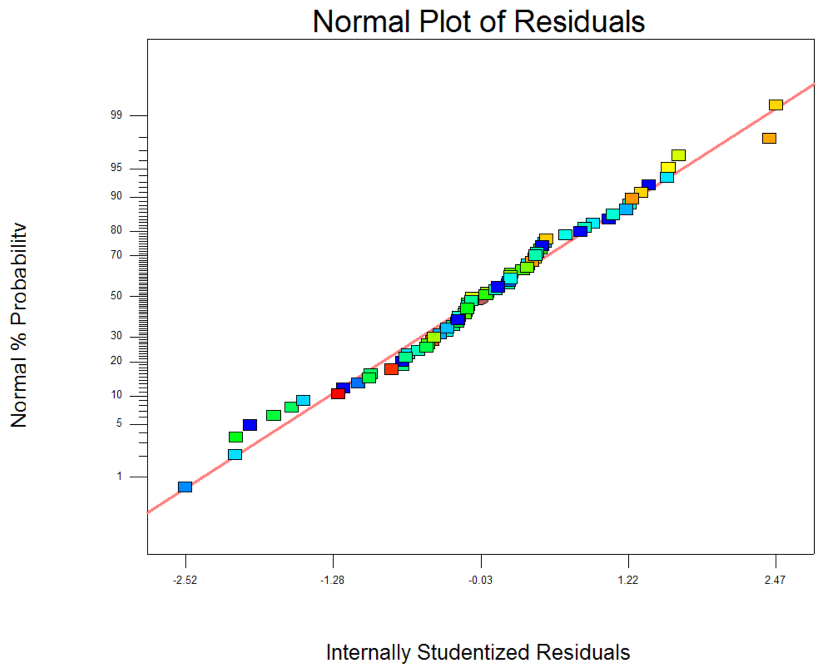

Figure 35. Normal Plot of Residuals

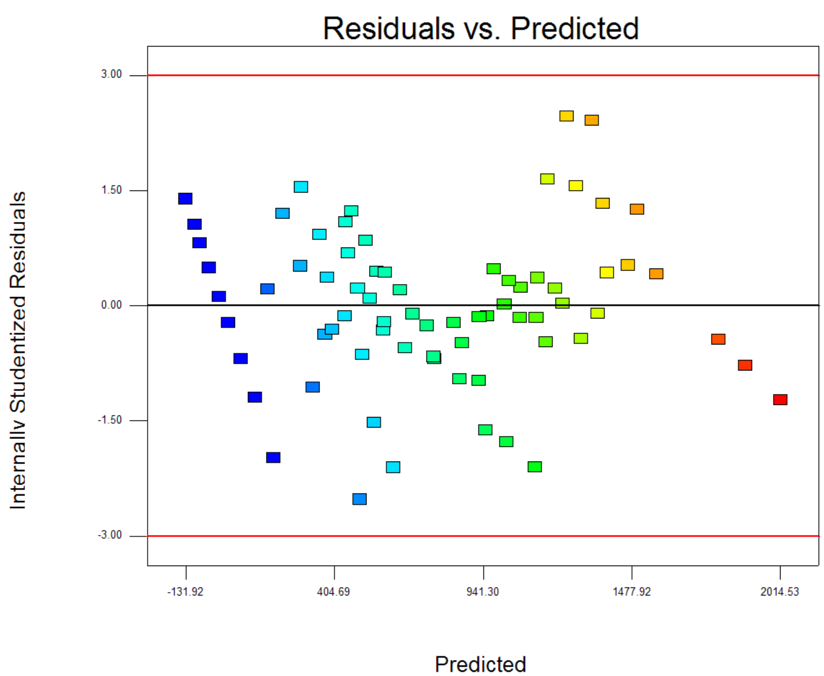

Figure 36. Plot of Residuals vs. Predicted values

The residual plots are shown in Figure 37 to Figure 40. From these plots it may be observed that they did not show any inequality in the variance

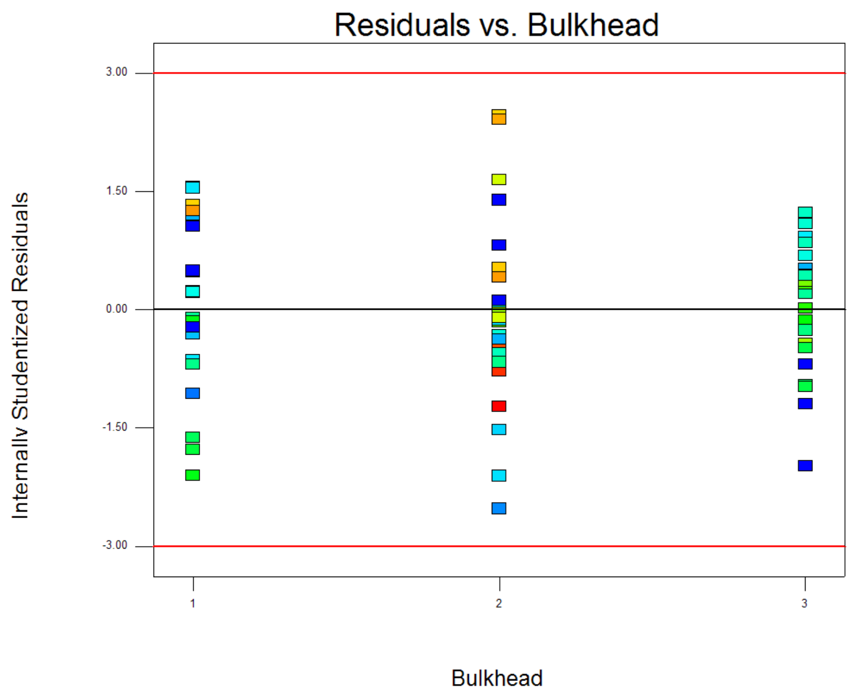

Figure 37 Plot of Residuals vs. Bulkhead

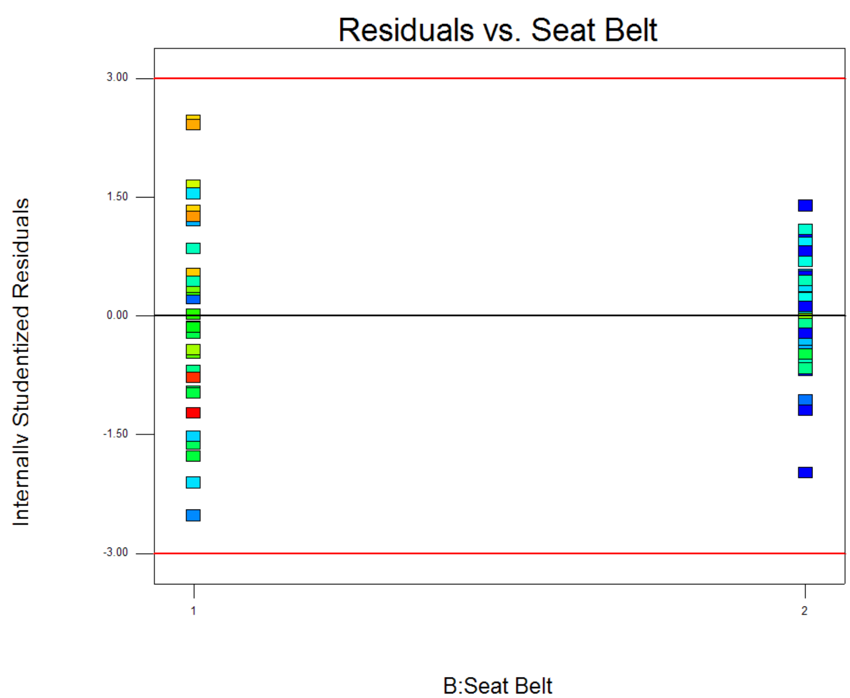

Figure 38. Plot of Residuals vs. Seat Belt

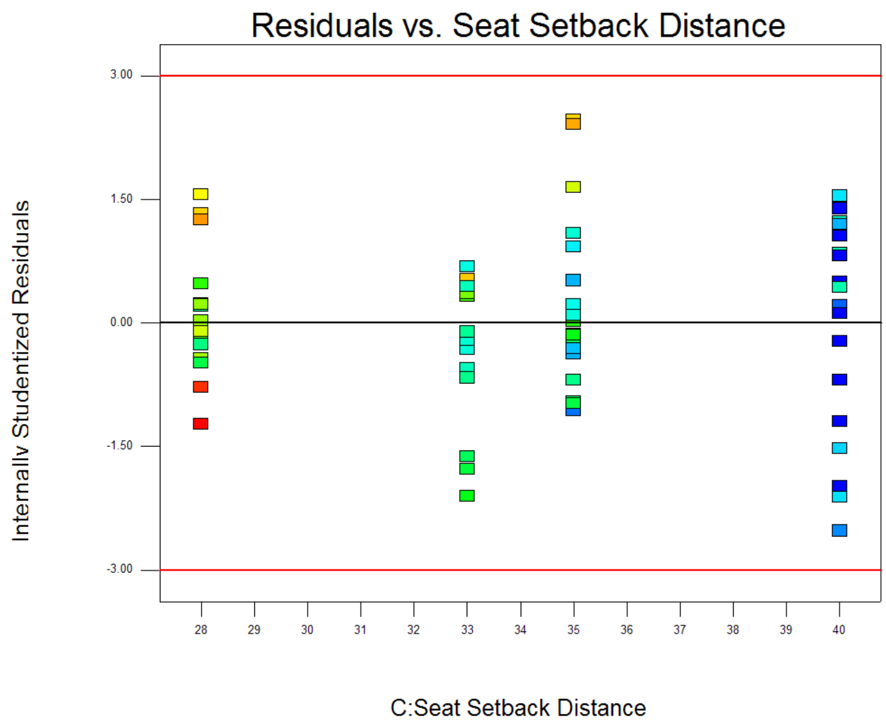

Figure 39. Plot of Residuals vs. Seat Setback Distance

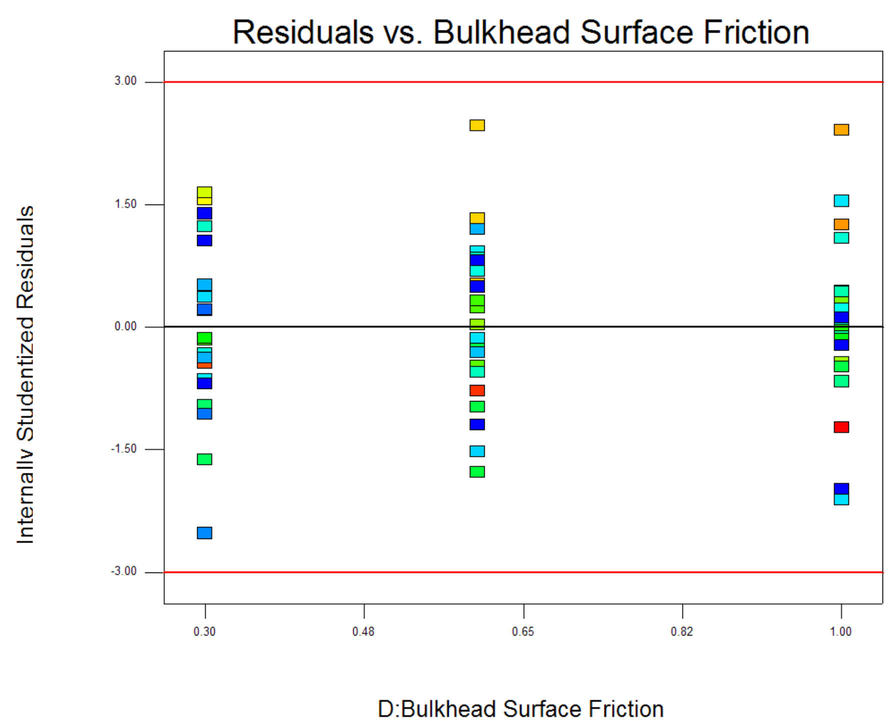

Figure 40. Plot of Residuals vs. Bulkhead Surface Friction

5.5 Response Surface Plot for Test – 2 DOE

Response surface plots were constructed for every combination of bulkhead type and seat belt type. The purpose of building these response surfaces was to get their underlying equations of the surface fitted through the design point within the design space.

The 2D contour plots and the response surface for HIC with all the combinations of bulkhead and seatbelts have been plotted and are shown in Figure 41 to Figure 52

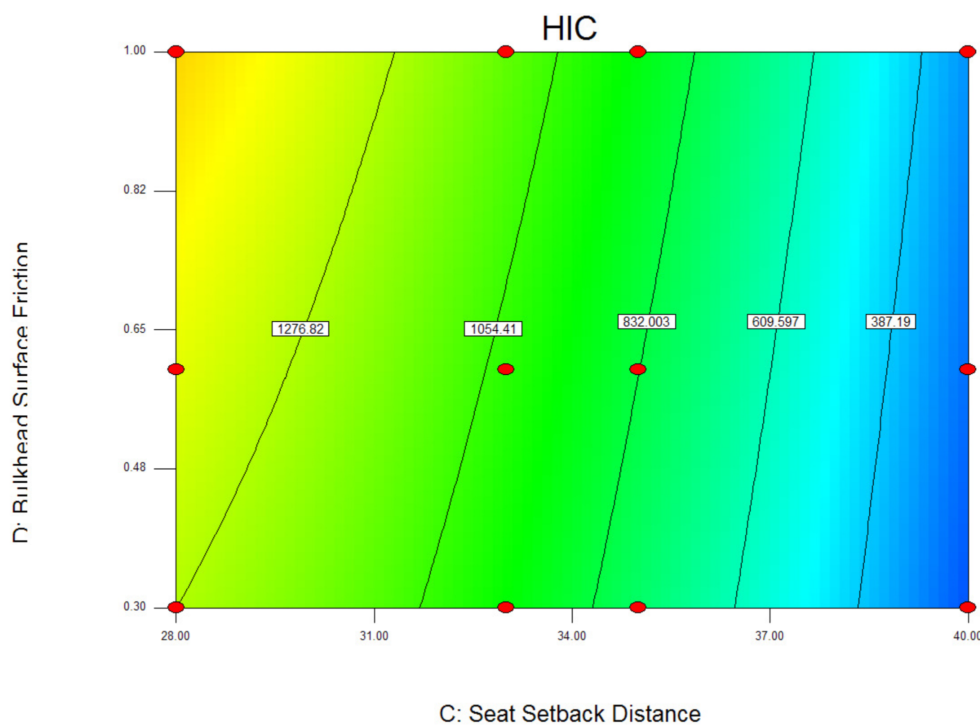

Figure 41. 2D contour plot for HIC when using Aluminum sheet as bulkhead and nylon seatbelt

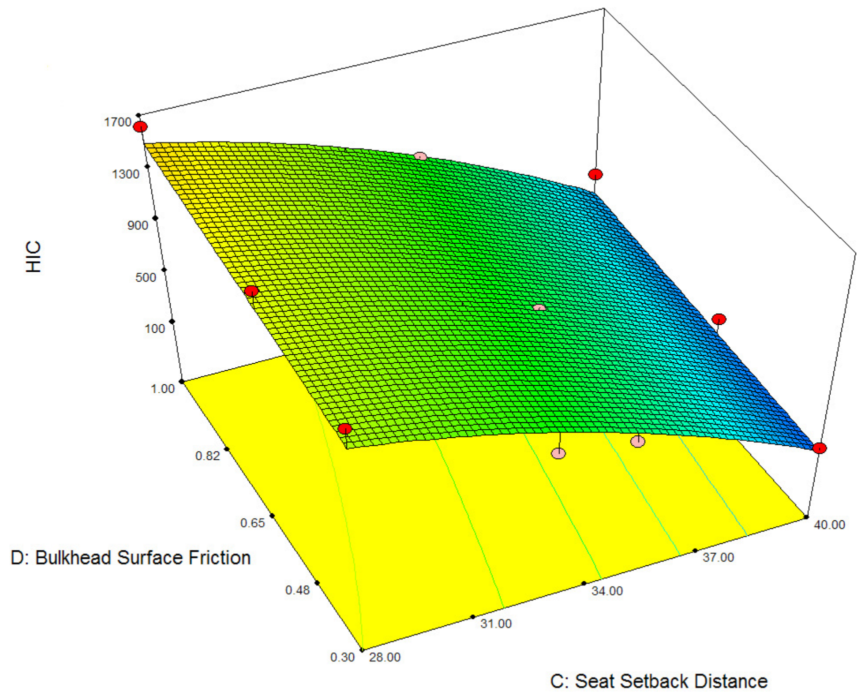

Figure 42. Response Surface Plot for HIC when using Aluminum sheet as bulkhead and nylon Seatbelt

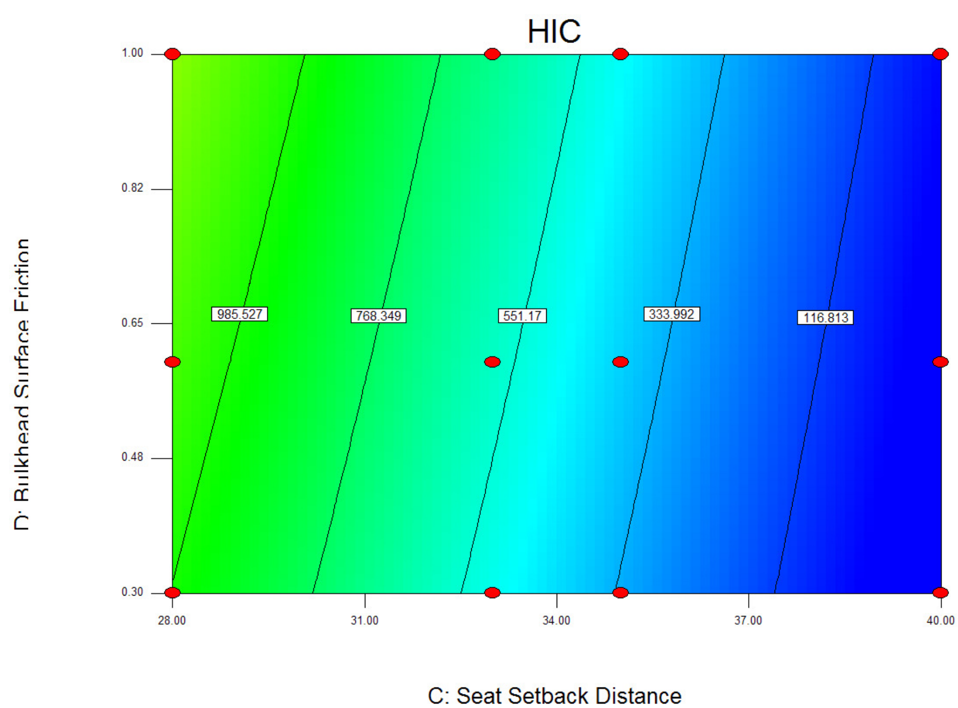

Figure 43. 2D contour plot for HIC when using Aluminum sheet as bulkhead and polyester seatbelt

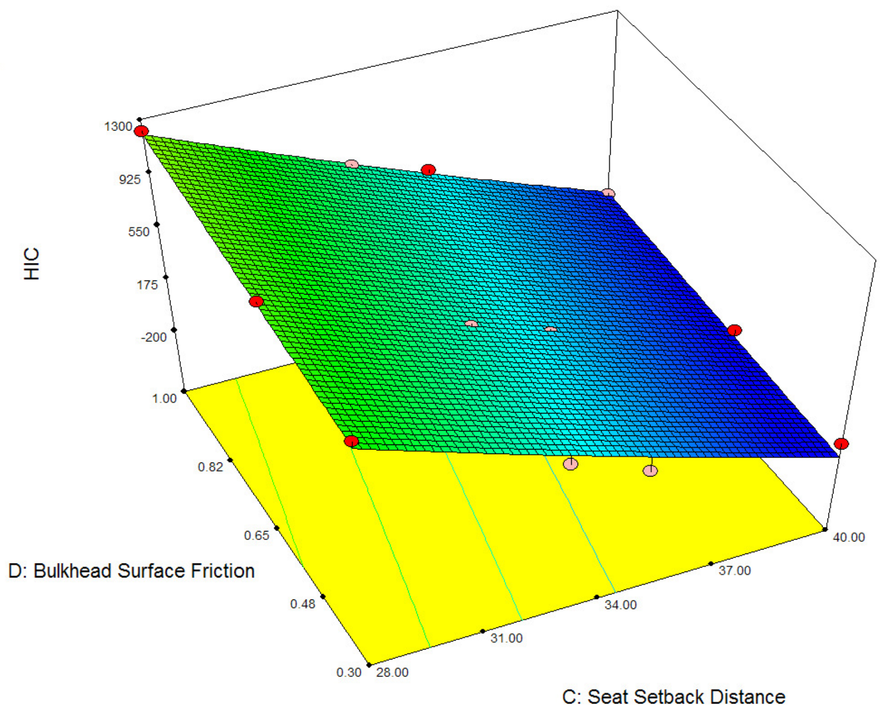

Figure 44. Response Surface plot for HIC when using Aluminum Sheet as bulkhead and polyester seatbelt

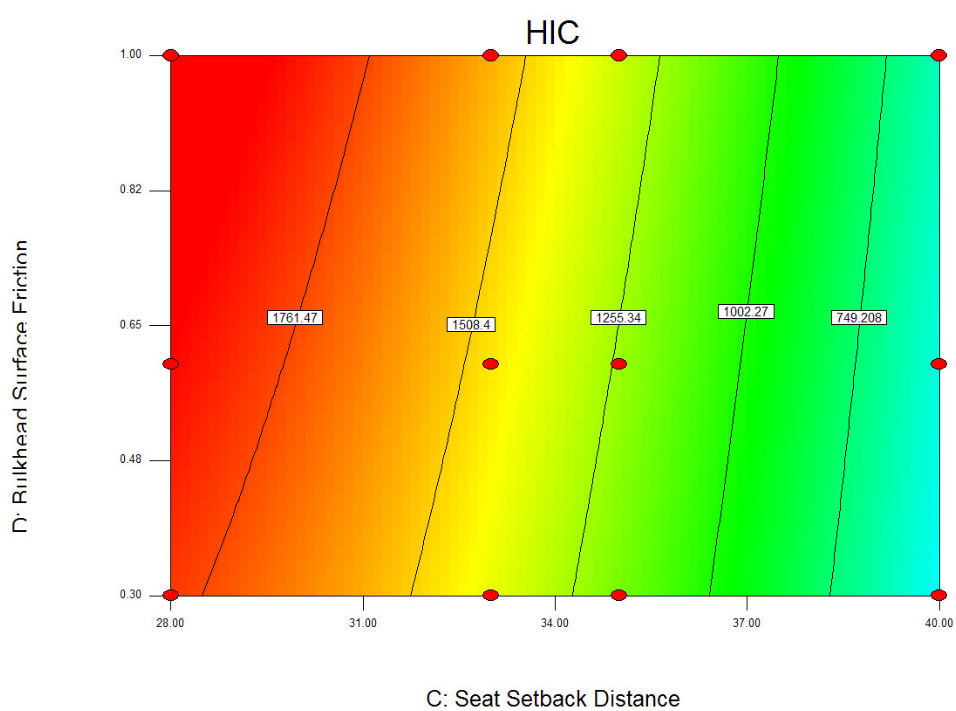

Figure 45. 2D contour plot for HIC when using Nomex honeycomb bulkhead and nylon seatbelt

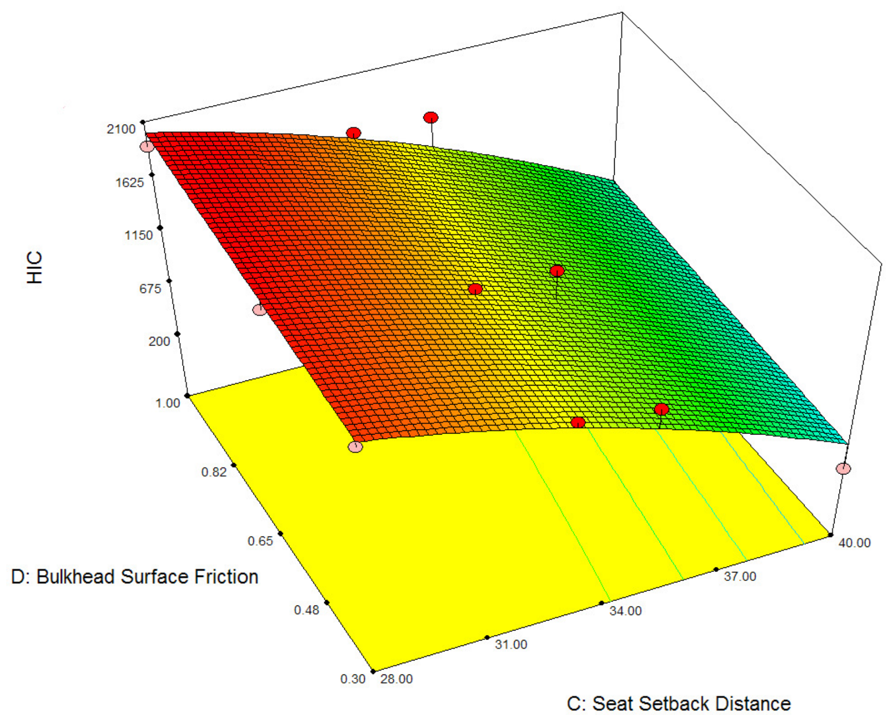

Figure 46. Response Surface plot for HIC when using Nomex Honeycomb bulkhead and nylon seatbelt

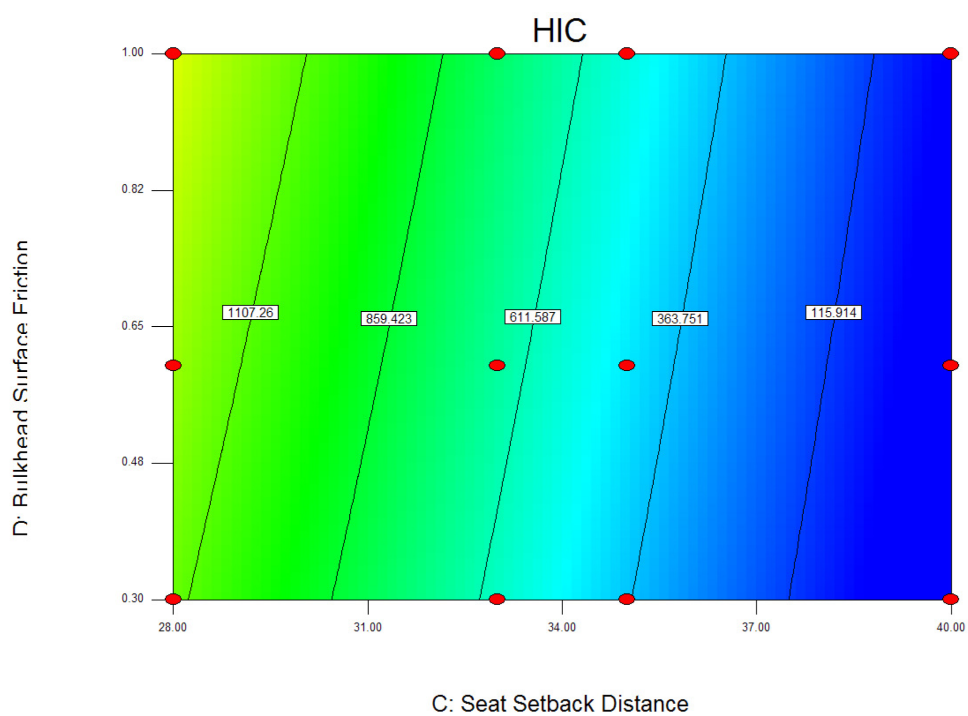

Figure 47. 2D contour plot for HIC when using Nomex honeycomb bulkhead and polyester seatbelt

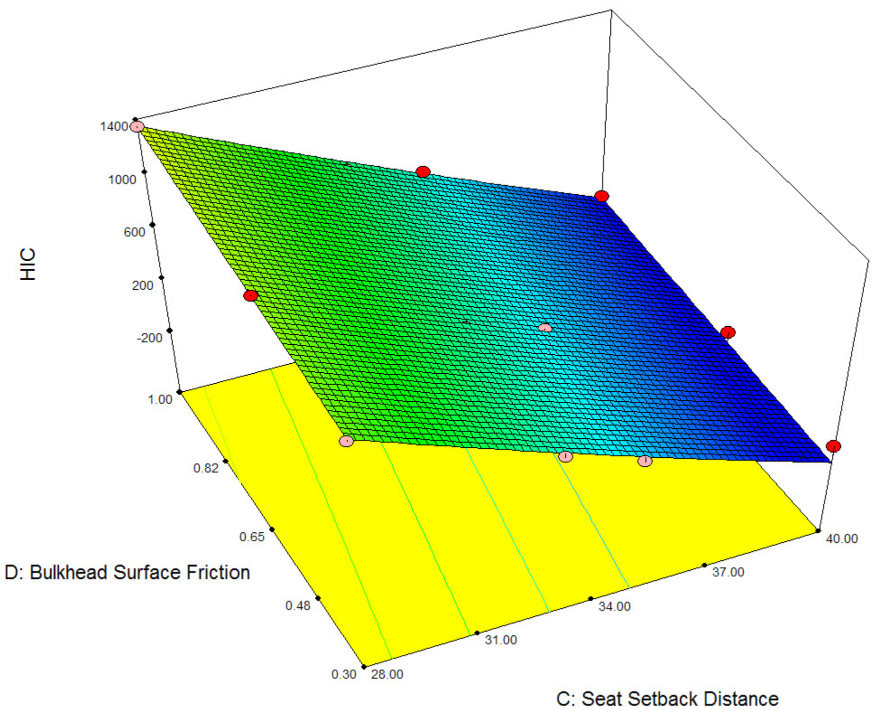

Figure 48. Response surface plot for HIC when using Nomex honeycomb bulkhead and polyester seatbelt

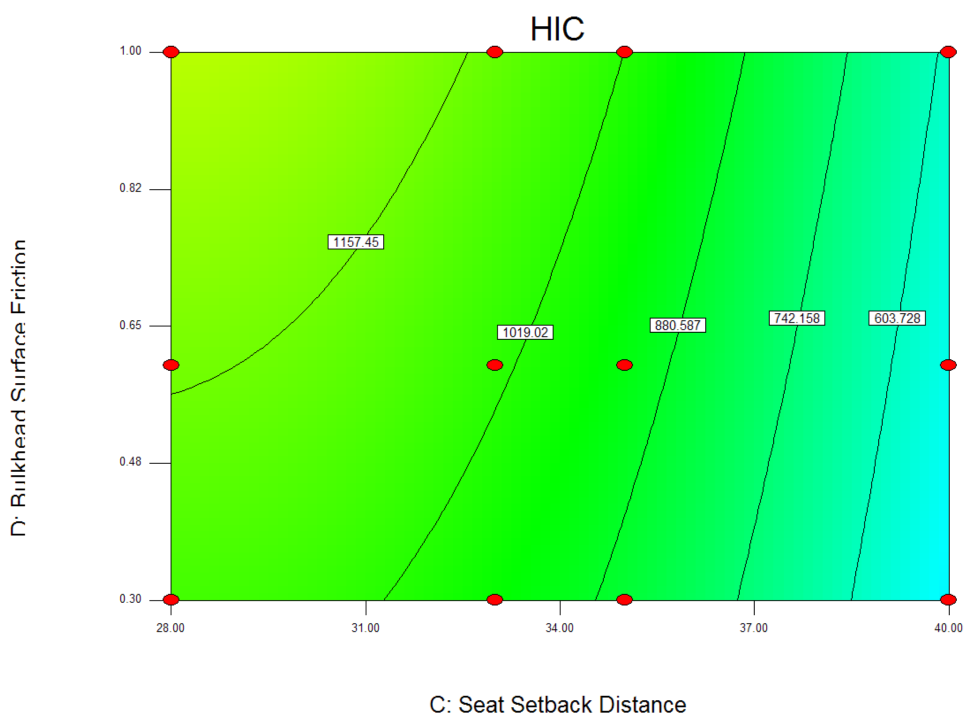

Figure 49. 2D contour plot for HIC when using Aluminum honeycomb bulkhead and nylon seatbelt

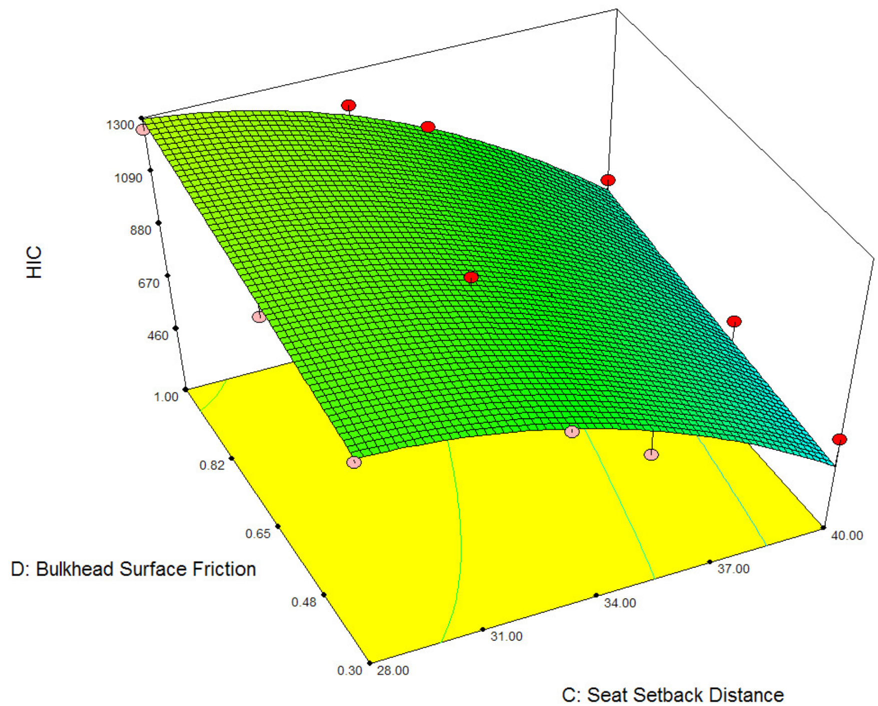

Figure 50. Response Surface plot for HIC when using Aluminum honeycomb bulkhead and nylon seatbelt

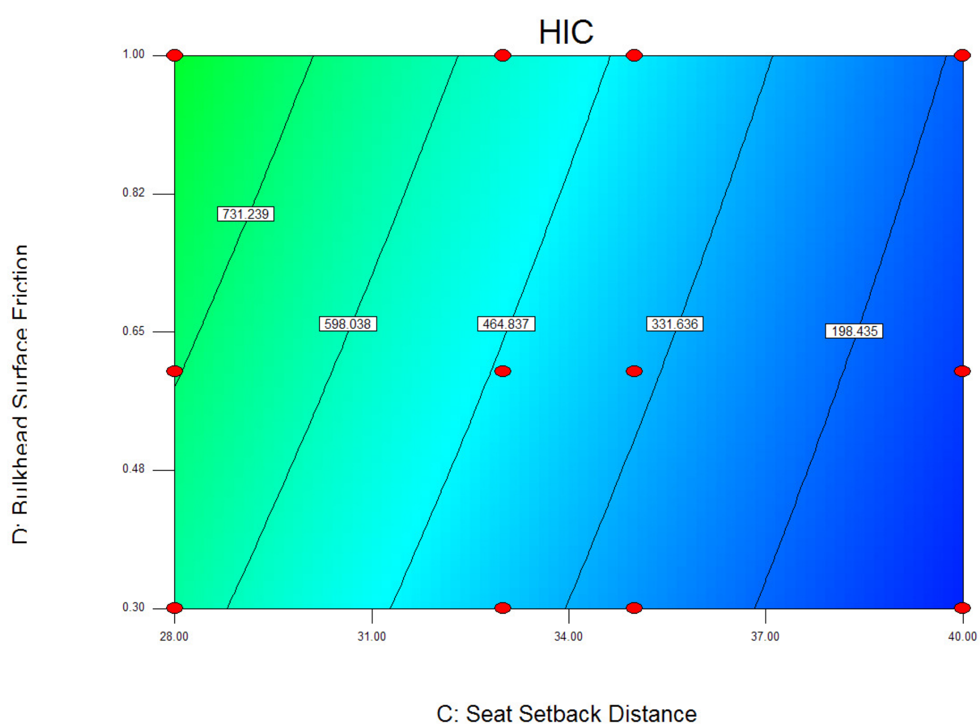

Figure 51. 2D contour plot for HIC when using Aluminum honeycomb bulkhead and polyester seatbelt

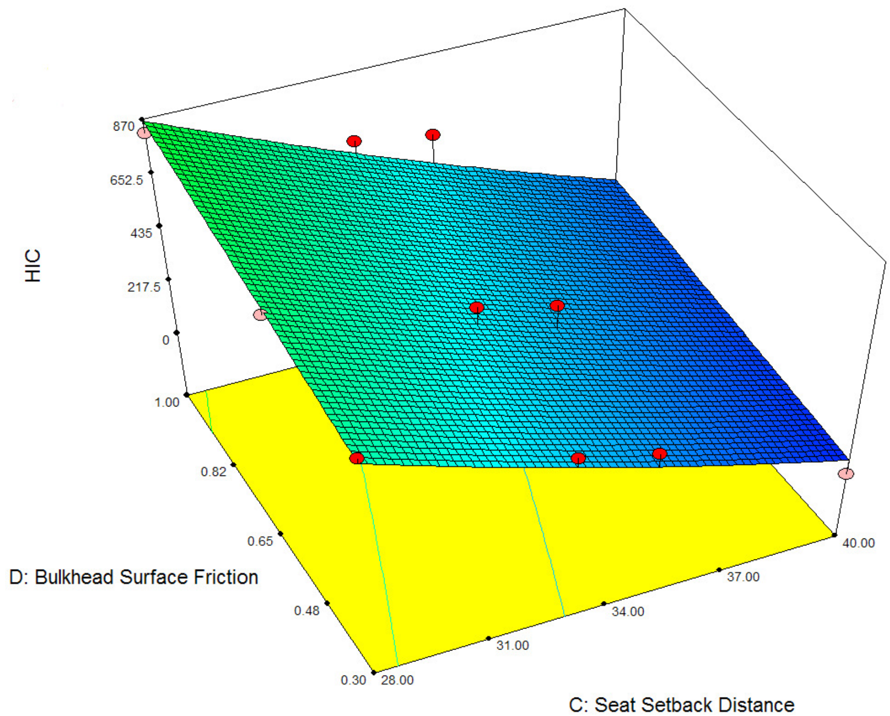

Figure 52. Response surface plot for HIC when using Aluminum honeycomb bulkhead and polyester seatbelt

Each of these response surfaces defines the design space in which the HIC is valid. The equations to the surface generated within the design space would help us in performing optimization where in we could minimize HIC for a set of parameters. The equation for the response surface plotted for each bulkhead seatbelt combination were computed by the Design Expert software and these are tabulated in Table 24.

According to this study it may be noticed that the HIC is quadratic function of the seat back distance and bulkhead surface friction. The coefficients of the terms change when we select various bulkhead types and various seatbelts. In this study the property of the bulkhead (stiffness) and the seatbelt (load-deflection) are categorical terms and numeric and hence a generalized equation for HIC is not generated.

TABLE 24

EQUATIONS FOR HIC

Bulkhead	Seatbelt	HIC
Aluminum Sheet	**Nylon**	*682.44851 + 175.56837 * Seat Setback Distance + 654.24184 * Bulkhead Surface Friction - 12.03951 * Seat Setback Distance * Bulkhead Surface Friction - 3.89206 * Seat Setback Distance*^{2}
	Polyester	*4083.83827 - 133.64609 * Seat Setback Distance + 654.24184 * Bulkhead Surface Friction - 12.03951 * Seat Setback Distance * Bulkhead Surface Friction + 0.69365 * Seat Setback Distance*^{2}
Nomex Honeycomb	**Nylon**	*262.06500 + 160.23954 * Seat Setback Distance + 654.24184 * Bulkhead Surface Friction - 12.03951 * Seat Setback Distance * Bulkhead Surface Friction - 3.89206 * Seat Setback Distance*^{2}
	Polyester	*4665.43512 - 148.97492 * Seat Setback Distance + 654.24184 * Bulkhead Surface Friction - 12.03951 * Seat Setback Distance * Bulkhead Surface Friction + 0.69365 * Seat Setback Distance*^{2}
Aluminum Honeycomb	**Nylon**	*- 2061.48230 + 217.55711 * Seat Setback Distance + 654.24184 * Bulkhead Surface Friction - 12.03951 * Seat Setback Distance * Bulkhead Surface Friction - 3.89206 * Seat Setback Distance*^{2}
	Polyester	*2569.88782 - 91.65735 * Seat Setback Distance + 654.24184 * Bulkhead Surface Friction - 12.03951 * Seat Setback Distance * Bulkhead Surface Friction + 0.69365 * Seat Setback Distance*^{2}

5.6 Optimization

In simple terms, optimization is the attempt to maximize a system’s desirable properties while minimizing its undesirable characteristics. Optimization problems are made up of three basic ingredients:

1. An objective function which we want to minimize or maximize. For instance, in this study of Test – 1 configuration, we might want to maximize the seat pan deflection or minimize the lumbar load. In fitting experimental data to a user-defined model, we might minimize the total deviation of observed data from predictions based on the model.

2. A set of unknowns or variables which affect the value of the objective function. In this study of test – 2 configuration, the variables might include the type of bulkhead used, the seat setback distance, etc. In fitting-the-data problem, the unknowns are the parameters that define the model.

3. A set of constraints that allow the unknowns to take on certain values but exclude others. For the test – 2 scenario, the seat setback distance cannot be less than a certain value or else it would make the seat unusable, and in most case it would make economic sense to have a extremely large seat setback distance, so we constrain all the "seat setback" variables to be with a upper and lower bound values.

The optimization problem is then: Find values of the variables that minimize or maximize the objective function while satisfying the constraints. Not all the component mentioned above are necessary of optimization.

Objective Function: Almost all optimization problems have a single objective function. The two interesting exceptions are:

- No objective function. In some cases, the goal is to find a set of variables that satisfies the constraints of the model. The user does not particularly want to optimize anything so there is no reason to define an objective function. This type of problems is usually called a feasibility problem.

- Multiple objective functions. Often, the user would actually like to optimize a number of different objectives at once. Usually, the different objectives are not compatible; the variables that optimize one objective may be far from optimal for the others. In practice, problems with multiple objectives are reformulated as single-objective problems by either forming a weighted combination of the different objectives or else replacing some of the objectives by constraints.

Variables: These are essential. If there are no variables, we cannot define the objective function and the problem constraints.

Constraints: Constraints are not essential. In fact, the field of unconstrained optimization is a large and important one for which a lot of algorithms and software are available.

5.6.1 Classifying Optimizers

After the problem at hand has been transformed into an objective function minimization problem, the next step is to choose to an appropriate optimizer. Table 25 classifies optimizers based, in part, on the number of points that they track through the problem space. This classification does not distinguish between multi-point optimizers that operate in parallel and multi-start algorithms that visit many points in sequence. The table also classifies the algorithms based on their reliance on objective function derivatives. Not all optimizers fit into these categories, the classification is more general in nature rather than going deeper into the nuances of various techniques these optimization methods employ.

TABLE 25

CLASSIFICATION OF OPTIMIZATION APPROACHES

	Single – Point	**Multi – Point**
Derivative – based	Steepest descent Conjugate gradient Quasi – Newton	Multi – start and clustering techniques
Derivative – free (direct search)	Random walk Hooke - Jeeves	Nelder - Mead Evolutionary algorithms Differential evolution

5.6.2 Evolution Strategies and Genetic Algorithms

Evolution strategies (ES) and genetic algorithms (GA) attempt to evolve better solutions through recombination, mutation and survival of the fittest [43]. Since they try to mimic Darwian evolution, ES, GS, differential evolution (DE) and their ilk are often collectively referred to as evolutionary algorithms (EA). Distinctions do exist between these methods. For example, ES is an effective continuous function optimizer, in part because it encodes parameters as floating-point numbers and manipulates them with arithmetic operators. While GA are often suited for combination optimization because they encode parameters as bit strings and modify them with logical operators.

5.7 Differential Evolution

Like nearly all EA,s differential evolution (DE) [44-45] is population based optimizer that attacks the starting point problem by sampling the objective function at multiple, randomly chosen initial points. Preset parameters define the domain from which the N_p vectors in this initial population are chosen. N_p is the number of population members Each vector is indexed with a number from 0 to N_p-1. Like other population-based methods, DE generates new points that are neither reflections nor sample from a predefined probability density function. Instead DE perturbs vectors with the scaled difference of two randomly selected population vectors. To produce the trial vector u_0, DE adds the scaled random vector difference to a third randomly selected population vector. In the selection stage, the trial vector competes against the population vector of the same index, which in this case is number 0. The vector with the lower objective function value is marked as member of the next generation. This procedure repeats until all N_p population vectors have competed against a randomly generated trial vector. Once the last trial vector has been tested, the survivors of the N_p pairwise competition become parents for the next generation in the evolutionary cycle. This process of mutation, recombination continues until some stopping criterion is reached.

The basics of DE may be explained by the following [46]

Suppose we want to optimize a function with *D* real parameters, we must select the size of the population *N* (it must be at least 4) The parameter vectors have the form: $x_{i,G} = [x_{1,i,G}, x_{2,i,G} \ldots x_{D,i,G}]\, i = 1, 2, ..., N$ where G is the generation number. Define upper and lower bounds for each parameter: $x_j^L \leq x_{j,i,l} \leq x_j^U$ Randomly select the initial parameter values uniformly on the intervals $[x_j^L, x_j^U]$. Each of the *N* parameter vectors undergoes mutation, recombination and selection and thereby expanding the search space. For a given parameter vector $x_{i,G}$ randomly select three vectors

$x_{r_1,G}, x_{r_2,G}$ *and* $x_{r_3,G}$ such that the indices *i, r_1, r_2* and *r_3* are distinct. Add the weighted difference of two of the vectors to the third $v_{i,G+1} = x_{r_1,G} + F\left(x_{r_2,G} - x_{r_3,G}\right)$. The mutation factor F is a constant from [0, 2] and $v_{i,G+1}$ is called the donor vector. Recombination incorporates successful solutions from the previous generation and the trial vector $u_{i,G+1}$ is developed from the elements of the target vector, $x_{i,G}$, and the elements of the donor vector, $v_{i,G+1}$. Elements of the donor vector enter the trial vector with a predefined probability CR.

$$u_{j,i,G+1} = \begin{cases} v_{j,i,G+1} \; if \; rand_{j,i} \; CR \; or \; j = I_{rand} \\ x_{j,i,G} \; if \; rand_{j,i} > CR \; or \; j \neq I_{rand} \end{cases} \quad i = 1, 2, ..., N; \; j = 1, 2, ..., D$$

where $rand_{j,i} \sim U[0, 1]$, I_{rand} is a random integer from [1, 2, ...,D] and I_{rand} ensures that $v_{i,G+1} \neq x_{i,G}$. The target vector $x_{i,G}$ is compared with the trial vector $v_{i,G+1}$ and the one with the lowest function value is admitted to the next generation

$$x_{i,G+1} = \begin{cases} u_{i,G+1} \; if \; f(u_{i,G+1}) \leq f(x_{i,G}) \\ x_{i,G} \; otherwise \end{cases} \quad i = 1, 2, ..., N$$

Mutation, recombination and selection continue until some stopping criterion is reached.

5.8 Applying DE to Test – 1 and Test – 2 DOE Studies

From the DOE studies performed earlier for Test -1 and Test – 2 configuration, equation for lumbar load and HIC were obtained for a particular set of parameters. These equations will be set as the objective function and optimization can be performed to minimize the injury criteria of lumbar load and HIC. In the case of lumbar load for particular type of seat cushion the variable would be seat cushion thickness and seat pan deflection. This will generate a set of four objective functions and for optimizations for reducing the lumbar using the data from the current study. The variable constraints would be the upper and lower bound values used for the DOES study.

For minimizing HIC, for every combination of bulkhead type and seat belt there is a function which predicts HIC and this function will be used as the objective function. The variables for minimizing HIC would seat setback distance and bulkhead surface friction. Similar to what was stated above the upper and lower values of the seat setback distance and bulkhead surface friction would serves as the upper and lower bound for the constraints on the variables.

CHAPTER 6

GRAPHICAL USER INTERFACE SYSTEM FOR AIRCRAFT CABIN INTERIOR DESIGN

It is important to develop tools keeping in mind the end users. Very often a methodology or tool can be so complex that it defeats the purpose for which it was designed. Keeping in mind this important criterion, it was felt that the tools developed as part of this study would prove to be too cumbersome for the designer to use. A user friendly graphical user interface (GUI) was developed which would help the aircraft cabin interior designers to select components that would minimize the injury criteria. The GUI sits on top of the optimization code which runs in the background when the user uses it to generate optimal solution to the problems at hand.

6.1 Differential Evolution Optimization Coded in Matlab

Differential evolution has been selected as optimization technique that would be used in this study. The primary advantage of this is faster solution and more accurate selection of the variable even when local minima are there in objective function.

There exists generic Matlab code for using this optimization methodology. This generic optimization code available in was modified so that it would suite this study. Modifications were made so that the results obtained from the optimization were consistent even when performing repeated optimization. The code had to be modified so that a large population is searched right from the beginning thereby covering a bigger chunk of the design space. The modified code for optimization is list in Appendix. The current object function is not very complex, but keeping in mind further expansions that could be made the code has been suitably adjusted

6.2 GUI using Visual Basic.net

A graphical user interface has been developed for easy use of information gleaned from this study. The basic flowchart of how the GUI behave is shown in Figure 53

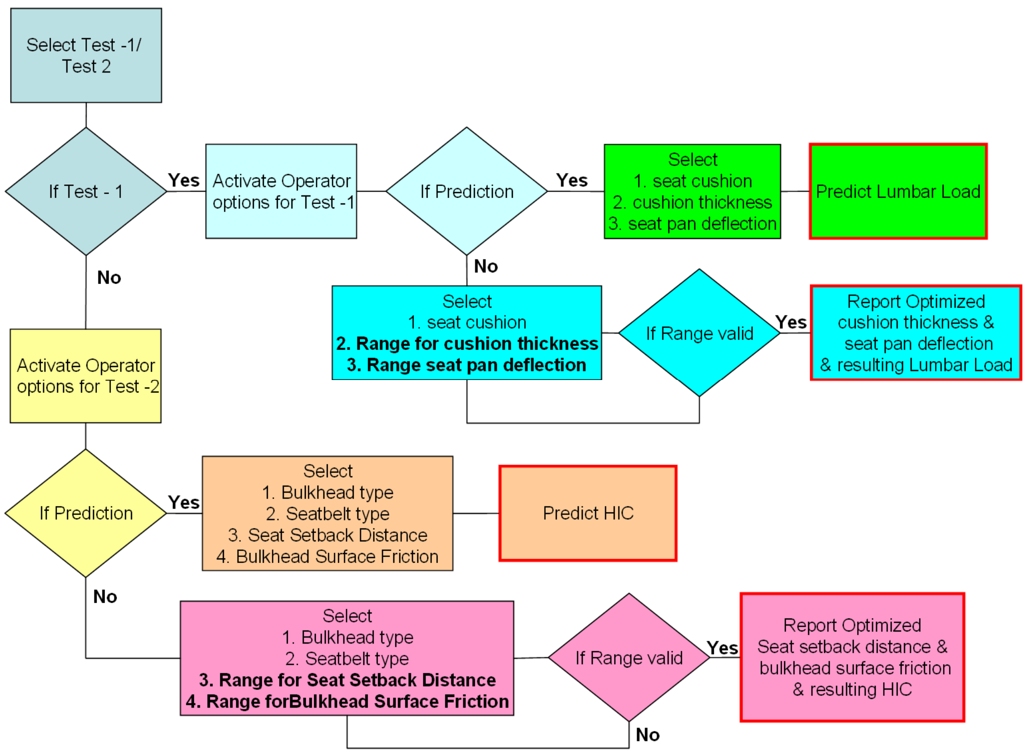

Figure 53. Flowchart for GUI operation

Visual Basic.net has been used develop the GUI. Visual Basic facilitates running of the external optimization process in Matlab by supplying the user defined parameter selected from the GUI and also extracting the results from the optimization reporting it.

Screen shots of the GUI performing optimization of lumbar load for a user selected set of input are shown in Figure 54 to Figure 57. Screen showing the optimized parameters

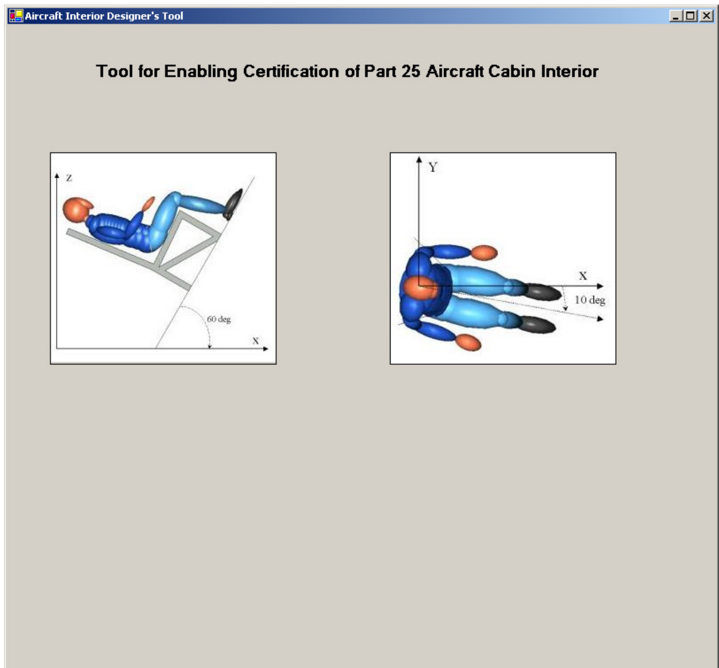

Figure 54. Initial Screen for selection of Test condition

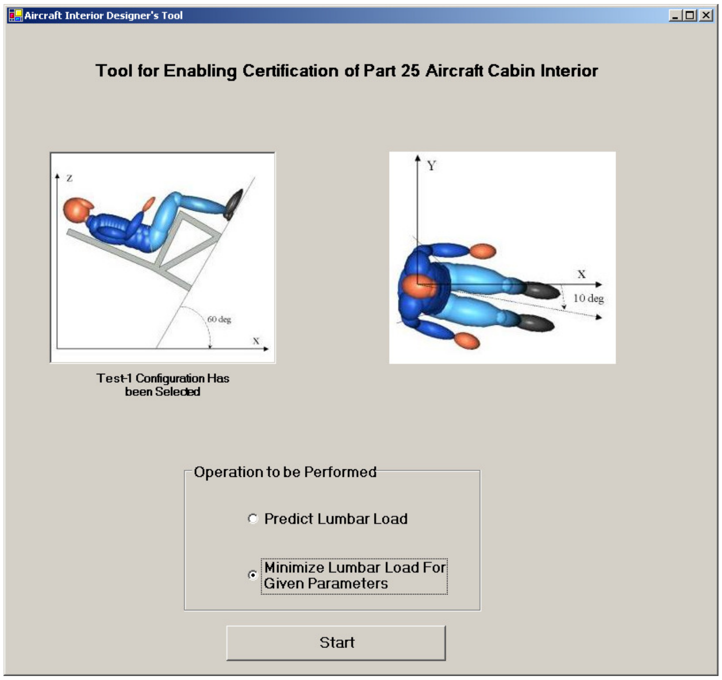

Figure 55. Screen showing available options

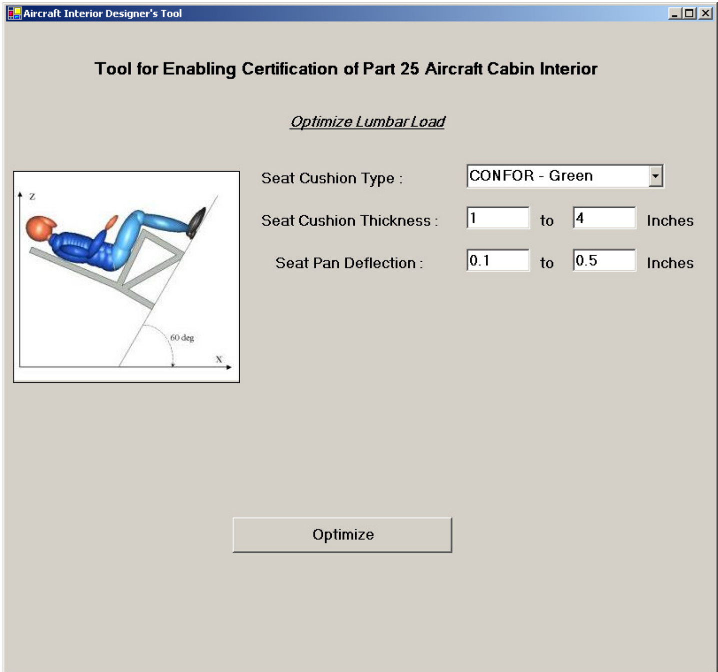

Figure 56. Screen showing the options for optimization

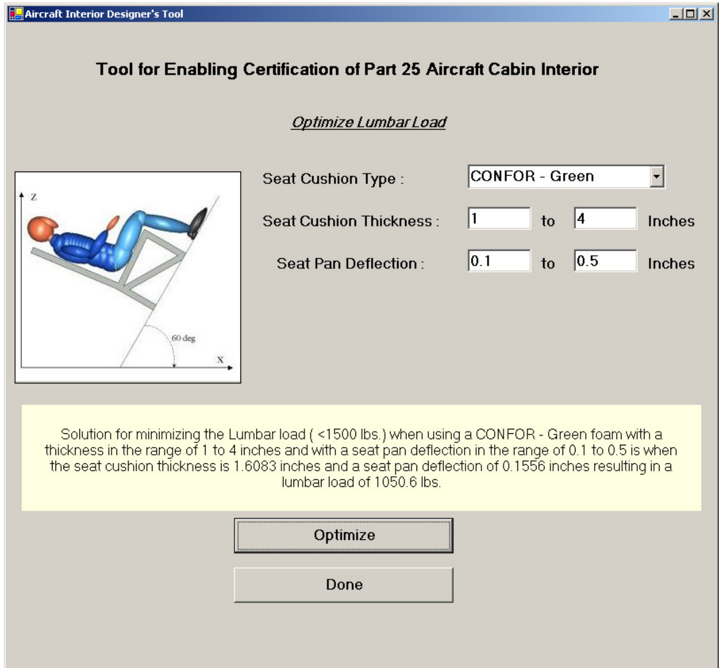

Figure 57. Screen showing the optimized parameters

The GUI is intuitive in nature and the user can put it use with very little learning involved. The initial screen shows the two test configurations and the user selects whichever option is needed by clicking on the image. Depending on the selection of the test configuration the user has the ability to predict the concerned injury criterion or try and get an optimized solution for a set of parameters. Once the choice has been made and has been confirmed the user displayed with the available choices. In some case like seat cushion in Test – 1 configuration and bulkhead type and seatbelt in test -2 configuration, the user makes a choice from a dropdown menu. Depending on where prediction or optimization was chosen, the user has to input the required range in the case of optimization or select the value that needs to be used for prediction. For prediction, as soon as the user is done with the selection and confirms the selection the predicted injury criterion is displayed. Before the prediction is performed the values entered for the various parameters are validated so that they are within the design space. If they are outside the design space, the user is notified and the values are also adjust to a predefined default value.

If the user was trying to optimize the parameter so that the injury criterion would be a minimum, a range of the parameters needs to be entered. Here too the values entered for the ranges are validated so that they are within the design space and so ensured that the upper bound value is greater than the lower bound value. The user is notified of any violation and like before a predefined default value is entered in the considered parameter fixing the problem. Once the validation is complete, the optimization takes place behind the scene and on completion, the user is displayed the optimized solution along with the minimized injury criterion.

The GUI has been tested and the results from the optimization have been crossed checked to ensure accuracy of result. It has been seen that the GUI is robust enough to handle all the scenarios for which it was tested. The GUI could prove to be a valuable tool which can be used by designers to develop aircraft interiors while ensuring that the injury criterion and kept to a minimum.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions

The Federal Aviation Regulations concerning Part 25 type aircraft provide for certification by analysis but has little or no information on what constitutes a valid model. The AC 20 -146 attempts to address this concern by stipulating the criteria that needs to be met and the type of model necessary for validating a test. The FAA is funding a program in attempt to clearly define how a model should be build for validating a test is currently underway. In all these studies, very little work has gone into understanding the inherent variations in dynamic sled testing and trying to quantify that variance. This study has successfully shown that there exist significant variations or scatter when conducting a sled test and this scatter has been statistically captured. Analytical models of the full-scale tests were build to represent the mean of the distribution and these models have been shown to be remarkably robust even when subjected to the actual sled pulse. It has been shown that if the models are allowed the same scatter as seen in the sled test generating valid models to replace sled testing is definitely feasible. The models so developed have been statistically shown to be as good as the test itself. The importance understanding the experiment before defining the parameter that would help in building an analytical model representing the experiment has been underlined by this study

The sensitivity analysis helped in getting a better understanding of the effect various variable have on the critical injury criteria. Using this study design tool were build so that aircraft interior designer would be able choose right kind of component when they design without conducting full-sled testing. By choosing a general optimization strategy which would versatile even when using a complex objective function has been chosen and has been shown to be effective. This tool would also help to optimize existing design and help in the certification by analysis process.

The GUI developed as a part of this study has been shown to be a good tool in helping aircraft cabin interior designer in choosing crashworthy components. This tool as been shown to be simple enough for designers to use with little or no learning involved. Such a tool would help in reducing the design time and cost while improving the safety of the flying public.

7.2 Future Work

This study has shown the importance in understanding the scatter in sled testing. The data collected for this study were from one test center. It is necessary to collect enough data sample from FAA approved test centers across the country and use that data to get the scatter or variance in sled testing. This is an important step before any recommendations can be made by the FAA in determining what constitutes a valid model representing a full-scale sled test.

Time and efforts needs to spent to understand the full-scale sled testing procedure produce so much variability and see if there can been any potential solutions to reducing the large scatter in data.

The current sensitivity analysis is only a limited one and more work needs to be done in this area to include more parameters and understand the effect each one of these have the injury criteria. Upon completion of a more comprehensive DOE study the GUI needs to be updated so that all the variables studied would be available as options to the intended end user of this GUI, the aircraft interior designers.

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APPENDICES

APPENDIX - A

Coefficients of {an-i+1}for the W Test for Normality for n = 2(1)50.

i \ n	2	3	4	5	6	7	8	9	10
1	0·7071	0·7071	0·6872	0·6646	0·6431	0·6233	0·6052	0·5888	0·5739
2	—	·0000	·1677	·2413	·2806	·3031	·3164	·3244	·3291
3	—	—	—	·0000	·0875	·1401	·1743	·1976	·2141
4	—	—	—	—	—	·0000	·0561	·0947	·1224
5	—	—	—	—	—	—	—	·0000	·0399

i \ n	11	12	13	14	15	16	17	18	19	20
1	0·5601	0·5475	0·5359	0·5251	0·5150	0·5056	0·4968	0·4886	0·4808	0·4734
2	·3315	·3325	·3325	·3318	·3306	·3290	·3273	·3253	·3232	·3211
3	·2260	·2347	·2412	·2460	·2495	·2521	·2540	·2553	·2561	·2565
4	·1429	·1586	·1707	·1802	·1878	·1939	·1988	·2027	·2059	·2085
5	·0695	·0922	·1099	·1240	·1353	·1447	·1524	·1587	·1641	·1686
6	0·0000	0·0303	0·0539	0·0727	0·0880	0·1005	0·1109	0·1197	0·1271	0·1334
7	—	—	·0000	·0240	·0433	·0593	·0725	·0837	·0932	·1013
8	—	—	—	—	·0000	·0196	·0359	·0496	·0612	·0711
9	—	—	—	—	—	—	·0000	·0163	·0303	·0422
10	—	—	—	—	—	—	—	—	·0000	·0140

i \ n	21	22	23	24	25	26	27	28	29	30
1	0·4643	0·4590	0·4542	0·4493	0·4450	0·4407	0·4366	0·4328	0·4291	0·4254
2	·3185	·3156	·3126	·3098	·3069	·3043	·3018	·2992	·2968	·2944
3	·2578	·2571	·2563	·2554	·2543	·2533	·2522	·2510	·2499	·2487
4	·2119	·2131	·2139	·2145	·2148	·2151	·2152	·2151	·2150	·2148
5	·1736	·1764	·1787	·1807	·1822	·1836	·1848	·1857	·1864	·1870
6	0·1399	0·1443	0·1480	0·1512	0·1539	0·1563	0·1584	0·1601	0·1616	0·1630
7	·1092	·1150	·1201	·1245	·1283	·1316	·1346	·1372	·1395	·1415
8	·0804	·0878	·0941	·0997	·1046	·1089	·1128	·1162	·1192	·1219
9	·0530	·0618	·0696	·0764	·0823	·0876	·0923	·0965	·1002	·1036
10	·0263	·0368	·0459	·0539	·0610	·0672	·0728	·0778	·0822	·0862
11	0·0000	0·0122	0·0228	0·0321	0·0403	0·0476	0·0540	0·0598	0·0650	0·0697
12	—	—	·0000	·0107	·0200	·0284	·0358	·0424	·0483	·0537
13	—	—	—	—	·0000	·0094	·0178	·0253	·0320	·0381
14	—	—	—	—	—	—	·0000	·0084	·0159	·0227
15	—	—	—	—	—	—	—	—	·0000	·0076

Coefficients of $\{a_{n-i+1}\}$ for the W Test for Normality for n = 2(1)50. (Contd.)

i \ n	31	32	33	34	35	36	37	38	39	40
1	0·4220	0·4188	0·4156	0·4127	0·4096	0·4068	0·4040	0·4015	0·3989	0·3964
2	·2921	·2898	·2876	·2854	·2834	·2813	·2794	·2774	·2755	·2737
3	·2475	·2463	·2451	·2439	·2427	·2415	·2403	·2391	·2380	·2368
4	·2145	·2141	·2137	·2132	·2127	·2121	·2116	·2110	·2104	·2098
5	·1874	·1878	·1880	·1882	·1883	·1883	·1883	·1881	·1880	·1878
6	0·1641	0·1651	0·1660	0·1667	0·1673	0·1678	0·1683	0·1686	0·1689	0·1691
7	·1433	·1449	·1463	·1475	·1487	·1496	·1505	·1513	·1520	·1526
8	·1243	·1265	·1284	·1301	·1317	·1331	·1344	·1356	·1366	·1376
9	·1066	·1093	·1118	·1140	·1160	·1179	·1196	·1211	·1225	·1237
10	·0899	·0931	·0961	·0988	·1013	·1036	·1056	·1075	·1092	·1108
11	0·0739	0·0777	0·0812	0·0844	0·0873	0·0900	0·0924	0·0947	0·0967	0·0986
12	·0585	·0629	·0669	·0706	·0739	·0770	·0798	·0824	·0848	·0870
13	·0435	·0485	·0530	·0572	·0610	·0645	·0677	·0706	·0733	·0759
14	·0289	·0344	·0395	·0441	·0484	·0523	·0559	·0592	·0622	·0651
15	·0144	·0206	·0262	·0314	·0361	·0404	·0444	·0481	·0515	·0546
16	0·0000	0·0068	0·0131	0·0187	0·0239	0·0287	0·0331	0·0372	0·0409	0·0444
17	—	—	·0000	·0062	·0119	·0172	·0220	·0264	·0305	·0343
18	—	—	—	—	·0000	·0057	·0110	·0158	·0203	·0244
19	—	—	—	—	—	—	·0000	·0053	·0101	·0146
20	—	—	—	—	—	—	—	—	·0000	·0049

i \ n	41	42	43	44	45	46	47	48	49	50
1	0·3940	0·3917	0·3894	0·3872	0·3850	0·3830	0·3808	0·3789	0·3770	0·3751
2	·2719	·2701	·2684	·2667	·2651	·2635	·2620	·2604	·2589	·2574
3	·2357	·2345	·2334	·2323	·2313	·2302	·2291	·2281	·2271	·2260
4	·2091	·2085	·2078	·2072	·2065	·2058	·2052	·2045	·2038	·2032
5	·1876	·1874	·1871	·1868	·1865	·1862	·1859	·1855	·1851	·1847
6	0·1693	0·1694	0·1695	0·1695	0·1695	0·1695	0·1695	0·1693	0·1692	0·1691
7	·1531	·1535	·1539	·1542	·1545	·1548	·1550	·1551	·1553	·1554
8	·1384	·1392	·1398	·1405	·1410	·1415	·1420	·1423	·1427	·1430
9	·1249	·1259	·1269	·1278	·1286	·1293	·1300	·1306	·1312	·1317
10	·1123	·1136	·1149	·1160	·1170	·1180	·1189	·1197	·1205	·1212
11	0·1004	0·1020	0·1035	0·1049	0·1062	0·1073	0·1085	0·1095	0·1105	0·1113
12	·0891	·0909	·0927	·0943	·0959	·0972	·0986	·0998	·1010	·1020
13	·0782	·0804	·0824	·0842	·0860	·0876	·0892	·0906	·0919	·0932
14	·0677	·0701	·0724	·0745	·0765	·0783	·0801	·0817	·0832	·0846
15	·0575	·0602	·0628	·0651	·0673	·0694	·0713	·0731	·0748	·0764
16	0·0476	0·0506	0·0534	0·0560	0·0584	0·0607	0·0628	0·0648	0·0667	0·0685
17	·0379	·0411	·0442	·0471	·0497	·0522	·0546	·0568	·0588	·0608
18	·0283	·0318	·0352	·0383	·0412	·0439	·0465	·0489	·0511	·0532
19	·0188	·0227	·0263	·0296	·0328	·0357	·0385	·0411	·0436	·0459
20	·0094	·0136	·0175	·0211	·0245	·0277	·0307	·0335	·0361	·0386
21	0·0000	0·0045	0·0087	0·0126	0·0163	0·0197	0·0229	0·0259	0·0288	0·0314
22		—	·0000	·0042	·0081	·0118	·0153	·0185	·0215	·0244
23	—	—	—	—	·0000	·0039	·0076	·0111	·0143	·0174
24	—	—	—	—	—	—	·0000	·0037	·0071	·0104
25	—	—	—	—	—	—	—	—	·0000	·0035

APPENDIX – B

Percentage Points of the W Test for n = 3(1)50

	Level								
n	**0·01**	**0·02**	**0·05**	**0·10**	**0·50**	**0·90**	**0·95**	**0·98**	**0·99**
3	0·753	0·756	0·767	0·789	0·959	0·998	0·999	1·000	1·000
4	·687	·707	·748	·792	·935	·987	·992	·996	·997
5	·686	·715	·762	·806	·927	·979	·986	·991	·993
6	0·713	0·743	0·788	0·826	0·927	0·974	0·981	0·986	0·989
7	·730	·760	·803	·838	·928	·972	·979	·985	·988
8	·749	·778	·818	·851	·932	·972	·978	·984	·987
9	·764	·791	·829	·859	·935	·972	·978	·984	·986
10	·781	·806	·842	·869	·938	·972	·978	·983	·986
11	0·792	0·817	0·850	0·876	0·940	0·973	0·979	0·984	0·986
12	·805	·828	·859	·883	·943	·973	·979	·984	·986
13	·814	·837	·866	·889	·945	·974	·979	·984	·986
14	·825	·846	·874	·895	·947	·975	·980	·984	·986
15	·835	·855	·881	·901	·950	·975	·980	·984	·987
16	0·844	0·863	0·887	0·906	0·952	0·976	0·981	0·985	0·987
17	·851	·869	·892	·910	·954	·977	·981	·985	·987
18	·858	·874	·897	·914	·956	·978	·982	·986	·988
19	·863	·879	·901	·917	·957	·978	·982	·986	·988
20	·868	·884	·905	·920	·959	·979	·983	·986	·988
21	0·873	0·888	0·908	0·923	0·960	0·980	0·983	0·987	0·989
22	·878	·892	·911	·926	·961	·980	·984	·987	·989
23	·881	·895	·914	·928	·962	·981	·984	·987	·989
24	·884	·898	·916	·930	·963	·981	·984	·987	·989
25	·888	·901	·918	·931	·964	·981	·985	·988	·989
26	0·891	0·904	0·920	0·933	0·965	0·982	0·985	0·988	0·989
27	·894	·906	·923	·935	·965	·982	·985	·988	·990
28	·896	·908	·924	·936	·966	·982	·985	·988	·990
29	·898	·910	·926	·937	·966	·982	·985	·988	·990
30	·900	·912	·927	·939	·967	·983	·985	·988	·900
31	0·902	0·914	0·929	0·940	0·967	0·983	0·986	0·988	0·990
32	·904	·915	·930	·941	·968	·983	·986	·988	·990
33	·906	·917	·931	·942	·968	·983	·986	·989	·990
34	·908	·919	·933	·943	·969	·983	·986	·989	·990
35	·910	·920	·934	·944	·969	·984	·986	·989	·990
36	0·912	0·922	0·935	0·945	0·970	0·984	0·986	0·989	0·990
37	·914	·924	·936	·946	·970	·984	·987	·989	·990
38	·916	·925	·938	·947	·971	·984	·987	·989	·990
39	·917	·927	·939	·948	·971	·984	·987	·989	·991
40	·919	·928	·940	·949	·972	·985	·987	·989	·991
41	0·920	0·929	0·941	0·950	0·972	0·985	0·987	0·989	0·991
42	·922	·930	·942	·951	·972	·985	·987	·989	·991
43	·923	·932	·943	·951	·973	·985	·987	·990	·991
44	·924	·933	·944	·952	·973	·985	·987	·990	·991
45	·926	·934	·945	·953	·973	·985	·988	·990	·991
46	0·927	0·935	0·945	0·953	0·974	0·985	0·988	0·990	0·991
47	·928	·936	·946	·954	·974	·985	·988	·990	·991
48	·929	·937	·947	·954	·974	·985	·988	·990	·991
49	·929	·937	·947	·955	·974	·985	·988	·990	·991
50	·930	·938	·947	·955	·974	·985	·988	·990	·991

APPENDIX – C

Visual Basic .net Code for the GUI

```
Public Class Form1

    Inherits System.Windows.Forms.Form

    Dim t1, t2, pr, op As Integer

    Dim tlb, tub, dlb, dub, sblb, sbub, flb, fub As Double

    dim dir as String

    Private Sub PictureBox1_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles PictureBox1.Click

        PictureBox1.BorderStyle = BorderStyle.Fixed3D

        PictureBox2.BorderStyle = BorderStyle.None

        Label2.Visible = True

        Label3.Visible = False

        GroupBox1.Visible = True

        predict.Visible = True

        optimize.Visible = True

        predict.Text = "Predict Lumbar Load"

        optimize.Text = "Minimize Lumbar Load For Given Parameters"

        predict.Checked = False

        optimize.Checked = False

        start.Visible = True

        t1 = 1

        t2 = 0

    End Sub

    Private Sub PictureBox2_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles PictureBox2.Click

        PictureBox2.BorderStyle = BorderStyle.Fixed3D

        PictureBox1.BorderStyle = BorderStyle.None

        Label3.Visible = True

        Label2.Visible = False
```

```
        GroupBox1.Visible = True

        predict.Visible = True

        optimize.Visible = True

        predict.Text = "Predict HIC"

        optimize.Text = "Minimize HIC For Given Parameters"

        predict.Checked = False

        optimize.Checked = False

        start.Visible = True

        t1 = 0

        t2 = 1

    End Sub

    Private Sub predict_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles predict.CheckedChanged

        If predict.Checked = True Then

            pr = 1

        Else

            pr = 0

        End If


    End Sub

    Private Sub optimize_CheckedChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles optimize.CheckedChanged

        If optimize.Checked = True Then

            op = 1

        Else

            op = 0

        End If

    End Sub

    Private Sub start_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles start.Click

        If pr <> 1 And op <> 1 Then
```

```
            MsgBox("Select either to optimize or predict",
MsgBoxStyle.Critical, "Selcet Operation")

        End If

        If pr = 1 And t1 = 1 Then

            cushion_lbl.Visible = True

            cushion.Visible = True

            thickness_lbl.Visible = True

            thickness.Visible = True

            thickness_unit.Visible = True

            pan_lbl.Visible = True

            pan.Visible = True

            pan_unit.Visible = True

            predict_btn.Visible = True

            t2_pic.Visible = True

            PictureBox1.Visible = False

            PictureBox2.Visible = False

            GroupBox1.Visible = False

            predict.Visible = False

            optimize.Visible = False

            start.Visible = False

            Label2.Visible = False

            Label3.Visible = False

            Label4.Text = "Predict the Lumbar Load"

            Label4.Visible = True

        End If

        If op = 1 And t1 = 1 Then

            t1_cushion_op_lbl.Visible = True

            t1_cushion_op.Visible = True

            t1_thickness_op_lbl.Visible = True

            t1_thickness_op_lb.Visible = True

            t1_thickness_op_ub.Visible = True
```

```
        t1_thickness_to_lbl.Visible = True
        t1_thickness_op_unit.Visible = True
        t1_pan_op_lbl.Visible = True
        t1_pan_op_lb.Visible = True
        t1_pan_op_ub.Visible = True
        t1_pan_to_lbl.Visible = True
        t1_pan_op_unit.Visible = True
        t1_op_btn.Visible = True
        't1_done_op_btn.Visible = True
        t1_pic_op.Visible = True
        Label4.Text = "Optimize Lumbar Load"
        Label4.Visible = True
        PictureBox1.Visible = False
        PictureBox2.Visible = False
        GroupBox1.Visible = False
        predict.Visible = False
        optimize.Visible = False
        start.Visible = False
        Label2.Visible = False
        Label3.Visible = False
    End If
    If pr = 1 And t2 = 1 Then
        t2_picbox.Visible = True
        t2_bulkhead_lbl.Visible = True
        t2_bulkhead.Visible = True
        t2_seatbelt_lbl.Visible = True
        t2_seatbelt.Visible = True
        t2_setback_lbl.Visible = True
        t2_setback.Visible = True
        t2_setback_unit.Visible = True
```

```
        t2_friction_lbl.visible = True
        t2_friction.Visible = True
        t2_hic_btn.Visible = True
        t2_done_btn.Visible = False
        Label4.Text = "Predict the Head Injury Criteria (HIC)"
        Label4.Visible = True
        PictureBox1.Visible = False
        PictureBox2.Visible = False
        GroupBox1.Visible = False
        predict.Visible = False
        optimize.Visible = False
        start.Visible = False
        Label2.Visible = False
        Label3.Visible = False
    End If
    If op = 1 And t2 = 1 Then
        t2_picbox_op.Visible = True
        t2_bulkhead_op_lbl.Visible = True
        t2_bulkhead_op.Visible = True
        t2_seatbelt_op_lbl.Visible = True
        t2_seatbelt_op.Visible = True
        t2_setback_op_lbl.Visible = True
        t2_setback_op_lb.Visible = True
        t2_setback_op_ub.Visible = True
        t2_setback_op_to_lbl.Visible = True
        t2_setback_op_unit.Visible = True
        t2_friction_op_lbl.Visible = True
        t2_friction_op_lb.Visible = True
        t2_friction_op_ub.Visible = True
        t2_friction_op_to_lbl.Visible = True
```

```
            t2_optimize_btn.Visible = True

            t2_done_op_btn.Visible = False

            Label4.Text = "Optimize Head Injury Criteria (HIC)"

            Label4.Visible = True

            PictureBox1.Visible = False

            PictureBox2.Visible = False

            GroupBox1.Visible = False

            predict.Visible = False

            optimize.Visible = False

            start.Visible = False

            Label2.Visible = False

            Label3.Visible = False


        End If

    End Sub

    Private Sub cushion_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
cushion.SelectedIndexChanged

        If cushion.Text = "Bare Iron Seat" Then

            thickness.Enabled = False

            pan.Enabled = False

            predict_lbl.Text = "Lumbar load when using a " &
cushion.Text & " is 992 lbs."

        Else

            thickness.Enabled = True

            pan.Enabled = True

            predict_lbl.Text = Nothing

        End If

        Done.Visible = False

        predict_lbl.Visible = False

    End Sub
```

```
    Private Sub predict_btn_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles predict_btn.Click

        Dim t, d As Double

        Dim l, c3, c4 As Integer

        If cushion.Text = "Bare Iron Seat" Then

            predict_lbl.Visible = True

        Else

            If cushion.Text = Nothing Then

                MsgBox("Selct type of cushion from the drop down menu",
MsgBoxStyle.Critical, "Selct Cushion Type")

                cushion.Text = "DAX 26"

                cushion.Focus()

            End If

            If thickness.Text = Nothing Then

                MsgBox("Selct cushion thickness between 0 and 6
inches", MsgBoxStyle.Critical, "Selct Cushion Thickness")

                thickness.Text = 1

                thickness.Focus()

            End If

            If pan.Text = Nothing Then

                MsgBox("Select seat Pan Deflection between 0 and 1
inches", MsgBoxStyle.Critical, "Select Seat Pan Deflection")

                pan.Text = 0.1

                pan.Focus()

            End If

            t = thickness.Text

            d = pan.Text

            If t > 6 Or t < 0 Then

                MsgBox("Cushion thickness should be between 0 and 6
inches", MsgBoxStyle.Critical, "Out of Bounds")

                thickness.Text = 1

                thickness.Focus()

            Else
```

```
                c3 = 1
            End If
            If d > 1 Or d < 0 Then
                MsgBox("Seat Pan Deflection should be between 0 and 1
inches", MsgBoxStyle.Critical, "Out of Bounds")
                pan.Text = 0.1
                pan.Focus()
            Else
                c4 = 1
            End If
            t = Nothing
            d = Nothing
            t = thickness.Text
            d = pan.Text
            If c3 = 1 And c4 = 1 Then
                If cushion.Text = "DAX 26" Then
                    l = 1019.07395 + 221.17599 * d + 284.54473 * t +
12.73419 * d * t - 27.04121 * d ^ 2 - 33.79543 * t ^ 2 + 2.56044 * d ^
2 * t - 3.63736 * d * t ^ 2 + 1.67569 * t ^ 3
                    predict_lbl.Text = "The lumbar load when using a "
& thickness.Text & " inch thick " & cushion.Text & " form on a seat
with a seat pan deflection of " & pan.Text & " inch is " & l & " lbs."
                    predict_lbl.Visible = True
                ElseIf cushion.Text = "DAX 55" Then
                    l = 1011.7959 + 236.93972 * d + 322.9338 * t +
8.54737 * d * t - 35.54121 * d ^ 2 - 38.11935 * t ^ 2 + 2.56044 * d ^ 2
* t - 3.63736 * d * t ^ 2 + 1.67569 * t ^ 3
                    predict_lbl.Text = "The lumbar load when using a "
& thickness.Text & " inch thick " & cushion.Text & " form on a seat
with a seat pan deflection of " & pan.Text & " inch is " & l & " lbs."
                    predict_lbl.Visible = True
                ElseIf cushion.Text = "CONFOR - Blue" Then
                    l = 1008.12647 + 173.49467 * d + 67.0273 * t +
2.80012 * d * t - 3.04121 * d ^ 2 - 11.86182 * t ^ 2 + 2.56044 * d ^ 2
* t - 3.63736 * d * t ^ 2 + 1.67569 * t ^ 3
```

```
                    predict_lbl.Text = "The lumbar load when using a " & thickness.Text & " inch thick " & cushion.Text & " form on a seat with a seat pan deflection of " & pan.Text & " inch is " & l & " lbs."

                    predict_lbl.Visible = True

                ElseIf cushion.Text = "CONFOR - Green" Then

                    l = 992.77808 + 123.47818 * d + 30.49045 * t + 1.6243 * d * t + 78.45879 * d ^ 2 - 7.10146 * t ^ 2 + 2.56044 * d ^ 2 * t - 3.63736 * d * t ^ 2 + 1.67569 * t ^ 3

                    predict_lbl.Text = "The lumbar load when using a " & thickness.Text & " inch thick " & cushion.Text & " form on a seat with a seat pan deflection of " & pan.Text & " inch is " & l & " lbs."

                    predict_lbl.Visible = True

                End If

                Done.Visible = True

            End If

        End If

    End Sub

    Private Sub thickness_TextChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles thickness.TextChanged

        Done.Visible = False

        predict_lbl.Visible = False

        predict_lbl.Text = Nothing

    End Sub

    Private Sub pan_TextChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles pan.TextChanged

        Done.Visible = False

        predict_lbl.Visible = False

        predict_lbl.Text = Nothing

    End Sub

    Private Sub Done_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles Done.Click

        cushion_lbl.Visible = False

        cushion.Visible = False

        thickness_lbl.Visible = False
```

```
        thickness.Visible = False

        thickness_unit.Visible = False

        pan_lbl.Visible = False

        pan.Visible = False

        pan_unit.Visible = False

        predict_btn.Visible = False

        t2_pic.Visible = False

        predict_lbl.Visible = False

        Done.Visible = False

        Label4.Visible = False

        PictureBox1.Visible = True

        PictureBox2.Visible = True

        GroupBox1.Visible = True

        predict.Visible = True

        optimize.Visible = True

        start.Visible = True

        If t1 = 1 Then

            Label2.Visible = True

        End If

        If t2 = 1 Then

            Label3.Visible = True

        End If

    End Sub

    Private Sub t1_op_btn_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles t1_op_btn.Click

        If t1_cushion_op.Text = Nothing Then

            MsgBox("Select the type of seat cushion",
MsgBoxStyle.Critical, "Cushion Selection")

            t1_cushion_op.Text = "DAX 26"

            t1_cushion_op.Focus()

        End If
```

```
        If t1_thickness_op_lb.Text = Nothing Then

            t1_thickness_op_lb.Text = "0.1"

        End If

        If t1_thickness_op_ub.Text = Nothing Then

            t1_thickness_op_ub.Text = "6"

        End If

        If t1_pan_op_lb.Text = Nothing Then

            t1_pan_op_lb.Text = "0"

        End If

        If t1_pan_op_ub.Text = Nothing Then

            t1_pan_op_ub.Text = "1"

        End If

        tlb = t1_thickness_op_lb.Text

        tub = t1_thickness_op_ub.Text

        dlb = t1_pan_op_lb.Text

        dub = t1_pan_op_ub.Text


        If tub > 6 Or tub < 0 Then

            MsgBox("The lower bound value for Cushion thickness should
be between 0 and 6 inches", MsgBoxStyle.Critical, "Out of Bounds")

            t1_thickness_op_ub.Text = 6

            t1_thickness_op_ub.Focus()

        End If

        If tub < tlb Then

            MsgBox("Upper bound value for cushion thickness should be
greater than or equal to the lower bound value", MsgBoxStyle.Critical,
"Error")

            t1_thickness_op_ub.Text = 6

            t1_thickness_op_lb.Focus()

        End If
```

```
        If dlb > 1 Or dlb < 0 Then

            MsgBox("The lower bound value for seat pan deflection
should be between 0 and 1 inches", MsgBoxStyle.Critical, "Out of
Bounds")

            t1_pan_op_lb.Text = 0.1

            t1_pan_op_lb.Focus()

        End If

        If dub > 1 Or dub < 0 Then

            MsgBox("The lower bound value for seat pan deflection
should be between 0 and 1 inches", MsgBoxStyle.Critical, "Out of
Bounds")

            t1_pan_op_ub.Focus()

        End If

        If dub < dlb Then

            MsgBox("Upper bound value for set pan deflection should be
greater than or equal to the lower bound value", MsgBoxStyle.Critical,
"Error")

            t1_pan_op_lb.Focus()

        End If

        If dub < dlb Or tub < tlb Then

            t1_thickness_op_lb.Focus()

        Else

            dir = CurDir()

            Dim length As Integer

            length = Len(dir)

            length = length - 3

            dir = Microsoft.VisualBasic.Left(dir, length)

            Dim objpath, fun As String

            objpath = dir & "dummy\objfun.m"

            If t1_cushion_op.Text = "DAX 26" Then

                fun = "F_lumbar = 1019.07395 + 221.17599 * FVr_temp(1)
+ 284.54473 * FVr_temp(2) + 12.73419 * FVr_temp(1) * FVr_temp(2) -
27.04121 * FVr_temp(1) ^ 2 - 33.79543 * FVr_temp(2) ^ 2 + 2.56044 *
FVr_temp(1) ^ 2 * FVr_temp(2) - 3.63736 * FVr_temp(1) * FVr_temp(2) ^ 2
+ 1.67569 * FVr_temp(2) ^ 3"
```

```
            ElseIf t1_cushion_op.Text = "DAX 55" Then

                fun = "F_lumbar =1011.7959 + 236.93972 * FVr_temp(1) +
322.9338 * FVr_temp(2) + 8.54737 * FVr_temp(1) * FVr_temp(2) - 35.54121
* FVr_temp(1) ^ 2 - 38.11935 * FVr_temp(2) ^ 2 + 2.56044 * FVr_temp(1)
^ 2 * FVr_temp(2) - 3.63736 * FVr_temp(1) * FVr_temp(2) ^ 2 + 1.67569 *
FVr_temp(2) ^ 3 "

            ElseIf t1_cushion_op.Text = "CONFOR - Blue" Then

                fun = "F_lumbar = 1008.12647 + 173.49467 * FVr_temp(1)
+ 67.0273 * FVr_temp(2) + 2.80012 * FVr_temp(1) * FVr_temp(2) - 3.04121
* FVr_temp(1) ^ 2 - 11.86182 * FVr_temp(2) ^ 2 + 2.56044 * FVr_temp(1)
^ 2 * FVr_temp(2) - 3.63736 * FVr_temp(1) * FVr_temp(2) ^ 2 + 1.67569 *
FVr_temp(2) ^ 3"

            ElseIf t1_cushion_op.Text = "CONFOR - Green" Then

                fun = "F_lumbar = 992.77808 + 123.47818 * FVr_temp(1) +
30.49045 * FVr_temp(2) + 1.6243 * FVr_temp(1) * FVr_temp(2) + 78.45879
* FVr_temp(1) ^ 2 - 7.10146 * FVr_temp(2) ^ 2 + 2.56044 * FVr_temp(1) ^
2 * FVr_temp(2) - 3.63736 * FVr_temp(1) * FVr_temp(2) ^ 2 + 1.67569 *
FVr_temp(2) ^ 3"

            End If

            Dim objfile As New System.IO.FileStream(objpath,
System.IO.FileMode.Create, System.IO.FileAccess.Write,
System.IO.FileShare.None)

            objfile.Close()

            Dim objfun As New System.IO.StreamWriter(objpath)

            objfun.BaseStream.Seek(0, System.IO.SeekOrigin.End)

            objfun.Write("function S_MSE= objfun(FVr_temp, S_struct)")

            objfun.WriteLine()

            objfun.Write(fun)

            objfun.WriteLine()

            objfun.Write("S_MSE.I_nc      = 0;")

            objfun.WriteLine()

            objfun.Write("S_MSE.FVr_ca    = 0;")

            objfun.WriteLine()

            objfun.Write("S_MSE.I_no      = 1;")

            objfun.WriteLine()

            objfun.Write("S_MSE.FVr_oa(1) = F_lumbar")

            objfun.WriteLine()
```

```
            objfun.Flush()

            objfun.Close()

            Dim runpath As String = dir & "dummy\run"

            Dim runopt As New System.IO.StreamReader(runpath)

            Dim runoptread As String

            runoptread = runopt.ReadToEnd

            runopt.Close()

            Dim runoptpath As String

            runoptpath = dir & "dummy\Rundeopt.m"

            Dim runoptfile As New System.IO.FileStream(runoptpath,
IO.FileMode.Create, System.IO.FileAccess.Write,
System.IO.FileShare.None)

            runoptfile.Close()

            Dim rundeopt As New System.IO.StreamWriter(runoptpath)

            rundeopt.BaseStream.Seek(0, System.IO.SeekOrigin.End)

            rundeopt.Write("F_VTR = 150;")

            rundeopt.WriteLine()

            rundeopt.Write("I_D = 2;")

            rundeopt.WriteLine()

            Dim l_opt_min As String = "FVr_minbound = [" & dlb & " " &
tlb & "];"

            rundeopt.Write(l_opt_min)

            rundeopt.WriteLine()

            Dim l_opt_max As String = "FVr_maxbound = [" & dub & " " &
tub & "];"

            rundeopt.WriteLine(l_opt_max)

            rundeopt.WriteLine()

            rundeopt.Write(runoptread)

            rundeopt.WriteLine()

            rundeopt.Write("exit")

            rundeopt.WriteLine()

            rundeopt.Flush()
```

```
            rundeopt.Close()

            Dim matpath As String

            matpath = dir & "dummy\mat.bat"

            Dim matlab As New System.IO.FileStream(matpath,
System.IO.FileMode.Create, System.IO.FileAccess.Write,
System.IO.FileShare.None)

            matlab.Close()

            Dim matrun As New System.IO.StreamWriter(matpath)

            ' Write the specified contents to the file.

            matrun.BaseStream.Seek(0, System.IO.SeekOrigin.End)

            matrun.Write("cd\")

            matrun.WriteLine()

            Dim rundir As String = "cd " & dir & "dummy"

            matrun.Write(rundir)

            matrun.WriteLine()

            Dim runmat, bsh1awk As String

            runmat = Nothing

            runmat = "c:\MATLAB701\bin\matlab.bat -nosplash -nodesktop
-minimize -r Rundeopt -logfile " & dir & "dummy\optimized.txt"

            matrun.Write(runmat)

            matrun.Flush()

            matrun.Close()

            Dim exematlab As String = dir & "dummy\mat.bat"

            Shell(exematlab)

            Dim msgvalue As Integer

            msgvalue = MsgBox("Optimization has Started with the given
parameters", MsgBoxStyle.Information, "Information")


            If msgvalue = 1 Then

                Dim oFile As System.IO.File

                Dim oRead As System.IO.StreamReader

                Dim LineIn As String
```

```
Dim lCtr As Long
Dim line As Integer
Dim line_lumbar As Integer
Dim Linenumber As Integer
Dim Linenumber_lumbar As Integer
Dim ReadLine As String
Dim ReadLine_lumbar As String
Dim optimizedpath As String
optimizedpath = dir & "\dummy\optimized.txt"
'Linenumber = strLines.Length - 3
oRead = oFile.OpenText(optimizedpath)
While oRead.Peek <> -1
    LineIn = oRead.ReadLine()
    lCtr = lCtr + 1
    If LineIn = "FVr_x =" Then
        line = lCtr
        Linenumber = line + 1
    End If
    If LineIn = "S_y = " Then
        line_lumbar = lCtr
        Linenumber_lumbar = line_lumbar + 4
    End If
    If lCtr = Linenumber Then
        ReadLine = oRead.ReadLine
    End If
    If lCtr = Linenumber_lumbar Then
        ReadLine_lumbar = oRead.ReadLine
    End If
End While
oRead.Close()
```

```
                Dim op_lumbar_length As Integer

                Dim op_lumbar_mod_length As Integer

                Dim op_pan As String

                Dim op_thick As String

                Dim op_lumbar As String

                op_lumbar_length = Len(ReadLine_lumbar)

                op_lumbar_mod_length = op_lumbar_length - 12

                op_lumbar =
Microsoft.VisualBasic.Right(ReadLine_lumbar, op_lumbar_mod_length)

                'Dim lumbar_convert As Integer =
Convert.ToInt32(op_lumbar)

                op_lumbar = op_lumbar / 1000

                op_lumbar = op_lumbar * 1000

                If op_lumbar > 1500 Then

                    Dim oFile1 As System.IO.File

                    Dim oRead1 As System.IO.StreamReader

                    Dim LineIn1 As String

                    Dim lCtr1 As Long

                    Dim line1 As Integer

                    Dim line_lumbar1 As Integer

                    Dim Linenumber1 As Integer

                    Dim Linenumber_lumbar1 As Integer

                    Dim ReadLine1 As String

                    Dim ReadLine2 As String

                    Dim optimizedpath1 As String

                    optimizedpath1 = dir & "\dummy\optimized.txt"

                    'Linenumber = strLines.Length - 3

                    oRead1 = oFile1.OpenText(optimizedpath)
```

```
                    While oRead1.Peek <> -1
                        LineIn1 = oRead1.ReadLine()
                        lCtr1 = lCtr1 + 1
                        If LineIn1 = "FVr_x =" Then
                            line1 = lCtr1
                            Linenumber1 = line1 + 1
                        End If
                        If lCtr1 = Linenumber Then
                            ReadLine1 = oRead1.ReadLine
                        End If
                    End While
                    oRead.Close()
                    op_pan = Microsoft.VisualBasic.Left(ReadLine1, 15)
                    op_pan = op_pan * 10
                    op_pan = op_pan / 10
                    op_thick = Microsoft.VisualBasic.Right(ReadLine1,
10)
                    op_thick = op_thick * 10
                    op_thick = op_thick / 10
                    t1_op_lbl.Visible = True
                    t1_op_lbl.Text = "No Solution exist for minimizing
the Lumbar load ( <1500 lbs.) when using a " & t1_cushion_op.Text & "
foam with a thickness in the range of " & t1_thickness_op_lb.Text & "
to " & t1_thickness_op_ub.Text & " inches and with a seat pan
deflection in the range of " & t1_pan_op_lb.Text & " to " &
t1_pan_op_ub.Text & ". The best possible case is when the seat cushion
thickness is " & op_thick & " inches and a seat pan deflection of " &
op_pan & " inches resulting in a lumbar load of " & op_lumbar & " lbs."
                    t1_done_op_btn.Visible = True
                Else
                    op_pan = Microsoft.VisualBasic.Left(ReadLine, 13)
                    op_pan = op_pan * 10
                    op_pan = op_pan / 10
```

```
                    op_thick = Microsoft.VisualBasic.Right(ReadLine,
13)

                    op_thick = op_thick * 10

                    op_thick = op_thick / 10

                    t1_op_lbl.Visible = True

                    t1_op_lbl.Text = "Solution for minimizing the
Lumbar load ( <1500 lbs.) when using a " & t1_cushion_op.Text & " foam
with a thickness in the range of " & t1_thickness_op_lb.Text & " to " &
t1_thickness_op_ub.Text & " inches and with a seat pan deflection in
the range of " & t1_pan_op_lb.Text & " to " & t1_pan_op_ub.Text & " is
when the seat cushion thickness is " & op_thick & " inches and a seat
pan deflection of " & op_pan & " inches resulting in a lumbar load of "
& op_lumbar & " lbs."

                    t1_done_op_btn.Visible = True

                End If

            End If

        End If

    End Sub

    Private Sub t1_cushion_op_SelectedIndexChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
t1_cushion_op.SelectedIndexChanged

        t1_done_op_btn.Visible = False

    End Sub

    Private Sub t1_thickness_op_lb_TextChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
t1_thickness_op_lb.TextChanged

        t1_done_op_btn.Visible = False

    End Sub

    Private Sub t1_thickness_op_ub_TextChanged(ByVal sender As
System.Object, ByVal e As System.EventArgs) Handles
t1_thickness_op_ub.TextChanged

        t1_done_op_btn.Visible = False

    End Sub

    Private Sub t1_pan_op_lb_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles t1_pan_op_lb.TextChanged

        t1_done_op_btn.Visible = False

    End Sub
```

```
    Private Sub t1_pan_op_ub_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles t1_pan_op_ub.TextChanged

        t1_done_op_btn.Visible = False

    End Sub

    Private Sub t1_done_op_btn_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles t1_done_op_btn.Click

        t1_cushion_op_lbl.Visible = False

        t1_cushion_op.Visible = False

        t1_thickness_op_lbl.Visible = False

        t1_thickness_op_lb.Visible = False

        t1_thickness_op_ub.Visible = False

        t1_thickness_to_lbl.Visible = False

        t1_thickness_op_unit.Visible = False

        t1_pan_op_lbl.Visible = False

        t1_pan_op_lb.Visible = False

        t1_pan_op_ub.Visible = False

        t1_pan_to_lbl.Visible = False

        t1_pan_op_unit.Visible = False

        t1_op_btn.Visible = False

        t1_done_op_btn.Visible = False

        t1_pic_op.Visible = False

        t1_op_lbl.Visible = False

        Label4.Visible = False

        Dim killpath1 As String = dir & "dummy\mat.bat"

        Dim killpath2 As String = dir & "dummy\optimized.txt"

        Dim killpath3 As String = dir & "dummy\objfun.m"

        Dim killpath4 As String = dir & "dummy\Rundeopt.m"

        Kill(killpath1)

        Kill(killpath3)

        Kill(killpath4)
```

```
        PictureBox1.Visible = True

        PictureBox2.Visible = True

        GroupBox1.Visible = True

        predict.Visible = True

        optimize.Visible = True

        start.Visible = True

        If t1 = 1 Then

            Label2.Visible = True

        End If

        If t2 = 1 Then

            Label3.Visible = True

        End If

    End Sub

    Private Sub t2_hic_btn_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs) Handles t2_hic_btn.Click

        If t2_bulkhead.Text = Nothing Then

            MsgBox("Select type of bulkhead from the drop down menu",
MsgBoxStyle.Critical, "Select Bulkhead")

            t2_bulkhead.Text = "Aluminum Sheet"

            t2_bulkhead.Focus()

        End If

        If t2_seatbelt.Text = Nothing Then

            MsgBox("Select type of seatbelt used from the drop down
menu", MsgBoxStyle.Critical, "Select Seatbelt")

            t2_seatbelt.Text = "Nylon"

            t2_seatbelt.Focus()

        End If

        If t2_setback.Text = Nothing Then

            MsgBox("Select the seat setback distance",
MsgBoxStyle.Critical, "Select Seat Setback distance")

            t2_setback.Text = "28"
```

```
            t2_setback.Focus()
        End If
        If t2_friction.Text = Nothing Then
            MsgBox("Select the bulkhead surface friction coefficient",
MsgBoxStyle.Critical, "Select Bulkhead Friction")
            t2_friction.Text = "0.3"
            t2_friction.Focus()
        End If
        Dim s, f As Double
        Dim hic, c1, c2 As Integer
        s = t2_setback.Text
        f = t2_friction.Text
        If s > 40 Or s < 28 Then
            MsgBox("Seat setback distance should be between 28 and 48
inches", MsgBoxStyle.Critical, "Out of Bounds")
            t2_setback.Text = "28"
            t2_setback.Focus()
        Else
            c1 = 1
        End If
        If f > 1 Or f < 0.3 Then
            MsgBox("Bulkhead surface friction should be between 0.3 and
1 inches", MsgBoxStyle.Critical, "Out of Bounds")
            t2_friction.Text = 0.3
            t2_friction.Focus()
        Else
            c2 = 1
        End If
        s = Nothing
        f = Nothing
        s = t2_setback.Text
        f = t2_friction.Text
```

```
        If c1 = 1 And c2 = 1 Then

            If t2_bulkhead.Text = "Aluminum Sheet" Then

                If t2_seatbelt.Text = "Nylon" Then

                    hic = 36352.20326 - 2912.75086 * s - 4213.52402 * f
+ 252.63183 * s * f + 80.86362 * s ^ 2 + 468.62398 * f ^ 2 - 3.34106 *
s ^ 2 * f - 17.6346 * s * f ^ 2 - 0.76825 * s ^ 3

                ElseIf t2_seatbelt.Text = "Polyester" Then

                    hic = 40680.50578 - 3208.05835 * s - 3672.57294 * f
+ 233.68674 * s * f + 85.44934 * s ^ 2 + 531.71922 * f ^ 2 - 3.34106 *
s ^ 2 * f - 17.6346 * s * f ^ 2 - 0.76825 * s ^ 3

                End If


            ElseIf t2_bulkhead.Text = "Nomex Honeycomb" Then

                If t2_seatbelt.Text = "Nylon" Then

                    hic = 29192.54342 - 2440.18412 * s - 4025.80257 * f
+ 248.3769 * s * f + 73.63743 * s ^ 2 + 418.17755 * f ^ 2 - 3.34106 * s
^ 2 * f - 17.6346 * s * f ^ 2 - 0.76825 * s ^ 3

                ElseIf t2_seatbelt.Text = "Polyester" Then

                    hic = 32755.28626 - 2723.13125 * s - 3512.65555 * f
+ 229.4318 * s * f + 78.22314 * s ^ 2 + 481.27279 * f ^ 2 - 3.34106 * s
^ 2 * f - 17.6346 * s * f ^ 2 - 0.76825 * s ^ 3

                End If

            ElseIf t2_bulkhead.Text = "Aluminum Honeycomb" Then

                If t2_seatbelt.Text = "Nylon" Then

                    hic = 28117.25787 - 2474.01585 * s - 4028.27683 * f
+ 242.49852 * s * f + 75.25648 * s ^ 2 + 578.2966 * f ^ 2 - 3.34106 * s
^ 2 * f - 17.6346 * s * f ^ 2 - 0.76825 * s ^ 3

                ElseIf t2_seatbelt.Text = "Polyester" Then

                    hic = 32952.79124 - 2787.40892 * s - 3530.33251 * f
+ 223.55343 * s * f + 79.84219 * s ^ 2 + 641.39184 * f ^ 2 - 3.34106 *
s ^ 2 * f - 17.6346 * s * f ^ 2 - 0.76825 * s ^ 3

                End If

            End If

            If hic <> 0 Then

                t2_predict_lbl.Visible = True
```

```
                t2_predict_lbl.Text = "The Head Injury Criteria (HIC) when using a " & t2_bulkhead.Text & " with a surface friction of " & f & ", and with a seatsetback distance of " & s & " inches and a " & t2_seatbelt.Text & " seatbelt is " & hic

                t2_done_btn.Visible = True

            Else

                t2_predict_lbl.Visible = True

                t2_predict_lbl.Text = "The Head Injury Criteria (HIC) when using a " & t2_bulkhead.Text & " with a surface friction of " & f & ", and with a seatsetback distance of " & s & " inches and a " & t2_seatbelt.Text & " seatbelt is " & hic & " as there is no head contact."

                t2_done_btn.Visible = True

            End If

        End If

    End Sub

    Private Sub t2_bulkhead_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles t2_bulkhead.SelectedIndexChanged

        t2_predict_lbl.Text = Nothing

        t2_predict_lbl.Visible = False

        t2_done_btn.Visible = False

   End Sub

    Private Sub t2_seatbelt_SelectedIndexChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles t2_seatbelt.SelectedIndexChanged

        t2_predict_lbl.Text = Nothing

        t2_predict_lbl.Visible = False

        t2_done_btn.Visible = False

    End Sub

    Private Sub t2_setback_TextChanged(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles t2_setback.TextChanged

        t2_predict_lbl.Text = Nothing

        t2_predict_lbl.Visible = False

        t2_done_btn.Visible = False

    End Sub
```

```
    Private Sub t2_friction_TextChanged(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles t2_friction.TextChanged

        t2_predict_lbl.Text = Nothing

        t2_predict_lbl.Visible = False

        t2_done_btn.Visible = False

    End Sub

    Private Sub t2_done_btn_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs) Handles t2_done_btn.Click

        t2_picbox.Visible = False

        t2_bulkhead_lbl.Visible = False

        t2_bulkhead.Visible = False

        t2_seatbelt_lbl.Visible = False

        t2_seatbelt.Visible = False

        t2_setback_lbl.Visible = False

        t2_setback.Visible = False

        t2_setback_unit.Visible = False

        t2_friction_lbl.Visible = False

        t2_friction.Visible = False

        t2_hic_btn.Visible = False

        t2_predict_lbl.Visible = False

        t2_done_btn.Visible = False

        Label4.Visible = False

        PictureBox1.Visible = True

        PictureBox2.Visible = True

        GroupBox1.Visible = True

        predict.Visible = True

        optimize.Visible = True

        start.Visible = True

        If t1 = 1 Then

            Label2.Visible = True
```

```
        End If

        If t2 = 1 Then

            Label3.Visible = True

        End If

    End Sub

    Private Sub t2_optimize_btn_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles t2_optimize_btn.Click

        Dim hic As Integer

        Dim hicfun As String

        If t2_bulkhead_op.Text = Nothing Then

            MsgBox("Select type of bulkhead from the drop down menu",
MsgBoxStyle.Critical, "Select Bulkhead")

            t2_bulkhead_op.Text = "Aluminum Sheet"

            t2_bulkhead_op.Focus()

        End If

        If t2_seatbelt_op.Text = Nothing Then

            MsgBox("Select type of seatbelt used from the drop down
menu", MsgBoxStyle.Critical, "Select Seatbelt")

            t2_seatbelt_op.Text = "Nylon"

            t2_seatbelt_op.Focus()

        End If

        If t2_setback_op_lb.Text = Nothing Then

            MsgBox("Select the lower bound value for seat setback
distance", MsgBoxStyle.Critical, "Select Seat Setback distance")

            t2_setback_op_lb.Text = "28"

            t2_setback_op_lb.Focus()

        End If

        If t2_setback_op_ub.Text = Nothing Then

            MsgBox("Select the upper bound value for seat setback
distance", MsgBoxStyle.Critical, "Select Seat Setback distance")

            t2_setback_op_ub.Text = "40"

            t2_setback_op_ub.Focus()

        End If
```

```
        If t2_friction_op_lb.Text = Nothing Then

            MsgBox("Select the lower bound value for bulkhead surface
friction coefficient", MsgBoxStyle.Critical, "Select Bulkhead
Friction")

            t2_friction_op_lb.Text = "0.3"

            t2_friction_op_lb.Focus()

        End If

        If t2_friction_op_ub.Text = Nothing Then

            MsgBox("Select the upper bound value for bulkhead surface
friction coefficient", MsgBoxStyle.Critical, "Select Bulkhead
Friction")

            t2_friction_op_ub.Text = "1.0"

            t2_friction_op_ub.Focus()

        End If

        sblb = t2_setback_op_lb.Text

        sbub = t2_setback_op_ub.Text

        flb = t2_friction_op_lb.Text

        fub = t2_friction_op_ub.Text

        If sbub > 40 Then

            MsgBox("The setback should be between 28 and 40 inches",
MsgBoxStyle.Critical, "Out of Bounds")

            t2_setback_op_ub.Text = 40

            t2_setback_op_ub.Focus()

        End If

        If sblb < 28 Then

            MsgBox("The setback should be between 28 and 40 inches",
MsgBoxStyle.Critical, "Out of Bounds")

            t2_setback_op_lb.Text = 28

            t2_setback_op_lb.Focus()

        End If

        If sbub < sblb Then

            MsgBox("Upper bound value should be greater than or equal
to the lower bound value", MsgBoxStyle.Critical, "Error")

            t2_setback_op_ub.Text = 40
```

```
            t2_setback_op_ub.Focus()
        End If
        If flb < 0.3 Then
            MsgBox("The bulkhead surface coefficient of friction should
be between 0.3 and 1", MsgBoxStyle.Critical, "Out of Bounds")
            t2_friction_op_lb.Text = 0.3
            t2_friction_op_lb.Focus()
        End If
        If fub > 1 Then
            MsgBox("The bulkhead surface coefficient of friction should
be between 0.3 and 1", MsgBoxStyle.Critical, "Out of Bounds")
            t2_friction_op_ub.Text = 1.0
            t2_friction_op_ub.Focus()
        End If
        If fub < flb Then
            MsgBox("Upper bound value should be greater than or equal
to the lower bound value", MsgBoxStyle.Critical, "Error")
            t2_friction_op_ub.Text = 40
            t2_friction_op_ub.Focus()
        End If
        If sbub < sblb Then
            t2_setback_op_lb.Focus()
        ElseIf fub < flb Then
            t2_friction_op_lb.Focus()
        Else
            dir = CurDir()
            Dim length As Integer
            length = Len(dir)
            length = length - 3
            dir = Microsoft.VisualBasic.Left(dir, length)

            Dim objpath, fun As String
```

```
            objpath = dir & "dummy\objfun.m"

            If t2_bulkhead_op.Text = "Aluminum Sheet" Then

                If t2_seatbelt_op.Text = "Nylon" Then

                    hicfun = "F_hic=36352.20326-2912.75086 *
FVr_temp(1)-4213.52402 * FVr_temp(2)+252.63183 * FVr_temp(1) *
FVr_temp(2)+80.86362 * FVr_temp(1)^2+468.62398 * FVr_temp(2)^2-3.34106
* FVr_temp(1)^2 * FVr_temp(2)-17.63460 * FVr_temp(1) * FVr_temp(2)^2-
0.76825 * FVr_temp(1)^3"

                ElseIf t2_seatbelt_op.Text = "Polyester" Then

                    hicfun = "F_hic=40680.50578-3208.05835 *
FVr_temp(1)-3672.57294 * FVr_temp(2)+233.68674 * FVr_temp(1) *
FVr_temp(2)+85.44934 * FVr_temp(1)^2+531.71922 * FVr_temp(2)^2-3.34106
* FVr_temp(1)^2 * FVr_temp(2)-17.63460 * FVr_temp(1) * FVr_temp(2)^2-
0.76825 * FVr_temp(1)^3"

                End If

            ElseIf t2_bulkhead_op.Text = "Nomex Honeycomb" Then

                If t2_seatbelt_op.Text = "Nylon" Then

                    hicfun = "F_hic=29192.54342-2440.18412 *
FVr_temp(1)-4025.80257 * FVr_temp(2)+248.37690 * FVr_temp(1) *
FVr_temp(2)+73.63743 * FVr_temp(1)^2+418.17755 * FVr_temp(2)^2-3.34106
* FVr_temp(1)^2 * FVr_temp(2)-17.63460 * FVr_temp(1)* FVr_temp(2)^2-
0.76825 * FVr_temp(1)^3"

                ElseIf t2_seatbelt_op.Text = "Polyester" Then

                    hicfun = "F_hic=32755.28626-2723.13125 *
FVr_temp(1)-3512.65555 * FVr_temp(2)+229.43180 * FVr_temp(1) *
FVr_temp(2)+78.22314 * FVr_temp(1)^2+481.27279 * FVr_temp(2)^2-3.34106
* FVr_temp(1)^2 * FVr_temp(2)-17.63460 * FVr_temp(1)* FVr_temp(2)^2-
0.76825 * FVr_temp(1)^3"

                End If

            ElseIf t2_bulkhead_op.Text = "Aluminum Honeycomb" Then

                If t2_seatbelt_op.Text = "Nylon" Then

                    hicfun = "F_hic=28117.25787-2474.01585 *
FVr_temp(1)-4028.27683 * FVr_temp(2)+242.49852 * FVr_temp(1) *
FVr_temp(2)+75.25648 * FVr_temp(1)^2+578.29660 * FVr_temp(2)^2-3.34106
* FVr_temp(1)^2 * FVr_temp(2)-17.63460 * FVr_temp(1) * FVr_temp(2)^2-
0.76825 * FVr_temp(1)^3"

                ElseIf t2_seatbelt_op.Text = "Polyester" Then

                    hicfun = "F_hic=32952.79124-2787.40892 *
FVr_temp(1)-3530.33251 * FVr_temp(2)+223.55343 * FVr_temp(1) *
FVr_temp(2)+79.84219 * FVr_temp(1)^2+641.39184 * FVr_temp(2)^2-3.34106
* FVr_temp(1)^2 * FVr_temp(2)-17.63460 * FVr_temp(1) * FVr_temp(2)^2-
0.76825 * FVr_temp(1)^3"
```

```
            End If

        End If

        Dim objfile As New System.IO.FileStream(objpath,
System.IO.FileMode.Create, System.IO.FileAccess.Write,
System.IO.FileShare.None)

        objfile.Close()

        Dim objfun As New System.IO.StreamWriter(objpath)

        objfun.BaseStream.Seek(0, System.IO.SeekOrigin.End)

        objfun.Write("function S_MSE= objfun(FVr_temp, S_struct)")

        objfun.WriteLine()

        objfun.Write(hicfun)

        objfun.WriteLine()

        objfun.Write("S_MSE.I_nc      = 0;")

        objfun.WriteLine()

        objfun.Write("S_MSE.FVr_ca    = 0;")

        objfun.WriteLine()

        objfun.Write("S_MSE.I_no      = 1;")

        objfun.WriteLine()

        objfun.Write("S_MSE.FVr_oa(1) = F_hic")

        objfun.WriteLine()

        objfun.Flush()

        objfun.Close()

        Dim runpath As String = dir & "dummy\run"

        Dim runopt As New System.IO.StreamReader(runpath)

        Dim runoptread As String

        runoptread = runopt.ReadToEnd

        runopt.Close()


        Dim runoptpath As String

        runoptpath = dir & "dummy\Rundeopt.m"
```

```
            Dim runoptfile As New System.IO.FileStream(runoptpath,
IO.FileMode.Create, System.IO.FileAccess.Write,
System.IO.FileShare.None)

            runoptfile.Close()

            Dim rundeopt As New System.IO.StreamWriter(runoptpath)

            rundeopt.BaseStream.Seek(0, System.IO.SeekOrigin.End)

            rundeopt.Write("F_VTR = 100;")

            rundeopt.WriteLine()

            rundeopt.Write("I_D = 2;")

            rundeopt.WriteLine()

            Dim l_opt_min As String = "FVr_minbound = [" & sblb & " " &
flb & "];"

            rundeopt.Write(l_opt_min)

            rundeopt.WriteLine()

            Dim l_opt_max As String = "FVr_maxbound = [" & sbub & " " &
fub & "];"

            rundeopt.WriteLine(l_opt_max)

            rundeopt.WriteLine()

            rundeopt.Write(runoptread)

            rundeopt.WriteLine()

            rundeopt.Write("exit")

            rundeopt.WriteLine()

            rundeopt.Flush()

            rundeopt.Close()

            Dim matpath As String

            matpath = dir & "dummy\mat.bat"

            Dim matlab As New System.IO.FileStream(matpath,
System.IO.FileMode.Create, System.IO.FileAccess.Write,
System.IO.FileShare.None)

            matlab.Close()

            Dim matrun As New System.IO.StreamWriter(matpath)

            ' Write the specified contents to the file.

            matrun.BaseStream.Seek(0, System.IO.SeekOrigin.End)
```

```
            matrun.Write("cd\")

            matrun.WriteLine()

            Dim rundir As String = "cd " & dir & "dummy"

            matrun.Write(rundir)

            matrun.WriteLine()

            Dim runmat, bsh1awk As String

            runmat = Nothing

            runmat = "c:\MATLAB701\bin\matlab.bat -nosplash -nodesktop
-minimize -r Rundeopt -logfile " & dir & "dummy\optimized.txt"

            matrun.Write(runmat)

            matrun.Flush()

            matrun.Close()

            Dim exematlab As String = dir & "dummy\mat.bat"

            Shell(exematlab)

            Dim msgvalue As Integer

            msgvalue = MsgBox("Optimization has Started with the given
parameters", MsgBoxStyle.Information, "Information")

            If msgvalue = 1 Then

                Dim oFile As System.IO.File

                Dim oRead As System.IO.StreamReader

                Dim LineIn As String

                Dim lCtr As Long

                Dim line As Integer

                Dim line_hic As Integer

                Dim Linenumber As Integer

                Dim Linenumber_hic As Integer

                Dim ReadLine As String

                Dim ReadLine_hic As String

                Dim optimizedpath As String

                optimizedpath = dir & "\dummy\optimized.txt"

                'Linenumber = strLines.Length - 3
```

```
                oRead = oFile.OpenText(optimizedpath)
                While oRead.Peek <> -1
                    LineIn = oRead.ReadLine()
                    lCtr = lCtr + 1
                    If LineIn = "FVr_x =" Then
                        line = lCtr
                        Linenumber = line + 1
                    End If
                    If LineIn = "S_y = " Then
                        line_hic = lCtr
                        Linenumber_hic = line_hic + 4
                    End If
                    If lCtr = Linenumber Then
                        ReadLine = oRead.ReadLine
                    End If
                    If lCtr = Linenumber_hic Then
                        ReadLine_hic = oRead.ReadLine
                    End If
                End While
                oRead.Close()
                Dim op_hic_length As Integer
                Dim op_hic_mod_length As Integer
                Dim op_setback As String
                Dim op_friction As String
                Dim op_hic As String

                op_hic_length = Len(ReadLine_hic)
                op_hic_mod_length = op_hic_length - 12
                op_hic = Microsoft.VisualBasic.Right(ReadLine_hic,
op_hic_mod_length)
```

```
                'Dim lumbar_convert As Integer =
Convert.ToInt32(op_lumbar)

                op_hic = op_hic / 1000

                op_hic = op_hic * 1000

                If op_hic > 1000 Then

                    Dim oFile1 As System.IO.File

                    Dim oRead1 As System.IO.StreamReader

                    Dim LineIn1 As String

                    Dim lCtr1 As Long

                    Dim line1 As Integer

                    Dim line_hic1 As Integer

                    Dim Linenumber1 As Integer

                    Dim Linenumber_hic1 As Integer

                    Dim ReadLine1 As String

                    Dim ReadLine2 As String

                    Dim optimizedpath1 As String

                    optimizedpath1 = dir & "\dummy\optimized.txt"

                    'Linenumber = strLines.Length - 3

                    oRead1 = oFile1.OpenText(optimizedpath)


                    While oRead1.Peek <> -1

                        LineIn1 = oRead1.ReadLine()

                        lCtr1 = lCtr1 + 1

                        If LineIn1 = "FVr_x =" Then

                            line1 = lCtr1

                            Linenumber1 = line1 + 1

                        End If

                        If lCtr1 = Linenumber Then

                            ReadLine1 = oRead1.ReadLine

                        End If

                    End While
```

```
                    oRead.Close()


                    op_setback = Microsoft.VisualBasic.Left(ReadLine1,
15)

                    op_setback = op_setback * 10

                    op_setback = op_setback / 10

                    'TextBox1.Text = op_setback

                    op_friction =
Microsoft.VisualBasic.Right(ReadLine1, 10)

                    op_friction = op_friction * 10

                    op_friction = op_friction / 10

                    'TextBox2.Text = op_friction

                    t2_op_lbl.Visible = True

                    t2_op_lbl.Text = "No Solution exist for minimizing
the Head Injury Criteria(HIC) ( <1000 ) when using a " &
t2_bulkhead_op.Text & " bulkhead with surface friction in the range of
" & t2_friction_op_lb.Text & " to " & t2_friction_op_ub.Text & " and
with a seat setback distance in the range of " & t2_setback_op_lb.Text
& " to " & t2_setback_op_ub.Text & " and using a " &
t2_seatbelt_op.Text & " seatbelt. The best possible case is when the
bulkhead surface friction is " & op_friction & " and a seat setback
distance of " & op_setback & " inches resulting in a HIC of " & op_hic
& " ."

                    t2_done_op_btn.Visible = True

                Else

                    op_setback = Microsoft.VisualBasic.Left(ReadLine,
13)

                    op_setback = op_setback * 10

                    op_setback = op_setback / 10



                    op_friction = Microsoft.VisualBasic.Right(ReadLine,
13)

                    op_friction = op_friction * 10

                    op_friction = op_friction / 10

                    t2_op_lbl.Visible = True

                    t2_op_lbl.Text = "Solution for minimizing the Head
Injury Criteria(HIC) ( <1000 ) when using a " & t2_bulkhead_op.Text & "
```

```
bulkhead with surface friction in the range of " &
t2_friction_op_lb.Text & " to " & t2_friction_op_ub.Text & " and with a
seat setback distance in the range of " & t2_setback_op_lb.Text & " to
" & t2_setback_op_ub.Text & " and using a " & t2_seatbelt_op.Text & "
seatbelt is when the bulkhead surface friction is " & op_friction & "
and the seat setback distance is " & op_setback & " inches resulting in
a HIC of " & op_hic & " ."

                    t1_done_op_btn.Visible = True

                End If

            End If

        End If

    End Sub

    Private Sub t2_done_op_btn_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles t2_done_op_btn.Click

        t2_picbox_op.Visible = False

        t2_bulkhead_op_lbl.Visible = False

        t2_bulkhead_op.Visible = False

        t2_seatbelt_op_lbl.Visible = False

        t2_seatbelt_op.Visible = False

        t2_setback_op_lbl.Visible = False

        t2_setback_op_lb.Visible = False

        t2_setback_op_ub.Visible = False

        t2_setback_op_to_lbl.Visible = False

        t2_setback_op_unit.Visible = False

        t2_friction_op_lbl.Visible = False

        t2_friction_op_lb.Visible = False

        t2_friction_op_ub.Visible = False

        t2_friction_op_to_lbl.Visible = False

        t2_optimize_btn.Visible = False

        t2_done_op_btn.Visible = False

        t2_op_lbl.Visible = False

        Label4.Visible = False

        Dim killpath1 As String = dir & "dummy\mat.bat"

        Dim killpath2 As String = dir & "dummy\optimized.txt"
```

```
        Dim killpath3 As String = dir & "dummy\objfun.m"
        Dim killpath4 As String = dir & "dummy\Rundeopt.m"
        Kill(killpath1)
        Kill(killpath3)
        Kill(killpath4)
        PictureBox1.Visible = True
        PictureBox2.Visible = True
        GroupBox1.Visible = True
        predict.Visible = True
        optimize.Visible = True
        start.Visible = True
        If t1 = 1 Then
            Label2.Visible = True
        End If
        If t2 = 1 Then
            Label3.Visible = True
        End If
    End Sub
End Class
```

APPENDIX – D

Matlab Code for Differential Evolution Optimization

```
function [FVr_bestmem,S_bestval,I_nfeval] = deopt(fname,S_struct)

%-----This is just for notational convenience and to keep the code
uncluttered.--------

I_NP         = S_struct.I_NP;

F_weight     = S_struct.F_weight;

F_CR         = S_struct.F_CR;

I_D          = S_struct.I_D;

FVr_minbound = S_struct.FVr_minbound;

FVr_maxbound = S_struct.FVr_maxbound;

I_bnd_constr = S_struct.I_bnd_constr;

I_itermax    = S_struct.I_itermax;

F_VTR        = S_struct.F_VTR;

I_strategy   = S_struct.I_strategy;

I_refresh    = S_struct.I_refresh;

I_plotting   = S_struct.I_plotting;

%-----Check input variables-------------------------------------------
-

if (I_NP < 5)

   I_NP=5;

   fprintf(1,' I_NP increased to minimal value 5\n');

end

if ((F_CR < 0) | (F_CR > 1))

   F_CR=0.5;

   fprintf(1,'F_CR should be from interval [0,1]; set to default value
0.5\n');

end

if (I_itermax <= 0)

   I_itermax = 200;
```

```
   fprintf(1,'I_itermax should be > 0; set to default value 200\n');
end
I_refresh = floor(I_refresh);


%-----Initialize population and some arrays----------------------------
---
FM_pop = zeros(I_NP,I_D); %initialize FM_pop to gain speed


%----FM_pop is a matrix of size I_NPx(I_D+1). It will be initialized---
---
%----with random values between the min and max values of the----------
---
%----parameters--------------------------------------------------------
---
rand('state',0); % - modified by Hari - fix random sequence


for k=1:I_NP
   FM_pop(k,:) = FVr_minbound + rand(1,I_D).*(FVr_maxbound -
FVr_minbound);
end


FM_popold     = zeros(size(FM_pop));  % toggle population
FVr_bestmem   = zeros(1,I_D);% best population member ever
FVr_bestmemit = zeros(1,I_D);% best population member in iteration
I_nfeval      = 0;                    % number of function evaluations


%------Evaluate the best member after initialization-------------------
---


I_best_index   = 1;                   % start with first population
member
S_val(1)       = feval(fname,FM_pop(I_best_index,:),S_struct);
```

```
S_bestval = S_val(1);                    % best objective function value
so far

I_nfeval  = I_nfeval + 1;

for k=2:I_NP                             % check the remaining members

  S_val(k)  = feval(fname,FM_pop(k,:),S_struct);

  I_nfeval  = I_nfeval + 1;

  if (left_win(S_val(k),S_bestval) == 1)

     I_best_index   = k;                 % save its location

     S_bestval      = S_val(k);

  end

end

FVr_bestmemit = FM_pop(I_best_index,:); % best member of current
iteration

S_bestvalit   = S_bestval;              % best value of current
iteration


FVr_bestmem = FVr_bestmemit;            % best member ever


%------DE-Minimization---------------------------------------------

%------FM_popold is the population which has to compete. It is--------

%------static through one iteration. FM_pop is the newly--------------

%------emerging population.----------------------------------------


FM_pm1   = zeros(I_NP,I_D);   % initialize population matrix 1

FM_pm2   = zeros(I_NP,I_D);   % initialize population matrix 2

FM_pm3   = zeros(I_NP,I_D);   % initialize population matrix 3

FM_pm4   = zeros(I_NP,I_D);   % initialize population matrix 4

FM_pm5   = zeros(I_NP,I_D);   % initialize population matrix 5

FM_bm    = zeros(I_NP,I_D);   % initialize FVr_bestmember  matrix

FM_ui    = zeros(I_NP,I_D);   % intermediate population of perturbed
vectors

FM_mui   = zeros(I_NP,I_D);   % mask for intermediate population
```

```
FM_mpo    = zeros(I_NP,I_D);   % mask for old population
FVr_rot   = (0:1:I_NP-1);               % rotating index array (size
I_NP)
FVr_rotd = (0:1:I_D-1);        % rotating index array (size I_D)
FVr_rt    = zeros(I_NP);                % another rotating index array
FVr_rtd   = zeros(I_D);                 % rotating index array for
exponential crossover
FVr_a1    = zeros(I_NP);                % index array
FVr_a2    = zeros(I_NP);                % index array
FVr_a3    = zeros(I_NP);                % index array
FVr_a4    = zeros(I_NP);                % index array
FVr_a5    = zeros(I_NP);                % index array
FVr_ind   = zeros(4);


FM_meanv = ones(I_NP,I_D);


I_iter = 1;
while ((I_iter < I_itermax) & (S_bestval.FVr_oa(1) > F_VTR) )
  FM_popold = FM_pop;                   % save the old population
  S_struct.FM_pop = FM_pop;
  S_struct.FVr_bestmem = FVr_bestmem;


  FVr_ind = randperm(4);                % index pointer array


  FVr_a1  = randperm(I_NP);                    % shuffle locations of
vectors
  FVr_rt  = rem(FVr_rot+FVr_ind(1),I_NP);      % rotate indices by
ind(1) positions
  FVr_a2  = FVr_a1(FVr_rt+1);                  % rotate vector locations
  FVr_rt  = rem(FVr_rot+FVr_ind(2),I_NP);
  FVr_a3  = FVr_a2(FVr_rt+1);
  FVr_rt  = rem(FVr_rot+FVr_ind(3),I_NP);
```

```
  FVr_a4   = FVr_a3(FVr_rt+1);

  FVr_rt   = rem(FVr_rot+FVr_ind(4),I_NP);

  FVr_a5   = FVr_a4(FVr_rt+1);


  FM_pm1 = FM_popold(FVr_a1,:);             % shuffled population 1

  FM_pm2 = FM_popold(FVr_a2,:);             % shuffled population 2

  FM_pm3 = FM_popold(FVr_a3,:);             % shuffled population 3

  FM_pm4 = FM_popold(FVr_a4,:);             % shuffled population 4

  FM_pm5 = FM_popold(FVr_a5,:);             % shuffled population 5


  for k=1:I_NP                              % population filled with
the best member

    FM_bm(k,:) = FVr_bestmemit;             % of the last iteration

  end


  FM_mui = rand(I_NP,I_D) < F_CR;  % all random numbers < F_CR are 1, 0
otherwise

    FM_mpo = FM_mui < 0.5;    % inverse mask to FM_mui


  if (I_strategy == 1)                             % DE/rand/1

    FM_ui = FM_pm3 + F_weight*(FM_pm1 - FM_pm2);   % differential
variation

    FM_ui = FM_popold.*FM_mpo + FM_ui.*FM_mui;     % crossover

    FM_origin = FM_pm3;

  elseif (I_strategy == 2)                         % DE/local-to-best/1

    FM_ui = FM_popold + F_weight*(FM_bm-FM_popold) + F_weight*(FM_pm1 -
FM_pm2);

    FM_ui = FM_popold.*FM_mpo + FM_ui.*FM_mui;

    FM_origin = FM_popold;

  elseif (I_strategy == 3)                         % DE/best/1 with
jitter

    FM_ui = FM_bm + (FM_pm1 - FM_pm2).*((1-
0.9999)*rand(I_NP,I_D)+F_weight);
```

```
    FM_ui = FM_popold.*FM_mpo + FM_ui.*FM_mui;

    FM_origin = FM_bm;

  elseif (I_strategy == 4)                          % DE/rand/1 with
per-vector-dither

     f1 = ((1-F_weight)*rand(I_NP,1)+F_weight);

     for k=1:I_D

        FM_pm5(:,k)=f1;

     end

     FM_ui = FM_pm3 + (FM_pm1 - FM_pm2).*FM_pm5;     % differential
variation

     FM_origin = FM_pm3;

     FM_ui = FM_popold.*FM_mpo + FM_ui.*FM_mui;      % crossover

  elseif (I_strategy == 5)                           % DE/rand/1 with
per-vector-dither

     f1 = ((1-F_weight)*rand+F_weight);

     FM_ui = FM_pm3 + (FM_pm1 - FM_pm2)*f1;          % differential
variation

     FM_origin = FM_pm3;

     FM_ui = FM_popold.*FM_mpo + FM_ui.*FM_mui;      % crossover

  else                                               % either-or-
algorithm

     if (rand < 0.5);                                % Pmu = 0.5

        FM_ui = FM_pm3 + F_weight*(FM_pm1 - FM_pm2);% differential
variation

        FM_origin = FM_pm3;

     else                                            % use F-K-Rule: K =
0.5(F+1)

        FM_ui = FM_pm3 + 0.5*(F_weight+1.0)*(FM_pm1 + FM_pm2 -
2*FM_pm3);

     end

     FM_ui = FM_popold.*FM_mpo + FM_ui.*FM_mui;      % crossover

  end



%---- confine population to bounds-------- Hari
```

```
for i=1:I_D

    work1= (FM_ui(:,i) < FVr_minbound(i)) | (FM_ui(:,i) >
FVr_maxbound(i));

    for j=1:I_NP

        if work1(j) == 1

            FM_ui(j,i) = FVr_minbound(i) + rand(1,1).*(FVr_maxbound(i)
- FVr_minbound(i));

%              fprintf(1,'parameter out of bounds.\n'); % uncommenting
slows

                                                     % down execution
considerably.

        end

    end

end



%-----Select which vectors are allowed to enter the new population-----
-------

  for k=1:I_NP



      %=====Only use this if boundary constraints are
needed==================

      if (I_bnd_constr == 1)

         for j=1:I_D %----boundary constraints via bounce back-------

            if (FM_ui(k,j) > FVr_maxbound(j))

               FM_ui(k,j) = FVr_maxbound(j) + rand*(FM_origin(k,j) -
FVr_maxbound(j));

            end

            if (FM_ui(k,j) < FVr_minbound(j))

               FM_ui(k,j) = FVr_minbound(j) + rand*(FM_origin(k,j) -
FVr_minbound(j));

            end

         end

      end
```

```
      %=====End boundary
constraints==========================================

      S_tempval = feval(fname,FM_ui(k,:),S_struct);   % check cost of
competitor
      I_nfeval  = I_nfeval + 1;
      if (left_win(S_tempval,S_val(k)) == 1)
         FM_pop(k,:) = FM_ui(k,:);                    % replace old
vector with new one (for new iteration)
         S_val(k)   = S_tempval;                      % save value in
"cost array"

         %----we update S_bestval only in case of success to save time-
----------
         if (left_win(S_tempval,S_bestval) == 1)
            S_bestval = S_tempval;                    % new best value
            FVr_bestmem = FM_ui(k,:);                 % new best
parameter vector ever
         end
      end
   end % for k = 1:NP

  FVr_bestmemit = FVr_bestmem;       % freeze the best member of this
iteration for the coming
                                     % iteration. This is needed for
some of the strategies.

%----Output section----------------------------------------------------
------

  if (I_refresh > 0)
     if ((rem(I_iter,I_refresh) == 0) | I_iter == 1)
        fprintf(1,'Iteration: %d,  Best: %g,  F_weight: %f,  F_CR: %f,
I_NP: %d\n',I_iter,S_bestval.FVr_oa(1),F_weight,F_CR,I_NP);
```

```
        %fprintf(1, 'Best: %f, \n',S_bestval.FVr_oa(1));
        %var(FM_pop)
        format short g;
        for n=1:I_D
           fprintf(1,'best(%g) = %g\n',n,FVr_bestmem(n));
        end
        if (I_plotting == 1)
           PlotIt(FVr_bestmem,I_iter,S_struct);
        end
     end
   end

   I_iter = I_iter + 1;
end %---end while ((I_iter < I_itermax) ...
```