Optimization Techniques in Conjunction with Complex ATD FE Models Using LS-DYNA®

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Abstract

This paper discusses the optimization methods used by Denton to create FE ATD models. Anthropomorphic Test Devices (ATDs also known as Dummies) are manufactured with a variety of hyperelastic and viscoelastic materials. The production processes used to manufacture ATD's result in variations between dummies that can have a significant influence on dummy performance. In addition the load cases present during testing with ATDs are very complex and of short time duration. A typical frontal crash test may last 100ms but the load cycle on an ATD body region may last only 10ms.

The end result is a complex series of issues that can be very difficult to solve in an FE model, using conventional techniques. The number of potential variables (sample list) associated with a specific performance metric (time history, acceleration, etc) can be very large. The settings for a given variable and the effect of that variable setting are difficult to determine given the complexity and short duration of the simulated event. In particular, the use of the hybrid adaptive SHERPA algorithm in the HEEDS software in conjunction with LS-DYNA for determining parameter values is discussed.

Introduction

Anthropometric Test Dummies (ATD's) are manufactured in low volumes and are made from a large number of hyperelastic and visco-elastic materials such as foams, rubbers and vinyl. These materials produce a large displacement and are strain rate sensitive in almost all relevant load cases. In addition, the material properties for each material continue to change of over time.

The combined effect is that ATD's have inherent performance variability designed to work between controlled legislative performance corridors. Test methods to evaluate the ATD performance with respect to the corridor can also be a source of variation therefore warrant consideration when addressing performance assessment and variation.

The end result can produce an ATD system performance variation that can influence restraint system design. In controlled sled tests, Denton has observed that biomechanical results between two dummies, that both meet the certification performance corridors, can be significantly different. Current simulation models do not account for dummy-to-dummy variations.

With respect to the numerical modeling of ATD FE models using LS-DYNA [Ref 1], Denton has produced a development process that identifies the source of variation and its contribution to the related performance. As a result, Denton is able to adjust the FE models to account for dummy-to-dummy variation in a realistic manner increasing the predictive capability of such models.

This development process meets a major new need in that a vehicle crash test development, using a virtual process, will need to account for the allowed dummy variability. This is required to remove uncertainty in full vehicle testing related to USNCAP ratings.

Denton Long Term Goals - Simulation

Denton aims to:

Create a FE model with a unique certification performance against a specific dummy calibrated in a specific laboratory, by a specific technician on a given day

Subsequently create a model(s) that can accommodate the range of allowable variability within the certification performance limits.

The first goal allows the engineer to better predict test results from a specific dummy. This allows engineers to make better decisions related to tuning and finalizing restraint performance against internal criteria via a virtual process

The second goal then allows the engineer to better predict and understand the effect of the allowed variation in dummy performance on the restraint system performance.

Denton Variability Process

Denton uses a numerical process to create FE dummies that account for dummy-to-dummy variation while also identifying areas for design improvement to reduce physical variation; this process is outlined in figure 1.

In a typical FE dummy model correlation, the model output is compared against a single test result and then tuned by adjusting dummy parameters until a reasonable correlation is achieved. The end result is that other, non-dummy related sources of variation can be embedded in the simulation model rendering the model less predictive in other load cases.

In the Denton process a baseline model is used in conjunction with a database of known variables associated with a given set of test conditions. The database is populated with dummy, testing and instrumentation variables. Results for a given test condition are compared with the simulation result and the Root Mean Square (RMS) difference between the test and simulation is calculated. Using a genetic algorithm the variables in the simulation are adjusted until the RMS difference is minimized.

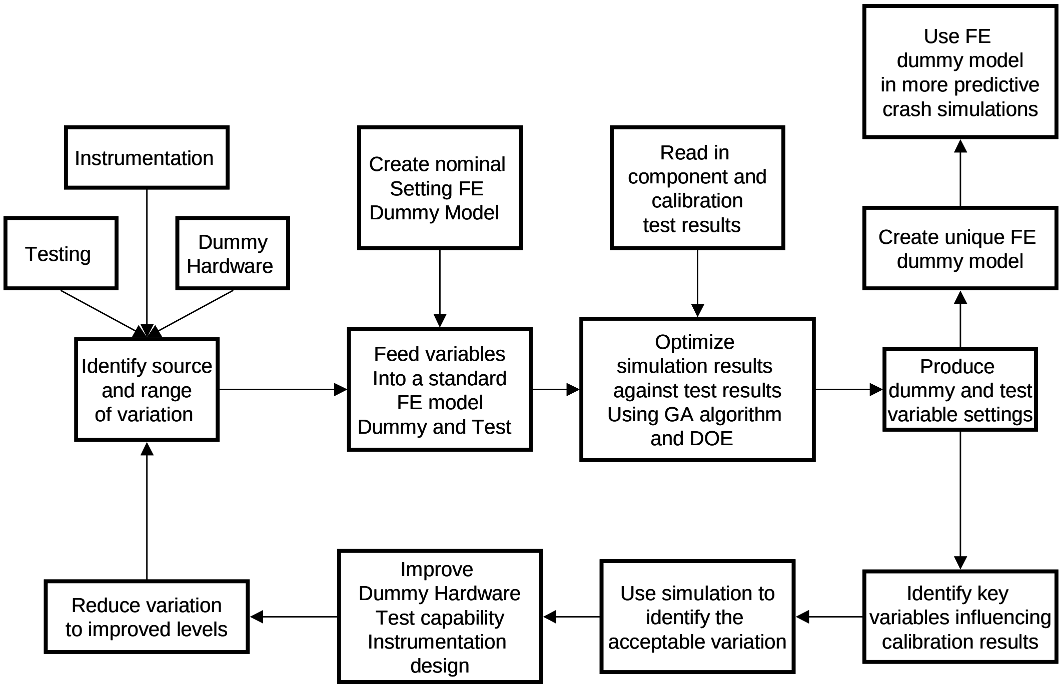
Denton uses the HEEDS' default search method to find the optimal variable settings that produce the minimized RMS Difference. The RMS difference is used by HEEDS to produce a HEEDS Performance Index [Ref 2]. The search method is a proprietary, hybrid and adaptive algorithm called SHERPA developed by Red Cedar Technology in Lansing, Michigan. SHERPA employs multiple search strategies at once and adapts to the problem as it "learns" about the design space.

Once the variable settings are determined it is then a relative easy process to extract the dummy model related settings from the test and instrumentation settings. These dummy settings can then be used in the dummy model for simulations in other load cases and provide the basis for improved predictions.

Figure 1: Reducing ATD Variability and Creating Predictive Simulation FE Dummies

Model Process Example

Even in the case of a simple example there can be numerous variables that influence dummy performance. An excellent example of this is the head drop test. In this test, a dummy head is dropped from a known height and orientation onto a hard surface. Figure 2 shows a typical head drop test set up via a simulation model.



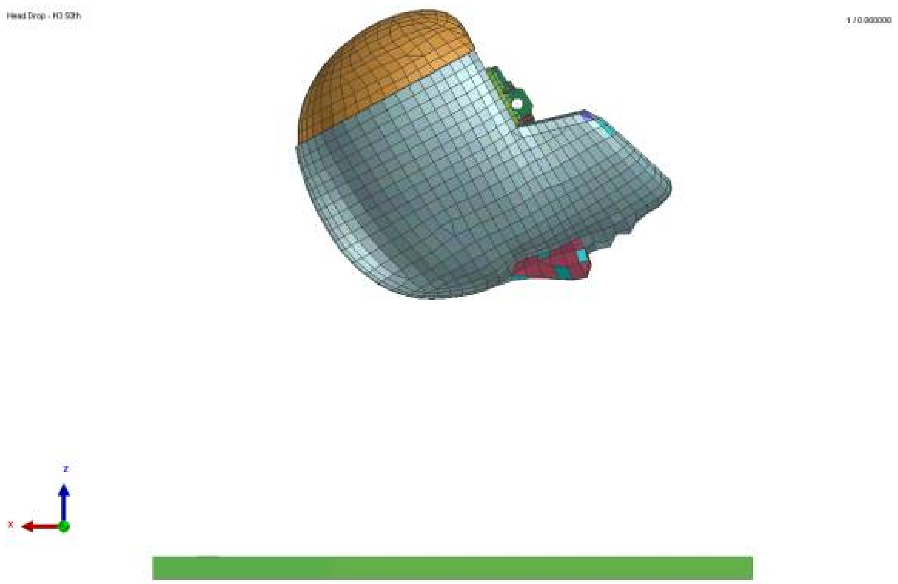


Figure 2: Simulation Model of a Head Drop Test

For this kind of condition the variables of interest include:

Dummy:

- Head mass – incorrect ballast weights
- Head CoG – incorrect ballast weights – head casting variations
- Head inertia – all of the above
- Head profile (geometric shape)
- Skin thickness
- Skin material properties
- Skin/head friction interface
- Skull material properties
- Skull profile (geometric shape)
- Skin/Skull fit (non-uniform)
- Skull cap incorrectly fitted (loose screws)

Test:

- Drop height
- Drop angle
- Initial head orientation at release height
- Contact point – due to head release mechanism
- Contact angle – due to head release mechanism
- Cable drag – improper release
- Impact velocity
- Table friction – dirt present on table
- Table level
- Table rigidity – mounting of table – loose mounting screws

Instrumentation:

- Head accelerometer mount position – mount face – unclean surface
- Accelerometer calibration
- Different accelerometer type used – 7231 (750g) or 7264 (2000g range)
- Accelerometer manufacturer (Endevco – MEAS)

As an example of the Denton process using the HEEDS search algorithm, the following variables and levels were chosen for the simulation optimization process using LS-DYNA

· Head Skin Material	Three different materials - A, B and C
· Skull Modeling Method	Two methods - A and B
· Skull Mass	+/-10% of the Nominal Mass
· Skull / Skin Interface Method	Two Methods – A and B
· Skull / Skin Interface Friction	+/- 0.3 of the Nominal Friction
· Drop Height / Impact Velocity	+/- 10% of the Nominal Height
· Head Orientation at release	+/- 5 deg in Head X and Y from Nominal
· Table Friction	+/- 0.3 of the Nominal Friction

The starting point for the process used the following settings:

· Head Skin Material	Materials A
· Skull Modeling Method	Methods A
· Skull Mass	Nominal Mass
· Skull / Skin Interface Method	Methods A
· Skull / Skin Interface Friction	Nominal Friction
· Drop Height / Impact Velocity	Nominal Height
· Head Orientation at release	Nominal Head X and Y
· Table Friction	Nominal Friction

Optimization Results

A total number of 617 simulations were needed to produce the simulation results shown in Figures 3-5

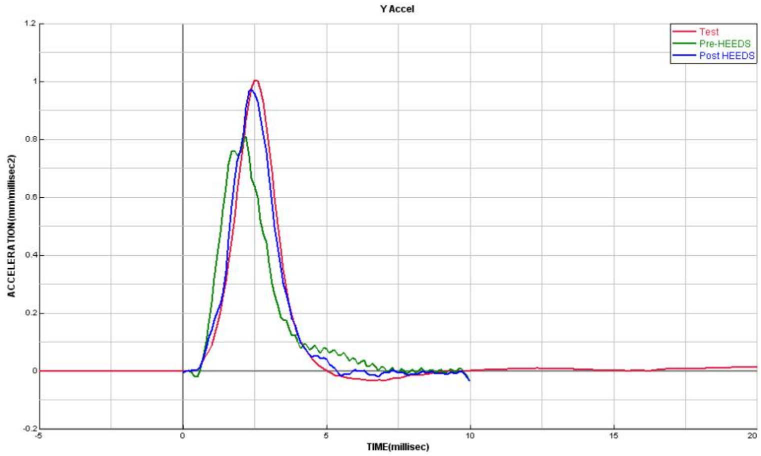


Figure 3: Head Y Acceleration

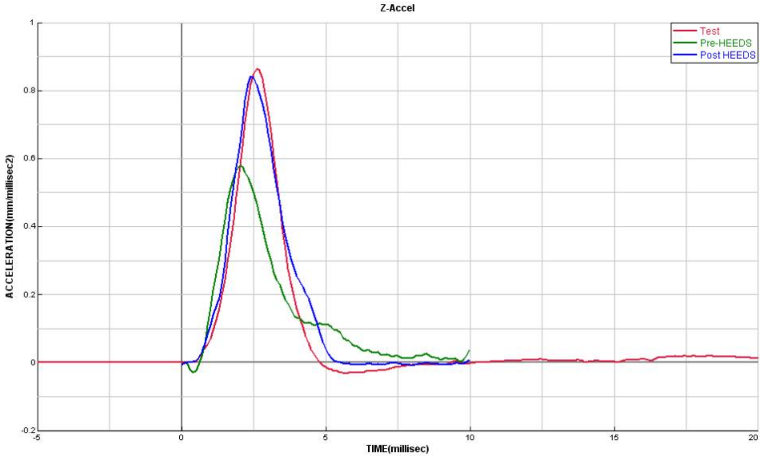


Figure 4: Head Z Acceleration

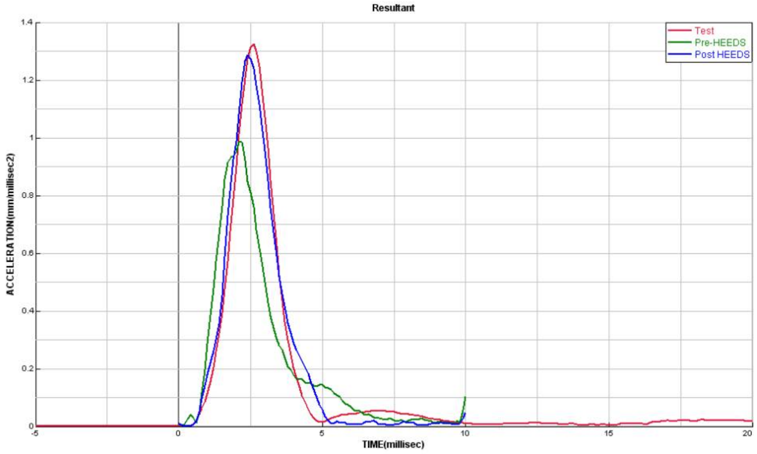


Figure 5: Head Resultant Acceleration

In this example the Heeds Performance Index values before and after the optimization were:

Before:	2278
After:	1020

Figure 6 shows how the HEEDS Performance Index changed with each run.

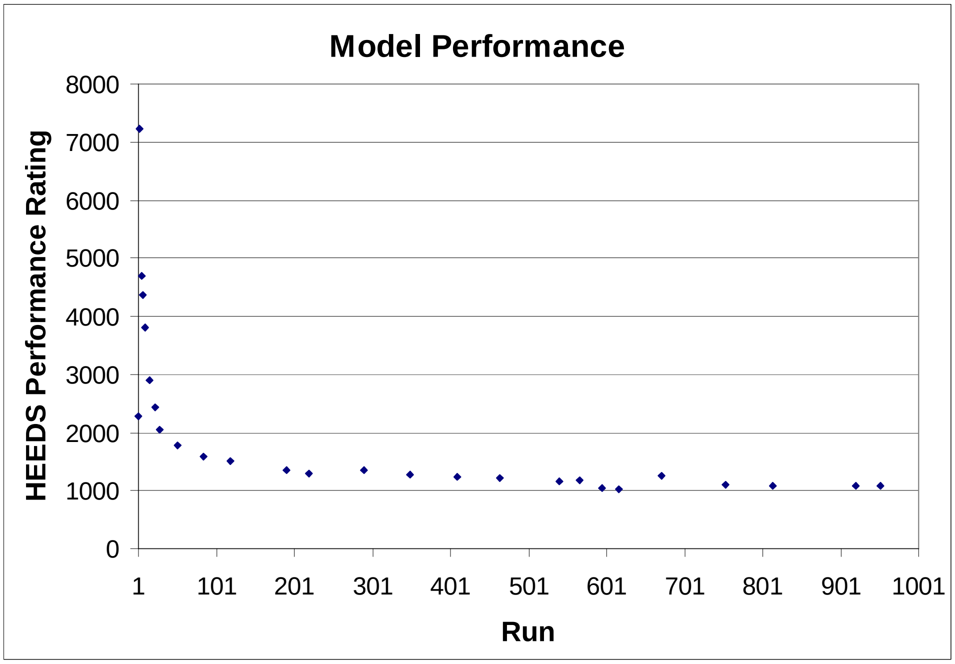


Figure 6: HEEDS Performance Index Versus LS-DYNA run

To achieve this performance the variable settings were determined by HEEDS as:

Head Skin Material	Materials B
Skull Modeling Method	Methods B
Skull Mass	Nominal Mass - 5%
Skull / Skin Interface Method	Methods B
Skull / Skin Interface Friction	Nominal Friction – 0.1
Drop Height / Impact Velocity	Nominal Height – 8%
Head Orientation at release	Nominal +4.6 deg X and +2.1 deg Y
Table Friction	Nominal Friction + 0.2

Discussion

The allowed variation of Dummy responses that still meet certification requirements has an increasing influence on USNCAP scores produced by a full vehicle crash test. The USNACP score can be shown to be sensitive to a number of these allowed variations. At the same time vehicle designs are changing with the introduction of new fuel economy requirements, the introduction of hybrid and electric vehicles and the pressure to reduce the vehicle development timing and cost. The total effect is test-to-test result variation due to differences in the dummy performance increase the complexity of the restraint design at a time when vehicle design changes are also placing higher demands on restraint design and making them more complex. Therefore, it is important to consider the dummy performance variation early in the design process using virtual methods.

Identifying the sources of variation has shown that they come from the dummy, the test method and the instrumentation. As such all these variation sources must be taken into account when validating a dummy FE model.

The process used by Denton allows the power of the HEEDS SHERPA algorithm in conjunction with the LS-DYNA software to identify the settings for each variable considered in order to achieve a specific dummy performance.

In the example chosen the simulation acceleration seen in the head drop test was matched with the test results very effectively. A total of 617 simulation runs were needed to find the solution presented. The HEEDS Performance Index between the simulation result and test result was reduced from 2278 to 1020 for the resultant acceleration. The final solution included changes to the initial settings from each area of dummy, test method and instrumentation variation.

Therefore, in addition to achieving excellent correlation levels with the test result, the simulation settings related to the dummy were identified and then used in the full FE dummy model. This subsequently increases the predictive capability of the full FE dummy model in other load cases.

Conclusions

HEEDS when used in conjunction with LS-DYNA can provide powerful and accurate solutions in solving dummy variation performance issues via modeling.

In the head drop example presented here, the HEEDS Performance Index was reduced from 2278 to 1020 while also identifying the settings for each variable examined.

Denton has been successful in applying this technique to create its Full FE Dummy models. In addition to achieving the accuracy desired Denton has also been able to identify the levels for each variable considered. Therefore accuracy and variability can be accommodated in the FE dummy model

References

[1] LS-DYNA® Keyword User's Manual Version 971, Livermore Software Technology Corporation, 2007

[2] HEEDS v5.3 User Manual, Red Cedar Technology, Inc., 2009