Aircraft Seat Row-to-row Head Injury Criteria (HIC) Simulation Using LS-DYNA®

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Abstract

Successful aircraft seat row-to-row HIC certification takes many test iterations and therefore is time intensive. Both developmental and certification tests are repeated to account for customized seat pitches, the range of occupant seated heights (from 5th percentile female to 95th percentile male), and several required impact zones.

Row-to-row HIC prediction using simulation can help early design concept development (e.g., evaluating energy absorption devices and breakover mechanisms), and in turn reduce the cost of testing and the associated lead time. The objective of this paper is to introduce row-to-row HIC analysis and prediction using LS-DYNA. The seat modeling techniques for the row-to-row simulation were summarized. Two cases were used to demonstrate HIC predictability using simulation.

Introduction

Aircraft passenger row-to-row seating is required to meet FAR 25-562 emergency landing dynamic conditions, where head impact with seats must not exceed a Head Injury Criterion (HIC) of 1,000 units. The level of HIC is defined by the equation:

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

Where
t1 is the initial integration time;
t2 is the final integration time;
a(t) is the time history of the total acceleration for the head strike;
(t) is in seconds, and (a) is in units of gravity (g).

To ensure compliance with 25.562, new seat design relies heavily on iterative dynamic developmental testing prior to the dynamic certification test. This developmental testing can be especially onerous for HIC evaluation on new seats used in a row-to-row configuration. Variables such as row pitch, occupant seated height, and impact zone requires testing multiple combinations.

To aid new seat development, this paper introduces utilization of computer modeling and simulation for row-to-row HIC assessment. Traditional forward facing 3-passenger seats were considered in this paper. The seat structures include floor fittings, seat legs, cross tubes, spreader bars, seat cushions, arm rests, and a seatback assembly. The seatback assembly, which is in the main load path for a row-to-row head impact condition, is equipped with a literature pocket, tray table assembly, and breakover and recline mechanism.

The following sections include: (1) description of the model setup and modeling practice; (2) results and discussion of the two row-to-row HIC simulations.

Modeling and Simulation

The model represents a typical row-to-row HIC sled test article and consists of six seats and two virtual dummies. The seats are arranged in two rows of three with the dummies placed in the left and right back row seats. See Figure 1.

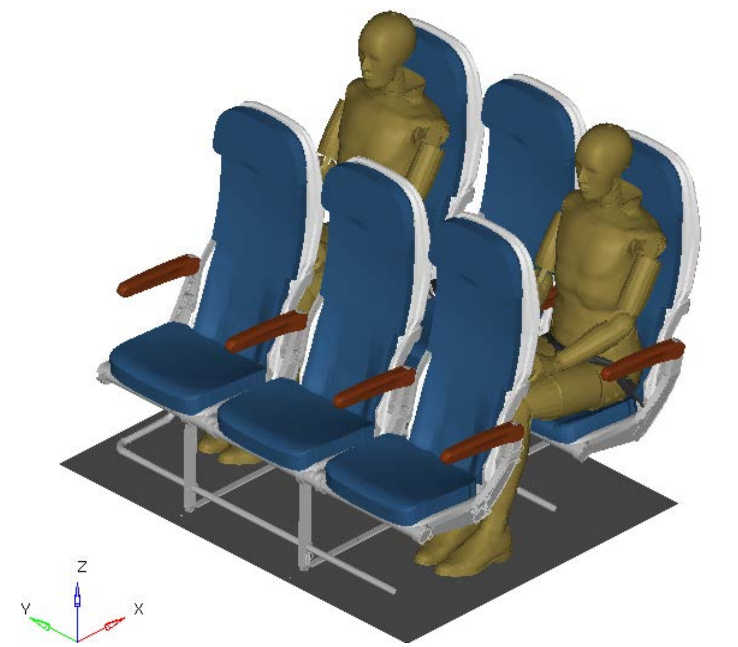


Figure 1: The Row-to-row Model for HIC Analysis

The seat model was made using the building block approach described in Section 6.2 of Ref. [3]. Each seat part was modeled separately and then assembled. The model was validated at the component, sub-system, and system level. Note that the seat structure modeling details such as meshing, element formulation types, and hourglass control are not the focus of this paper.

The virtual dummy used in the simulation was the Humanetics FAA HIII-50TH v-ATD model. And, LS-DYNA R8.0 explicit analysis (Ref. [2]) was used to solve for the row-to-row head impact response.

There were various material models used in the simulation. For aluminum and steel alloys, the material properties and stress-strain data in MMPDS (Ref. [4]) were used. The keyword for these metallic materials was *MAT_PIECEWISE_LINEAR_PLASTICITY.

Many plastic parts (e.g., arm rests) in the model are considered linearly elastic, and therefore *MAT_ELASTIC was used. Others that act as an energy absorber were modeled using *MAT_PLASTICITY_POLYMER. The stress-strain data for the energy absorbers was acquired from the material vendor.

The seat foam material was characterized using the strain rate dependent material model *MAT_FU_CHANG_FOAM. The data for the loading and unloading curves in the foam material model were obtained from quasi-static and dynamic uniaxial compression tests.

To simulate the test article, the dummy was restricted with a two-point lap belt restraint system. The seatbelt was modeled using combined 1D seatbelt elements and 2D shell elements. The seatbelt material models *MAT_SEATBELT and *MAT_FABRIC were generated for the 1D and 2D elements, respectively, using data collected from seatbelt webbing elongation tests. A 10-lb belt preload was applied using retractor elements.

There are several different contact interface types employed in the model. The seat foam to seat pan, and seat tracks to floor fixture interfaces used *CONTACT_TIED_SURFACE_TO_SURFACE. A global contact *CONTACT_AUTOMATIC_SINGLE_SURFACE is defined to account for the interaction between seat structure parts. The interface between the dummy and the seat foam, and between the belt and the dummy is modeled using *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE.

Another important element of the model is the initial position of the dummy. This includes the location of the H-Point relative to the seat, the position of the head, torso, and limbs relative to each other and to the seat. Varying the position of any one of these will likely lead to different HIC values. Because the goal of the initial simulations was test correlation, the dummy initial positions in the model were arranged as closely as possible to the position of a dummy in a typical HIC sled test article. In addition to dummy position, the back and bottom cushions at the occupied seats were pre-stressed in a deformed shape that is conformed to the initial position of the dummies. Figure 2 illustrates the pre-stressed seat foam and the dummy initial position.

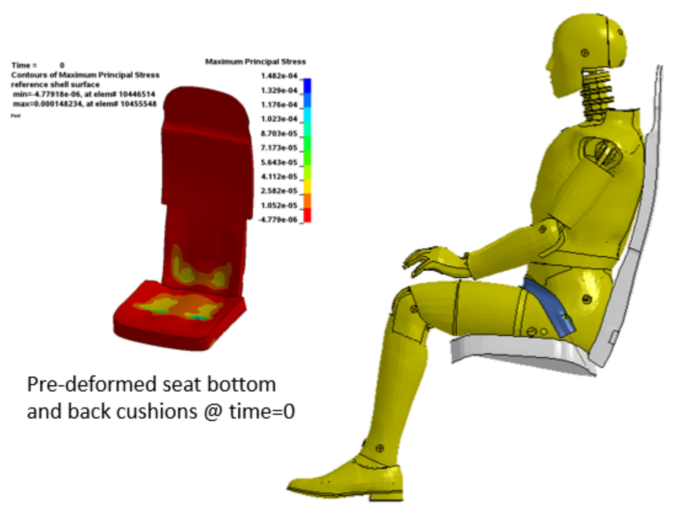


Figure 2: the Dummy Initial Position and Pre-stressed Seat Foam

Boundary conditions are applied such that the floor and seat track fixtures are constrained in all degrees of freedom. But, a 16G force input is imposed on the full seat/dummy model. This force was applied as the ideal triangular pulse shown in Figure 3 using *LOAD_BODY_X.

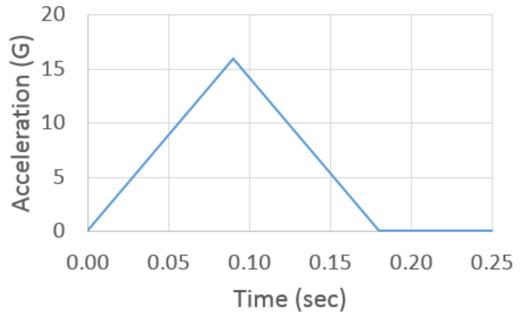


Figure 3: the 16G Ideal Triangular Pulse

The test article that was modeled had a unique mechanism referred as breakover feature. This breakover mechanism articulates the seat back during head impact with the goal of reducing the HIC value. Proper modeling of the seatback articulation is therefore essential for the HIC prediction. An example of verifying the seatback and breakover modeling using quasi-static analysis is provided in Figure 4.

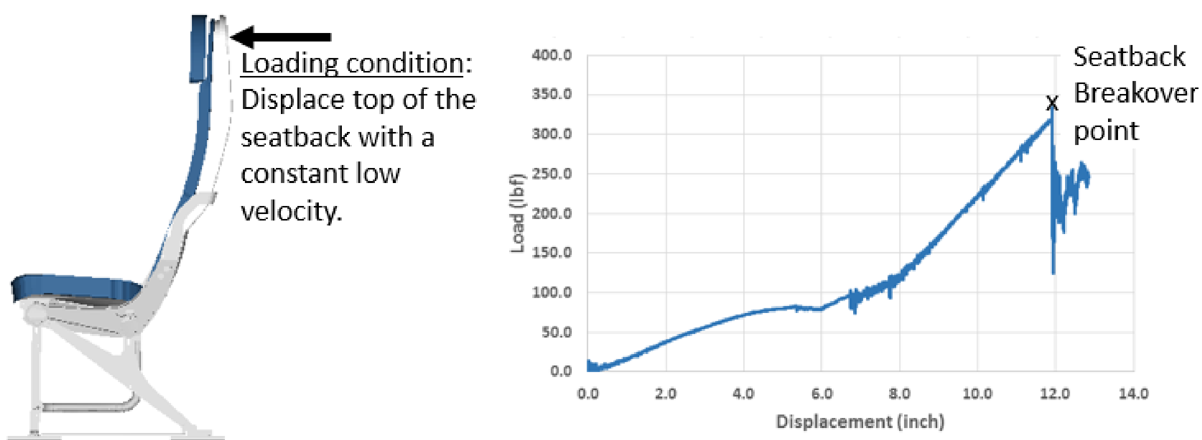


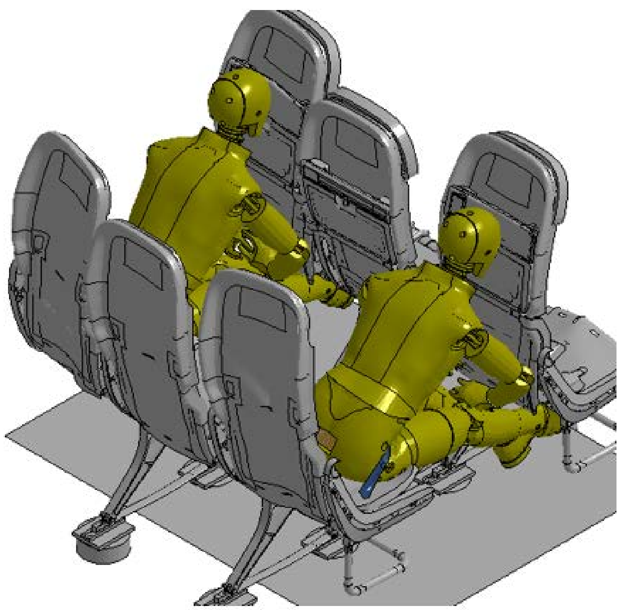
Figure 4: Verification of the Seatback Breakover Load

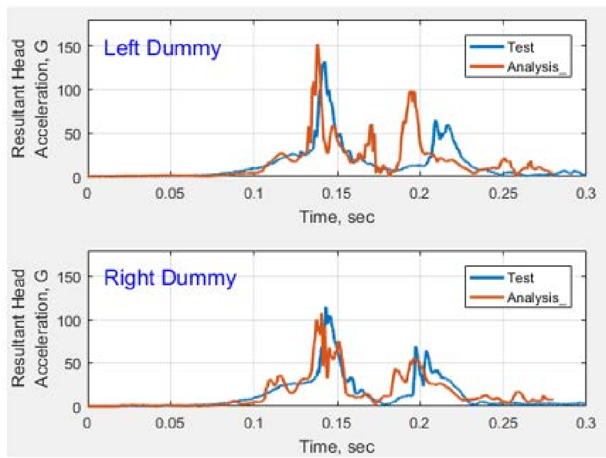
Two row-to-row pitch cases were simulated to use as examples: (1) a 37-inch pitch representing an exit row; and (2) a 29-inch pitch representing a standard row. Both cases simulated straight forward impact on the seatback.

Results and Discussion

Figure 5 shows head accelerations and calculated HIC values for both the 37-inch pitch simulation and the corresponding test. Overall, the simulation reasonably predicts the head impact accelerations. The calculated average HIC value between the test and simulation is comparable.

However, the test has a disparity in HIC values between the left and right dummies that is more than 200 units. This difference is attributable to test variability. In fact, there are many factors that can significantly influence HIC results; e.g., positions of the dummies. To capture effects of these factors, future work will include sensitivity study in the HIC simulation.





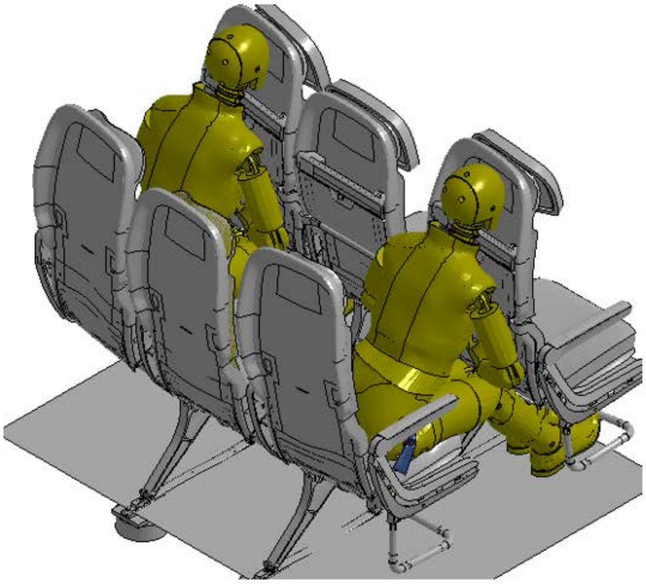
HIC Level Comparison	Left Dummy	Right Dummy
Test	972	721
Simulation	842	837

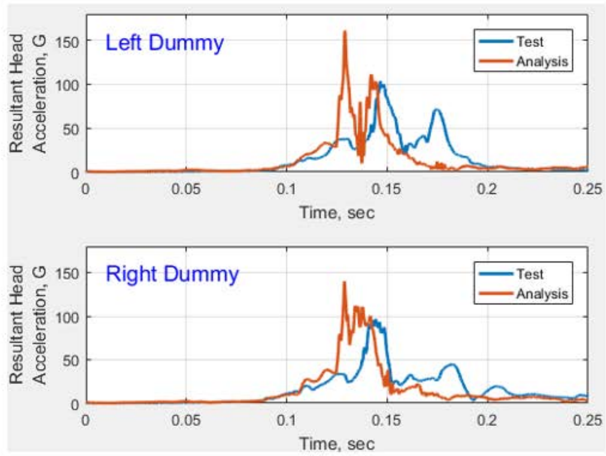
Figure 5: The Comparison of the HIC Test and Simulation Results For the 37-inch Pitch Exit Rows

Figure 6 shows head accelerations and calculated HIC values for both the 29-inch pitch simulation and the corresponding test. The test and simulation results in this seat pitch do not correlate well as in the 37-pitch case. One noticeable difference between the test and simulation is the head impact location.

In fact, as the seat row space narrows, the articulation of dummy's neck, arms and hands becomes crucial. During the dynamic test, the dummy's hands and arms pushed the seatback forward, the upper torso moved with the support of the arms and hands, and subsequently the head hit the surface of the literature pocket. By contrast, from the simulation, the hands and arms of the virtual dummy did not push the seatback forward, and thus the head impacted on top of the back panel.

To improve the HIC predictability for the seat rows with shorter pitches, it is necessary to ensure proper joint stiffness for the limbs of the virtual dummy. This is currently the subject under investigation by Humanetics.





HIC Level Comparison	Left Dummy	Right Dummy
Test	911	720
Simulation	1126	1559

Figure 6: The Comparison of the HIC Test and Simulation Results for the 29-inch Pitch Standard Rows

Acknowledgement

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References

[1] FAA Advisory Circular AC25.562-1B – Dynamic Evaluation of Seat Restraint Systems and Occupant Protection on Transport Airplanes, January 2006
[2] LS-DYNA Keyword User's Manual, R8.0, Volumes I & II, Livermore Technology Software Corporation (LSTC), March 2015
[3] LS-DYNA Aerospace Working Group, Modeling Guidelines Document, Version 17-1, September 2017
[4] Metallic Materials Properties Development and Standardization (MMPDS-11)