Certification by Analysis of a Typical Aircraft Seat

Nilesh Dhole, Vikas Yadav and Gerardo Olivares
Computational Mechanics,
National Institute for Aviation Research, Wichita, KS 67260, USA

Abstract

Advancements in computer hardware in recent years have made it possible to solve complex real world problems using finite element methods (FEM). Full scale dynamic certification testing of aircraft seats is a very complex, expensive and time consuming process. A high acceleration pulse is applied on the seat structure in a short duration of period, and the seat structure has to pass stringent FAA certification criteria. FAA and the aircraft industry are working together to reduce the cost and time required for certification of the seat while improving occupant safety. This is being achieved by using a process known as Certification by Analysis or CBA where the seat is certified using finite element methods. The process and guidelines for CBA are described in advisory circular AC 20-146 developed by the FAA. As per the AC 20-146, FE models can replace the actual dynamic testing scenarios such as: 1) demonstrating compliance to standard test requirements for changes to a baseline seat design, 2) establishing the critical seat installation/configuration in preparation for dynamic testing.

This paper describes in detail different techniques that can be used for the validation of a FE model of typical aircraft seat using the finite explicit code LS DYNA. As an example, the FE model of an aircraft seat is validated against the full scale dynamic test conducted as per AC 25.562.

Introduction

As per AC 25.562 there are two types of dynamic seat certification tests. Test I is a vertical test where the seat is accelerated at 14 g's and occupants lumbar load is the critical criteria for the test. Test II is a horizontal test conducted at 16 g's pulse and its primary focus is on the seat structure. For test II the seat structure is deformed before actual dynamic test to represent floor warping, which is a worst case condition for structural loading.

To simulate these conditions using FEM is a very challenging task. As the seat structure undergoes large deformations or sometimes experiences failure, detailed mechanical properties of the seat components are required for accuracy of the model. For FE modeling of aircraft seats validation is a key step in determining whether the model is acceptable for further use. Different methods used to compare FE model with the actual test are explained with an example. An accurately defined and validated FE model could potentially be used to evaluate the seating system instead of physical testing as per the guidelines of AC 20-146.

AC 20-146: Procedure and Guidelines for CBA

This is a brief overview of the advisory circular (AC) 20-146 [1]. It provides guidance on how to validate the computer model and under what conditions the model can be used to support certification. It also discusses the acceptable applications, limitations, validation process and minimum documentation requirements involved when substantiation by computer modeling is used to support a seat certification program.

Application Specific Validation Criteria

There are various criteria important for the validation but they are application specific, applicant should validate parameters that are relevant to the application of model [1]. Following are some of the criteria used to evaluate the computer model:
- Occupant Trajectory
- Floor Reaction Loads
- Restraint Systems
- Head Injury Criteria (HIC)
- Spine/Lumbar Load
- Femur Compressive Load

Description of Computer Model

This advisory circular also spreads some light on a document that provides the analytical results and comparison to test data when computer modeling is submitted as engineering data, known as the Validation and Analysis Report (VAR). VAR contains a detailed description of the computer model, including the input data. It must include a discussion on the following topics:
- Engineering assumptions
- FE modeling of physical structure
- Material models
- Constraints or boundary conditions
- Load application
- Occupant simulation
- General analysis control parameters

Finite Element Modeling Techniques

This section describes the procedure used to create the finite element model of the aircraft seat. Figure 1 shows a flowchart defining the steps used to create and validate the finite element model. Modeling process begins with the simplification of a detailed cad model of the seat to get good quality finite element mesh. Every part was meshed as per strict guidelines and documented to keep track of the quality of the model. After each part was meshed it was defined by section and material properties and assembled using finite element constraints. Boundary conditions and contacts for the seat model were then defined to get it ready for explicit dynamic simulation. Modeling procedure described on the flow chart was strictly followed through all stages to create a sound and accurate finite element model.
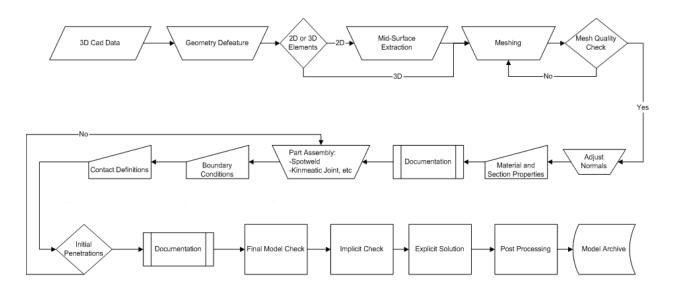
Figure 1 Flow Chart for FE Modeling Process [2]

Quality criteria used for meshing the seat is shown in Table 1.

Table 1 Mesh Quality Criteria

Quality Parameter	Allowable min /max
Min. Side Length	5 mm
Max. Side Length	30 mm
Max. Aspect Ratio	5
Min. Quad Angle	45 deg
Max. Quad Angle	140 deg
Min. Tri Angle	30 deg
Max. Tri Angle	120 deg
Max. Warpage Angle	15 deg
Min. Jacobian	0.6

Using the correct definitions for fasteners and kinematic joints, and defining the contacts between different parts of the seat structure and occupant is very important. Global control cards are some of the specialized control parameters that can control, accelerate and terminate the analysis. So it becomes very important to define correct parameters in control cards as these can enhance the performance of the software and reduce the computational time.

Material Characterization
Different tests were conducted to get the mechanical properties for metals, cushions and seat belts used for the seat FE model. Test data obtained from coupon tests was first used to validate the material models at component level and then implemented in seat model.

Seat Belt Test and Modeling

FE seatbelt was modeled by the combination of FE shell elements and 1D seatbelt segments. 1D seatbelt segments were used to represent seatbelt webbing. Material card used for 1D segments was MAT_B01 i.e. MAT_SEATBELT. This card requires the input of force versus engineering strain [3] which can be obtained through testing of the seatbelt webbing.

Test method introduces a displacement controlled loading/unloading profile designed to provide information on the tensile elongation limits of the belt webbing. The loading profile is broken into two subsequent segments. In the first segment, the seat belt is loaded up to 2,600 pounds. Then without interruption, the seat belt is unloaded to zero pounds, back to the starting position [4]. Figure 2 shows the test setup used for the belt test.

Figure 2 Seat Belt Test Setup (NIAR Test Facility)

Cushion Test and Modeling

LS DYNA offers wide variety of material models, each with different capabilities and designed to capture the unique behavior of different types of materials. There are several material cards available to model foam for the seat cushion. Material characterization has to be done accurately to model the foams for precise results. The test procedure for foam testing is based on report number DOT/FAA/AR-05/5, Development and Validation of an Aircraft Seat Cushion Component Test—Volume I [5]. This procedure is appropriate for typical upholstery and flotation foams used in the construction of aircraft seat bottom cushions.

Cushion test setup from NIAR test facility is shown in Figure 3. Compression test of the cushion is divided into two segments. For the loading phase, specimen is loaded in compression under controlled displacement at a rate of 30 in/sec. The maximum deflection will correspond to $\Delta L/L$ of 0.9. For the unloading phase, the actuator will return to its original position at a rate of 30 in/sec [4].

Figure 3 Cushion Test Setup (NIAR Test Facility)

Metal Coupon Test and Modeling

The Material model used for most of the deformable structural parts was MAT_24 i.e. mat piecewise linear plasticity. This card allows us to define an elastic-plastic material with an option to input an arbitrary stress versus strain curve and arbitrary strain rate dependency [3]. All the material properties used for the model are referred from MMPDS and from NIAR testing database. Test setup used at NIAR test facility for metal coupon testing is shown in Figure 4.
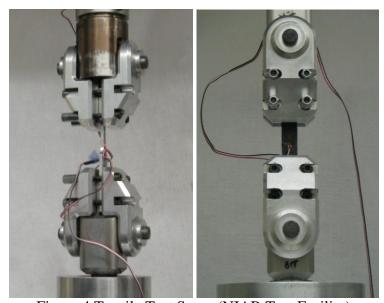

Figure 4 Tensile Test Setup (NIAR Test Facility)

Coupons were prepared from metals used for seat structure. Strain gages were used to measure strain experienced by the coupons during the test. Coupon tests were conducted at different strain rates.

Model Validation

By definition validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended use of the model [6]. As with any form of analytical modeling, validation is a key step in determining whether the model is acceptable for use in certification.

To validate the finite element model of the seat, results from the certification tests were used as reference data. Tests used for validation of the model were conducted as per AC 25.562 at the sled test facility of Civil Aero Medical Institute (CAMI). Dummy initial positions and seat deformation were recorded, floor loads and belt loads were recorded using load cells, accelerations on important parts of occupant were measured using accelerometers and high speed cameras were used to capture the kinematics of the seat and occupant. Validation of the finite element model of the seat is based on criteria's from AC 20-146 and SAE ARP 5765 document.

Detailed CAD geometry was not available for the seat, but a physical seat was provided by CAMI. To generate the geometrical CAD data, the seat was taken apart and every part was measured accurately and digitized. Non metallic parts like cushions were also modeled using the same procedure of reverse engineering. Figure 5 shows actual seat and its CAD geometry.

Figure 5 Comparison of Actual Seat and CAD Model

Finite element procedure explained earlier in this paper was strictly followed to create a typical aircraft seat model, which is shown in Figure 6. Material properties generated from coupon testing of metals, cushion and seat belts were used while defining material cards in LS DYNA. Pulse generated from actual test was used for simulation model.

Figure 6 FE Model of Typical Aircraft Seat

Two tests were conducted by CAMI as per 14 CFR PART 25.562 test condition. Test and simulation setup comparison is shown in Figure 7 and Figure 8.
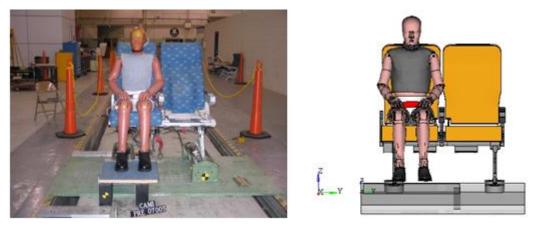

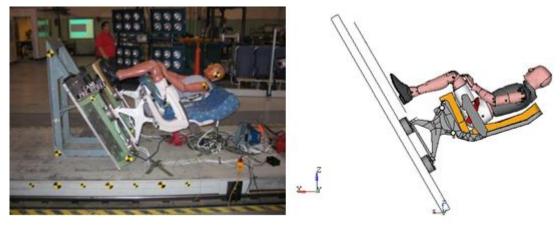Figure 7 0 Degree Forward Test Setup Comparison

Figure 8 60 Degree Test Setup Comparison

Validation Criteria

Two different criteria were used to validate the simulation model: 1) Dummy kinematics and 2) Quantitative comparison of results.

Dummy Kinematics:

Dummy kinematics from simulation and testing were visually compared. Also frames, captured at certain time intervals, were used to compare the kinematics of simulation model to the physical testing.

Quantitative Comparison of Results:

With increasing role of computational modeling in safety assessment, improved methods are needed for comparing computational and experimental results. There are many validation metric methods used. Sprague and Geers method was selected based on its intuitive score values, easy implementation, and bias towards experimental data which is consistent with certification procedures.

The Sprague and Geers method considers a magnitude error factor that is insensitive to phase discrepancies, a phase error factor that is insensitive to magnitude discrepancies. The magnitude error method is a very common and well known metric, used to compare two values quantitatively in the form of percentage difference. This method does not consider time variations or phasing, so it is only good for comparing the maximum magnitude of a response. A shape error is the difference of phase between two profiles.

Validation of Simulation Model for 0 degree Forward Condition

As discussed earlier, kinematic frames comparison and quantitative comparison were used as the validation tools.

Kinematic Comparison

Comparison of kinematics till 190 ms is shown in Figure 9. Kinematic frames show that the simulation dummy follows a similar pattern as that of test dummy. Movement of head and pelvis from simulation model follows closely to that of test. Structural deformation of seat back was also observed to be similar to that of test article.
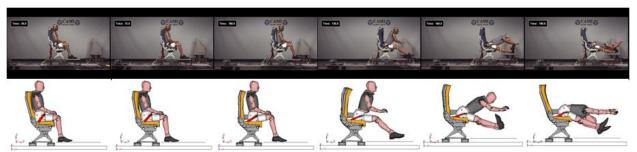

Figure 9 Kinematic Frames Comparison

Quantitative Comparison of Results

For this test, belt forces and floor loads were compared with the test data. On the test article dummy was sitting on right side of the seat, making the right side load cells more important than left side as they would be heavily loaded. Peak force comparison is shown in Figure 10.
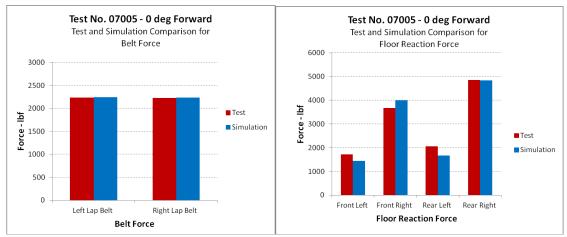

Figure 10 Peak Foce Comparison [7]

Time history plots of the floor loads from test and simulation are compared in Figure 11. And as can be seen simulation model predicted the same trend of load transfer as that of test.
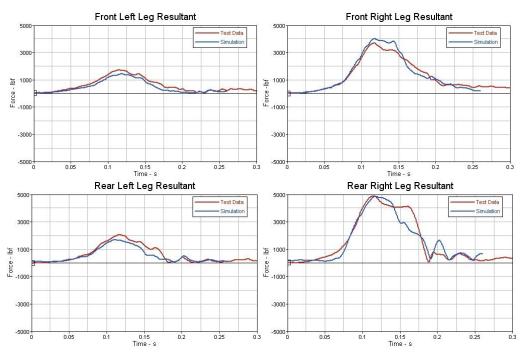

Figure 11 Floor Load Time History Plots Comparison [7]

Table 2 shows the profile validation results obtained using Sprague and Geers method. All of the critical simulation output channels (highlighted with bold letters) showed good comparison with that of test data and have the difference of peak values less than 10%. Shape error values also indicate that the simulation model closely followed the load transfer profile of the test.

Table 2 Quantitative Comparison of Results [7]

Component	Output channel	Mag. Error	Shape Error
Lap Belt	**Left Lap Belt**	**0%**	**8%**
	Right Lap Belt	**0%**	**8%**
Floor Loads	Front Left Leg	15%	19%
	Front Right Leg	**9%**	**9%**
	Rear Left Leg	18%	20%
	Rear Right Leg	**1%**	**9%**

The result comparison for front left and rear left loads shows higher percentage differences. This is because that the magnitudes of the original test values for these channels were very small and hence even a small difference between the test and simulation results in a higher percentage change.

Validation of Simulation Model for 60 degree Condition

Simulation results obtained from 60 degree impact condition are compared with the test data in this section.

Kinematic Frames Comparison

Comparison of test and simulation kinematic frames in Figure 12 shows that simulation model closely followed the kinematics of the test.
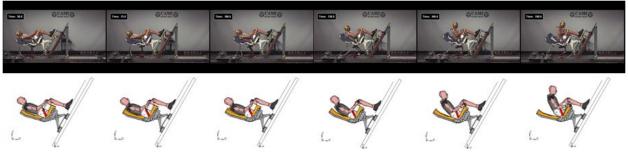

Figure 12 Kinematic Frames Comparison

Quantitative Comparison of Results

Primary purpose of 60 degree impact test or vertical test is to measure the lumbar load, which is the most critical channel for validation in this test. For vertical test modeling of cushion is very important as it directly affects the lumbar load of the occupant. Test data obtained from the compression test of the seat cushion was used to model the FE cushion. Comparison of peak lumbar force and time history plot is shown in Figure 13. The simulation model shows very good correlation with test data.
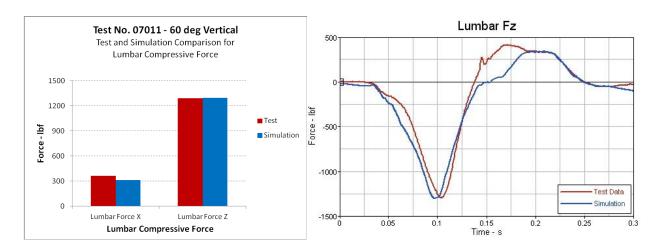
Figure 13 Lumbar Force Comparison [7]

Comparison of test and simulation results obtained from Sprague and Geers is shown in Table 3. Peak lumbar force predicted by the simulation model was exactly same as that of test data as can be seen in Table 3.

Table 3 Quantitative Comparison of Results [7]

Component	Output channel	Mag. Error	Shape Error
Lumbar	Lumbar Force X	12%	16%
	Lumbar Force Z	**0%**	**8%**

Conclusions

As per the requirements of AC 20-146, simulation model show's a good correlation with test data and was successfully validated for both test conditions. This model can be used to find worst case configuration for structural loading. A validated FE model can be used to substantiate any additional testing required when a part gets changed or modified. To use simulation for seat certification physical tests have to be conducted in controlled environment and have to be documented properly. With increasing improvements in computational tools, CBA will directly help in reducing the cost for seat design and certification.

References

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