Dynamic Simulation of Flight Passenger Seats

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Abstract:

The approval of aircraft seats for air traffic strongly depends upon the seat structures' performance under emergency landing conditions. In the progress of seat certification the legislator demands the seat developers to provide evidence of meeting several structural and biomechanical limits like HIC value, spinal loads and integrity of load paths. Within the scope of this work the applicability of dynamic simulation with LS-Dyna for this aircraft application is being investigated.

Keywords:

Aircraft seats, emergency landing, passenger safety

1 Introduction

Today's extent of air traffic requires a remarkable amount of legal regulations for the certification and assessment of structural components of aircrafts especially in terms of safety. From a technical point of view, aircraft seats are the structural interface between passenger and aircraft and therefore one of the most influential mechanical components on the safety of flight passengers. From 1980's studies it is commonly known that passengers in fatal flight crash situations who are still able to free themselves independently and escape the aircraft have a good chance to survive such accidents (e.g. emergency landing) [1,2]. Hence, safety demands particularly on flight passenger seats today emphasize on two criteria: Biomechanical loading of occupants and integrity of seat structures' load paths during crash (in order to assure survival space between seat rows) and consequently, crash safety has evolved to an important design criterion for seat developers. The University of Applied Sciences Hamburg in co-operation with AIDA Development GmbH has investigated the applicability of the dynamic simulation method with LS-Dyna in flight passenger seat design as an accompanying development tool in the run-up to certification testing.
Chapter 2 of this paper describes some general aspects of aircraft seat design and the legal regulations that apply to seat development with respect to dynamic performance as well as some considerations on certification testing. Chapter 3 focuses on the concrete work with LS-Dyna regarding three different seat designs. The paper closes with the results in chapter 4 and a conclusion of the current work and an outlook on further activities in chapter 5.

2 Aircraft Seats

2.1 Aircraft Seat Configurations

A typical passenger seat structure as shown in the left picture of figure 1 can be roughly divided into a lower (primary supporting) structure and an upper structure [3]. The lower structure normally consists of the seat legs, e.g. of milled aluminum parts, and one or more extruded transversal ducts connecting the seat legs. Built upon this is the upper structure, including seat pans, back shells, handrails, etc. Further, passenger seat structures cover double and triple seat configurations, depending on the aircraft's seat alignment (figure 1, right). The lower structure makes up the primary load path, i.e. the load transfer from the passengers into the aircraft floor, and is mainly the point of interest here from a mechanical point of view.

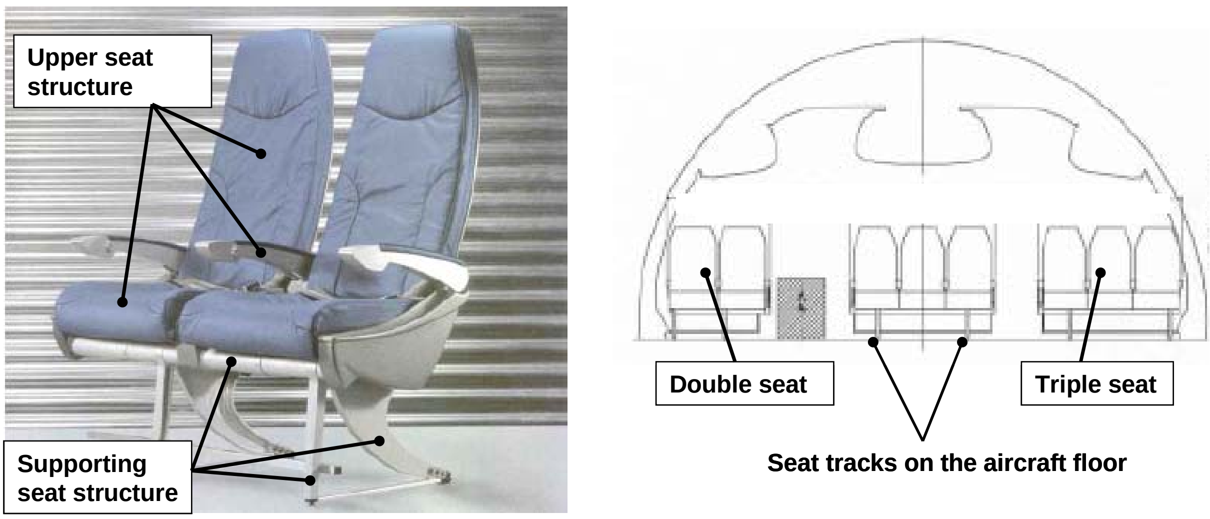


Fig. 1: Double seat configuration (left) and seat layout of an Airbus A340 aircraft

Due to the fact that the certification of flight passenger seats is very cost-intensive, the modular assembly of seat structures is a basic design principle. Today's aircrafts are quite different in seat alignment and hence, it is a major goal for the seat developers to find basic seat designs that allow up to 95% of structural members to be reused in different seat configurations on different seat track layouts. Taking this into account, the legal regulations accept the merging of different seat

configurations into seat families, e.g. if only shifting seat spreaders and seat legs on the transversal ducts for different seat track spacing. This idea of seat families significantly reduces time and costs for the seat certification.
The design of a passenger seat is affected by a wide range of requirements as there are spacing between seat rows in the aircraft, prescribed seating height, placement of baggage and life vests, stiffness requirements and of course costs, comfort and appearance, product life-time and maintenance considerations. All these needs leave to the seat designer few freedom to additionally fulfill the legal requirements in terms of crash safety.

2.2 Legal Regulations for Passenger Safety

Speaking of legal rules in terms of flight passenger safety, one typically is concerned with a number of regulations issued by the US aviation board, the Federal Aviation Administration (FAA) and its European equivalent, the European Aviation Safety Agency (EASA). In order to establish uniform standards in European and US aviation requirements, the Certification Specifications (CS) [4] and the Federal Aviation Regulations (FAR) [5] are to some extent agreeing in content. The CS/FAR are a self-contained works of all relevant requirements in international commercial aviation, containing for example crew licensing considerations, flight training procedure specifications and airworthiness requirements for the operating of aircrafts in commercial aviation.

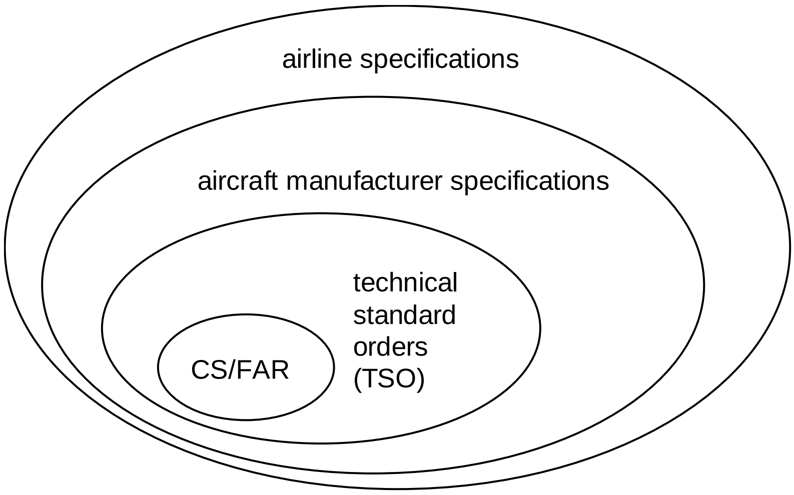


Fig. 2: Overview of relevant regulations for passenger seat development

The airworthiness paragraphs, which are located in Part 25 (CS/FAR-25), contain the complete catalogue of technical requirements for the developers of aircrafts and therefore for the seat developers and other component suppliers. CS/FAR-25 splits up into a number of paragraphs, two of which are the CS/FAR-25.561 and CS/FAR-25.562 (certification specifications). These specifications describe the static and dynamic emergency landing conditions to be applied for the seat approval process for commercial air traffic. In addition to these certification specifications the aviation boards have attached so called Advisory Circulars (for aircraft seats: AC-25.562 1B [6]), which give more detailed instructions of how to integrate the certification specifications in the development process of aircraft components. Further regulations to be considered are the Technical Standard Orders (TSO) and the aircraft manufacturers' and airline specifications (figure 2).
Usually, an aircraft is not being approved for air traffic with seats included to preserve the possibility of subsequent modifications to the seat layout, i.e. the alignment of seats in the aircraft interior. Certified seats can then be assembled into the aircraft in a certifiable layout using these seats.
For the certification of seats the TSO C127A [5] is the currently valid reference document. This document in turn refers to the SAE AS 8049A (Performance Standards for Seats in Civil Rotorcraft, Transport Aircraft and General Aviation Aircraft), which in detail defines the minimum requirements for a seat to be approved, e.g. structural requirements including dynamic testing for crash loads. Up to the 1980s seat approval had been performed by static testing only. With the above mentioned regulations certification of passenger seats has become more extensive with respect to dynamic performance requirements.

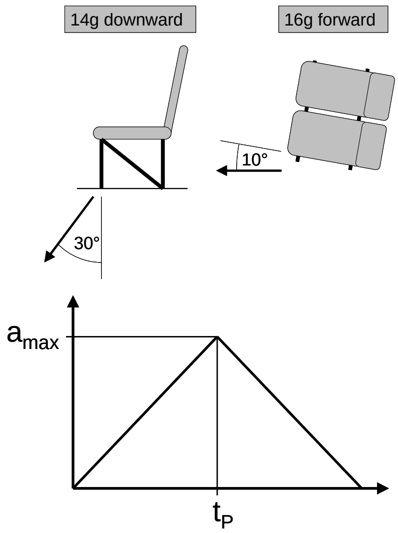
2.3 Certification Testing of Aircraft Seats

Conforming to CS/FAR-25 aircraft seats must withstand all possibly occurring working loads, i.e. handling loads and crash loads. The CS/FAR defines the emergency landing conditions to apply for certification as given in figure 3.

	9g Rule (old)		16g Rule (new)	
Item	Seat Certification	Seat in A/C Certif.	Seat Certification	Seat in A/C Certif.
Rule	TSO C 39b	FAR 25.561	TSO C127a	FAR 25.561 & .562
Reference	NAS 809		AS 8049b	(AC 25.562-1A)
Static Test	9g fwd	9g fwd	9g fwd	9g fwd
	3g side	3g side	4g side	4g side
	2g up	3g up	3g up	3g up
	6g down	6g down	6g down	6g down
	no rear	1,5g rear	1,5g rear	1,5g rear
Dynamic Test	No	No	16g fwd	16g fwd
			14g down	14g down
Deformation Limits (beside others)	No	No	3.0″ fwd	3.0″fwd or 6.0″ free between deformed and undeformed seat
Detail Requirements (passenger seats)			Lumbar Load	Lumbar Load
			HIC for one standard seat to seat	HIC for every seat place
				HIC for front row
			Femur Load	Femur Load

Fig. 3: Seat certification requirements

The dynamic proofs (16g rule, figure 3) of the seat structure consist of a 16g forward and a 14g downward test. The dynamic testing procedure roughly splits up into biomechanical and structural tests. Both, structural and biomechanical tests are to be performed under the loading conditions illustrated in figure 4.



	Downward test	Forward test
Deceleration applied under	30° pitch	10° yaw
Initial velocity	10,67 m/s	13,41 m/s
Max. deceleration pulse a_{max}	14g	16g
Half deceleration time t_P	80 ms	90 ms

Fig. 4: Dynamic test conditions

2.3.1 Structural tests and injury criteria

Dynamic testing of seats can be divided into structural and biomechanical tests. The goal of the structural test procedures is to measure the maximum loads introduced into the aircraft floor by the seat (14 downward test) and the permanent (plastic) deformation of the seat (16g forward test) to determine the survival space left for passengers after a crash (see chapter 1). A maximum permanent deformation in forward direction of three inch in the 16g forward test is allowed. The interface loads of the aircraft floor are subject to aircraft manufacturer specifications. Figure 5 shows a structural test setup for a triple seat configuration. The test in preparation is a 16g forward load case with two dummies included. Figure 6 shows a section of the aircraft seat track and the lower supporting structure of the seat. The seat is attached to the aircraft seat track via a double stud element (figure 7).

Fig. 5: 16g forward structural test setup for seat certification

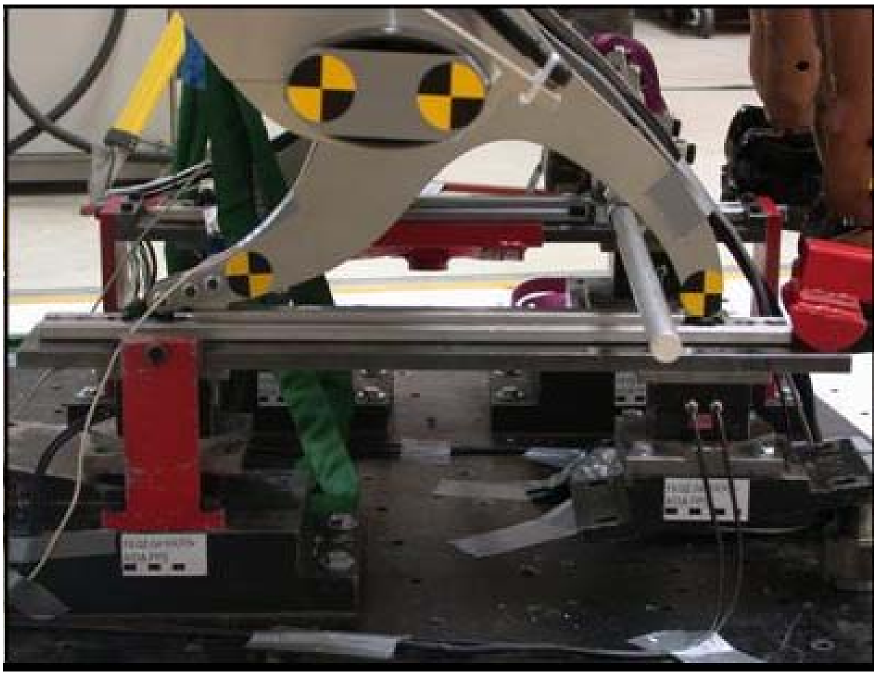


Fig. 6: Seat attachment on the aircraft seat tracks

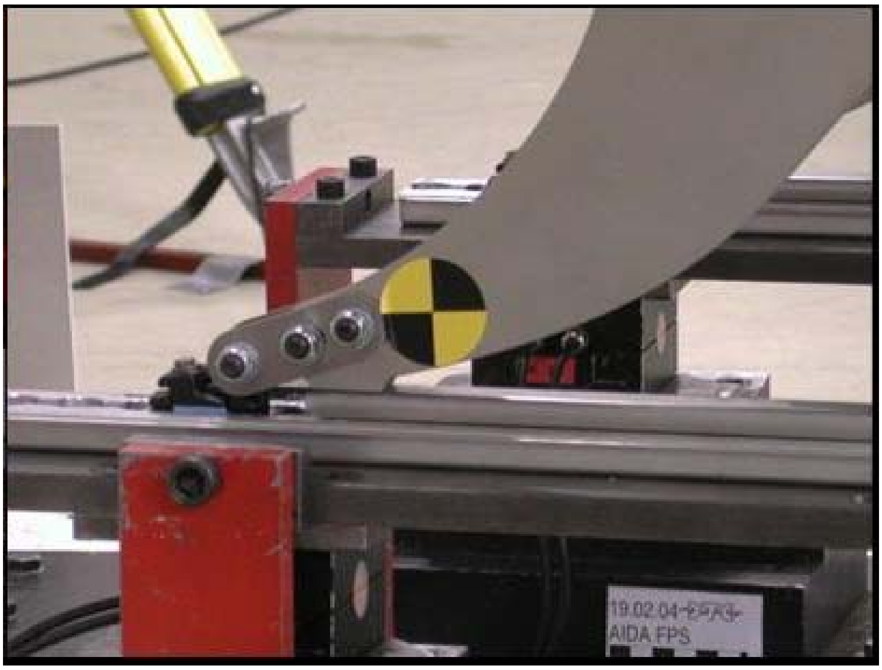


Fig. 7: Double stud for the seat attachment on the aircraft seat track

For the structural tests it is assumed, that the aircraft floor is pre-damaged from the crash situation. Therefore, the seats are mounted on the test sled with 10° pitch on one side and 10° roll on the other side of the seat (figure 8). This increases the bending moment in the transversal members and generally the pre-stress in the seat.

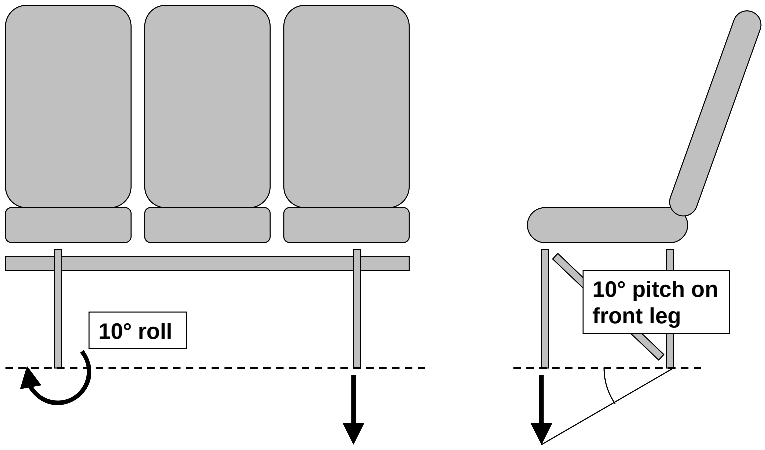


Fig. 8: Pre-deformation applied for structural test

While the structural tests can be performed with a single seat structure, in the majority of cases the biomechanical tests are done using a row-to-row test setup. That is, a tandem of seats is arranged successively to simulate a possible head or knee strike on the leading seat. The critical seats in the aircraft for head strikes (e.g. laterally offset seats, stiff areas like tables on the back shells) are determined by the passengers' head trajectory in preparation for the tests. In the best of all cases a kinematics analysis shows that head strike doesn't occur. All other seats then have to be tested with special focus on the expected area of head contact. Critical injury criteria to be determined in the biomechanical tests are:

- Head injury criterion (HIC)
- Femur compressive loads (knee strike in 16 forward test)
- Spinal (lumbar) loads (14g downward test)

2.3.2 Additional requirements

The certification of seats according to the above standards can be seen as a minimum requirements certification. The aircraft manufacturer defines additional requirements, one of which is the maximum allowable loads to be introduced into the aircraft floor by the seats via the seat track. These loads may be defined as maximum values with respect to a single lip of the seat track (see figure 13, e.g. Boeing specification) or alternatively with respect to the seat attachment characteristic (e.g. Airbus specification). In the latter case the load allowables refer to either single stud or double and triple stud attachments (see figure 7). Figure 9 gives an overview of the load allowables from an Airbus specification in flight direction (F_x), lateral direction (F_y) and upward direction (F_z) for double and triple studs.

Load direction	Allowable load [N] (without fitting factors)
Fx	20300
Fy	12000
Fz	26300

Fig. 9: Allowable loads for a double or triple stud (Airbus specification)

These loads can be understood as ultimate loads not depending on a certain load case. Hence, it is the seat developer's responsibility to identify the critical load case regarding the seat track's strength.

2.4 Numerical Simulation of Aircraft Seats

Due to the high expenditure of cost and time in seat certification it is recommended by the legislator to use computational methods - particularly the dynamic finite element analysis - as a compliant means to accompany the process of seat approval. This requires validated methods and finite element models, not only for the seat structures but also for the dummy models. Today's method's in computational structural analysis are capable to handle full-scale simulation models of an aircraft seat test setup. Although we are not yet able to replace dynamic testing of aircraft seats with simulation methods, the dynamic simulation can amongst others serve in

- the assessment of stress distribution in the seat structure and the estimation of maximum stressing of members to find critical structural areas and reveal room for constructive improvements,
- the evaluation of load introduction into the aircraft floor,
- the estimation of head trajectories and injury criteria,
- concept studies,
- robust analyses,
- design optimization,

and therefore save time and costs by avoiding multiple failed testing before certification is passed [7].

3 Simulation of Certification Tests with LS-Dyna

Until now three different seats were calculated with LS-Dyna under different premises. One of the major points in that the simulation of aircraft seats differs from for example automotive crash applications is the long crash durations. The prescribed load history of 180ms and an overall of approximately 250ms to cover all relevant events is a challenge for the use of the explicit solver.
However, the goal was to prove suitability of LS-Dyna simulation for the assessment of the points given in paragraph 2.4. The main focus was put on the structural behavior of the seats in the 16g forward load case, which has been identified from years of seat development as the most critical one in terms of crash performance. This is due to the concurrent design goals of stiff behavior (minimum deformation to provide survival space) and best amount of energy absorption. The problem of energy absorption arises in the form of high tensile loads in the aircraft seat track at the rear floor attachments when seat structures are too stiff, and is one of the most critical problems in seat design. Some basic features of the introduction of dynamic simulation to seat development are described in the following.

3.1 Crash Model Preparation

The static testing (see figure 3) of passenger seats at AIDA Development is currently simulated with the MSC Nastran solver. These models were taken as the base models for the dynamic simulation of two seats (Foldable Passenger Seat, FPS, and Advanced Economy Class Seat, AECS). For obvious reasons the static models are to a great extent simplified, for example, loads from occupants and attached parts like back shells, armrests, seat pan, etc. are modelled as lumped masses and connector elements are modelled as beam and rigid body elements. The process of model generation for the LS-Dyna simulation therefore splits up into the following points:

1. translation of existing geometry into LS-Dyna format,
2. adding of „physical“ models of relevant parts (dummies, seat belts, test sled, simple seat surfaces),
3. definition of contacts
4. definition of dynamic load cases,

the most critical of which is the first. Figure 10 and figure 11 show the static and dynamic models of the FPS and the AECS seats as they were used in the respective analyses. Generally, there exist a number of ways to prepare a MSC Nastran model for dynamic simulation, each of which having its own advantages:

- Using a pre-processor capable of reading and exporting MSC Nastran models in LS-Dyna format
- Including a MSC Nastran model via the *INCLUDE_NASTRAN keyword
- Using self-written procedures for formatted reading of NASTRAN input files and converting into LS-Dyna format
- Mixed manual and automated text editor-based conversion of input files.

In this work a combination of the above possibilities was used. In the first step the model was split into sub-files, each containing a consistent set of finite element entities, such as one „nodes“-file, one „beams“-file and so on. Sorting the model like this prevents the translation process from producing an „unreadable“ model in case of unsupported keywords and each file can be tested for correct translation independently. Further the expense for self-written procedures and automated editor-based translation is reduced, if finite element entity types do not have to be each located in a „mixed“ file.

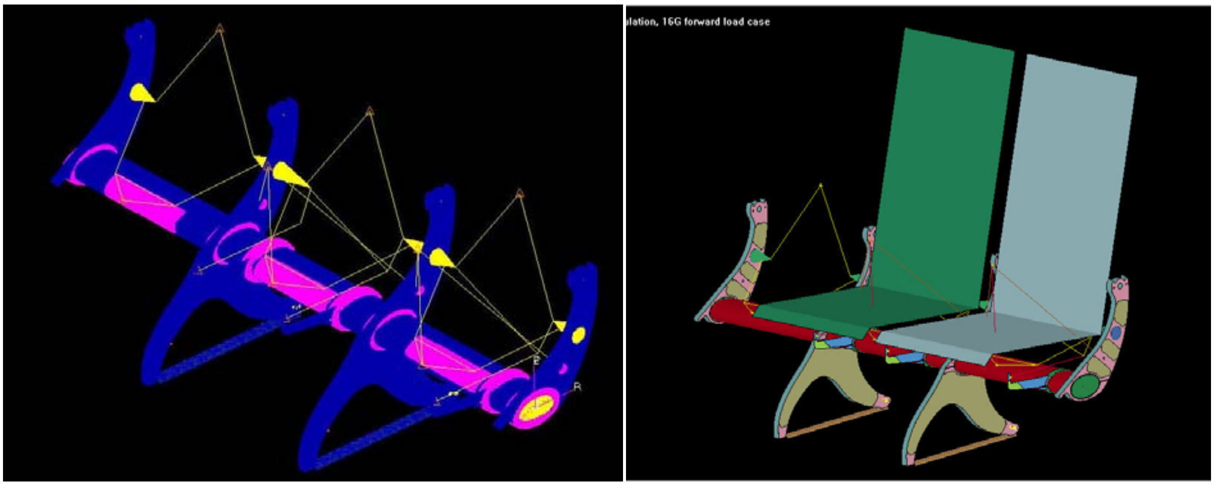


Fig. 10: FPS finite element model: MSC Nastran (left) and LS-Dyna (right)

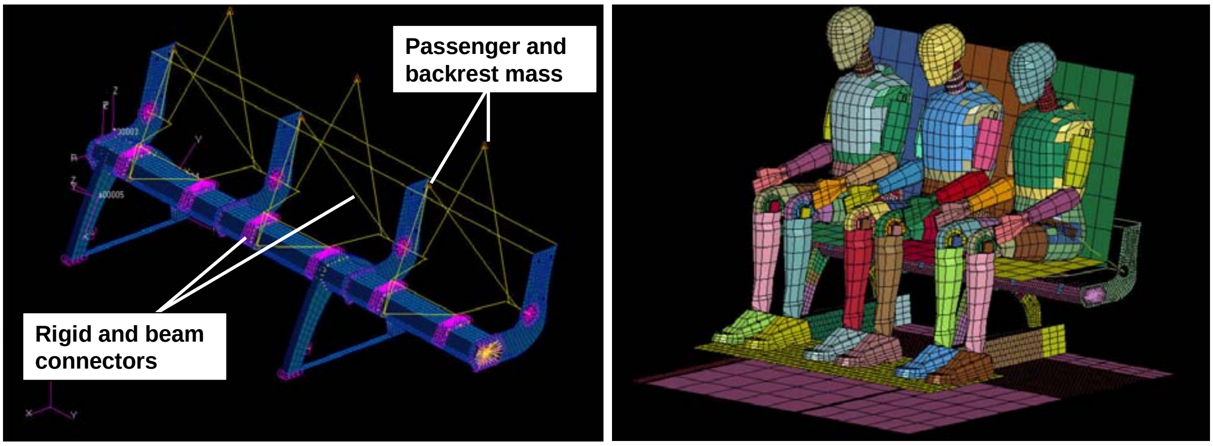


Fig. 11: AECS finite element model: MSC Nastran (left) and LS-Dyna (right)

The resulting files can be easily reassembled or included in a superior file via the *INCLUDE keyword. For the translation of „standard“ keywords like *NODE, *ELEMENT_SHELL, etc. it is convenient to use LS-PrePost or the *INCLUCDE_NASTRAN keyword (a list of officially supported keywords can be found in the LS-Dyna keyword manual). Problems with this technique arise, if MSC Nastran features are used in the model, that differ conceptually from LS-Dyna definitions, such as globally oriented beam elements (LS-Dyna: third node orientation; *ELEMENT_BEAM_ORIENTATION keyword is not supported by MPP-version 970) or material orientations for composite materials that refer to a local coordinate system (LS-Dyna: global or element-edge orientation). In these cases a manual translation with a self-written program becomes inevitable. In some cases the „search and replace“ function of a simple text editor (in an automated run) may help, e.g. to translate CROD cards into the very similar formatted LS-Dyna type 3 beams. Manual textual translation of “non-geometry” entities (e.g. property and material cards with only few occurrences throughout the model) can easily be done manually.

3.2 Seat to Floor Attachment

3.2.1 Problems of seat attachment

For the rear seat legs' attachment the tensile load in upward direction in the 16g forward load case usually turns out to be critical. The seat is attached to the floor via a seat track that's fixed to the aircraft floor. The seat track lips shown in figure 13 (usually aluminium) have certain strength and one task of seat design is to prevent the seat from ripping the studs out of the seat track. To assess the characteristics of a seat's load introduction into the aircraft floor, in the first step the attachment was modelled as a rigid body connection and the loads were measured in the sled socket. The results for the FPS are shown in figure 12.

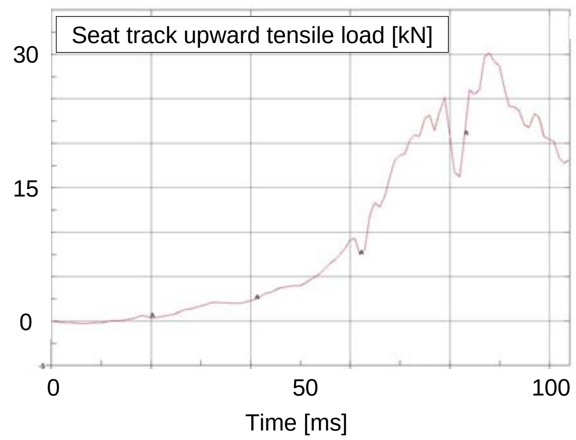


Fig. 12: Sled socket upward load (sae1000 filtered) for the FPS forward load case

Compared to the force limit given in figure 9 the maximum load of 30kN is much too high to pass the certification test.

For the AECS the floor attachment was modelled with a substitute discrete beam element with linear elastic force-deflection-behavior (translational stiffness 12kN/mm) to roughly account for certain energy absorption of the seat track rather than the use of rigid bodies. Figure 14 shows a detail view of the respective area.

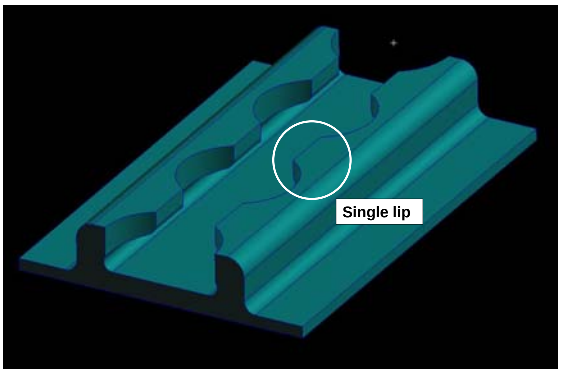


Fig. 13: Section of an aircraft floor rail for seat attachment

The discrete beam element has a quadratic failure criterion incorporating three translational and three rotational deflections with the limits given in figure 9.

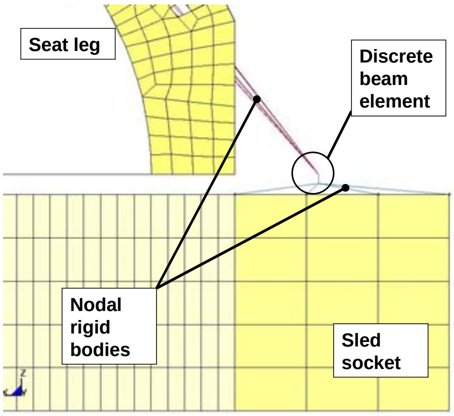


Fig. 14: Substitute element for rear seat leg attachment

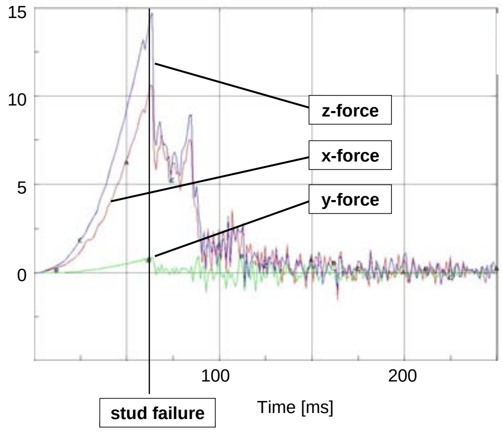


Fig. 15: Force components in the discrete beam element (left rear leg) for AECS forward load case in kN

3.2.2 Deformation elements

One approach made in seat development to solve the problem of energy absorption is the use of deformation elements. Among the different types of energy absorbing elements (e.g. viscous dampers) a method using plastic deformation was chosen for investigation. Figure 16 shows a possible way of having a deformation element integrated in the rear seat leg of the AECS. The seat leg is made of composite laminate and the approach was to investigate, if controlled failure of the composite material could be utilized to absorb kinetic energy by plastic deformation. Therefore two bolts were assumed to rip the seat leg in the lower area in case of 16g forward loading.

In a first step a refined model of the lower seat leg section including two bolts was used to investigate the seat leg laminate's general plastic behavior. The substitute model was fixed in space and two rigid bolts with prescribed time-proportional displacement were drawn through the seat leg (figure 18) in order to generate a characteristic force-displacement curve for the use in the main seat simulation. The seat leg laminate was made of 40 layers in 0° and 45° direction (i.e. direction of bolt displacement), making up a total thickness of 14mm.

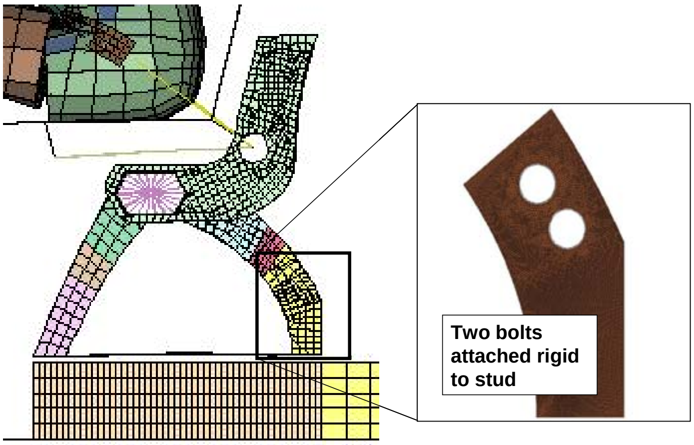


Fig. 16: Deformation element making use of two rigid bolts

The used laminate layup (which was primarily selected for stiffness purposes) turned out to be too stiff to absorb an observable amount of kinetic energy (figure 19). The following table gives an overview of the material used for a single layer.

LS-Dyna material	*MAT_LAMINATED_COMPOSITE_FABRIC
E_a=E_b	64.000 N/mm^2
G_{ab}	5.700 N/mm^2
G_{bc}=G_{ca}	1.250 N/mm^2
X_c	490 N/mm^2
X_t	540 N/mm^2
Y_c	510 N/mm^2
Y_t	495 N/mm^2

Fig. 17: Single layer material data

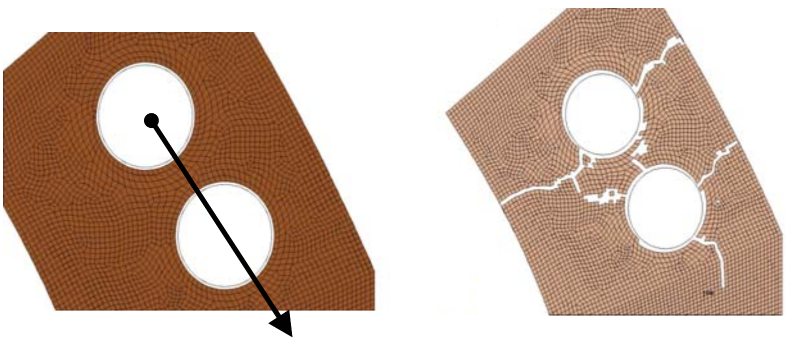


Fig. 18: Prescribed (assumed) bolt displacement u(t) ~ t in direction of arrow (left) and initial crack propagation (right)

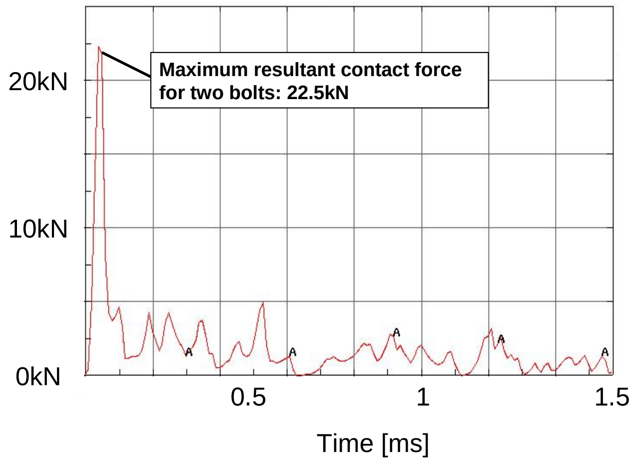


Fig. 19: Summed contact force for two bolts

However, further investigations on this show that the use of composite materials for deformation elements may be a reasonable solution, depending on the composite layup. Figure 20 shows a principal model of a plate ripped by a rigid bolt made of two layers ([+45° -45°] layup). No diffuse cracking but a smooth failure of the plate is observed in this case [8].

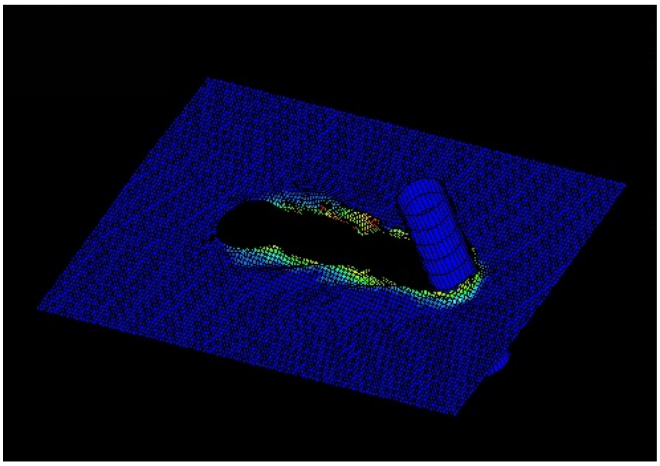


Fig. 20: Rigid bolt pulled through a laminated composite plate

3.3 Seat Pre-Deformation

The seat pre-deformation is applied to the seat in line with the dynamic test preparation. The seat pre-deformation can be assumed to be a static load case, because the seat is mounted on the test sled in this deformed state. The FPS and the AECS were calculated without this pre-deformation. For the third seat (Business Class seat, BC) an attempt was made to use a mixed implicit-explicit calculation as well as a solely explicit calculation for the integration of pre-deformation loads in the simulation. Generally, there are two possible ways of joining a pre-deformation load case and a main (crash) load case, the first of which is a static one.

- via a technique, that comes from metal forming applications,
  that is, the pre-deformation is applied within a reasonable loading time (e.g. 60 sec.), using an implicit dynamic or implicit static solution. With an *INTERFACE_SPRINGBACK_LSDYNA keyword the pre-deformed stress and deformation state is exported and nodal coordinates after pre-deformation are output with LSPrePost (*dynain* file in 970 version). These data are included

in the 16g/14g load case with the *INITIAL_STRESS_*OPTION* (stress and deformation state) and the *INCLUDE (nodal coordinates) keywords.

- via explicit/implicit switching within a simulation run,
  which implies mainly the same load definitions but joins both load cases in one simulation. This saves the handling of intermediate stress states but requires a curve to be defined, that determines phases of explicit and implicit calculation (*CONTROL_IMPLICIT_GENERAL keyword, IMFLAG < 0).
- via an overlay of both load cases in a solely explicit solution sequence
  This is a rather undesirable way of pre-deforming the structure, because the pre-deformation of the seat must be applied in a total amount of time in the order of tenth seconds (to keep explicit computation time within reasonable limits), which has not yet been closely investigated for the results quality.

Unfortunately, in this work the implicit code did not tend to converge throughout 60 sec. of pre-deformation of the BC seat, so the third way (solely explicit) was chosen to be applied (see figure 21 and figure 22).

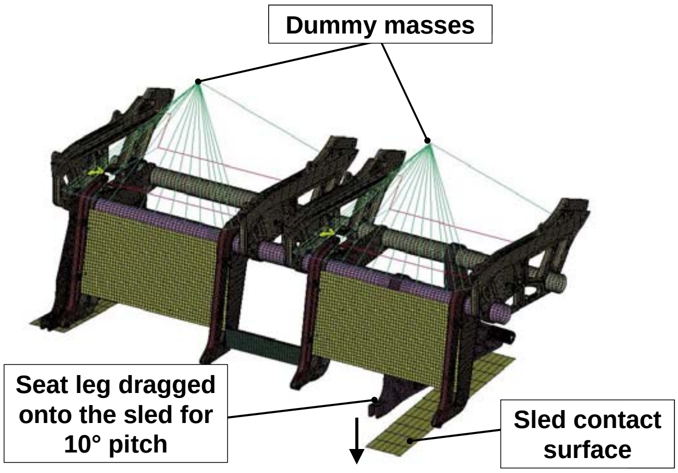


Fig. 21: Pre-deformation of the BC seat

The implicit solver first tried for the pre-deformation was able to correctly handle contact definitions but for some undetermined reason stuck in a convergence failure at the end of the pre-deformation loading. A possible solution for this could be the automatic explicit/implicit switch option of LS-Dyna (*CONTROL_IMPLICIT_GENERAL keyword, IMFLAG=4) if converge can't be established in implicit mode. This will be subject to a closer look in future work.

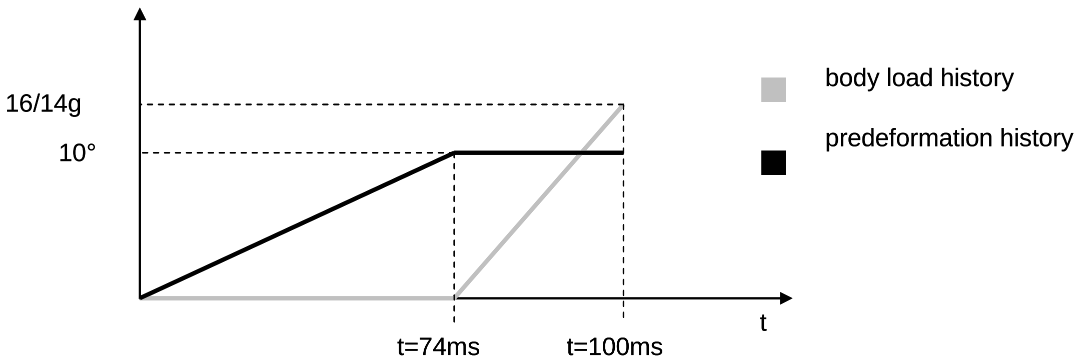


Fig. 22: History of synchronous pre-deformation and crash loading in an explicit calculation for the BC seat

3.4 Further considerations

The simulations done can be seen as simulations of structural testing. For proper load introduction LDD H3 dummy models (Dynamore "Load Device Dummies", Rel. 1.2) with simple seat belts have been used. These dummies are not validated for the measurement of injury criteria, and their physical equipment does not support measuring of lumbar and femur loads (the dummy skeleton is made of rigid, so no stress integration can be applied). As a consequence, there was no need to build up a model for row-to-row testing. However, the used dummy models can at least be used to estimate the head trajectories, for example in a kinematics analysis to determine HIC-critical seats in the aircraft interior layout. Figure 23 shows a head trajectory of a dummy on an AECS subject to 14g downward loading. Within LS-PrePost nodal coordinates can easily be traced through time. If the crash loads are not applied as gravity loadings (*LOAD_BODY_OPTION keyword) but through a decelerated sled geometry, an additional reference node on the sled must be traced, too, to determine the trajectory from the coordinate differences. If necessary, the head trajectory can be determined from the envelope of several node traces, for example in MS-Excel.

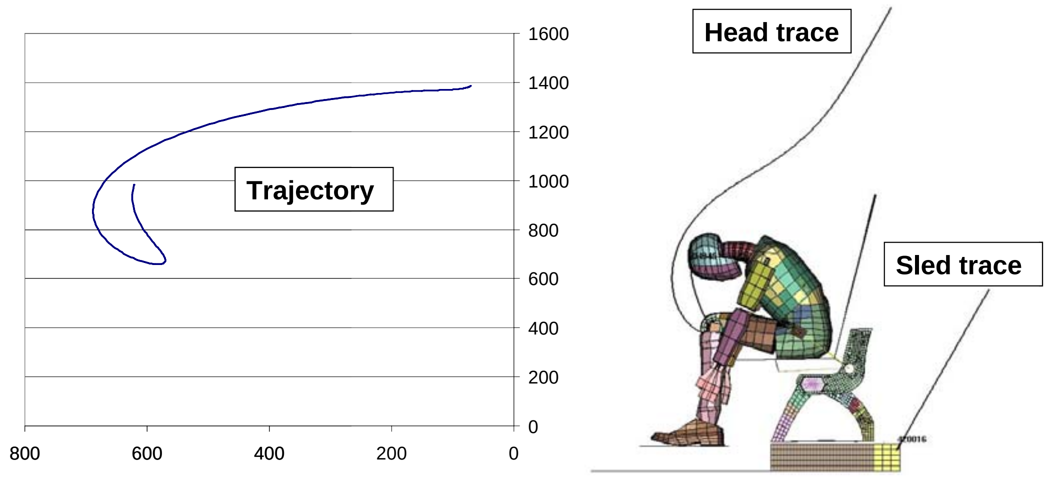


Fig. 23: Traces and trajectory for a single head node, processed in LS-PrePost and MS-Excel

4 Results

From years of seat development it is commonly known that the 16g forward load case is the most critical in terms of dynamic behavior. The major challenge for the seat designers is the compromise between stiffness requirements and energy absorption in this load case.

Figure 24 shows results of the 16g forward load case calculation of the FPS compared to a video of the hardware test. Although the general behavior of the simulated seat structure looks quite similar to the real test, the rupture of the rear seat leg could not be exactly predicted. In the hardware test the rupture occurred on the right seat leg, while the simulation predicted a rupture in the corresponding structural area on the left seat leg. Furthermore in the hardware test the rupture followed a detaching of the seat leg from the seat track, which in the simulation could only be observed through the exceeding of the maximum loads in the sled socket. The most probable reason for these differences is the absence of a pre-deformation for this seat in the LS-Dyna simulation. Implicit static calculations have shown that by the pre-deformation alone not only the aircraft seat tracks but also the seat itself can be highly stressed in the near of its tolerable limits. This underlines the need of finding a solution to include the pre-deformation in a reasonable way in the dynamic simulation and therefore draw more detailed conclusions on the structural behavior of seats in forward crash.

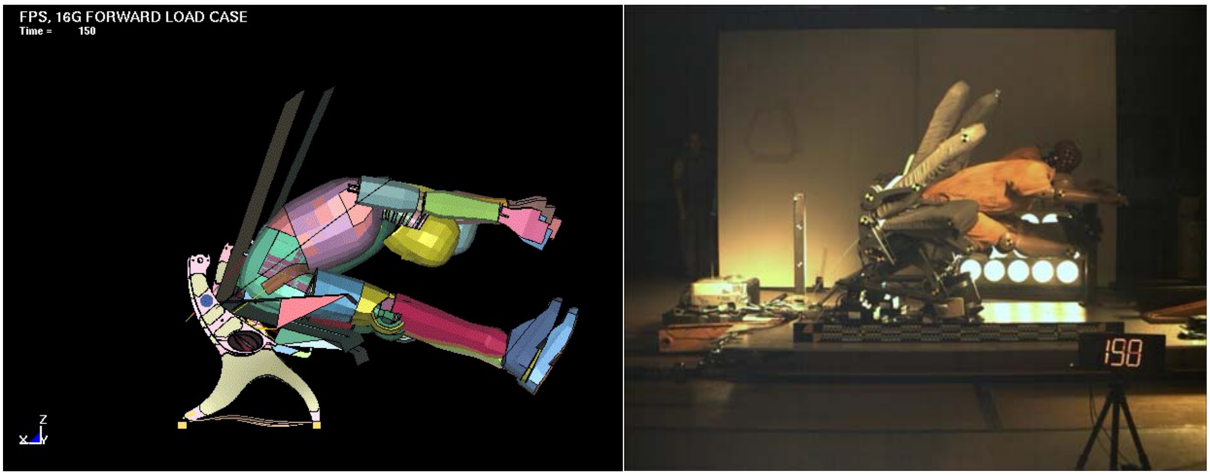


Fig. 24: 16g forward test of the FPS: LS-Dyna calculation (left) and hardware test (right)

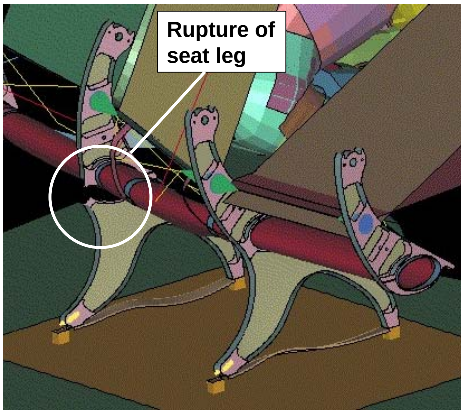


Fig. 25: Seat leg rupture in the 16g forward load case

Figure 25 shows the predicted rupture of the left seat leg in the LS-Dyna simulation. Furthermore, the measurement of loads on the seat track would have shown that the rear seat stud and the seat track could possibly not carry the loads from the forward load case.
The current setup of the finite element model can - although lacking the pre-deformation - give us a good hint where to expect problems on the seat's crash performance and, combining the results of implicit static analyses of the pre-deformation with the current LS-Dyna results concerning the seat leg rupture, the simulation could have helped in this case to identify the rear seat leg as a critical area for probable failure.

5 Conclusion

The simulations of aircraft seats performed until now all concerned structural testing. It was the main intention to assess stress distribution and aircraft floor load introduction for the three seats to test the suitability of the LS-Dyna software as a means to predict the structural performance of seat designs in certification testing to some extent. Having the pre-deformation applied to the simulation, we will be able to draw detailed conclusions on the seat's behavior in the required load cases. Some further work to be done amongst others is:

- the validation of simulation models by correlation with hardware test results.
- a more detailed modelling of the upper seat area (cushions, dummy positioning)

- the use of validated, fully equipped dummy models to perform biomechanical testing in row-to-row simulations
- the use of the LS-Dyna implicit solution capabilities to realize a pre-deformation

It can be stated so far, that dynamic finite element analysis with LS-Dyna is a suitable method in aircraft seat development to predict crash behavior and since the dynamic properties of aircraft seats are such an important design criterion today, it is most likely that this method will still more enter the product development process as we are now able to perform other important tasks like for example design optimization for crash performance.

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