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Hybrid III Numerical Model for Aircraft Seat Crash Performance Assessment

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Anthropomorphic test devices are used to develop structures proficient in guaranteeing the survivability of the passengers during a crash. The numerical model of a Dummy Hybrid III 50th-percentile developed to assess aircraft seat crash performances is here described. The numerical model was validated, at the beginning, considering the subcomponents and, then, referring to a down test carried out to investigate the crash behavior of a physical Hybrid III. The accuracy and the reliability of the overall model was verified using the homologation test of an actual helicopter seat equipped with impact energy absorption devices. The close correlation between experimental and numerical results demonstrates that the model is a feasible numerical tool for crash event analysis as well as for aircraft seat assessment.

I. Introduction

MOST life-threatening and disabling injuries caused by a crash involving humans can be minimized by the design of crashworthy devices and safety restraint systems for ground vehicles and aircraft.

Anthropomorphic test devices (ATDs), also known as *anthropomorphic dummies*, are human surrogates used in crash tests: a tradeoff between typical human behavior at a specified location in the body and overall kinematic behavior vs reproducibility, durability, and confidence. An ATD is meant to reproduce human physical characteristics such as size, shape, inertial properties, stiffness, and energy absorption and dissipation properties.

The use of ATDs has made it possible to evaluate the occupant protection potential of various types of restraint systems and impact energy absorption devices. ATDs, in fact, allow monitoring the mechanical response of a human body during a crash event by equipping it with transducers measuring accelerations, deformations, and loading of the various parts of the body. Analyses of these measurements are used to assess the effectiveness of crash safety systems.

The significant increase of computational power and acceptance of virtual testing has led to the development of more advanced numerical models of vehicles as well as of the human body. At the same time, sophisticated numerical models of the ATDs used in the crash tests have been demonstrated to be a flexible and reliable tool for investigating the crash response of complex dynamic systems. A numerical ATD with numerical sensors allows for collecting the same data as in a physical test in various parts of the model: accelerations (head, thorax, pelvis), deformations, and loads (lumbar spine). Furthermore, with respect to a physical test, a numerical simulation offers a remarkable advantage: it is possible to measure every physical quantity at any instant in time during the event. Experimental tests are difficult to arrange and expensive, and therefore, numerical simulations represent a convenient way to reduce development time and cost. Nevertheless, experimental tests are not superfluous because they represent the necessary reference to develop and validate the numerical models used in the simulations.

A number of different numerical models of ATDs exist. The outcomes of research aimed at developing a finite element (FE) model of a Dummy Hybrid III 50th-percentile (DH350), shown in Fig. 1, for the assessment of the crash performance of aircraft seats accordingly with Federal Aviation Administration (FAA) prescriptions [1] are presented. The research consisted of two phases. In the first phase, the numerical model of the DH350 was developed and validated, initially, referring to tests on subcomponents carried out for the approval of the physical ATDs [2], and then, referring to a down test carried out at the TNO of Delft to improve the crash behavior of FAA DH350 numerical models [3]. In the second phase, the accuracy and the reliability of the overall numerical model was verified referring to the homologation test of an actual helicopter seat equipped with impact energy absorption devices [4] meant to reduce the loads on the occupant when a crash landing becomes unavoidable. Eventually, referring (*qualitatively*) to the crash behavior of the ATD and (*quantitatively*) to the lumbar spine load, a close numerical–experimental correlation was obtained. In view of that, it was concluded that the model is a feasible tool for investigating the considered event readily extendible to the analysis of analogous crash events and different impact scenarios. The model is a convenient tool for improving the design of high-efficiency restraint systems and impact energy absorption devices.

II. FAA-DH350 Numerical Model

The main characteristics of a physical FAA-DH350 and how these characteristics were included in the numerical model are described in this section.

A. Physical FAA-DH350

Since the first attempt to create a human surrogate, different anthropomorphic dummies have been developed. The National Highway Traffic Safety Administration (NHTSA), recognizing a need for standardization and reliability of the ATD models, selected and contributed to the development of standard ATDs to be used in approval crash tests for the automotive industry. NHTSA indicated, with detail, for each one of the recognized ATDs, the components (number, design, and features) and the requirements for the homologation of the ATDs [1]: each component must be verified by prescribed testing procedures. Allowed materials are listed and characterized. Instrumentation on the ATDs must comply with the standard specifications.

The Hybrid III is one of the most advanced anthropomorphic test devices and, therefore, it is widely used in crash testing. The Dummy

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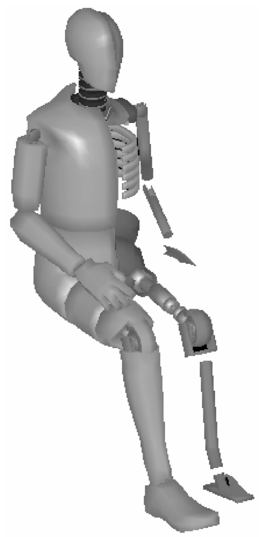
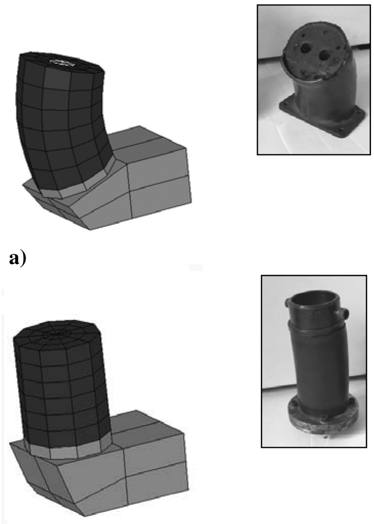


Fig. 1 Hybrid III 50th-percentile FE model.



a)

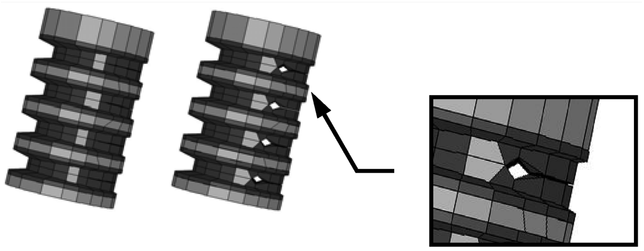
b)

Fig. 2 Lumbar spine of a) original LSTC and b) LAST FAA-DH350 FE models.

Hybrid III 50th-percentile (male) was first introduced in an automotive crash test [2]. During a car crash, the decelerations are mainly longitudinal, and therefore, the most critical parts are the neck and the thorax. During an aircraft crash, the most relevant deceleration component is vertical, and therefore, one of the most critical parts is the lumbar spine. In view of that, the DH350 for aeronautical applications was equipped with a straight lumbar spine element (Fig. 2) to accommodate a load cell and measure the lumbar spine loads. Hybrid III characteristics are described in the Code of Federal Regulation (CFR) 14, Part 572 Subpart E, Hybrid III test dummy [2], whereas the modifications in the lumbar spine are described in the Federal Aviation Regulations (FAR) and the analogous Joint Aviation Regulations (JAR) Advisor Circular 25.562-1 [Society of Automotive Engineers (SAE) paper 1999-01-1609].

B. FAA-DH350 Numerical Model

The FE model of a DH350 comes as a part of the FE code used in this research, that is, LS-Dyna 970 [5] developed by Livermore Software Technology Corporation (LSTC). This DH350 model consists of rigid elements and is intended to investigate automotive crash events and therefore the lumbar spine is curved (Fig. 2a). A number of research projects aimed at improving the geometry and materials of this model have been carried out.



a) b)

Fig. 3 Neck of a) original LSTC and b) LAST FAA-DH350 FE model.

Moving from the built-in model and benefiting of the outcomes of the mentioned research, an FAA-DH350 model meant to assess aircraft seat crash performances has been developed at the Laboratorio per la Sicurezza dei Trasporti (LAST) Crash Labs of the Politecnico di Milano, Italy. The resulting LAST FAA-DH350 model consists of the same component assemblies defined for the physical ATD: 109 parts (61 rigid and 48 deformable) and 5588 elements (1784 shells, 26 beams, 3768 solids, and 10 discrete elements). The degrees of freedom of the ATD, which are a convenient approximation of the degree of freedom of the human body, are reproduced by means of revolute and spherical joints, whereas the possible interaction between the parts is taken into account by defining the necessary contact interfaces.

The most evident difference with the original LSTC-DH350 model is in the lumbar spine elements that were modified and the spine straightened to include a sensor for the measurement of the lumbar spine loads (Fig. 2b). Changes with respect to the automotive ATD were necessary to measure lumbar loads and to more accurately describe the kinematic behavior in the vertical loading condition. The straight lumbar spine is based on the Hybrid II model that stands as a reference in the aviation crash world.

The straightened spine is not the only improvement to the LSTC-DH350 model. The model here introduced is the outcome of an ongoing research [3,4] aimed at developing a reliable FAA-DH350 numerical model for aircraft seat crash performance assessment. Indeed, the research concerned not only the lumbar spine element (Fig. 2), but also the contact definitions among the ATD subcomponents, the geometry of the cervical area (Fig. 3) and other less-evident adjustments in the geometry and material definitions necessary to improve the overall ATD impact behavior.

III. Subcomponent Validation

The development and the validation of the LAST FAA-DH350 numerical model is now described. In particular, the model was initially developed and validated by subcomponents. The numerical results were evaluated, *quantitatively*, referring to the requirements for the DH350 homologation contained in CFR 49-Part 572 [2] and, *qualitatively*, referring to the data collected during subcomponents tests carried out for the calibration of the FAA-DH350 used at LAST Crash Labs for helicopter seat homologation tests. Automotive and aviation subcomponent tests described within Part 572 section are the same, but further tests on the lumbar spine of FAA-Hybrid III are required, and an example of these tests is provided in the next section.

The aim of this phase of the research was to develop a reliable DH350 numerical model (i.e., a numerical model that meets the homologation requirements), which also exhibits behavior matching the physical ATD.

Four different tests were considered because of the importance in evaluating the dangerousness of an aircraft crash events: A) the head drop test, B) the neck flexion and neck extension tests, C) the thorax impact test, and D) the knee impact test. The results of the tests and the value ranges allowable for the DH350 homologation are reported in Table 1.

A. Head Drop Test (Fig. 4)

The homologation requirements prescribe a *head drop test* in which the head is dropped from a height of 376 mm with a peak

Table 1 DH350 subcomponent tests [2]

Subcomponent test	Physical quantity	Allowable range	Numerical result
Head drop test	Head acceleration, g	225–275	273.4
Neck flexion test	Deflection angle, deg	64–78	77.1
	Moment on the neck, Nm	88.1–108.4	91.5
Neck extension test	Deflection angle, deg	81–106	94.3
	Moment on the neck, Nm	52.9–80	56.9
Thorax impact test	Deflection, mm	63.5–72.6	67.7
	Force on the impactor, N	5160–5894	6200
Knee impact test	Force on the impactor, N	4715–5782	5418

resultant acceleration no less than 225 g and no more than 275 g. The acceleration/time curve for the test has to be unimodal (i.e., oscillations after main pulse <10%) to the extent that oscillations occurring after the main peak are less than 10% of the peak resultant acceleration. Lateral acceleration must not exceed 15 g.

Numerical simulations were carried out dropping the head on a rigid surface. As a result, the peak value of the acceleration was within the prescribed range, the profile in time was unimodal, and the lateral accelerations were negligible.

B. Neck Flexion and Extension Tests (Fig. 5)

Two calibration tests are prescribed for the neck assembly: the neck flexion test and the neck extension test. In both the cases neck and head assemblies are considered. The head–neck assemblies are mounted on a rigid pendulum (Fig. 5a). The pendulum is then left free to impact a honeycomb block that imposes a prescribed deceleration pulse.

1. Neck Flexion Test (Fig. 5b)

In the neck flexion test, the condyle plane has to rotate between 64 and 78 deg, which has to occur between 57 and 64 ms from time zero. The neck flexion peak value obtained in the simulations was within the range. The moment about the occipital condyles is required to have a maximum value between 88.1 and 108.4 Nm, occurring between 47 and 58 ms. The maximum peak value obtained in the simulations was within the prescribed range with a delay in time of about 1 ms.

2. Neck Extension Test (Fig. 5c)

In the neck extension test, the pendulum impact velocity has to be between 5.94 and 6.19 m/s. The maximum rotation of the occipital condyles plane has to be between 81 and 106 deg and occur between 72 and 82 ms from time zero. The moment about the occipital condyles is calculated as in the neck flexion test and is required to have a maximum between 52.9 and 80 Nm, occurring between 65 and 79 ms. The results obtained in the simulations were within the range specification.

C. Thorax Impact Test (Fig. 6)

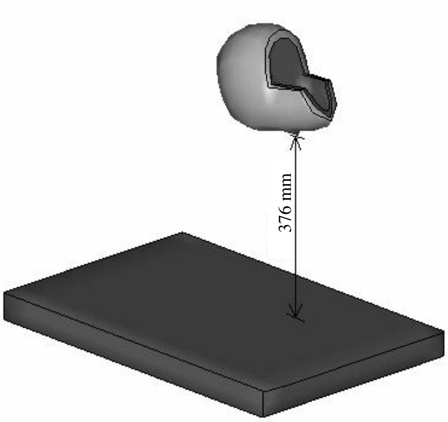
A pendulum impact test is prescribed to measure the response of the thorax. The impactor velocity measured by a test probe has to be 6.71 ± 0.12 m/s. The thorax has to react with a force between 5160 and 5894 N and a maximum sternum deflection in an interval between 63.5 and 72.6 mm. The internal hysteresis in each impact has to be more than 69% but not less than 85%. The maximum sternum deflection obtained in the simulations was in the prescribed range, whereas the error on the resistive force was smaller than 5%. Hysteresis ratio was in the prescribed range.

D. Knee Impact Test (Fig. 7)

The knee impact test measures the response of the knee assembly when impacted by a 5-kg impactor with a velocity of 2.1 m/s. The peak value of the knee impact force must have a minimum value of no less than 4715 N and a maximum value of no more than 5782 N. The impact force obtained in the simulations falls within the prescribed range.

IV. Down Test

A down test with a rigid seat was carried out at The Netherlands Organisation for Applied Scientific Research (TNO) of Delft, Netherlands, to acquire relevant knowledge about FAA-DH350 impact behavior. The data collected during that test were meant to improve the existent FAA-DH350 numerical models and to develop new and more accurate ones. The *head acceleration* and the *lumbar loads* measured during the test were used to improve the overall impact behavior of the model previously described.



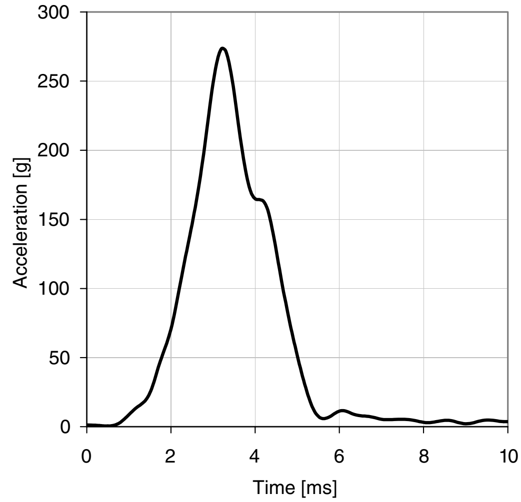
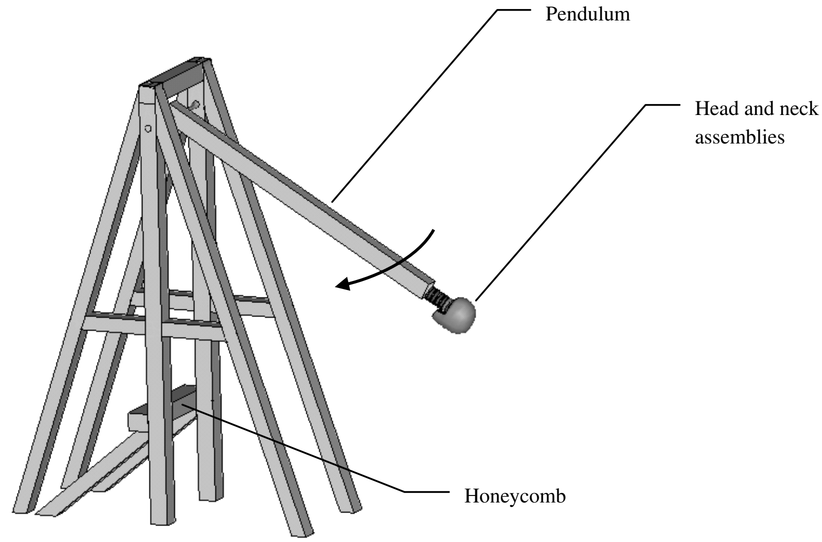
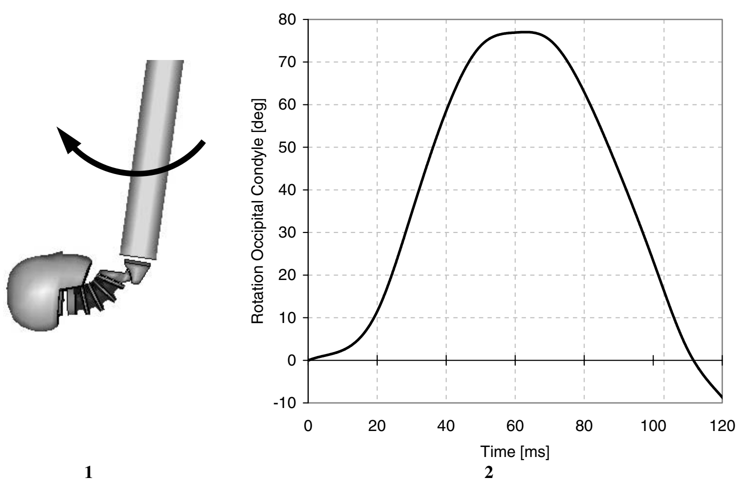


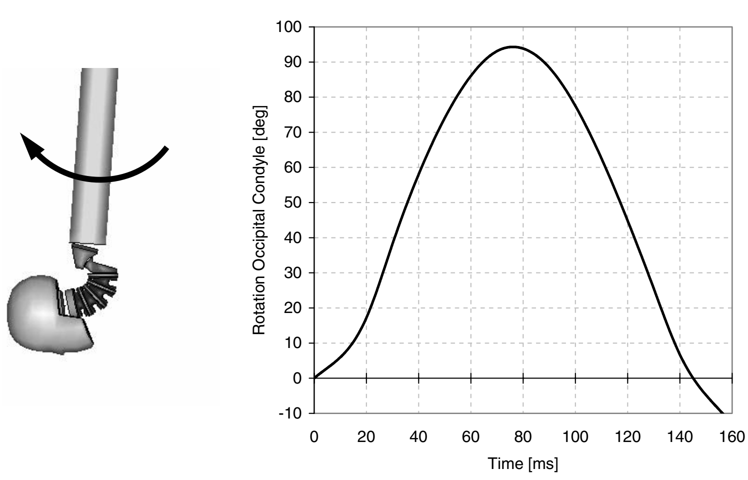
Fig. 4 Head drop test.



a) Neck flexion/extension test facility



b) Neck flexion tests



c) Neck extension tests

Fig. 5 Neck flexion and extension tests.

A. Experimental Test

The Federal Aviation Administration has established two standard tests for the homologation of helicopter seats [6]: the *forward test*, critical for the seat structure, and the *down test*, critical for the occupant being characterized by a high axial spine deceleration component.

The test used as a reference, described in detail in [3], was carried out accordingly with the impact conditions prescribed for a down test (Fig. 8a). The instrumented ATD (head deceleration and lumbar load were measured) was fastened to the seat with a four-point harness and the seat positioned on a test sled with a 60-deg pitch angle with respect to the forward direction. The sled was accelerated by an

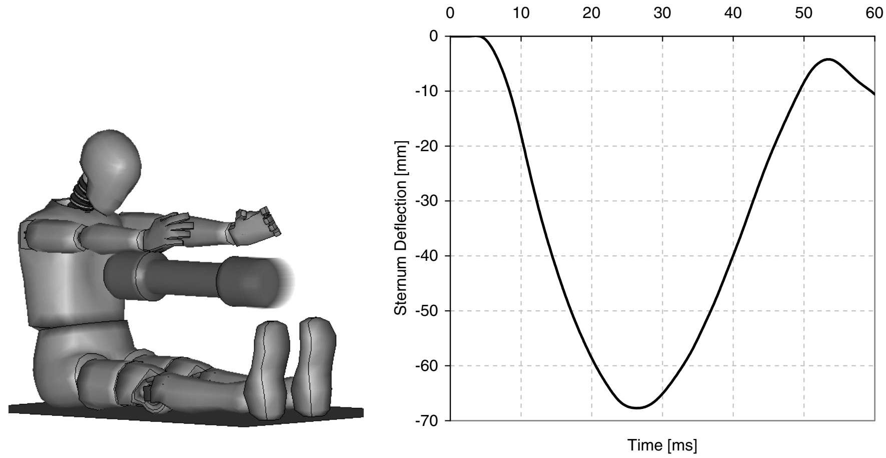


Fig. 6 Thorax test.

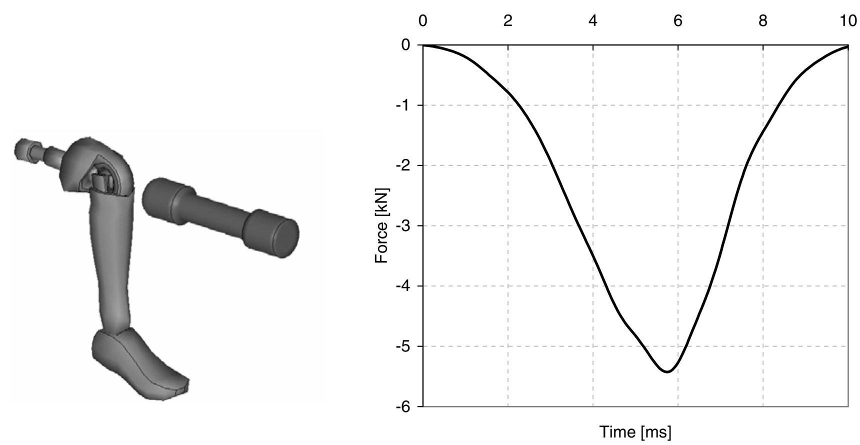
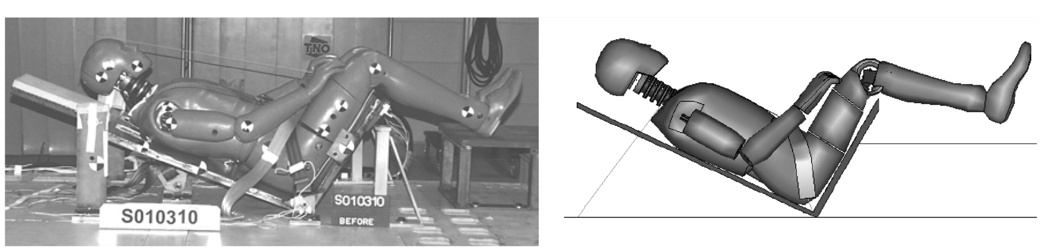


Fig. 7 Knee impact test.



a) **b)**

Fig. 8 Rigid seat down test: a) experimental test and b) numerical model.

oleopneumatic system to obtain the desired triangular deceleration pulse reaching the maximum value of 30 g in 31 ms and decreasing to zero in 31 ms.

The test aimed at assessing the performance of the FAA-DH350 by isolating as much as possible the response of the ATD from the seat. Therefore, a rigid seat consisting of two thick steel plates was used. A thin layer of Teflon was interposed between the ATD and the seat to minimize the effects of friction.

B. Numerical Model

In the FE simulations the configuration of the experimental tests was carefully reproduced (Fig. 8b). The ATD model was positioned with an iterative procedure to obtain the correct position of the model on the seat as in the actual test. Indeed, simulations carried out in a preliminary analysis phase demonstrated the strong sensitivity of the ATD response to its position on the seat. The Teflon plate was not modeled explicitly, but its effects were taken into account by calibrating the friction coefficients in the definition of the contact interface between the ATD limbs and the seat. The four-point harness was explicitly modeled using shell elements in the region of contact between the ATD and the belts and 1-D discrete elements for the other segments; both elements were modeled with the same material. A retractor system was also included in the model. The use of the two types of seatbelt elements is necessary because the retractor numeric model requires 1-D discrete element, whereas the seatbelt–thorax contact is more efficient using shell elements. The seat was modeled with shell elements and fixed to a perfectly rigid structure, representing the test sled. The deceleration pulse from the experimental test was imposed to the sled as a boundary prescribed motion. Gravitational loads were applied to the model, providing a settling time to achieve an equilibrium configuration of the ATD (on the seat) subjected to these body forces.

C. Numerical Model Enhancements

This phase of the research moved from comparing experimental (i.e., measured quantities and high-speed movies) and numerical results to evaluate and, in case, to improve the crash behavior of the FAA-DH350 numerical model. In particular, it was observed that compenetrations due to an inappropriate definition of the contacts affected the load transfer mechanism among the parts of the ATD and, hence, its crash behavior and the value of the quantities of interest measured during the test. In view of that, the following contact interfaces were redefined: chin with thorax, hands with thighs and knees, upper body with abdomen and limbs, segments of the legs with themselves. The contacts (right-hand side and left-hand side) between femur and the pelvis were defined: the lack of these contacts in the original DH350 model significantly affected the load transfer mechanism from the legs to the lumbar spine via pelvis and hence the value of the lumbar loads.

With regard to the interaction between the ATD and the seat, reference tests and a sensitivity analysis were carried out to evaluate the influence of the friction coefficients on the interaction between the steel backseat and the polyvinyl chloride (PVC) skin of the ATD and between the Teflon plate and PVC skin of the ATD. Eventually, a static friction coefficient of 0.40 was defined for the contact between steel and PVC, whereas a static friction coefficient of 0.17 was defined for the contact between Teflon plate and PVC. With these values, it was possible to obtain more realistic results in terms of the ATD dynamics (with regard to the sliding on the seat) and in terms of the most relevant parameters characterizing the event (i.e., the accelerations in the head and the lumbar spine loads).

In this phase of the research, it was also recognized that an improvement in the geometry of the cervical area was necessary in effort to reduce the excessive stiffness of the neck: holes similar to the ones in the physical ATD neck were created (Fig. 3b).

D. Numerical–Experimental Correlation

The results of simulations carried out after enhancing the DH350 model and the data collected in the experimental test were eventually compared, referring to the ATD dynamics and two of the most relevant parameters for the analysis of the event and for helicopter crashworthiness: the head acceleration and the lumbar load.

1. Impact Dynamics (Fig. 9)

The overall crash behavior of the ATD model in the simulations was consistent and close to the one of the physical ATD observed in the high-speed movies of the event. Also, event timings corresponded almost perfectly.

2. Head Acceleration (Fig. 10)

The accelerations measured in the head during the test and the ones obtained in the numerical simulations are shown in Fig. 10. The time history of the two accelerations is similar in terms of values and timing.

3. Lumbar Spine Load (Fig. 11)

The lumbar load is measured on the lower lumbar spine, corresponding to segments T12 and L2 of the human vertebrae.

The loads in the lower lumbar spine measured during the test (in the local reference system) and the ones obtained in the numerical simulation are shown in Fig. 11. The numerical–experimental correlation is good. The simulation results show only a slightly faster growing profile than the experimental test: nevertheless, the agreement in terms of maximum peak load and duration of the load pulse is good.

V. Helicopter Seat Homologation Test

To further verify the accuracy and the reliability of the developed ATD model and to investigate the feasibility of the overall numerical model as a tool to assess aircraft seat crash performances, the homologation test [6,7] of an actual helicopter seat carried out at the LAST Crash Labs was considered. The seat was equipped with impact energy absorption devices meant to limit lumbar spine loads within the limit physically admissible [8].

A. Experimental Test

The homologation test here considered is a down test. The configuration of the test (Fig. 12a) was similar to the one previously described. The ATD was placed on the seat and fastened by means of a four-point harness. The seat was fixed on the test sled. During the test, the sled was accelerated to a prescribed velocity and then decelerated by an oleopneumatic braking system, providing the prescribed triangular deceleration pulse.

B. Numerical Model

To reproduce the test, the helicopter seat structure was modeled in detail (Fig. 12b). The ATD was placed on the seat and the test impact scenario was recreated.

1. Seat Structure and Cushion

The seat structure (Fig. 12) consists of two parts: an upper part and a lower part. The two parts of the seat can slide the one on the other by means of two rails. In normal usage conditions, the impact energy absorption devices avoids this motion. During a crash landing, the sudden high deceleration consequence of the impact activates the impact energy absorption devices that start dissipating the impact energy, allowing a controlled sliding of the two parts of the seat [4]. The FE model of the seat consisted of 5092 four-node shell elements. The structure of the seat is made of an aluminum alloy. The material was modeled using an elastic piecewise linear plastic constitutive law. The influence of the strain rate was also considered by means of Cowper–Symonds coefficients [5].

During the test, the seat was covered with a cushion fixed to the structure by means of Velcro strips. The cushion had an important influence on the overall ATD crash behavior and hence on the measured neck accelerations and lumbar loads. In view of that, the cushion was carefully modeled: the mesh consisted of 1560 eight-node solid elements, static and dynamic tests were carried out to characterize its dynamic behavior, and a kinematic constraint was defined to reproduce the fitting system.

2. Impact Energy Absorption Device

One of the most important features of an aircraft seat is the impact energy absorption device, which is meant to reduce the loads transferred to the occupant in case of a crash landing in emergency.

Over the years, several different absorption systems have been perfected. The most common impact energy absorption devices are characterized by a sacrificial metallic element (usually a tube) that dissipates the impact energy and reduces the impact deceleration by a progressive plastic deformation. The overall crash behavior of an aircraft seat equipped with impact energy absorption devices is extremely difficult to model, and therefore, experimental tests are mandatory to develop effective impact energy absorption systems.

Experimental test are time-consuming, expensive, and difficult to perform. Indeed, the numerical model here introduced is also meant to be a feasible numerical tool for the design of effective impact energy absorption devices and to contribute to the reduction of the costs by cutting the incidence of the development tests.

The impact energy absorption device of the seat considered (Fig. 12c) consisted of two parts: a slender metallic tube and two small metallic wheels blocked on it. The two opposite ends of the tube are fixed to the lower part of the seat. The deceleration wheel pivots are fixed to the upper part of seat. In normal usage condition, the deceleration wheels avoid the relative motion of the two parts of the seat structure. As a consequence of a crash landing, when the inertial forces surpass a prescribed threshold (that is, a relevant design parameter of the seat) the two wheels start sliding on the tube that, plastically deforming, opposes a reaction force. The impact energy absorption device was modeled using discrete elements: that is, two (1-degree-of-freedom) springs characterized by a nonlinear stiffness. These spring elements worked along the direction that links their two extremities: one fixed to the upper part and the other to the lower part of the seat structure FE model. The force/displacement

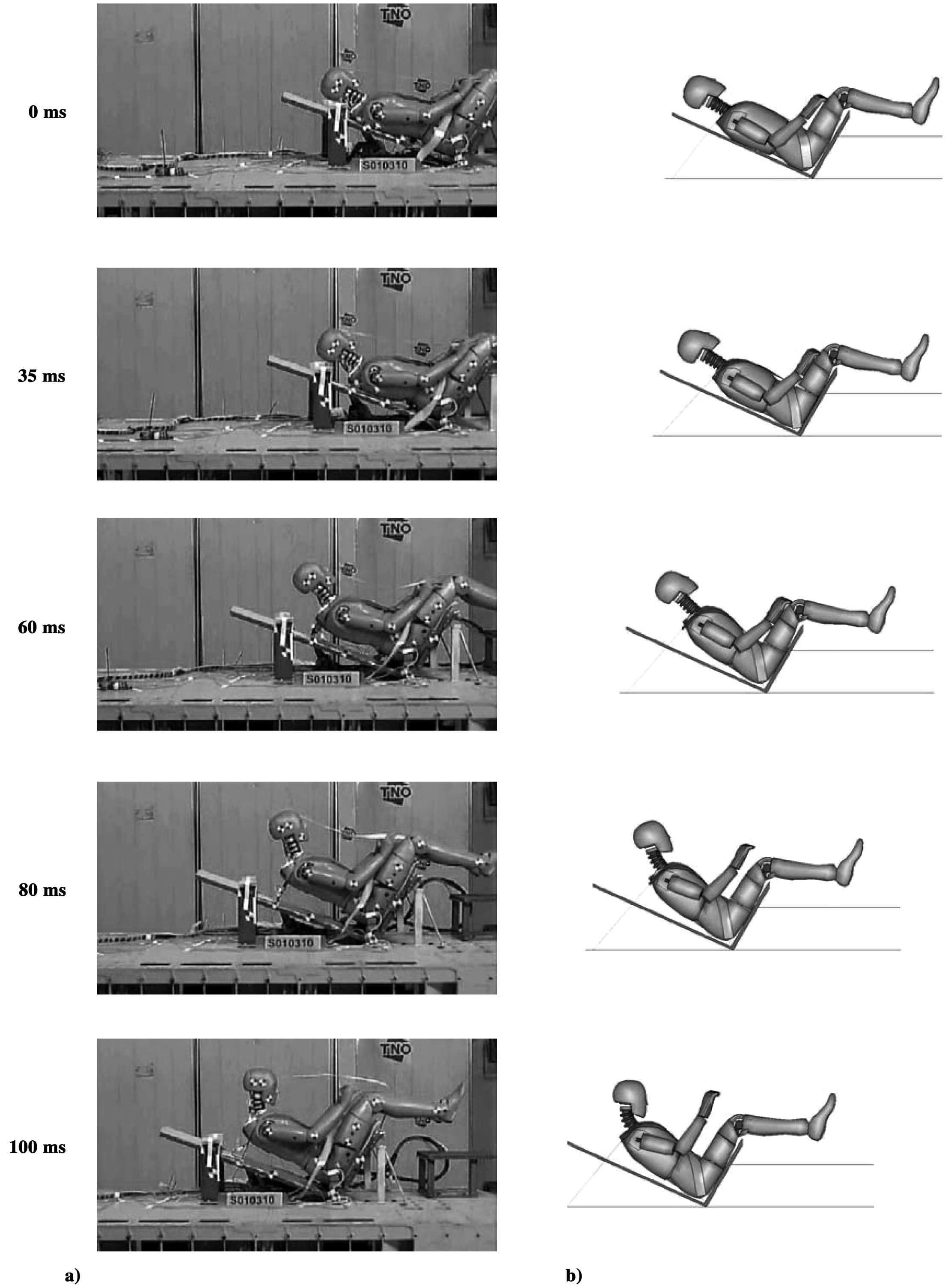


Fig. 9 Rigid seat down test: a) experimental and b) numerical results.

curve that characterizes the spring behavior was defined referring to the data collected during specific experimental tests.

C. Numerical–Experimental Correlation

The accuracy of the results numerically obtained were evaluated referring to the description of the impact dynamics and to the lumbar spine load.

1. Impact Dynamics (Fig. 13)

The behavior of the ATD model in the simulations was similar to the one observed during the tests. In Fig. 13, in particular, a frame from the high-speed movie and the correspondent from the numerical simulation are shown for a comparison.

2. Lumbar Load (Fig. 14)

The lumbar load is measured on the lower lumbar spine, corresponding to vertebrae T12 and L2.

The lumbar load obtained in the simulation is close in values and timings to the one measured in the test. In Fig. 14, the time histories of the lumbar load measured in the test and the one obtained in the simulations are shown. The correlation is good: the relative error on

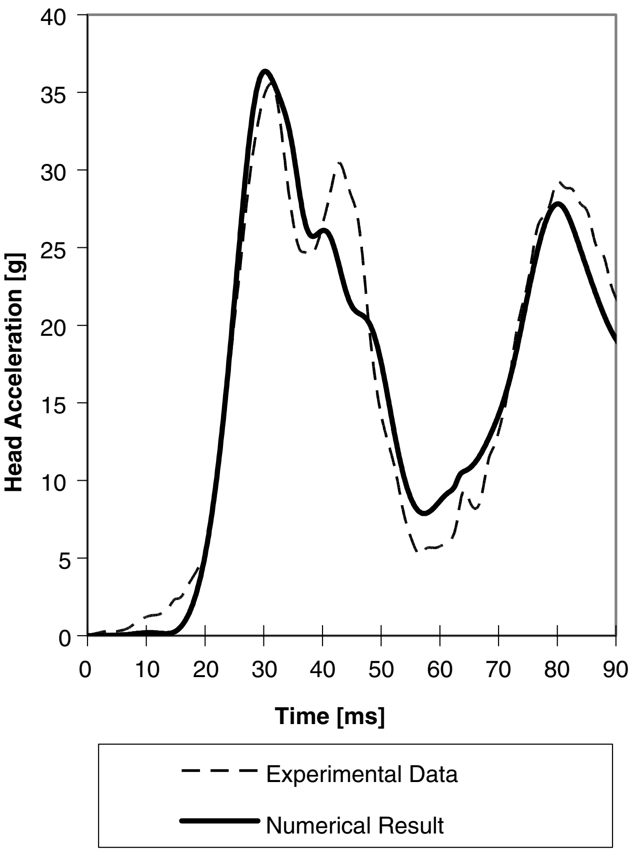


Fig. 10 Rigid seat down test: head acceleration.

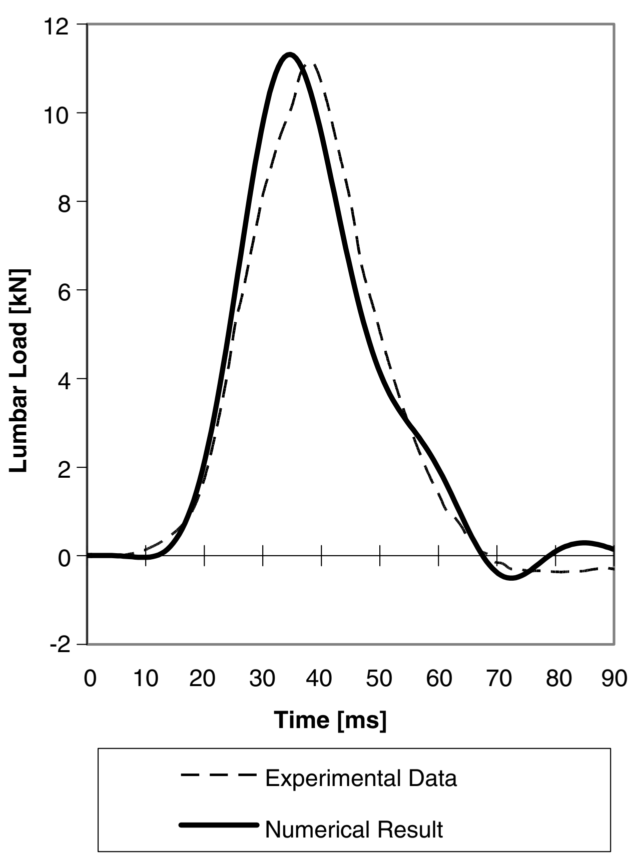


Fig. 11 Rigid seat down test: lumbar spine load.

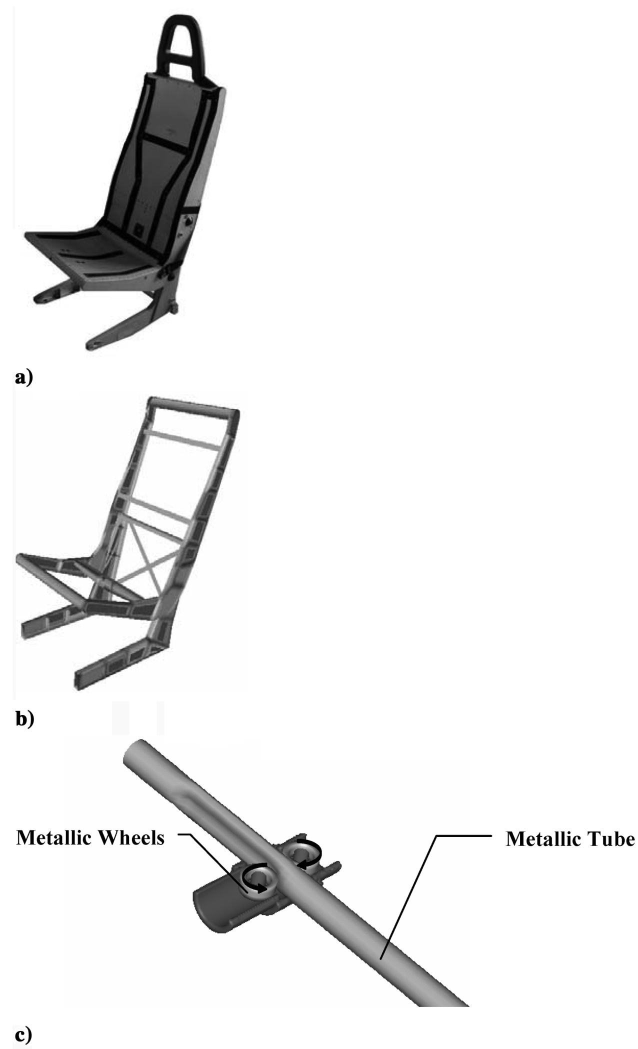


Fig. 12 Helicopter seat a) actual structure, b) corresponding FE model seat down test, and c) impact energy absorption device.

the maximum peak value is smaller than 2%, and the difference in timing is negligible.

3. Upper Seat Stroke (Fig. 15)

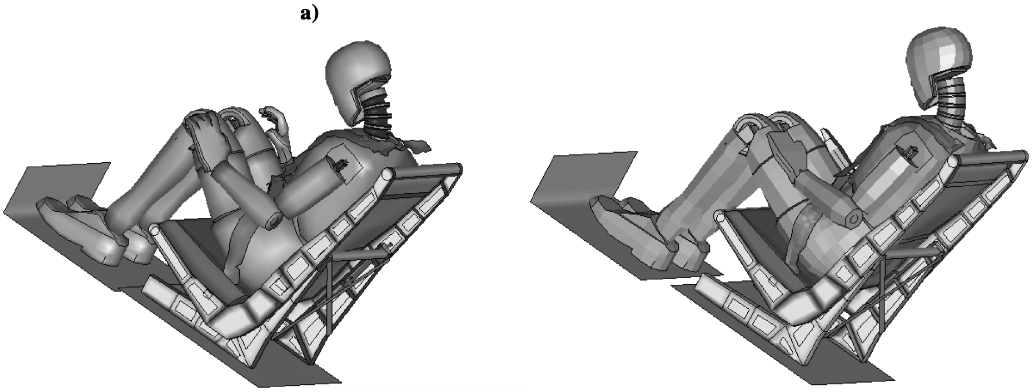
The upper seat stroke obtained in the simulation with LAST FAA Hybrid III is very close in values and timings to the one measured in the test, whereas the results obtained in the simulation with LSTC Hybrid III was higher than 40%. In Fig. 15, the time histories of the upper seat stroke measured in the test and the one obtained in the simulations are shown.

VI. Remarks

The close numerical–experimental correlation eventually obtained demonstrated the reliability of the FAA-DH350 model here introduced and, at the same time, represents both a good reason and an incentive to extend the use of this model to the analysis of analogous crash events.

To give a measure of the relevance of the outcomes achieved, in Fig. 14 also the lumbar load curve obtained using the ATD model available at the beginning of the research is shown. The curve comes from a simulation of the helicopter seat homologation test carried out after replacing the newly developed LAST FAA-DH350 model with the LSTC DH350 model. Indeed, with regard to remaining issues, the impact scenario was the same: the same initial position, the same seat model, the same harness system, and the same deceleration time history. When comparing the curve obtained with the LSTC DH350

a)



b) c)

Fig. 13 Helicopter seat homologation test: a) experimental test and numerical simulation with b) LAST-FAA model and c) LSTC model.

model, the curve obtained with the LAST FAA DH350 model, and the experimental curve, the enormous difference in values and timings is apparent. The maximum value of the lumbar load obtained with the LSTC DH350 model, in particular, is much higher than the one measured in the test and far above the physically allowable limit [8].

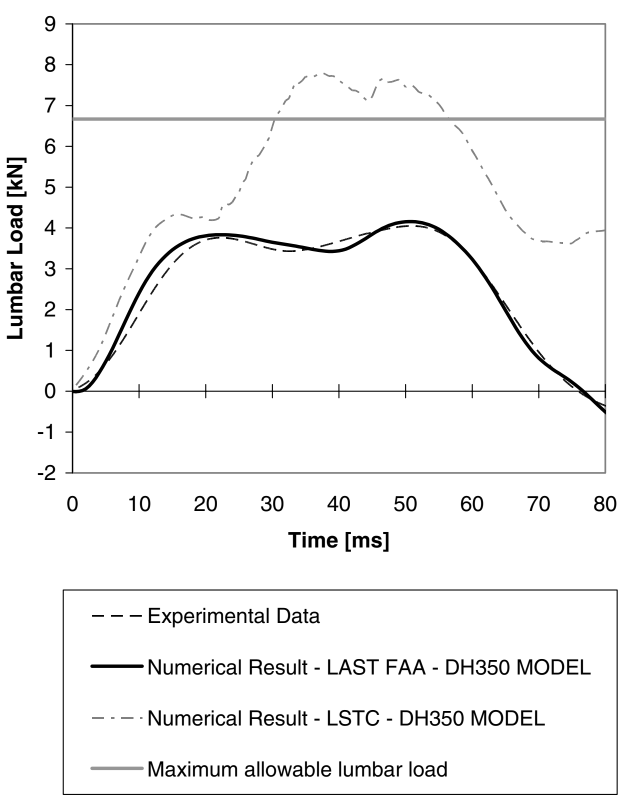


Fig. 14 Lumbar load during a helicopter seat down test.

The FAA-DH350 model introduced here was developed based on the LSTC LS-Dyna model, which is a proven nonlinear explicit FE code widely diffused in crash event analysis. Nevertheless, the procedure followed to develop the model is independent from the code used in the simulations and it is readily extendible to other explicit FE codes, such as ESI-Group PamCRASH/PamSAFE or HKS ABAQUS/Explicit.

VII. Conclusions

Anthropomorphic test devices are used to develop structures that maximize the survivability of passengers when a crash event becomes unavoidable. The numerical model of a 50th-percentile Hybrid III dummy for aeronautical applications (FAA-DH350) was introduced. The model is the outcome of long-term research aimed at developing a reliable numerical tool for the assessment of the aircraft seat crash performances.

The research consisted of two phases. In the first phase, the numerical model of a 50th-percentile Hybrid III was developed and validated, at the beginning, considering the ATD subcomponents, part by part, to meet the requirements for the homologation of a physical DH350 and, subsequently, referring to a down test carried out to acquire relevant knowledge about the impact behavior of the a FAA-DH350. In the second phase, the accuracy and the reliability of the model were verified referring to the homologation test of an actual helicopter seat equipped with impact energy absorption devices. Eventually, a close numerical–experimental correlation was obtained.

In view of that, it was concluded that the developed LAST FAA-DH350 model is a feasible tool for the analysis of aircraft crash tests carried out using Dummies Hybrid III and hence a rather convenient design-by-analysis tool in terms of reduction of times and costs required for the development of new structures or for the assessment of existing structures.

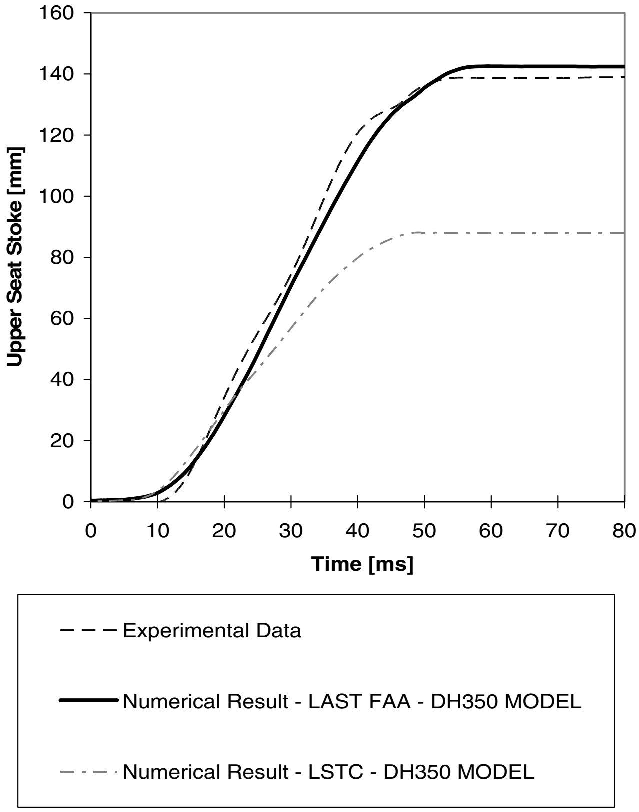


Fig. 15 Upper seat stroke during a helicopter seat down test.

Furthermore, the good correlations obtained for the impact scenarios that were considered in this research indicate that the LAST FAA-DH350 model may be also useful in other scenarios to improve the aircraft seat crash performance by improving the design of restraint systems and the efficiency of impact energy absorption devices.

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