NUMERICAL MODELS OF ANTHROPOMORPHIC TEST DEVICES TO INVESTIGATE HUMAN RELATED IMPACT EVENTS

Marco ANGHILERI, Luigi-M L CASTELLETTI (<u>luigi.castelletti@polimi.it</u>), and Emanuele FRACASSO Dipartimento di Ingegneria Aerospaziale, Politecnico di Milano via La Masa 34, 20156 Milano, Italia

ABSTRACT

Anthropomorphic test devices are frequently used to design structures proficient in guaranteeing the survivability of the passengers during potentially fatal accidents such as crash landings. Objective of the present research has been the development of advanced numerical models of aeronautical Hybrid III ATDs. In a first phase, the numerical model of a Hybrid III 50th percentile was validated: at the beginning, considering the ATD part-by-part so to meet the requirements for the homologation and, then, referring to a down test carried out to assess the performances of an aeronautical Hybrid III ATD. Hence, the reliability of the model was further verified referring to the homologation test of a helicopter seat. In a second phase, the same approach was applied to the validation of the models of a Hybrid III 5th and 95th percentile. Eventually, a comparison among the results obtained considering the homologation test of the helicopter seat and using the three different models was proposed and, in view of that, a number of related conclusions were drew.

KEYWORDS

Crashworthiness, Occupant Safety, Hybrid III, Anthropomorphic Test Device, Helicopter Seats

ACRONYMS

- ATD Anthropomorphic Test Device
- FAA Federal Aviation Administration
- FAR Federal Aviation Regulations
- FEM Finite Element Method
- LAST Laboratorio per la Sicurezza dei Trasporti

INTRODUCTION

Most of the life threatening and highly disabling injuries caused by an accident event involving human beings can be prevented by the study and design of crashworthy devices and safety restraint systems for ground vehicles and aircraft.

The use of *Anthropomorphic Test Devices* (ATDs), commonly referred to as *crash test dummies*, allows crashworthiness engineers to evaluate the occupant protection potential of various types of restraint systems in laboratory-simulated collisions.

Current ATDs reproduce faithfully human physical characteristics such as: size, shape, inertial properties, stiffness, and energy absorption and dissipation properties.

The main advantage of using ATDs lies in the possibility of monitoring accurately the mechanical response of the device by equipping it with transducers and 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 considerable increase in the use of computer simulations in the crash safety research has led to the development of numerical models of vehicles as well as of the human body.

The better availability and easier measurability of data for ATDs has obviously led to the development and use of numerical models of these devices in conjunction with the numerical description of the vehicle structure and restraint systems. This approach proved, in fact, a very economical and versatile method for the analysis of the crash response of complex dynamic systems. Several areas of *research and development* benefit by this approach: reconstruction of accidents, computer-aided design of crashworthy structures (vehicles, seats, safety devices, roadside facilities, and similar), human impacts and biomechanical studies and occupant protection.

In this research, the feasibility of numerical models of aeronautical Hybrid III ATD as a means to evaluate impact dynamics and loads during a crash landing and, hence, as a means to improve the crashworthiness of the structures has been investigated.

A number of recent publications (Ref. 5, 6) show a renewed interest in this topic. Here, in particular, the attention is focus on the differences in the results obtained with different versions of the Hybrid III ATD and eventually the results obtained in simulation carried out with the Hybrid III 50th percentile (the most used in the experimental tests) are compared with the ones obtained in simulation carried out with the Hybrid III 5th and the 95th percentile ATDs.

In the first phase of the research, the numerical model of a Hybrid III 50th percentile was validated: at the beginning, considering the ATD part-by-part as to meet the requirements for the homologation of the physical ATD (Ref. 1) and, then, referring to a down test specifically carried out to develop reliable numerical models of the Hybrid III 50th percentile (Ref. 3).

The accuracy of the model was hence verified referring to the homologation test of a helicopter seat. As a result, a good numerical-experimental correlation was obtained (*qualitatively*) in the overall behaviour of the ATD and (*quantitatively*) on the most significant parameters monitored in the tests: head acceleration and lumbar spine load.

In the second phase of the research, the same approach was applied to the validation of the numerical model of Hybrid III 5th and 95th percentile. Unfortunately, no experimental data were available for these ATDs with regard to the helicopter seat homologation test. Therefore, even if the results obtained are close with experience and definitively verisimilar, tests to further validate the 5th and 95th percentile models seem recommendable.

A comparison among the results obtained reproducing the homologation test of the helicopter seat with the three different ATD models is eventually provided and remarks on the actual efficiency of the restrain system and the energy absorption devices drew.

The results obtained clearly indicate the feasibility and proficiency of using numerical models to improve the design of crashworthy structures such as restrain systems and energy absorption devices suitable for people of different body shapes and with regard to different impact scenarios.

<u>1. HYBRID III 50TH PERCENTILE</u>

Moving from the FE model part of the code used in the analyses, the numerical model of a Hybrid III 50th percentile was initially developed to fulfil the specification listed and described with detail in the Federal Airworthiness Regulation (Ref. 4).

Hence, the model was validated referring to the part-by-part tests prescribed for the homologation of the physical ATDs (Ref. 1).

1.1. Physical ATDs

Since the first attempt to create a human surrogate for crash test (the Sierra Sam aged early forties), a number of different ATDs have been developed.

The National Highway Traffic Safety Administration (NHTSA) gave a significant contribution to the development of the ATDs as (reliable) substitutes of the humans in the crash tests carried out to investigate human related impact event.

The NHTSA eventually selected a number of feasible ATDs and for each one of these indicates with great detail the components (number, design, and features of the parts) and the requirements for the homologation (Ref. 1). Instrumentation on the ATDs, as well, has to comply with the standard specifications.

Among the ATDs, the Hybrid III is certainly the most advanced: therefore, it is not surprisingly that it is also the most used in the experimental tests. An *enhanced* version of the standard Hybrid III was also developed for aeronautical purposes (Ref. 3, 4).

In the aeronautical industry the Hybrid III ATDs are commonly used to investigated the consequences on the human body of a *crash landing* (i.e. a ground impact in emergency conditions) and, hence, to develop high-efficiency restraint systems and impact energy absorption devices.

In *automotive*-related crash event, where the decelerations are mainly horizontal, the most critical parts of the body are the neck and the thorax.

In *aircraft*-related crash event, where the decelerations are mainly vertical, the most critical parts of the body are the head and the lumbar part of the spine.

The different needs led to develop a *specific* ATD with a straight lumbar spine element in order to include a load cell and measure the lumbar spine load (Figure 2-LHS).

1.2. Numerical model

The numerical model of the ATD (Figure 1) was initially developed moving from the one of a *standard Hybrid III* 50^{th} *percentile male* – part (built-in) of the code used in the simulation (Ref. 7).

The original model addresses to the typical configuration used in automotive to assess the crashworthiness performance of ground vehicles and, as mentioned before, differs from the aeronautical version in the lumbar spine element.

The lumbar spine element in the model was modified and straightened, including a sensor for the measurement of the *lumbar spine loads*.

The two versions of the lumbar spine are shown in Figure 2.

The model consists of the same component assemblies defined for the physical ATD - 109 parts of which 61 parts were modelled as perfectly rigid and 48 as deformable.

The FE model counts 5688 elements: 1788 shells, 26 beams, 3864 solids and 10 discrete elements.

The correct degrees of freedom of the physical ATD (mimicking the human body) are reproduced by means of revolute and spherical joints, while the possible interaction between the parts is taken into account by defining appropriate contact interfaces.



Figure 1. Hybrid III 50th percentile FE model.



Automotive Hybrid III



Aeronautical Hybrid III

Figure 2. Hybrid III lumbar spine element.

A numerical simulation offers the great advantage with respect to a physical test of providing a measure of every physical quantity at any instants in time.

The numerical model here developed, in particular, was endowed with numerical sensors to collect the same data as in a physical tests – such as accelerations (head, thorax, pelvis), deformations and loads (lumbar spine) in various parts of the model.

1.3. Validation of the ATD subcomponents

The (*modified*) numerical model of the Hybrid III 50th percentile was initially validated part-by-part referring to the requirements for the homologation of the physical ATD.

The certification tests on the subcomponents were reproduced in detail and the results compared with the prescriptions for the homologation – *Code of Federal Regulations CFR 49-PART 572* (Ref. 1).

Four different tests were considered (Ref. 5, 6).

- 1. The head drop test.
- 2. The neck tests: the neck flexion test and the neck extension test.
- 3. The thorax impact test.
- 4. The knee impact test.

<u>Head drop test.</u> The specifications prescribe a calibration head drop test in which the head is dropped from a height of 376 mm and the peak resultant acceleration is no less than 225 g and no more than 275 g. The acceleration/time curve for the test has to be *unimodal* to the extent that oscillations occurring after the main peak are less than ten percent of the peak resultant acceleration. Lateral acceleration has not to exceed 15 g.

Numerical simulations were carried out dropping the head on a tough 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.

<u>Neck tests.</u> 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 assembly are considered.

The head-neck assemblies are mounted on a rigid pendulum. The pendulum is then left free to impact a honeycomb block that imposes a prescribed deceleration pulse.

In the *neck flexion test* the condyle plane has to rotate between 64 and 78 deg, which has to occur between 57 ms and 64 ms from time zero.

The neck flexion peak value obtained in the simulations was only slightly above the maximum allowable peak range and it occurred with a small time delay: the relative errors on the peak value and timing were within the 4% and the 9% respectively.

The moment about the occipital condyles is required to have a maximum value between 88.1 Nm and 108.4 Nm, occurring between 47 ms and 58 ms.

The maximum peak value obtained in the simulations had a relative error within the 8% and a delay in time of about 12 ms.

In the *neck extension test*, pendulum impact velocity has to be between 5.94 m/s and 6.19 m/s.

The maximum rotation of the occipital condyles plane has to be comprised between 81 deg and 106 deg and occur between 72 ms 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 Nm and 80 Nm, occurring between 65 ms and 79 ms.

The maximum rotation of the neck about the occipital condyles in the numerical extension test resulted within the prescribed range, although occurring with a certain delay in time. The maximum peak of the condyles moment is less than 15% above the range and it occurs consistently with a delay in time as in the neck rotation history.

<u>Thorax impact test.</u> A pendulum impact test is prescribed to measure the response of the thorax. The impactor velocity measured by a test probe has to be $6.71 \text{ m/s} \pm 0.12 \text{ m/s}$.

The thorax has to react with a force between 5160 N and 5894 N and a maximum sternum deflection in an interval between 63.5 mm 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, while the error on the resistive force was smaller than 10%. Hysteresis ratio was in the prescribed range.

<u>Knee impact test.</u> 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 is required to 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.

2. DOWN-TEST SIMULATION

After the part-by-part validation, the numerical model of the Hybrid III 50th percentile was further improved referring to the data collected during a *down test*.

The test was carried out at the TNO of Delft (Ref. 3) to assess the performances of an aeronautical Hybrid III 50th percentile ATD.

2.1. Experimental test

The US Federal Aviation Administration (FAA) established two *standard* tests for the homologation of a helicopter seat: the *forward test* and the *down test*.

The *forward test* is characterised by a dominant longitudinal deceleration pulse and proves to be critical for the structure of the seat.

The *down test* simulates the conditions of a crash landing and it is characterised by a dominant vertical deceleration pulse. This condition is extremely critical for the occupant, since it presents a high spine-ward deceleration component that led to high levels of lumbar spine loads.

The impact conditions prescribed for a *down test* were considered in the experimental tests used as a reference for the validation of the ATD model.

Accordingly to the *down test* specifications, the seat in test is required to have a 60 deg pitch angle with respect to the forward direction – with the pitch axis lying in a vertical plane defined by the velocity vector and the longitudinal axis of the helicopter.

The prescribed (theoretical) deceleration pulse has to be triangular, reaching the maximum value of 30 g in 31 ms and decreasing to zero in 31 ms.

The reference experimental test was carried out at the TNO within the test campaign for the HELISAFE programme.

The tests were carried out with the objective to assess the performance of an aeronautical Hybrid III 50th percentile by isolating as much as possible the response of the ATD from the one of the seat.

The ATD was placed on a rigid seat – consisting of two thick steel plates. A thin layer of Teflon was interposed between the ATD and the seat to avoid frictions.

The seat was positioned on a test sled that during the test was accelerated by an oleo-pneumatic system, giving the prescribed triangular acceleration pulse.

The ATD was constrained to the seat by means of a four-point harness and instrumented according to the specifications.

The configuration of the test is shown in Figure 3-A.

2.2. Numerical model of the test

In the numerical simulations, the configuration of the test was accurately reproduced (as shown in Figure 3-B).

The steel seat was modelled with four-node shell elements and constrained to a rigid structure representing the test sled.

The ATD model was positioned with an *iterative procedure* to obtain the (exact) position on the seat as in the experimental test.

Preliminary simulations demonstrated, in fact, the substantial sensitivity of the response of the ATD to the initial position on the seat.

The Teflon plate was not explicitly modelled, but its effects were reproduced by introducing specific friction coefficients in the definition of the contact between the ATD limbs and the seat.

The four-point harness was explicitly modelled around the ATD model, using shell elements in the region of contact between the ATD and the belts and specific elements (Ref. 7) for the other segments. The belt was given the characteristics measured in a specific tensile test. A retractor system was also included in the model.

The complete numerical model including the ATD is shown in Figure 3-B.

The deceleration pulse from the experimental test was imposed to the sled as a prescribed motion boundary condition (Ref. 7).

Gravitational loads were applied to the model providing a settling time in order to achieve an equilibrium configuration on the seat of the ATD model subjected to these loads.

2.3. ATD model enhancements

Using the model described, a number of simulations were carried out and, eventually, it was recognised that the definition of the contact among some of the parts in the ATD model and between the ATD and the seat needed to be assessed.

It was found out, in particular, that, in order to accurately reproduce the impact behaviour of the ATD and hence to correctly evaluate the lumbar loads, it was paramount important to re-define the contact among the parts in the ATD model.

The following contacts were therefore improved in the definition.

- Contact between chin and thorax.
- Contact between hands and thighs/knees.
- Contact between body and abdomen/limbs.
- Contact between the two legs.

Furthermore, it was defined from new the contact between the femurs and the pelvis – which was demonstrate to have a significant influence on the *load transfer mechanisms* from the lower part of the body to the lumbar spine.

With regard to the interaction between the ATD and the seat, a sensitivity analysis was carried out in order to evaluate the influence of the frictional coefficients on the interaction between the steel backseat and the PVC skin of the ATD and between the Teflon plate and PVC skin of the ATD.

Eventually, it was observed that the *static friction* coefficient has a relevant influence on the results.

A static friction coefficient of 0.40 was defined for the contact between steel and PVC; a static friction coefficient of 0.17 was defined for the contact between Teflon and PVC.

When adopting these values, it was possible to obtain a more realistic description of the ATD dynamics with regard to the sliding on the seat and a closer numerical-experimental correlation in terms of the most relevant parameters in the event.

2.3. Numerical-experimental correlation

The results obtained in the simulations carried out after assessing the model and the experimental evidences were eventually compared with regard to the *impact dynamics* of the ATD and two of most relevant parameters for structure crashworthiness: the *head acceleration* and the *lumbar spine loads*.

Impact dynamics (Figure 3). The overall impact behaviour of the ATD model in the simulations is consistent with the one of the actual ATD in the high-speed movies of the test:

Also, the timings of the event have an absolute correspondence.

<u>Head accelerations.</u> The time profile of the accelerations in the head measured during the test and the one obtained after the numerical simulations is similar: values and timings are very close (Ref. 6).

The high-frequency noise that affects the numerical results (common in explicit codes and due to the time integration scheme) is definitively negligible.

<u>Lumbar spine loads.</u> The numerical-experimental correlation with regards to the loads in the lumbar spine is absolutely satisfactory (Ref. 6).

The simulation results show a *slightly* faster growing than the experimental test: notwithstanding this, the agreement in terms of maximum peak load and duration of the load pulse is good. The maximum lumbar load obtained in the numerical simulation, in particular, showed a modest 5% relative error with respect to the peak load experimentally measured.







Figure 3. Down test with a rigid seat: (A) experimental evidence and (B) numerical result.

<u>3. HELICOPTER SEAT HOMOLOGATION TEST</u>

The validity of the numerical model developed was further verified referring to the homologation test carried out with a helicopter seat at LAST Crash Laboratory of the Politecnico di Milano (Ref. 5, 6). The seat, in particular, was endowed with *impact* energy absorption devices.

The impact energy absorption devices are meant to maintain the value of the lumbar spine loads during a crash landing within the limit physically admissible (Ref. 2): this aim is usually achieved by introducing a sacrificial element meant to dissipates the impact energy (Ref. 8).

3.1. Experimental test

As previously mentioned, US FAA established two different test typologies for helicopter seat homologation: the forward test and the down test. The test here considered is a down test, which is to be the more severe for the occupant.

The configuration of the test (Figure 4-A) was similar to the one previously described.

The ATD was placed on the seat and constrained to that by means of a four-point harness. The seat was fixed on the test sled: during the test, the sled was accelerated and then decelerated by an oleopneumatic *braking* system, providing the prescribed triangular acceleration pulse (Ref. 5).

The ATD was instrumented according to the standard specifications.

3.2. Numerical model

In order to reproduce in detail the test, the structure of the seat and the test devices were introduced in the model.

<u>Structure of the seat.</u> The structure of seat 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 energy absorption device avoids this motion. During a crash landing, the consequent suddenly high deceleration activates the energy absorption device that starts dissipating the impact energy allowing a *controlled* sliding of the two parts of the seat.

The FE model of the seat consisted of 5092 fournode shell elements.

The structure of the seat is in aluminium alloy – that was modelled using an elastic piecewise linear plastic constitutive law. The influence of the strain rate was also considered specifying the Cowper-Symond coefficients of the material.

<u>Comfort covering.</u> The physical seat is covered with a cushion fixed to the structure by means of Velcro strips.

The cushion was modelled with 1560 eight-node solid elements. A cinematic constraint was defined to reproduce the fasten system.

Static and dynamic tests were carried out to characterise the behaviour of the cushion.

<u>Energy absorption device.</u> The impact energy absorption device consists of two parts (Ref. 8): a slender hollow tube, the *sacrificial element*, and two smaller solid cylinders, the *deceleration wheels*.

The two opposite extremities of the hollow tube are fixed respectively one to the upper and the other to the lower part of the seat structure. The cylinders are fixed to the upper part of the seat structure and clamped on the tube.

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 pass a threshold (that is a *project variable* to decide carefully) the deceleration wheels start sliding on the hollow tube that, plastically deforming, opposes a reaction force – the value of which depends also on the magnitude of the deceleration.

The impact energy absorption device was modelled with a discrete element: a (one degree of freedom) spring with a nonlinear stiffness.

This spring element acts along the direction that links its two extremities: one fixed to the upper part and the other to the lower part of the seat structure FE model. The force/displacement curve that characterises the spring behaviour was defined referring to (specific) experimental data. <u>Test facilities.</u> The part of the sled that directly interacted with the ATD was explicitly modelled.

In front of the feet of the ATD, it was introduced a (fictitious) step that simulated the presence of the empty seat as in the experimental tests.

The overall test facility model eventually consisted of 377 four-node shell elements and had the mechanical properties of the steel.

3.2. Numerical-experimental correlation

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

<u>Impact dynamics (Figure 4).</u> The behaviour of the ATD model in the simulations was similar to the one observed during the tests.

In Figure 4 is shown the comparison between a frame from the high-speed movie of the test and the correspondent frame form the numerical simulation.



(A)



Figure 4. Down test with a helicopter seat: (A) experimental evidence and (B) numerical result.

<u>Lumbar spine load (Figure 5).</u> The lumbar load obtained in the simulation was close in values and timings to the one measured in the test.

In Figure 5, in particular, are shown the curves of the lumbar load measured in the test and the one obtained in the simulation. The correlation is good: the error on the maximum value is smaller than the 2% and the difference in timings is definitively negligible.



Figure 5. Lumbar load during a down test using a helicopter seat.

3.3. Final remarks and discussion

The good numerical-experimental correlation obtained demonstrates the proficiency of the numerical model of the aeronautical Hybrid III 50th percentile here developed and, at the same time, indicates the possibility to extend the use of this model to the analysis of events similar to the one here considered.

In order to give a measure of the importance of the results here achieved, in Figure 5 is also shown the time profile of the lumbar loads obtained using the ATD model from which the research started.

When comparing the numerical results obtained with this model and the experimental data, it is immediate to notice the *significant* difference in values and timings. The maximum value of the lumbar load, in particular, is much higher than the one measured and far above the limit physically admissible (Ref. 2). That (also) proves that the original model of the Hybrid III 50th percentile is definitively *not feasible* for the analysis of aeronautical crash event.

4. HYBRID III 5TH AND 95TH PERCENTILE

The Hybrid III 50^{th} percentile is meant to share the body features of half the world population – by definition, the 50% of the world population has a smaller or equal body shape (Ref. 1, 2).

The Hybrid III 50th percentile, indeed, represents the *typical* human being and, therefore, it is reasonable that it has become the natural *reference* when developing crashworthy structures. Nevertheless, it has long been recognised that structures designed to be crashworthy for the *typical* human being could be not equally effective when considering individual with different body shapes (short/tall or thin/fat man, women, and children). That is the key motivation in developing different versions of the Hybrid III. Similarly, here, the numerical models of a Hybrid III (male) 5th and 95th percentile have been developed and validated – following the same methodological approach used for the Hybrid III 50th percentile.

4.1. Numerical models

The FE models of the Hybrid III 5^{th} and 95^{th} percentile (Figure 6) were obtained scaling the *geometry*, the *mass* and the *inertia* of the 50^{th} percentile (Ref. 1).

Parts and mechanical properties of the materials are the same of the Hybrid III 50th percentile.

4.2. Validation of the ATDs subcomponents

The numerical models of the Hybrid III 5th and 50th percentile were validated part-by-part referring to the requirements for the homologation of the ATD in the *Code of Federal Regulations CFR 49-PART 572* (Ref. 1).

The same four tests previously described with detail were considered.

The values obtained in the numerical simulations for both the ATD models, 5th and 95th percentile, were mostly in the ranges prescribed for the physical ATD homologation. When the values were not in the range, the error is within the tolerance usually associated to nonlinear explicit FE analyses and therefore practically negligible.



Figure 6. Hybrid III 5th percentile (LHS) and 95th percentile (RHS).

5. HELICOPTER SEAT DOWN TEST

The previously described down test carried out at LAST for a helicopter seat homologation was here reproduced using the numerical models of the Hybrid III 5th and 95th percentile validated par-by-part.

Unfortunately, no experimental data with regard to full-scale tests carried out with Hybrid III 5th and 95th percentile were available.

Nevertheless, since the methodological approach to the validation of these ATD models was the same successfully used for the Hybrid III 50th percentile, it was assumed that the numerical models of the 5th and 95th were accurate.

Moving from this assumption, the *performances* of the helicopter seat (and of its energy absorption device, as well) were evaluated when, in the case of a crash landing, a small or a huge man is seat on it.

5.1. Motivations

A number of researches were carried out to develop high efficiency absorption system (Ref. 8, 9), but most of these focused on a standard being.

In that, the objective of this phase of the research was to demonstrate that eventually an impact energy absorption device optimised for the typical man (i.e. a man with an average body shape) could be inadequate for a small man or for a tall man.

5.2. Numerical model

The developed models of the Hybrid III 5th and 95th percentile (Figure 6) replaced the 50th percentile in the down test carried out to homologate the helicopter seat (Figure 4-B).

The impact scenario and the numerical model of seat and test facility were the same previously described.

5.3. Results obtained

The results obtained using the models of the Hybrid III 5th and 95th percentile were evaluated referring to the impact dynamics and to the value of the lumbar spine loads.

Impact dynamics (Figure 7 and Figure 8). The impact behaviour of the two ATDs obtained, as predictable, was rather different: that is evident (especially for what about the *neck deflection* and *seat shortening*) when considering the results shown in Figure 7 and in Figure 8.





Figure 7. Helicopter seat homologation test using an ATD Hybrid III 5th percentile.

Figure 8. Helicopter seat homologation test using an ATD Hybrid III 95th percentile.

With reference to the Hybrid III 5th percentile simulation (Figure 7), the impact energy absorption device has a *delay* in activation and eventually has only a minor part in the event.

With reference to the Hybrid III 95th percentile simulation (Figure 8), the impact energy absorption device is rather ineffective and that is the cause of the significant neck rotation. Indeed, the impact energy absorption device starts to effectively contrast the downward motion of the ATD only when the ultimate shortening limit is reached.

<u>Lumbar spine load (Figure 9).</u> The lumbar loads obtained with the two ATD models were rather different in the initial slopes and in the peak values – though the latter were within the limits of the physical tolerance (Ref. 2).

The comparison between the two curves is shown in Figure 9.



Figure 9. Lumbar spine loads.

5.3. Final remarks and discussion

The (numerical) results obtained suggest a number of considerations.

Independently from the body size of the occupant, the impact energy absorption device is feasible to maintain the lumbar spine load within the limits physically admissible. Nevertheless, the energy absorption system is not fully satisfactory when considering men with different body shapes – who could eventually report serious injuries.

With regard to the case considered, in particular, a trunk-conical hollow tube as a sacrificial element could be use to reduce this danger. Further investigations are necessary to demonstrate it and the ATD models here developed seems a definitively reliable tool for such investigations.

CONCLUSIONS

In this research work, numerical models of different versions of the Hybrid III ATD to be used for the assessment of the crash performance of aeronautical seats have been developed and validated.

In a first phase, the numerical model of an aeronautical Hybrid III 50th percentile ATD was developed. Initially, the subcomponents of the ATD were validated comparing the simulation results with the requirements for the homologation. Hence, the numerical model was developed referring to a down test with a rigid seat and, eventually, used to reproduce a helicopter seat homologation test. The good numerical-experimental correlation obtained proved that the model is a reliable tool for the study of similar event.

In a second phase, adopting the same approach, the numerical models of a Hybrid III 5th and 95th percentile were developed and validated. These models were eventually used to evaluate the crash performance of a helicopter seat when men with different body shapes are seat on it. As a result, it was shown that, even if the seat is such to maintain the lumbar loads within the physically admissible limits, improved performances with regard to men with uncommon body shapes are achievable and recommendable. In that, the numerical models here developed definitively represent a convenient aideddesign tool.

REFERENCES

- U.S. Department of Transportation, National Highway Traffic Safety Administration: "Laboratory Test Procedures for Occupant Crash Protection (FMVSS 208)", Part 572. Washington D.C. January 2003.
- A. Eiband: "Human tolerance to rapidity applied accelerations". NASA Memorandum No 5-19-59E. 1959.
- C.D. Waagmeester, M.R. van Ratingen, V. Giavotto, L. Notarnicola, S. Goldner: "Enhanced FAA – Hybrid III dummy for aircraft occupant safety assessment". SAFE Symposium, Jacksonville. Sep 2002.
- 4. US Federal Aviation Administration (FAA) / FAR Parts 23, 25, 27 and 29, Section 562.
- E. Oldani, E. Fracasso, L.-M. L. Castelletti and M. Anghileri: "Development of a Numerical Model of an Anthropomorphic Test Device for the Study of Human Related Impact Events". 5th European LS-Dyna Users Conference. Birmingham, UK. May 2005.
- M. Anghileri, L.-M. L. Castelletti, and E. Fracasso: "Sviluppo di un modello numerico di manichino antropomorfo per lo studio di impatti che coinvolgono l'uomo" (In Italian) XVIII Congresso Nazionale AIDAA. Volterra, Italy. Settembre 2005.
- J. O. Hallquist: "LS-DYNA Theoretical Manual" Livermore Software Technology Corporation (1998)
- P. Astori, P. Ceresa, and M. Morandini: "Numerical optimisation of a seat energy absorber", 4th International K.RASH Users' Seminar. Amsterdam. June 2003
- M. Anghileri, L Lanzi, E. Oldani, and R. Denni: "Multi-objective optimization of helicopter seats under crashworthiness requirements". 24th Congress of International Council of Aeronautical Sciences. ICAS 2004. Yokohama, Japan. Sep 2004.