MULTI-BODY SIMULATIONS FOR HELICOPTER CRASHWORTHINESS AND EXPERIMENTAL RESULTS

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Abstract

In the last year two drop tests of Agusta A109 helicopters were performed, in order to learn the complex technique associated to this kind of experimental testing and refine methods for the numerical simulation of helicopter crash.
The complexity of the technique is due to the fact that the experiment consists in a one-shot destructive test on a complete fuselage, which should be in discrete conditions, fully instrumented and, in one case, with a couple of anthropometric dummies on board.
Other difficulties derive from the fuselage preparation for testing, i.e. the reinstatement of the structural conditions in case the fuselage had been previously damaged, the location of ballast to substitute systems and plants, and the choice of the fuselage parts to be instrumented.
The numerical simulation was performed with a multi-body code developed at this Department. The model was based on the experimental characterisation of the main structural elements.
The same code was also used for the optimisation of the energy absorbers of a new crashworthy seat for helicopters, manufactured by SICAMB and dynamically tested, with a dummy, at 30 g's according to current international rules.
The results obtained confirm the importance of the multi-body simulation in helicopter crashworthiness, both for the fuselage structure and the internal restraint systems.
At design level the simulation may be efficiently used for optimisation of the main crashworthy components of the structure and allows to spare time and costs of part of the experimental testing.

Complete Helicopter Fuselage

Introduction

Accident analysis of the last decades allowed the determination of the most typical crash scenarios and the impact conditions an occupant could be expected to survive.
A significant number of civil rotorcraft impacts occurs at a vertical main component of velocity, less than 7.93 m/s, almost level attitude (Ref. 1). During this kind of crash landing the main parts involved in energy absorption and occupant protection are the landing gear, lower fuselage and seat/restraint system, but the problem of cabin intrusion by external elements, such as the transmission box, is of great importance too.
Proper design of these components increase accident survivability, reducing both the risk of fuel leakage and the loads on occupants.
In 1994 Agusta, in co-operation with CIRA (Centro Italiano Ricerche Aerospaziali) and Politecnico di Milano, began a research programme with the purpose of improving the knowledge in crash problems. The activity began with the realisation of two A109 drop tests under the above mentioned impact conditions. Actually the design of this kind of helicopter was not based on crashworthiness concepts, but the experimental activity provided a good training tool for future testing and for numerical simulation refinement.

Experimental Set-up

The first problem faced for the experimental set up was the fuselage preparation for testing, i.e. replacement of damaged parts, distribution of ballast and fixing of sensors for the acquisition system.
The two fuselages belonged to different versions of the same helicopter, so that they were roughly similar in structure. The great difference consisted in the landing gear, which was not present in the first case.
Actually the first drop test was performed as a pilot test, in order to verify the correct set-up of the experimental field, i.e. release system, data acquisition system, high speed cameras, lighting and experimental procedure. Therefore the second drop test will be mainly referenced in this work.

At initial conditions the helicopter was suspended by its rotor axis at 3.208 m clearance from ground, consisting in a rigid pavement. Fig.1 shows the initial conditions of Test 2.

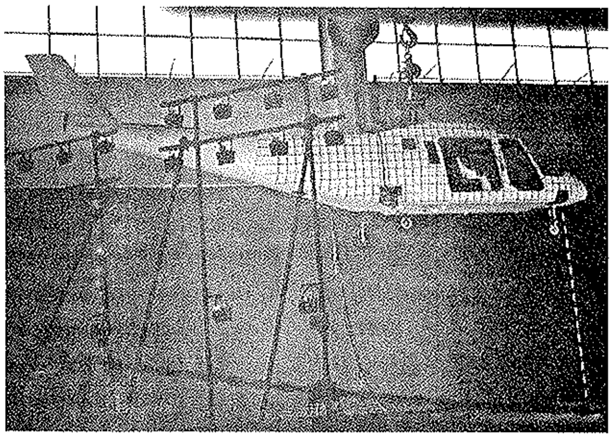

Fig.1 - Test 2 before crash

The release procedure was controlled by a PLC system, which first of all started the acquisition system and high speed cameras; then, after the function signals from acquisition and cameras were received by the control system for a suitable duration, the release was activated and the helicopter dropped with the highest possibility that all the systems were on.

In the first drop test 29 accelerometers and 16 strain gage bridges were installed, while in the second 27 accelerometers and 33 strain gage bridges. The most important locations for the accelerometers were the transmission gearbox, engine ballast, cabin roof, along the tail, main posts and landing gear (when present).

In Test 2 one anthropometric test dummy was also instrumented with one accelerometer in the chest while the other one had a lumbar load cell. Fig, 2 shows the 2 dummies on board; the seats were equipped with a rough energy absorber, in order to reduce the risk of damage to the dummies; the absorber, made of bent metal sheet, was characterised by computer simulation and tested separately before installation.

Fig. 3 is a photo of the helicopter after the impact.

The main landing gears were broken and the front section was severely deformed due to the strength of the front landing gear. A moderate fuel leakage was evidenced by the coloured water used to fill the tanks.

The seat energy absorber worked properly, avoiding high loads in the dummies lumbar spine.

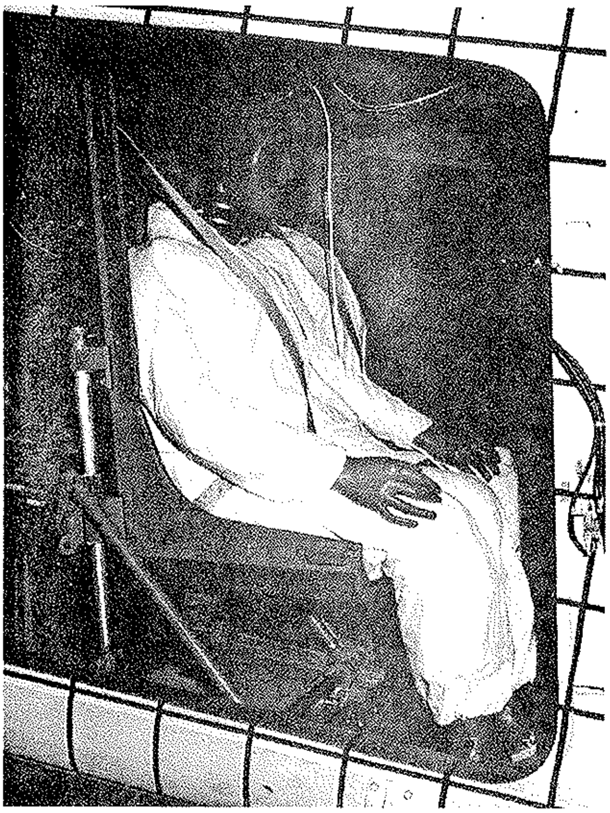

Fig. 2 - Anthropometric Test Dummies

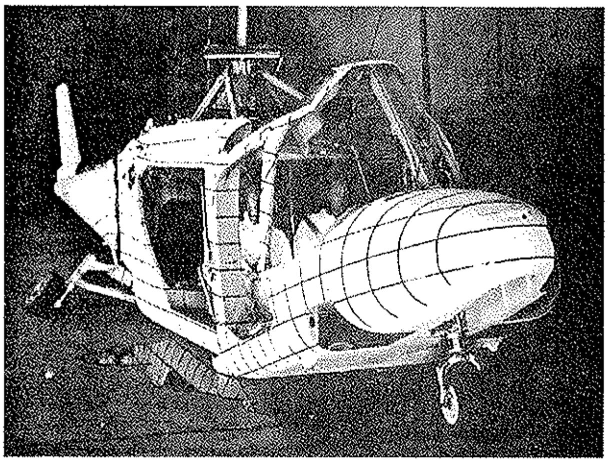

Fig.3 - Test 2 after crash

All data were sampled and post-processed according to the international standard SAE J211 (Ref. 6).

Most of the data channels were acquired by a boarded anti-shock system, while some were transmitted to ground by cable connection.

Computer Simulation

One of the purposes of the test was to improve usage of numerical modelling.

Full scale crashes are usually simulated with lumped mass codes, based on multi-body dynamics. One of the most important codes is KRASH, at present used at Agusta's. In the present paper the results of another code will be presented, called VEDYAC, used and developed at the Department of Aerospace Engineering as a multi-purpose multi-body code.
The theoretical formulation is close to KRASH, i.e. the structure is discretised into a suitable number of lumped masses connected by massless beams (or other types of deformable elements). Of course the rigid bodies must reproduce the inertial characteristics of the local section of the structure, while the deformable bodies must reproduce the pattern of deformation of the local structural component. This characteristic is usually derived by experimental testing on those components, in terms of stiffness, plastic point and rupture point.
The main difference between VEDYAC and KRASH is the way contacts are computed. While in KRASH some contact points are defined, connected to the main structure by elastic springs, in VEDYAC contact surfaces can be defined and therefore the contact force is function of intersection area, volume, surface hardness (given through a reference pressure) and relative velocity.
On the other hand, VEDYAC is not specialised in rotorcraft crashworthiness and has no modules computing the metering pin effect in the landing gear; this problem was solved by using some different types of viscous elements in parallel connection, linking the wheel group to the lateral arm.
Fig. 4 represents a presentation view of the VEDYAC model of the complete fuselage, with landing gear. Fig. 5 represents the same model with no presentation graphics, i.e. only the structural definition (deformable bodies and contact bodies only; rigid bodies are not evidenced).
The deformable elements were mainly beams, representing longeron and frame sections, tail beam, suspensions and posts. Rods were used to connect the engines and transmission to the roof. The total number of deformable bodies was 102.
The masses are lumped in areas such as the intersection of the longitudinal longerons with the transverse frames, in the centre of the nose, the wheel groups, the lateral landing gear arms and along the tail beam. The second model consisted of 45 rigid bodies.
The surfaces representing the contact area of the structure were 37, plus a flat hard plane representing the pavement.

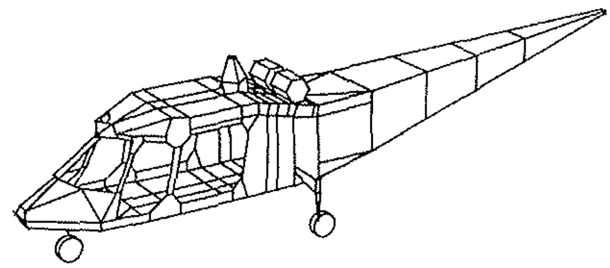

Fig. 4 - VEDYAC model - graphic view

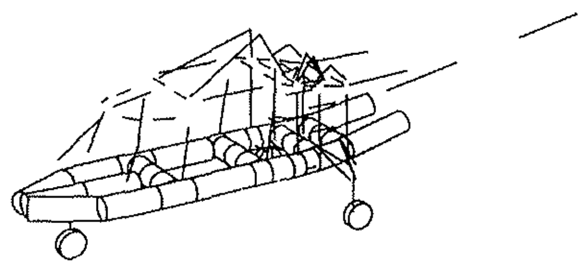

Fig. 5 - VEDYAC model - structural view

The total number of nodes, which were used to define the extremes and intrinsic reference frames of the deformable elements and the contact element, were 300.
The simulated time was fixed to 0.4 s, starting from a few moments before ground contact and with an initial velocity close to 7.93 m/s. One complete simulation lasted 37 CPU seconds on a RISC HP9000/735 workstation.
The graphic output is represented in fig. 6.

Subcomponents Characterisation

Characterisation of the structural components was available only for a few elements, and this resulted in a strong limitation of the work. The main post was tested in compression until failure. Vibration tests were available for the tail beam. The rods fixing the transmission box and engines had very simple cross sections and their instability compressive load could be determined by manual computations. The mechanical characteristics of a few other components only could be evaluated, resulting in a final lack of reliable input data for the model.
Therefore Test 1 was also used to calibrate the model in some parts, but due to the uncertainty of some important elements, a complete agreement

between experimental acquisition and numerical simulation was not possible anyway.

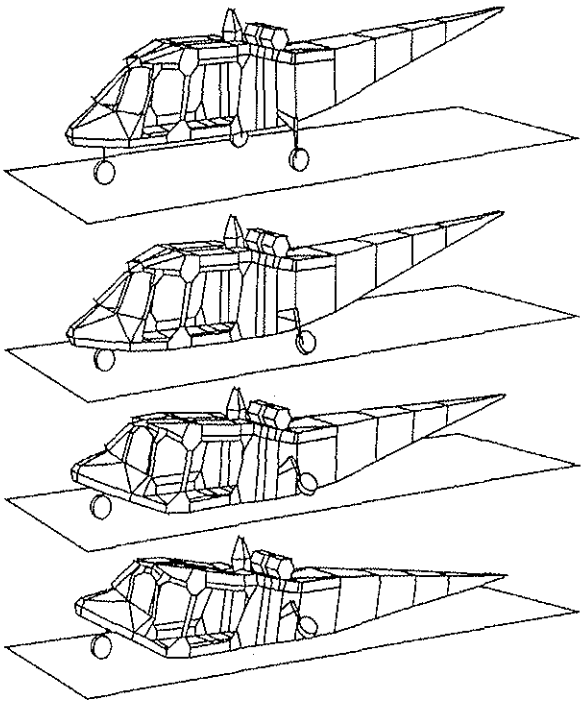

Fig. 6 - VEDYAC simulation

The second model was substantially equal to the first one plus the landing gears, whose drop tests were available at different velocities, so that a satisfactory characterisation of the suspensions was possible.

Results

As final result, the sequence of drawings coming from the numerical simulation (fig. 6) shows a behaviour similar to that coming from the high speed film frames; but, from a quantitative point of view, only about half of the plotted results coming from the simulation had shapes and peak values that can be considered in satisfactory agreement with the experimental data, while the remaining had bad correlation.

As an example fig. 7 represents the compressive load in one frontal rod of the transmission box, fig. 8 the vertical acceleration at the base of the principal post, fig. 9 the vertical acceleration in the transmission box and fig. 10 the vertical acceleration in the instrumented engine.

The worst data, in terms of simulation-experiment correlation, were obtained for the tail rotor area and other parts having high frequency content, which are not reported here. It is evident anyway that higher frequencies are not correctly reproduced by the model. Further experimental activity on structural components should be required in order to refine characterisation and input data reliability.

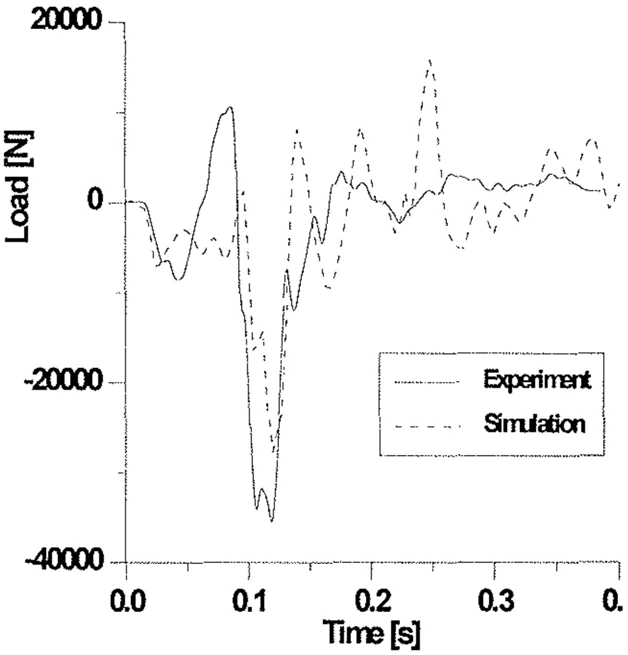

Fig. 7 - Compressive load in transmission box rod

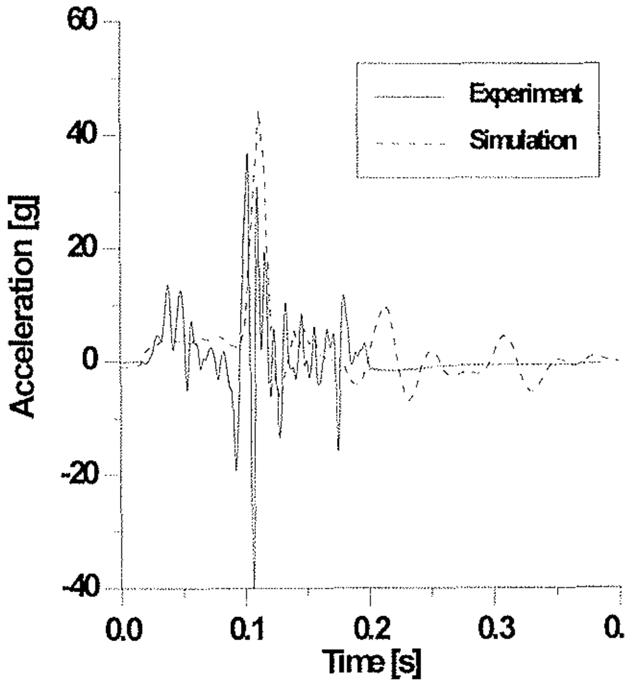

Fig. 8 - Vertical acceleration in principal post

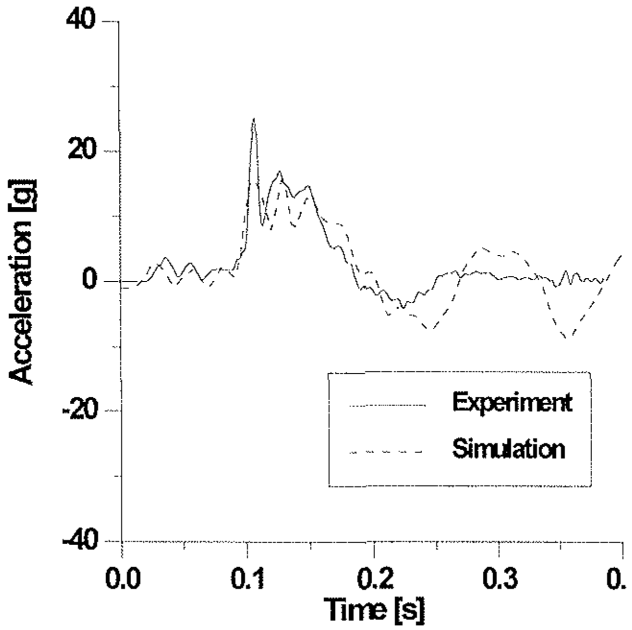

Fig. 9 - Vertical acceleration in transmission box

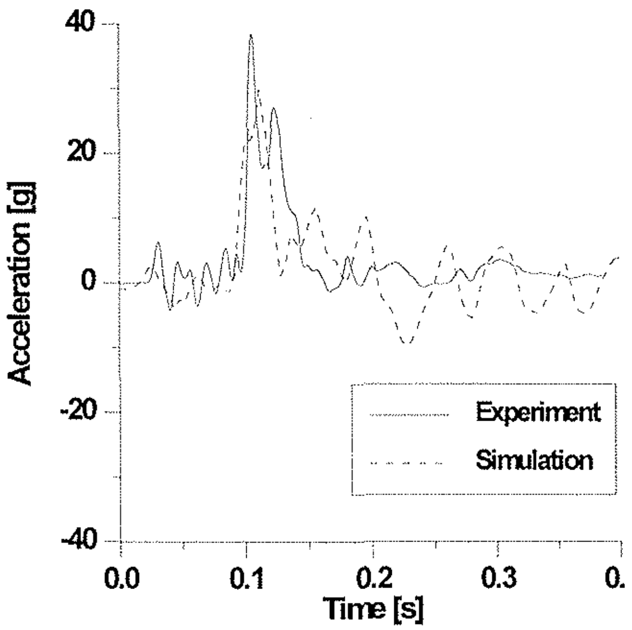

Fig. 10 - Vertical acceleration in engine

Seat / Restraint System

Introduction

As pointed out in the first part of this work, seat and restraint system design are relevant in occupant protection during a crash landing.
Since 1993 Politecnico di Milano has been performing certification crash tests on aircraft seats, using a deceleration sled facility. The new international rules require, for the certification of civil helicopter seats, some dynamic tests reproducing typical crash landing load conditions. It is expensive and complicated to perform development tests to optimise the seat structure for final certification. In this case numerical simulation may provide important directions for structure improvement, reducing the number of development tests.

International Rules for Seat Crash Testing

The rules (Ref. 3) require 2 kinds of dynamic tests on the seat, both with a 50th percentile anthropometric dummy properly seated and fastened, to be performed with a triangle shaped acceleration impulse; as indicated in fig. 11, in the first one the impact velocity vector, opposite to the acceleration pulse, lies on the symmetric plane of the aircraft and is directed downward and forward 30° with respect to the vertical axis, with peak greater or equal to 30 g's, time to peak less or equal to 0.031 s and velocity change greater or equal to 9.14 m/s; the second one is roughly a longitudinal test, with a small angle of pitch, peak greater or equal to 18.4 g's, time to peak less or equal to 0.071 s and velocity change greater or equal to 12.8 m/s. Fig. 12 shows the seat, manufactured by SICAMB, and dummy mounted on the sled facility for Test 1. As it is a horizontal sled facility, the seat is mounted in a 60° nose up configuration.

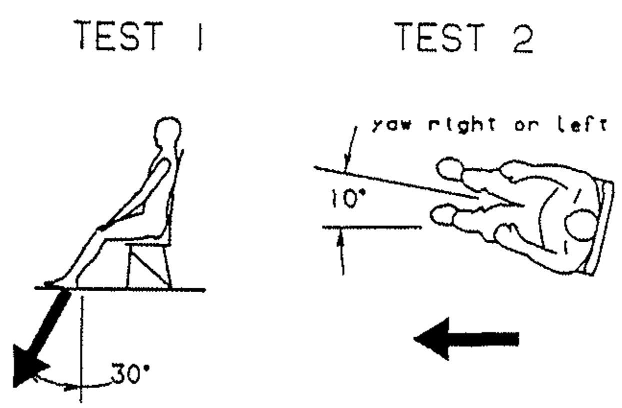

Fig. 11 - Seat attitude in dynamic tests

In Test 1 the main problem is the lumbar spine of the occupant, bevause it experiences a high compression due to the inertial load of the upper torso and arms. The prescribed safety value for this compression is 6670 N; in the second case the test involves principally seat to floor mountings and restraint system.

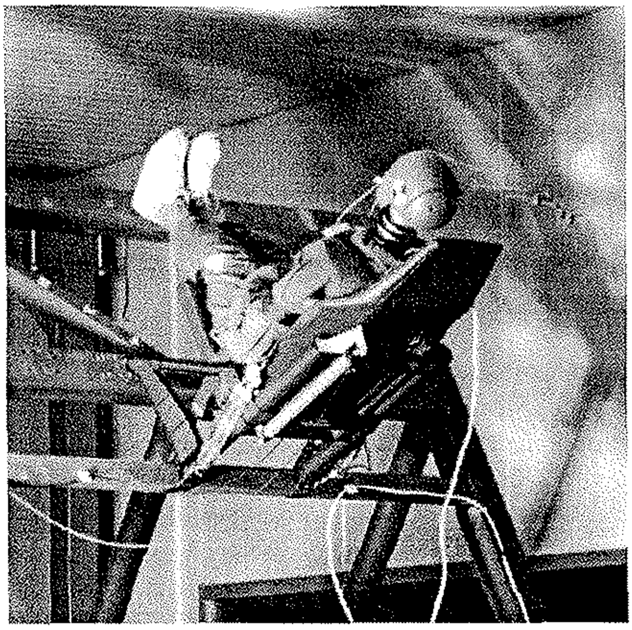

Fig. 12 - SICAMB seat on crash sled facility

Seat Design

The maximum value in the prescribed lumbar spine load can be reduced to the prescribed limit only if an energy absorber is installed between the seat and its mountings.
The optimised energy absorber must have a reduced elasticity and a plastic limit which remains constant during the seat stroke to floor, calibrated in such a way to use the total stroke before bottoming. The mechanical properties of the absorber are also influenced by the hardness of the cushion-seat pan system.
The proper calibration of the absorbers is the main difficulty for the seat manufacturer, because a too low plastic limit should result in bottoming and a too high one should not reduce the lumbar spine load under the limit of 6670 N. It is possible to reach the solution through a series of complete tests with different energy absorbers, but it is obviously expensive.

Computer Simulation

In the last years our crash research group has refined an experience in aircraft seat optimisation for final certification, using a numerical-experimental hybrid method to optimise the seat structure (Ref. 4, 5, 7). The numerical method is based on multi-body simulation with the VEDYAC code, while the experimental activity consists in static and dynamic testing on structural subcomponents.
In order to optimise SICAMB crashworthy seat, once the manufacturers provided the preliminary geometric design, a computer model was set up of the seat, showed in fig. 13 together with a 50th percentile anthropometric dummy which was already in database.

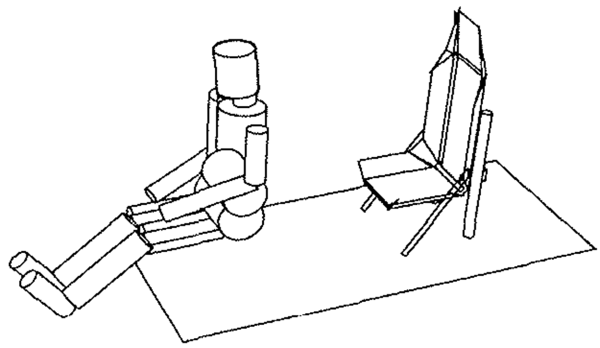

Fig. 13 - Seat and ATD model

The dummy model is made of 13 rigid bodies, associated to with cylindrical volumes for contact evaluation and connected by spherical hinges representing the articulations.
The seat model is made of one rigid body representing the movable part, i.e. seat pan and back rest, and one part fixed to the floor environment. These 2 parts were connected through 4 deformable joints that provided high stiffness in the longitudinal and lateral direction and a characteristic to be calibrated in the vertical direction, representing the energy absorber action. Seat fixed part and floor were subjected to a prescribed acceleration history reproducing the impulse required. The seat moving part and dummy motion were computed under those conditions.
Some simulations were performed changing the energy absorber mechanical characteristics, until reaching the minimum value for the lumbar spine load.
Of course the energy absorber coming out from this procedure is not defined geometrically, it is a sort of black box, whose tensile only behaviour is determined. SICAMB designed and manufactured some energy absorbers which were first tested statically at the factory and then dynamically at our laboratory, for final choose of the one that most

responded to the specifications determined by computer simulation.
The seat was finally tested only once, obtaining a result that was in good agreement with simulation.
Fig. 14 represents a sequence of drawings of the simulation, while fig. 15 is the plot of the lumbar spine load vs time, both in the numerical analysis and from experimental data acquisition.

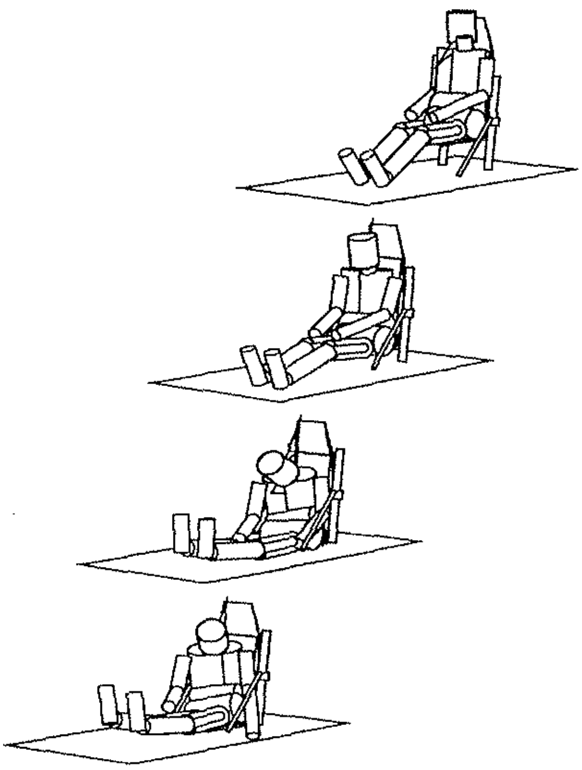

Fig. 14 - VEDYAC simulation

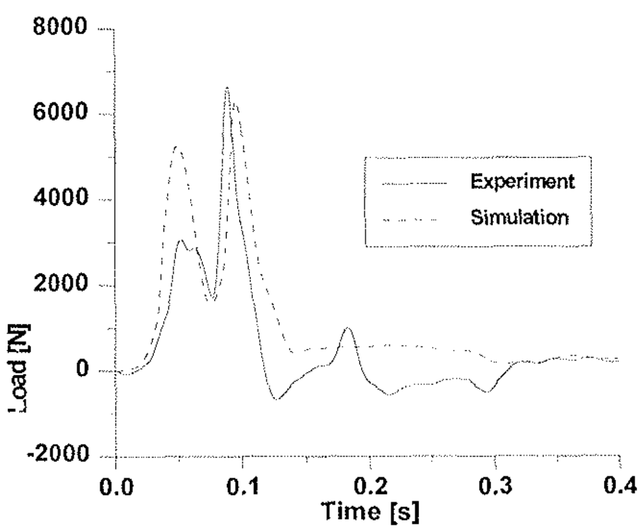

Fig. 15 - Lumbar spine load

Conclusions

This work confirm the importance of the hybrid simulation for different aerospace applications.
At present there are many problems both in aerospace and road crashworthiness where a finite element analysis cannot be easily applied. One of these problems is the evaluation of the global behaviour of a large structure during a crash, like a helicopter impacting the ground or a car impacting a deformable side barrier. The global behaviour is for example the acceleration in some parts of the aircraft, the load in some structural components and the dynamic deflection of some parts. It is evident that a finite element model would provide more detailed results about stress and deformation, but first of all in many cases such a detail is not requested, second the mesh preparation and computation would require very long times. Finite element modelling is more suitable for structural subcomponent analysis, in place of experimental testing, for the characterisation of the macroelements to be input in the multi-body model. Component characterisation appears to be in fact the most important aspect of hybrid simulation and a lack in this phase may compromise a correct and reliable modelling.
The effectiveness of the hybrid simulation is perhaps more evident in the second application above discussed. The anthropometric dummies used in aerospace and road crash testing are well defined mechanical systems which are fit for multi-body modelling, because they are a linkage of rigid bodies connected by spherical hinges with some degrees of freedom suppressed. Almost all the injury criteria (Ref. 2) are based on the acceleration measured in the centre of mass of some bodies or the load in some connections: this kind of data results directly from a multi-body technique, which is commonly used in biomechanics of impacts.

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