IMPACT PULSE SHAPE ANALYSIS

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ABSTRACT

The paper presents a study on the characteristics and the limits of the current aircraft seat crash test homologation standards; complying with them, a seat with an Anthropomorphic Test Dummy must succesfully complete dynamic tests in which direction, changing velocity, impact acceleration and corresponding rise time are prescribed by FAR-25.562. Information and guidance regarding acceptable means of compliance with PART 25 of FAR, as well as graphical evaluation to compare different test deceleration curves is provided in AC 25.562-1A. However, it was noticed that different pulse shapes, although complying with the graphical procedure mentioned, lead to different loads on the dummy, allowing test facilities to obtain disagreeing results for the homologation of a seat. Focusing attention on the so-called "down" test it was intended to numerically analyze, with the aid of experimentally validated seat-occupant models, the consequences of using an erroneus test pulse shape and thus propose the use of an alternative equivalence criteria.

INTRODUCTION

Nowadays aircraft seats must comply with two different dynamic homologation tests. One is the so-called "forward" test, in which the acceleration is only in the seat floor plane; the other is the so-called "down" test, in which the acceleration is mainly in the vertical direction (fig. 1).

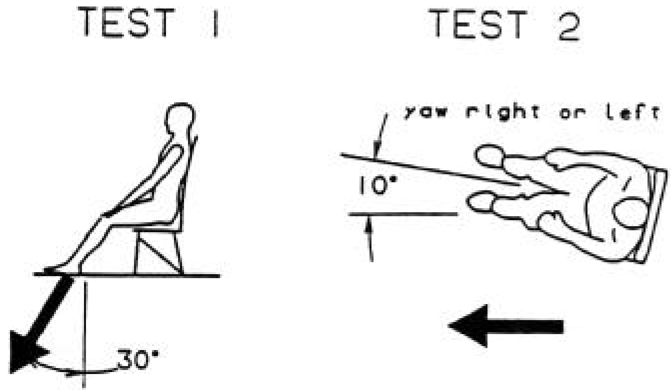

FIGURE 1: DOWN AND FORWARD CRASH TEST.

Risk of injury is evaluated by measuring the HIC parameter (1000 *s* maximum), femur loads (10000 *N* maximum) and upper torso restraint loads (7780 *N* for individual straps or 8900 *N* for dual straps maximum) in the forward test and the compression load in the lumbar spine in the down test (6670 *N* maximum). Both test are characterised by a triangular acceleration pulse shape of at least G_{req}=16/14 *g* peak and a maximum rise time of T_{req}=90/80 *ms* respectively for the forward and the down test (fig. 2) (FAA, 1996).

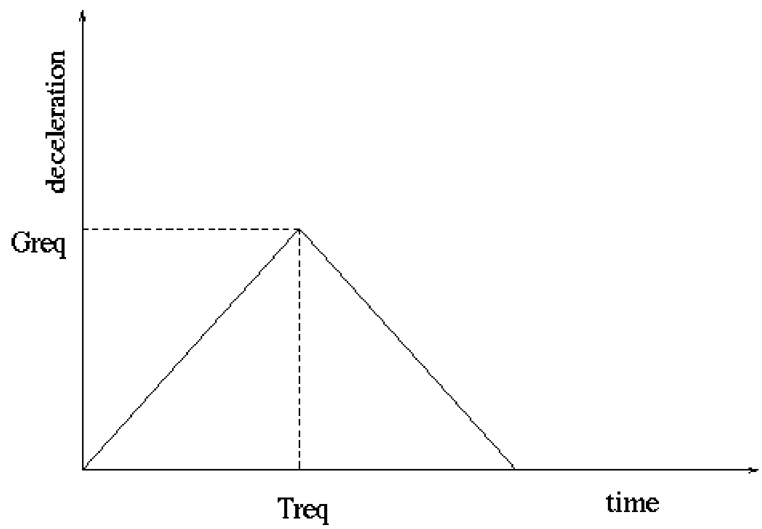

FIGURE 2: IDEAL PULSE SHAPE.

The test pulse must be digitally filtered with a standard Butterworth 4 pole phaseless filter with a cutoff frequency of 60 *Hz* (SAE, 1995). The filtered acceleration pulse is acceptable if the plotted data are equal to or greater than the ideal impact pulse. However, this can lead to using a test pulse significantly higher than the ideal pulse unless the test facility has precise control in generating the test pulse. To avoid that problem, an alternate graphic technique may be used to evaluate test impact pulse shapes which are not precise isosceles triangles.

This graphic technique (which in the meantime has been modified by FAA) uses the following steps on the filtered acceleration test pulse:

a. Locate the maximum acceleration (*Gp*), which shall equal or exceed G_{req}.
b. Construct reference lines parallel to the calibration baseline at levels of 0.1, 0.9 and 1 *Gp*.
c. Construct an onset line through the intersection points of the 0.1 and 0.9 *Gp* reference lines with the increasing portion of the data plot. The data plot should not return to zero *g* between the two points selected.
d. Locate the intersection of the onset line with the baseline as the start of the acquired pulse, T_1. Using T_1 as the start time, construct the ideal pulse required for the test condition. Draw a vertical line and a horizontal line through the peak of the ideal pulse, G_{req}. The vertical line through G_{req} will intersect the time axis at the maximum allowed rise time, T_3. Draw another vertical line at the first intersection of the horizontal line through G_{req} and the acquired pulse after T_1. This vertical line will intersect the time axis at T_2. The actual rise time, T_r=T_2-T_1, must be less then or equal to T_{req} for the acquired pulse to be acceptable.

e. The area under the data plot curve within the time interval between T_1 and T_3 of the test impact pulse shall represent at least one half of the required impact velocity (13.41 forward and 10.67 *m/s* down).
f. The area under the data plot curve from T_1 and a later time not more than 2.3 times T_{req} shall equal or exceed the minimum impact velocity.
g. Construct a line parallel to the ideal pulse and offset 2 *g*'s in magnitude less than the ideal during the time interval between T_1 and T_2. If the magnitude of the acquired pulse is 2 *g*'s less than the ideal at any point during this interval, the pulse is not acceptable.

If the pulse shape satisfies this graphical procedure and the injury criteria are within their limits, then the seat is considered homologated.
While the abovementioned procedure should be used to asses “minor” pulse shapes deviations from the ideal one, it was noticed that different test facilities used it to validate pulse shapes that are very different from the ideal one (fig. 3, MIRA sled acceleration). It was also noticed that different pulse shapes, although complying with the graphical procedure, lead to different loads on the dummy, allowing test facilities to obtain disagreeing results for the homologation of a seat. For these reasons, and after a test evaluation of the effects of erroneous pulse shapes (Gowdy, 1997), the graphical procedure described above and here taken into consideration has recently been modified by FAA with a memorandum (FAA, 1997).

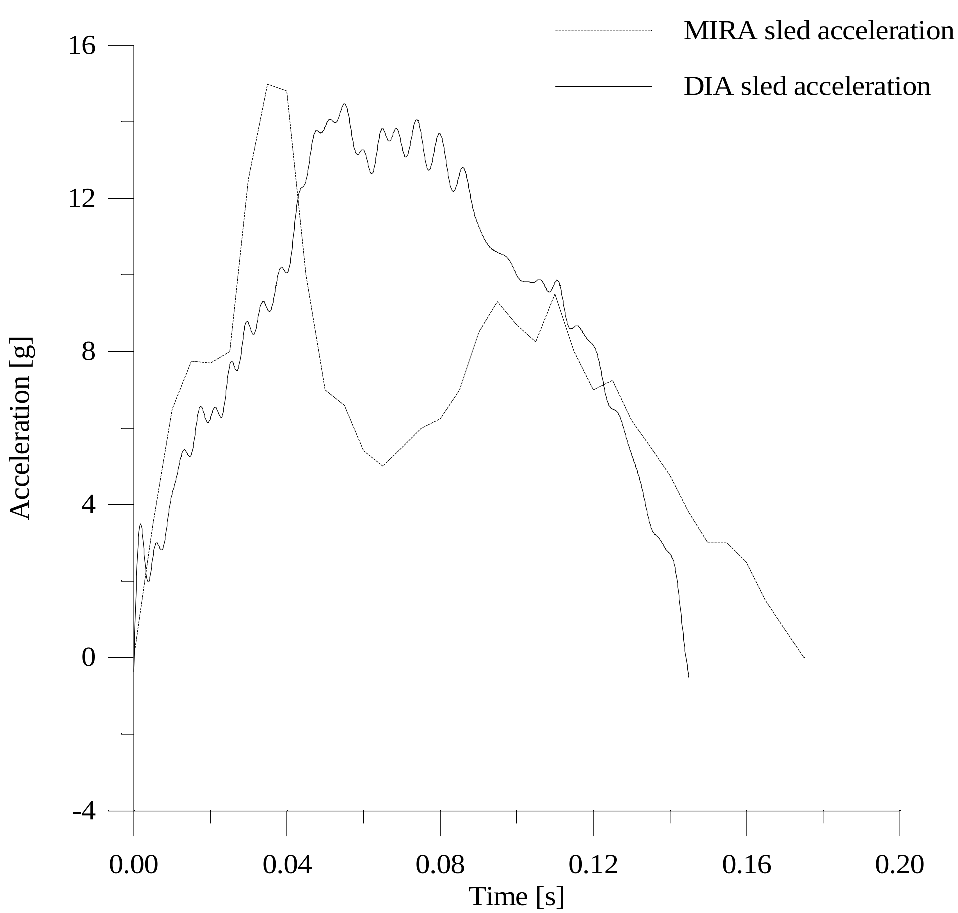

FIGURE 3: DIFFERENT EXPERIMENTAL ACCELERATION PULSE SHAPES.

In order to point out, with the use of numerical simulations, the effects of different pulse shapes, deceleration curves that maximize and minimize the compression of the lumbar spine were found; the first not satisfying and the second satisfying the above-mentioned criteria of “equivalence”.

THE MODEL

Investigation was carried out with the extensive use of a multi-body program named *VeDyAC* for the simulation of the impact dynamic of the seat-occupant system.

The seat, manufactured by an Italian society, is a double seat row, with four legs that must be connected to the floor tracks of the airplane and are asymmetrical if seen in a frontal view. The main seat structure is made of aluminium alloy. The occupants are 50th percentile HYBRID II anthropomorphic dummies (fig. 4).

The model of the ATD is made of 13 rigid bodies, each having the inertia properties of the corresponding part of a 50th percentile HYBRID II dummy. Each body is surrounded by cylindrical contact surfaces simulating the actual stiffness of the corresponding surfaces of the dummy. Such rigid parts are connected by hinges corresponding to the actual articulations of the dummy; each hinge has rotational restraints, elastic and friction reactions taken from dummy data. The dummy model is compliant with dummy's calibration standards (CFR, 1993). The mechanical properties of the cushion, which play a main role in the down test, were instead obtained by means of a drop tower.

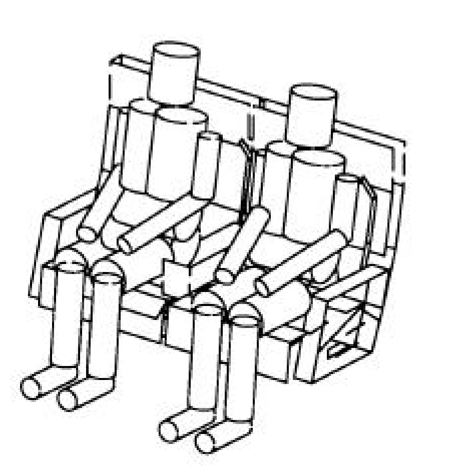

FIGURE 4: VEDYAC MODEL OF THE SEAT-OCCUPANT SYSTEM.

The model was developed in a previous work (Astori, 1995) and experimentally validated using the crash test facilities of the Aeronautical Department of the “Politecnico di Milano” (fig. 5).

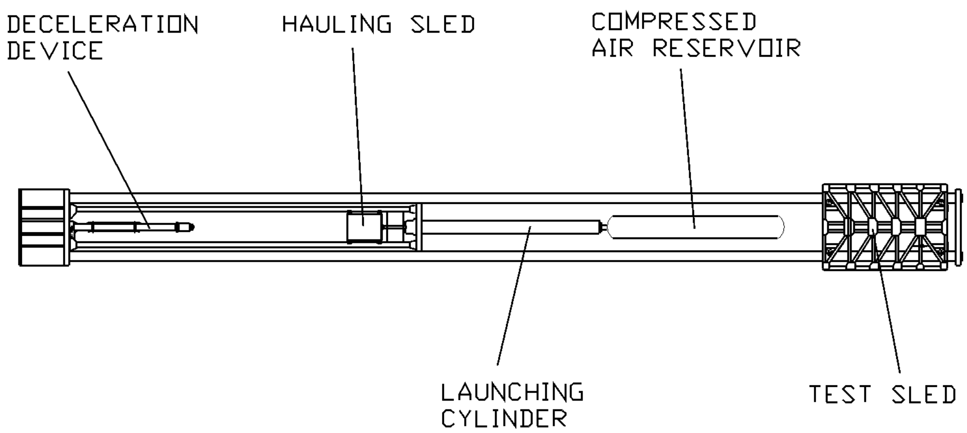

FIGURE 5: CRASH TEST SLED FACILITY.

This is a *deceleration sled facility*. The seats are mounted on the test sled running on two horizontal rails. The initial velocity is reached by means of a compressed air piston that pushes the hauling sled to which the test sled is connected by means of a series of wire rope pulleys. The run distance is relatively long (19 meters), so that the acceleration is slow enough to prevent the dummies to move from their correct seated position. After a few metres of free run, the sled is decelerated by means of a pre-calibrated hydro-pneumatic brake that provides the requested pulse. During the impact phase data acquisition systems and high speed cameras are running.

The deceleration pulses used to validate the seat-occupant model correspond to FAR requirements, even if it was not important for the validation in itself. As shown in following figures (fig. 6), good agreement is obtained between numerical and experimental results, especially for the lumbar load.

THE OPTIMIZATION PROBLEM

As mentioned before, the intention is to understand how the shape of the deceleration pulse can influence the results of an homologation test still satisfying the equivalence criteria imposed by the standards.
It must be stressed that the subject of the investigation is not the adequacy
of the ideal triangular pulse shape, but the equivalence criteria between the ideal and a real homologation test curve.
With the experimental validation of the seat-occupant model it has been possible to analyse the response of the dynamic system subjected to a generic deceleration history.
Allowing arbitrary variation of the deceleration pulse shape, it was possible to minimize the dummy's lumbar load still satisfying the standards' equivalence criteria; on the other side, it was also possible to maximize the lumbar load without satisfying the standards. Clearly, the last is done imposing criteria which are exactly the opposite of those prescribed by the standards.

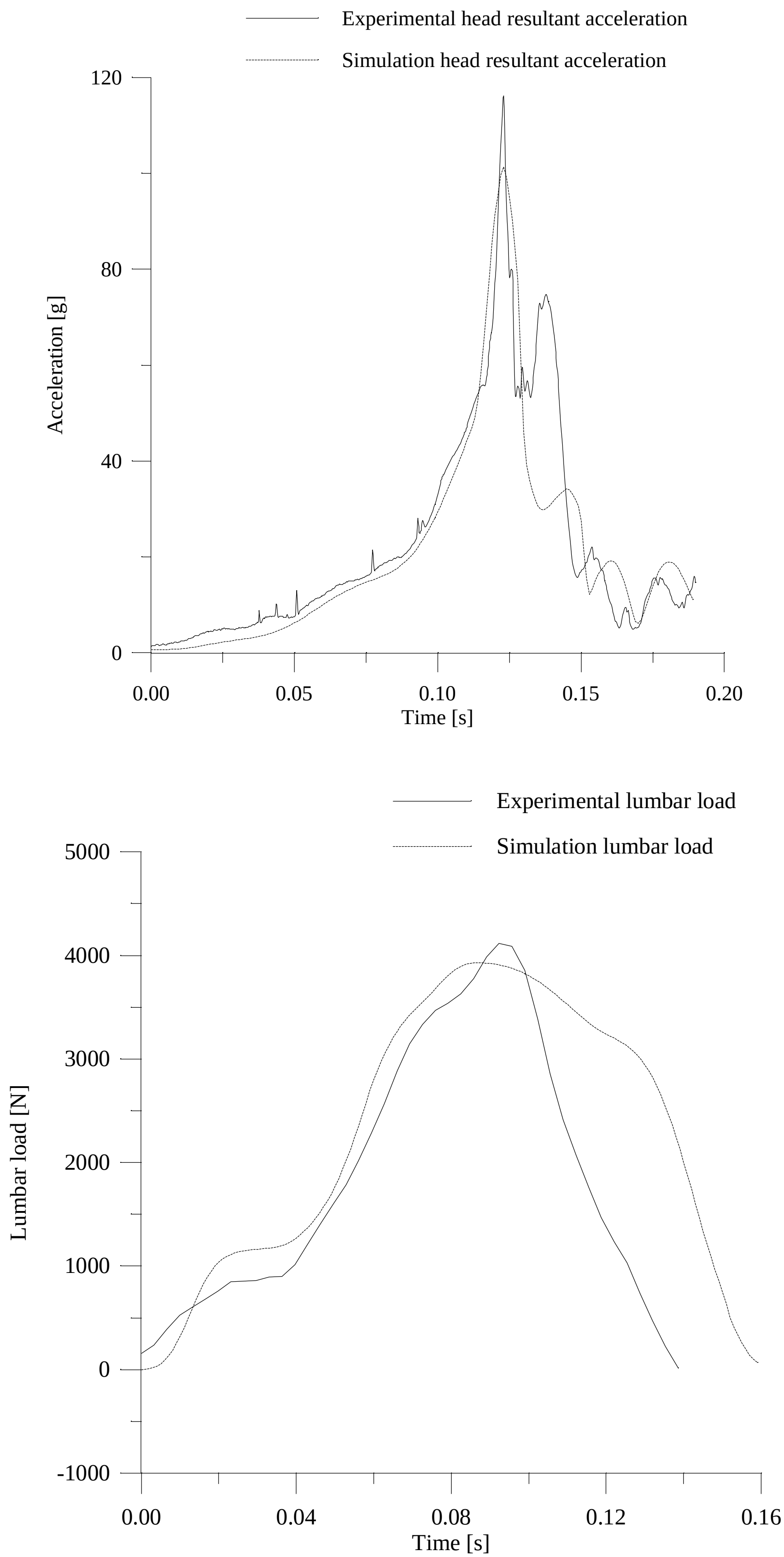

FIGURE 6: EXPERIMENTAL - NUMERICAL COMPARISON (ASTORI, 1995).

These problems can be addressed with numerical methods used for the solution of non-linear constrained optimization problems. That is:

$$\begin{aligned} &\min/\max \ f(\boldsymbol{x}) \text{ subject to} \\ &\boldsymbol{g}(\boldsymbol{x}) \leq 0 \end{aligned} \tag{1}$$

where $f(\boldsymbol{x})$ is the lumbar load, and $\boldsymbol{g}(\boldsymbol{x})$ are the constraints.
The optimization was performed using a genetic algorithm, which need only objective function evaluation and are quite insensitive to the hill-conditioning of the response surface and the presence of local minima (Goldberg, 1989). For these reasons they seemed to be the best choice for the analysis of this type of problems.

RESULTS

Results are quite disappointing in that one would expect to find very similarvalues for the minimum and maximum compression load in the lumbar spine, while it was possible to find a difference of more than one thousand Newton between the maximum and the minimum lumbar load (fig 7).
To find a minimum in the lumbar load, the easiest way is to maintain it constant over the entire duration of the pulse.
The corresponding deceleration curve reflects this kind of search, showing an initial peak which determines the initial lumbar load peak; being this acceleration peak at the very beginning of the entire pulse, and having to satisfy the change in velocity requirements of the standards, the acceleration curve does not go to zero and changes in such a way to produce a practically constant value in the lumbar spine compression.
On the other side, the maximum lumbar load is achieved with an abrupt deceleration at the end of the pulse, the initial peak being prevented by the constraints imposing the violation of the equivalence criteria, and especially of the minimum rise time T_{req}.
It's quite impressive to notice that the "minimum" deceleration curve is similar to those used in some crash test laboratories (fig. 3), while the "maximum" deceleration curve led to an almost identical lumbar load to that of the ideal triangular pulse (fig. 8).
Imposing the magnitude of the acquired pulse to be at most 2 *g*'s less than the ideal at any point during the entire time interval, led to a substantial decrease of the difference between the minimum and maximum lumbar load (fig. 9).
The results of these analysis show that not only the initial peak, but the entire deceleration history is critical in evaluating the risk of injury in the vertical impact test. In fact, without a reduction of the deceleration after the initial peak, and a subsequent proper shape, it wouldn't be possible to keep the lumbar load at a low, constant level. Imposing the magnitude of the acquired pulse to be at most 2 *g*'s less than the ideal, during the entire time interval, a deceleration history leading to a constant lumbar load could not be achieved, and the difference between the maximum and the minimum lumbar load becomes nearly negligible.

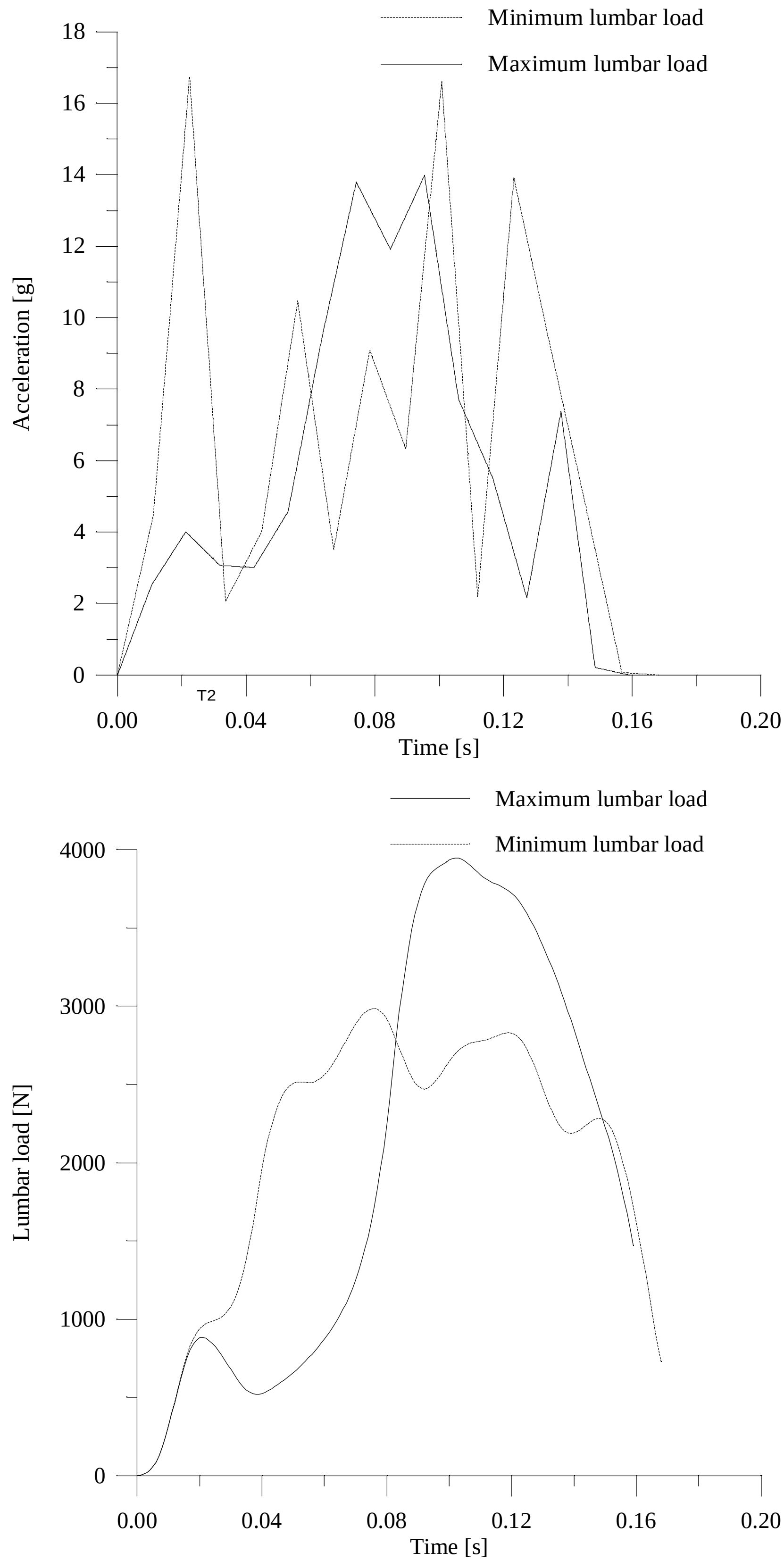

FIGURE 7: UNFITERED DECELERATION CURVES AND CORRESPONDING LUMBAR LOADS.

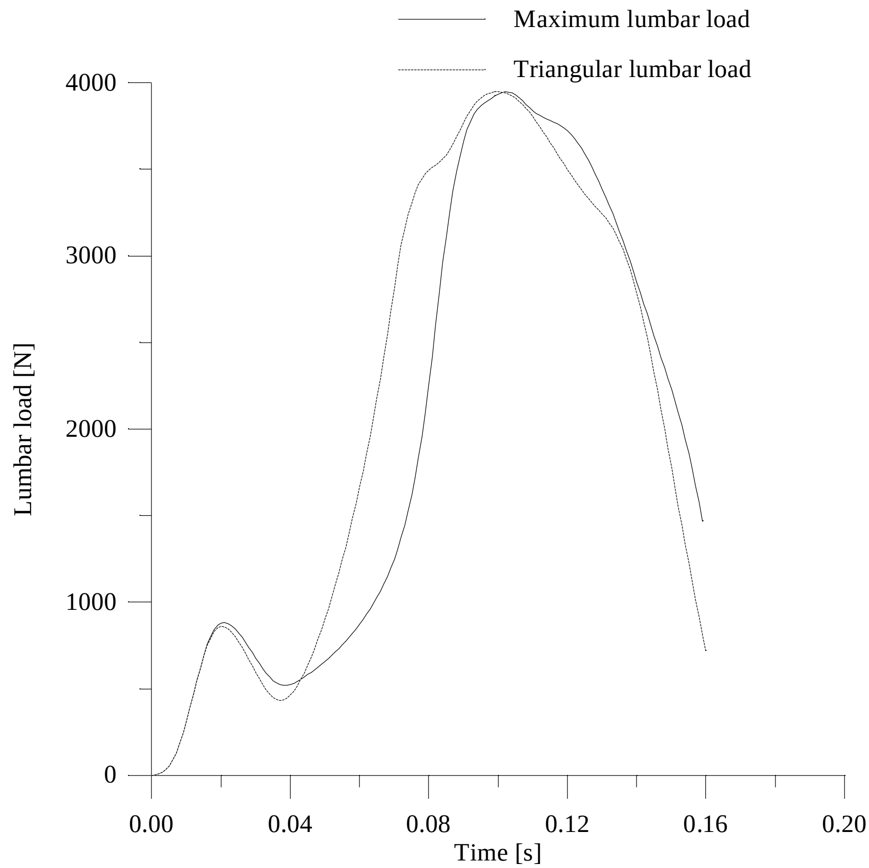

FIGURE 8: LUMBAR LOADS FOR THE "MAXIMUM" AND THE TRIANGULAR DECELERATION CURVES.

CONCLUSIONS

An extensive investigation on the effect of different pulse shapes for the “down” test homologation standards was performed.
This was carried out with the aid of experimental data and numerical analysis.
Results clearly show the inadequacy of the equivalence criteria taken into consideration, and the importance of its review. Also they do agree with those obtained during test conducted by FAA's Civil Aeromedical Institute (Gowdy, 1997) which have brought a revision in the graphical procedure.
The equivalence criteria here taken into consideration does not characterize an univocal pulse shape if one takes into account, as a critical factor, the initial deceleration slope and not the entire deceleration time history.
From these considerations, an alternative equivalence criteria is proposed in the effort to prevent disagreeing results being obtained from different crash test laboratories. This equivalence criteria, which is not dissimilar to that adopted by FAA (1997), imposes the test pulse shapes to be at most 2 *g*'s less than the ideal at any point during the entire time interval, thus preventing the use of erroneuos pulse shapes in the effort to reduce to a minimum the arbitrariness of the results of the test in terms of injury risk.

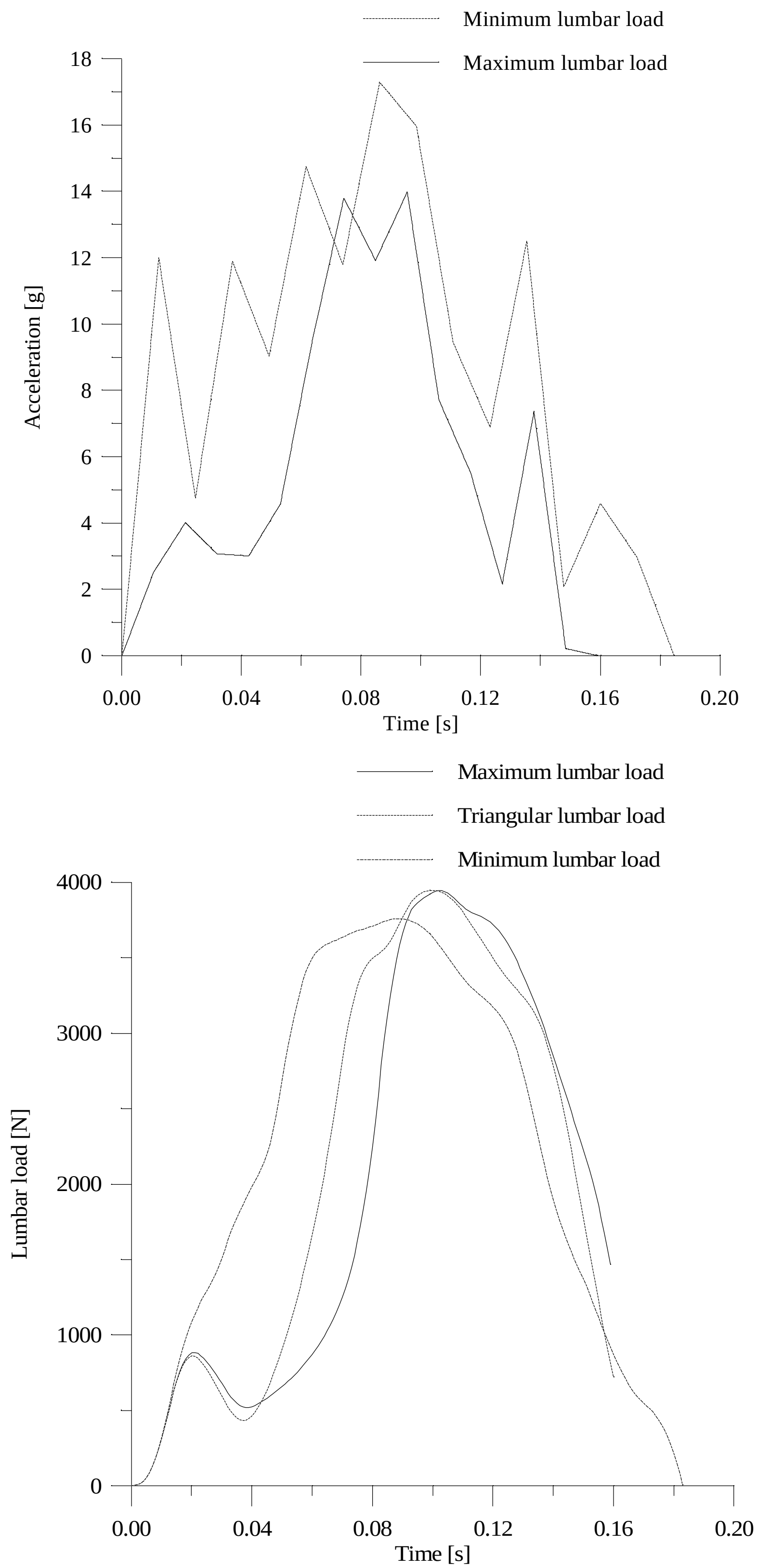

FIGURE 9: UNFITERED DECELERATION CURVES AND CORRESPONDING LUMBAR LOADS.

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