Analysis of aircraft seat crash test pulse shapes with the aid of genetic algorithms

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Abstract

The paper presents the use of genetic algorithms for the study of the dynamic behaviour of a complex aircraft seat-occupant system. Nowadays aircraft seats must comply with both static and dynamic homologation tests. In particular, the dynamic aircraft seat crash test is usually carried out to ensure acceptable safety levels for the occupant; up to this point, a seat with an antrophomorfic dummy is subjected to a somewhat "typical" deceleration pulse, and the resulting loads measured on the dummy must be within certain tolerable limits. This "typical" pulse is the result of several analyses of full-scale crash tests of the general aviation and seat-occupant response made in the past thirty years.

Genetic algorithms proved to be a powerful search tool allowing a deep insight into the characteristics and limits of the current aircraft seat crash test standards.

Introduction

Attention was focused on the so-called "down" test, where the deceleration is mainly in the vertical direction and the risk of injury is the compression load in the lumbar spine (fig. 1).

The down test is characterised by a triangular acceleration pulse shape of at least $G_{req} = 14g$ peak and a maximum rise time of $T_{req} = 80ms$ (fig. 1)[7, 4]. The test 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.

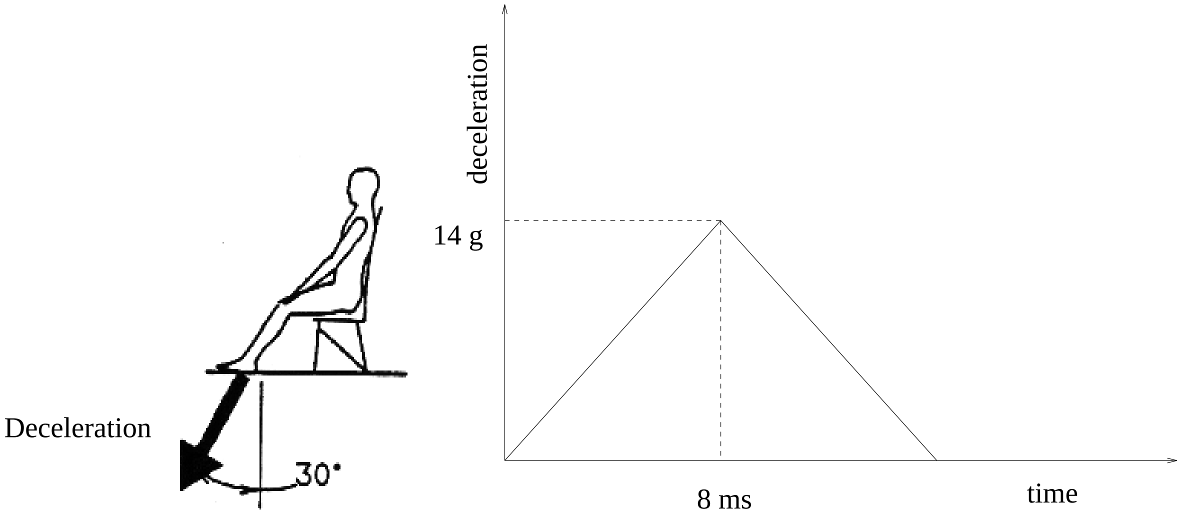

Figure 1: Down crash test and ideal pulse shape.

This graphic technique uses the following steps:

a. Locate the maximum acceleration (Gp), which shall equal or exceed 14 g.

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 (10.67 m/s).

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.

However it was noticed that different pulse shapes, although standardised, lead to different lumbar loads, allowing test facilities to obtain disagreeing results for the homologation of a tested seat.

In order to point out, with the use of crash tests and numerical simulations, the importance of a review of the actual standards in use, 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 optimization problem

First, the variational problem was transformed to a mathematical programming one.

For this purpose, the value of the deceleration was sampled n times, and a linear interpolation between two samples was used (fig. 2). This lead to $n + 1$ subintervals of linearly-varying deceleration, which, with the total time, completely defined the pulse shape; note that, in this way, the sample frequency of the deceleration curve wasn't fixed.

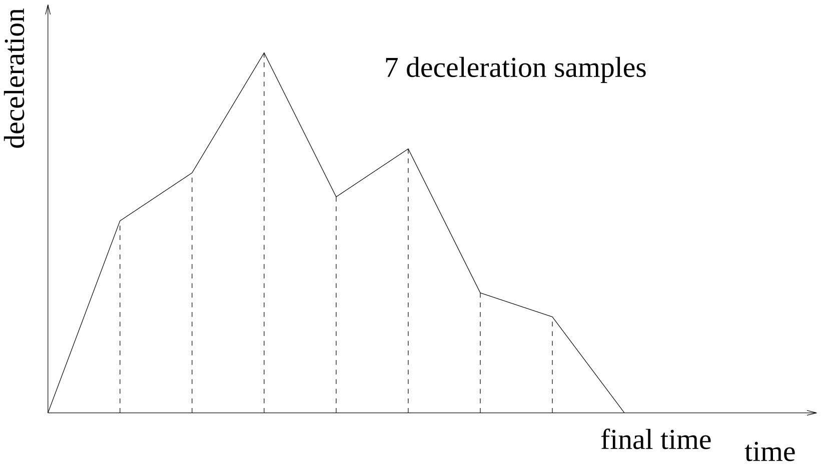

Figure 2: Discretized pulse shape

Equivalence criteria were imposed via the penalty functions method [6, 5]
No information were available on the existence and number of local minima; moreover, sensitivities information could be obtained only using the finite difference method, possibly leading to irregular response surfaces due to numerical imprecision [3].
Genetic algorithms are known to need only objective function evaluations and to be quite insensitive to the hill-conditioning of the response surface and the presence of local minima. For this reasons they seemed to be the best choice for the analysis of this type of problems.

The optimization code, derived from D. Goldberg's SGA [5], was written in Fortran with MIL-STD-1753 extensions.

Main features added to the code are:

- single or double cross-over;
- linear mapping from binary or gray codes to real values;
- different linear scaling strategies;
- maximization or minimization of the objective function;
- sharing.

Results

First results were obtained with a simplified 4 masses and 4 springs model of the human body and of the seat cushion [2]: a minimization and a maximization run for the lumbar load was carried out. The main control parameters of the problem are shown in the table:

Population size	100
Number of variables	15
Total number of bit	120
Gray coding	
Mutation probability	0.0001
Double crossover probability	0.5

Every variable was given 8 bit of coding and linearly mapped; acceleration variables could range between 0 and 18 g's, leading to a step of about 7E-2 g's, while the time variable could vary between 0.08 and 0.2 seconds, with a step of about 5E-4 seconds.

In the first case the equivalence criteria had to be satisfied; on the contrary, in the second case the maximum lumbar load did not satisfy the criteria still remaining below the maximum g level.

Fig. 3 show the obtained pulse shapes for both runs and how they influence the lumbar load.
Next step was to carry out the optimization with a more sophisticated model of the human body and of the seat cushion (fig. 4). Simulations were performed with a multi-body code named *VeDyAC* [1], with which an antrophometric test dummy Hybrid II and a rigid seat pan with a cushion was modelled. The numerical model was experimentally validated using the crash test facility of the Aeronautical Department of the "Politecnico di Milano" (fig. 5).
In such a way no deformability of a real aircraft seat was taken into account, but only that of the cushion, so to better understand the influence of each structural component of an aircraft seat on the lumbar load.
Figures 6 compares the vertical components of the deceleration curves and the relative lumbar load curves.
Optimization using a completely deformable model of an Airbus A340 business class seat (fig. 7), was finally performed. The seat model was experimentally validated in a previous work [1].
Figure 8 shows obtained results.

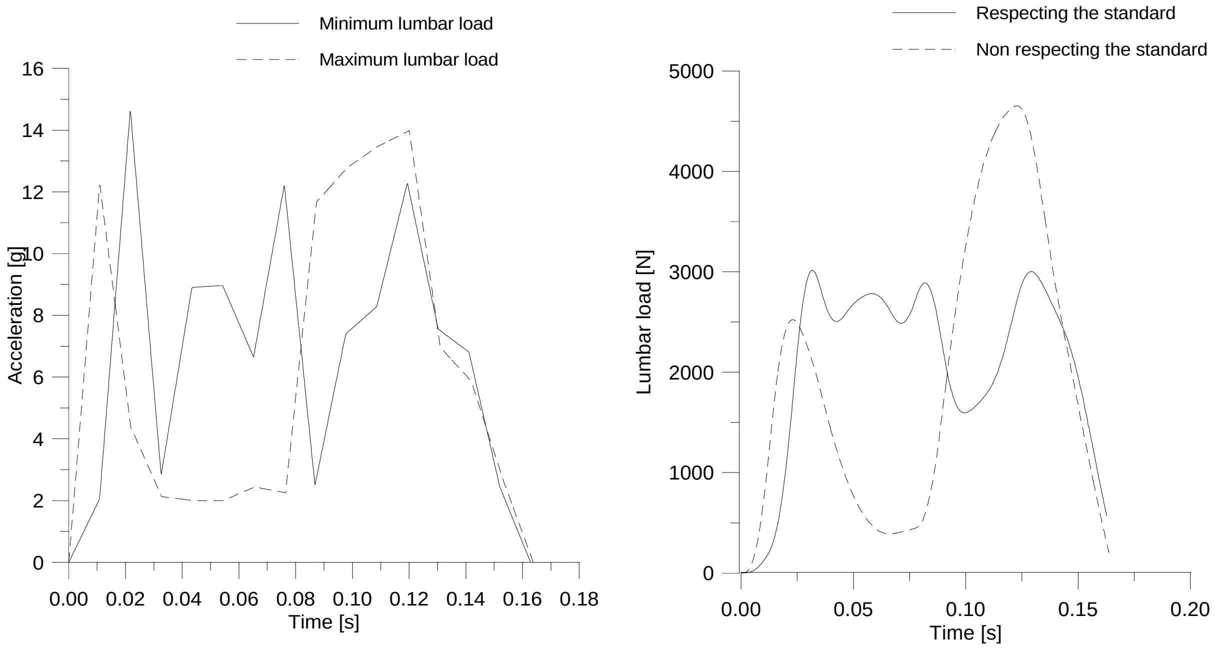

Figure 3: Optimized acceleration pulses and corresponding lumbar loads for the spring model.

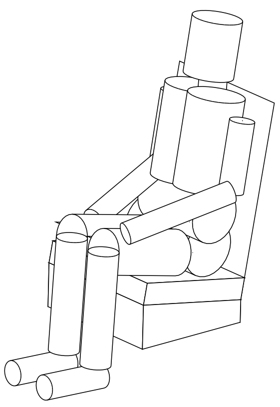

Figure 4: *VeDyAC* model of the cushion and occupant system.

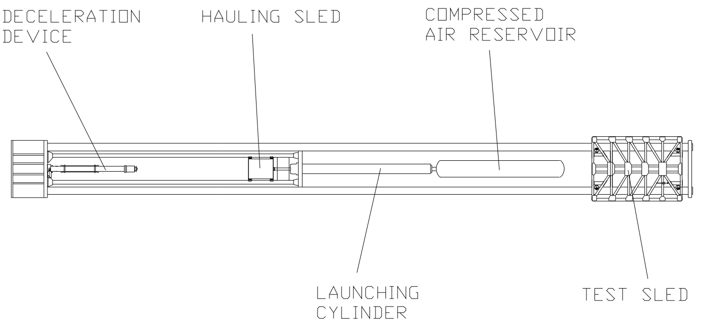

Figure 5: Crash test sled facility.

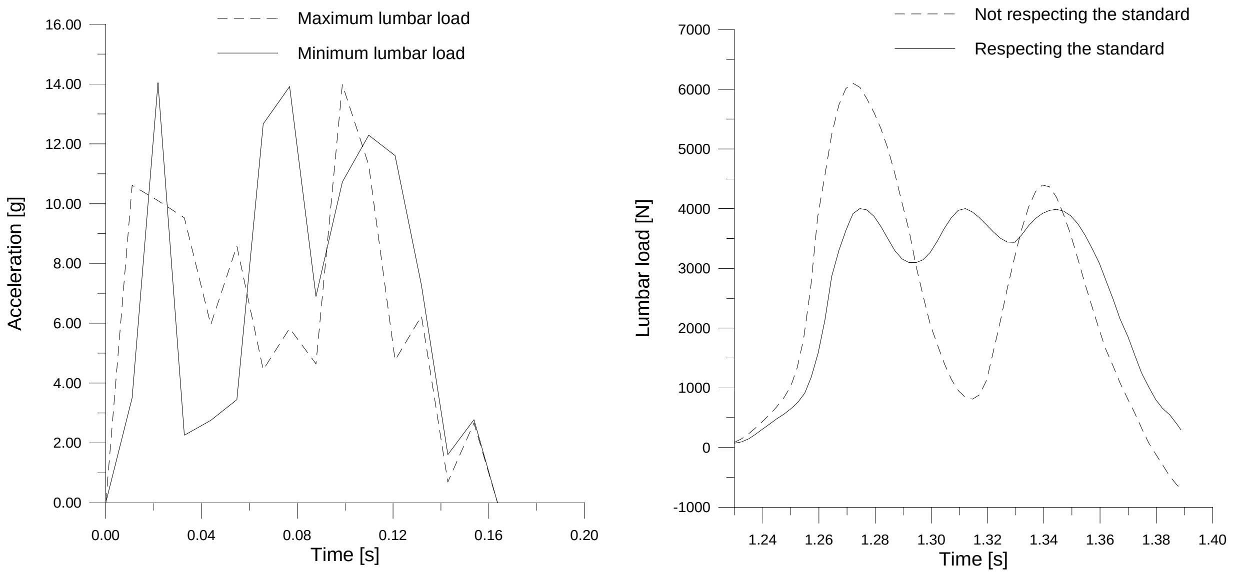

Figure 6: Optimized acceleration pulses and corresponding lumbar loads for the cushion model.

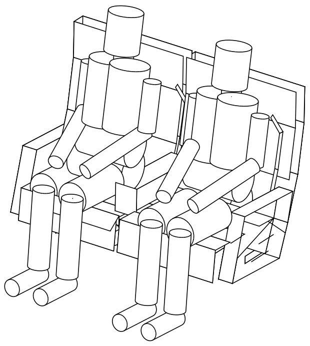

Figure 7: *VeDyAC* model of the aircraft seat.

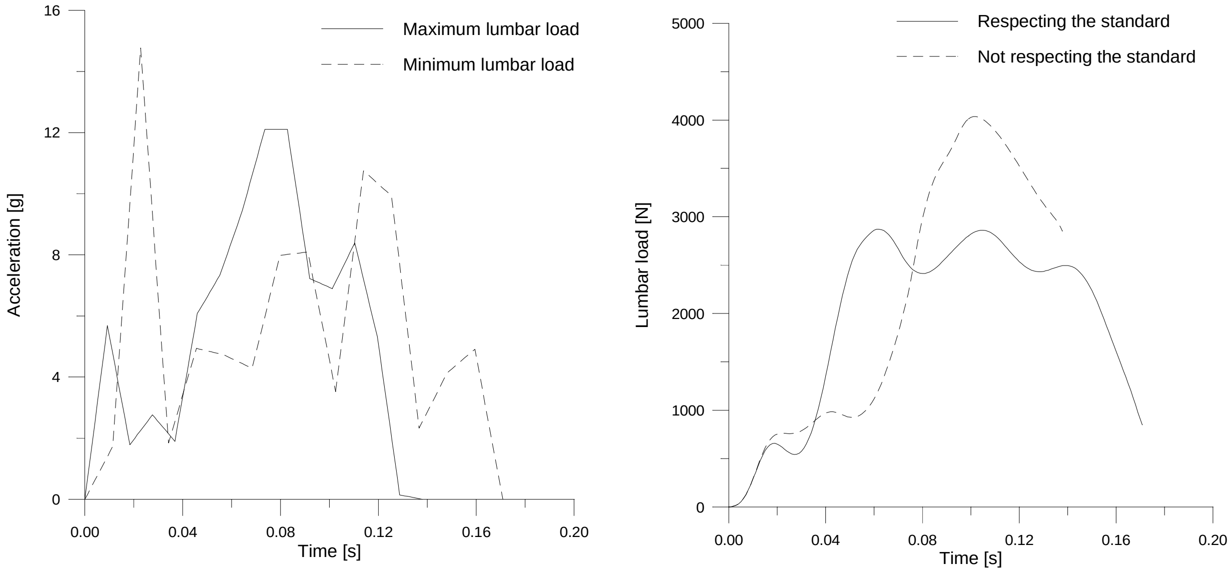

Figure 8: Optimized acceleration pulses and corresponding lumbar loads for the completely deformable model.

Conclusions

The behaviour of a complex, highly non-linear, aircraft seat-occupant dynamic system was successfully investigated with the use of genetic algorithms.

Notwithstanding the use of penalty functions, the genetic algorithm has given good results without requiring specific tuning of the algorithm's parameters.

However, increasing the complexity of the dynamic model, the single evaluation increased substantially, up to 1 minute of CPU time on a Silicon Graphic's Indigo^2, leading to a total computation time of more than two days.

Clearly, increasing the number of variables would probably require an unacceptable increase in computation time with a scalar computer, but for this particular type of problem there was no interest in a parametric study of such effects.

References

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