Numerical Investigation of a Glider Seat Cushion Under Shock Loading Using LS-DYNA®

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Abstract

The objective of this study was to numerically simulate the shock mitigation capability of a glider seat cushion structure, at attenuating impact loading on the human pelvis. The cushion structure was comprised of two dissimilar 1" foam layers, T-41 and HS-70 foam, each colloquially known as Temper foam and Ethafoam, respectively. The Low Density Foam (Mat_57) constitutive material model was used to model the behavior of each cushion layer. The material model used the stress-strain curve to predict the response of the foam; this allowed for the rate sensitivity of foams to be modelled via different stress-strain curves. Pre-stressing of the cushion was achieved through gravitational loading until the cushion reached a steady state at which time the nodal stresses and strains were exported to the shock analysis. The simulated cushion was subjected to a 6.3g shock loading using the Frequency_Domain_Domain Response Spectrum keycard and random input profile using the Frequency_Domain_Random_Vibration keycard. In both cases the acceleration experienced by a human pelvis seated on the cushion was obtained and compared with available experimental data. The results showed the maximum acceleration experienced by the pelvis was in good agreement with experimental data. The model was then extended to determine the effectiveness of increasing the cushion thickness at attenuating shock loading on the pelvis. Comparing results with those found in literature, the numerical results were consistent in showing that increasing the cushion thickness is highly effective within a couple of inches after which increasing the thickness no longer provides any mitigating effects.

Introduction

Glider aircraft are used to train young air cadets, within a span of six weeks, trainees learn and practice skills necessary to pilot the aircraft. As their skills progress, the cadets have opportunities to perform solo flights to obtain glider their pilot license. Throughout their training air cadets undergo multiple landings daily. Despite every effort to reduce and mitigate the risks associated with hard landings, there still exist the possibility of injury on the lower back from excessive landing shock loads.

The National Research Council Canada (NRC) was tasked with investigating glider landing shock load on glider aircraft occupants. NRC completed the investigation in three phases. The first phase was focused on instrumenting a glider to demonstrate recording of landing shock loads during flight operations by pilots. The shock loads were measured at the interfaces between the pilot and seat cushions and analyzed in accordance with ISO 2631-5:2004 titled “Mechanical vibration and shock evaluation of human exposure to whole body vibration, Part 5: Method for evaluation of vibration containing multiple shocks” [1].
The second phase involved shock testing on a NRC mechanical shaker facility using a mock-up glider seat frame, a Hybrid III manikin, a current in-service seat cushion and a shock load profile gathered from phase I. The objective was to evaluate the OEM cushions provided by the glider manufacturer. The third phase objective was to investigate the effect and trending of the energy absorbing cushion foam under severe shock load inputs though numerical simulation and experimental validation. The end goal was to determine the appropriate cushion thickness to help mitigate the shock experienced by the occupant

Seat Cushion

The current in-service 2” seat cushion was comprised of two layers of foam housed in a porous cloth pouch: the top layer was a 1” thick medium stiffness energy absorbing T41 Temperfoam and the bottom layer a 1” thick high stiffness HS-70 Ethafoam, shown in Figure 1.

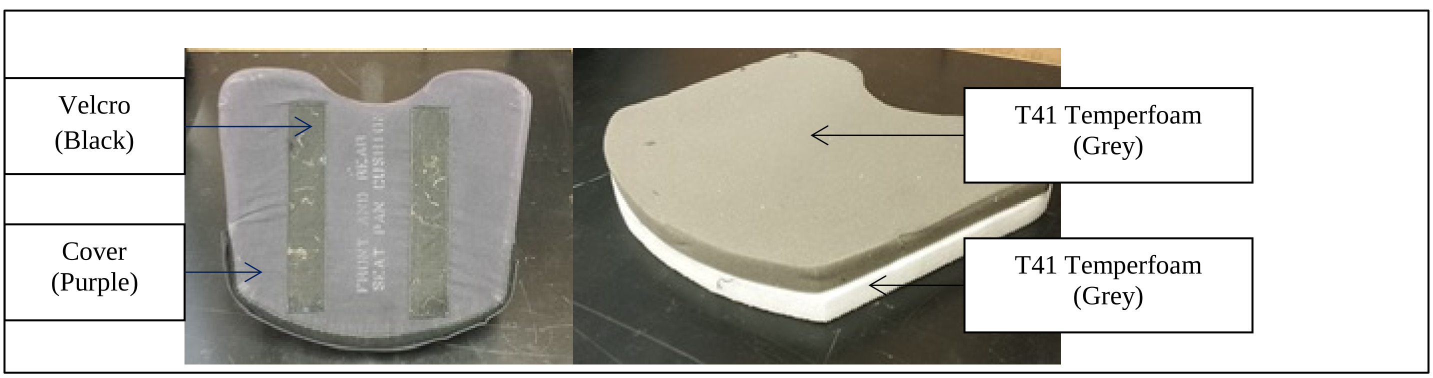


Figure 1: In-Service 2” Seat Cushion

T41 Temperfoam is a polyurethane foam developed by NASA during the 1960s. There are a number of variants for this type of foam, it is often referenced as: memory foam, shape memory polyurethane, “viscoelastic” foam or low-resilience polyurethane foam. The material parameters for the low density foam are listed in Table 1 and referenced from [2]. The response of the T41 Temperfoam follows a predetermined path based on a stress-strain curve, for one given stress see Figure 2.
HS-70 Ethafoam, polyethylene is a white, low density plastic foam that is characterized by its hardness. It is less flexible than the memory foam and exhibits minimal compression as was observed in the compression test. The material parameters used for the HS-70 Ethafoam are listed in Table 1 and referenced from [3].

Table 1: T41 Temperfoam Properties

Material Property	Symbol	Dimensions	T41 Temper Foam	HS-70 Ethafoam
Elastic Modulus	E	kPa	600.0	1240.0
Density	ρ	kg/m^3	63.2	99.0

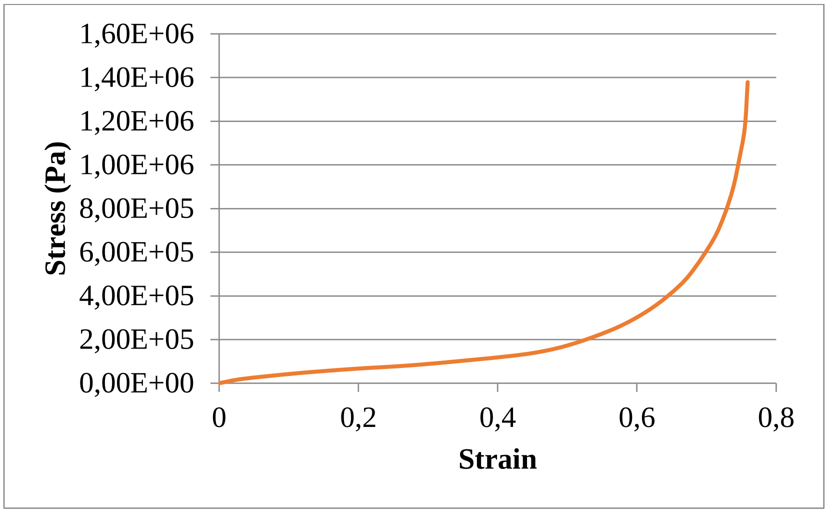


Figure 2: T41 Temperfoam Stress-Strain Curve

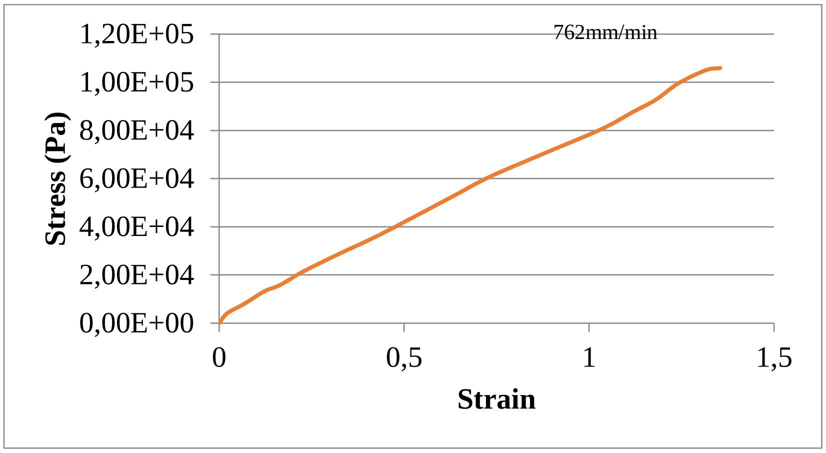
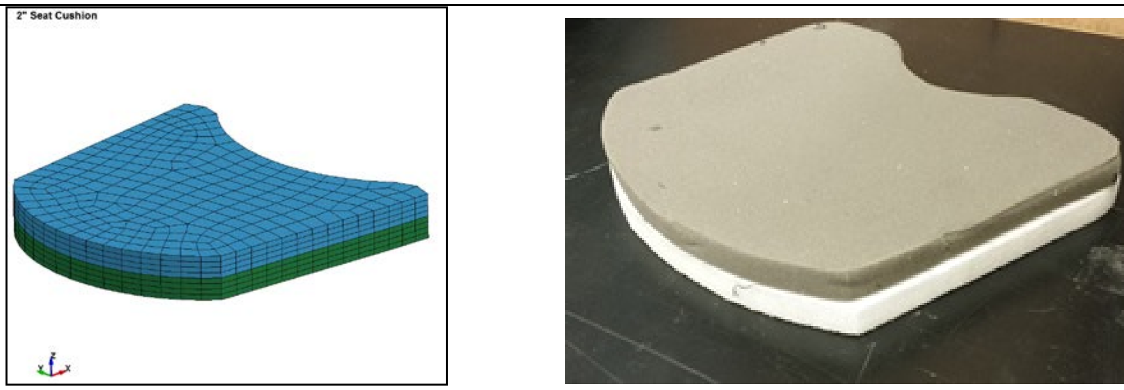


Figure 3: HS-70 Ethafoam Stress-Strain Curve

Finite Element Model

The numerical model was composed of 2 different parts representing the different cushion components, shown in Figure 4; the upper foam is T41 Temperfoam while the lower foam is HS-70 Ethafoam. The model used 2868 solid elements, with the smallest elements measuring approximately 6.0 mm and with element formulation 1. Both cushions used the Low Density Constitutive Material Model to predict deformation behavior.



762mm/min

Simulation Cushion

Figure 4: Simulation Model of the Cushion

Compression Test

As a means of first level of confidence in the simulation, a compression test was performed using a 45 kg steel weight loaded onto the cushion top, as shown in Figure 5. The initial unloaded thickness of the cushion varied between 5.4 and 5.6 cm, with the steel plate loaded on top of the cushion, it was compressed between 1.2 - 0.9 cm to reach a final thickness between 4.2 and 4.7 cm. The cushion was compressed less in the back portion than the front due to its structural design. The same 45kg steel mass was loaded in the numerical simulation, through a gravity field and a rigid wall at the base of the cushion, Figure 6. The cushion showed a uniform compression of 0.9 cm, having a final thickness of 4.5 cm after loading, as seen in Figure 6.

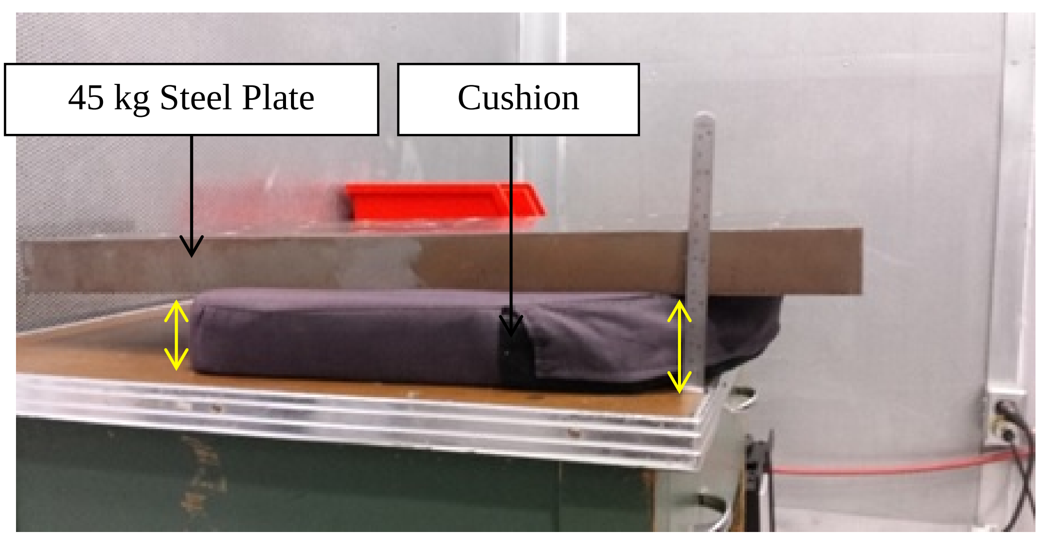


Figure 5: Compression Test Setup

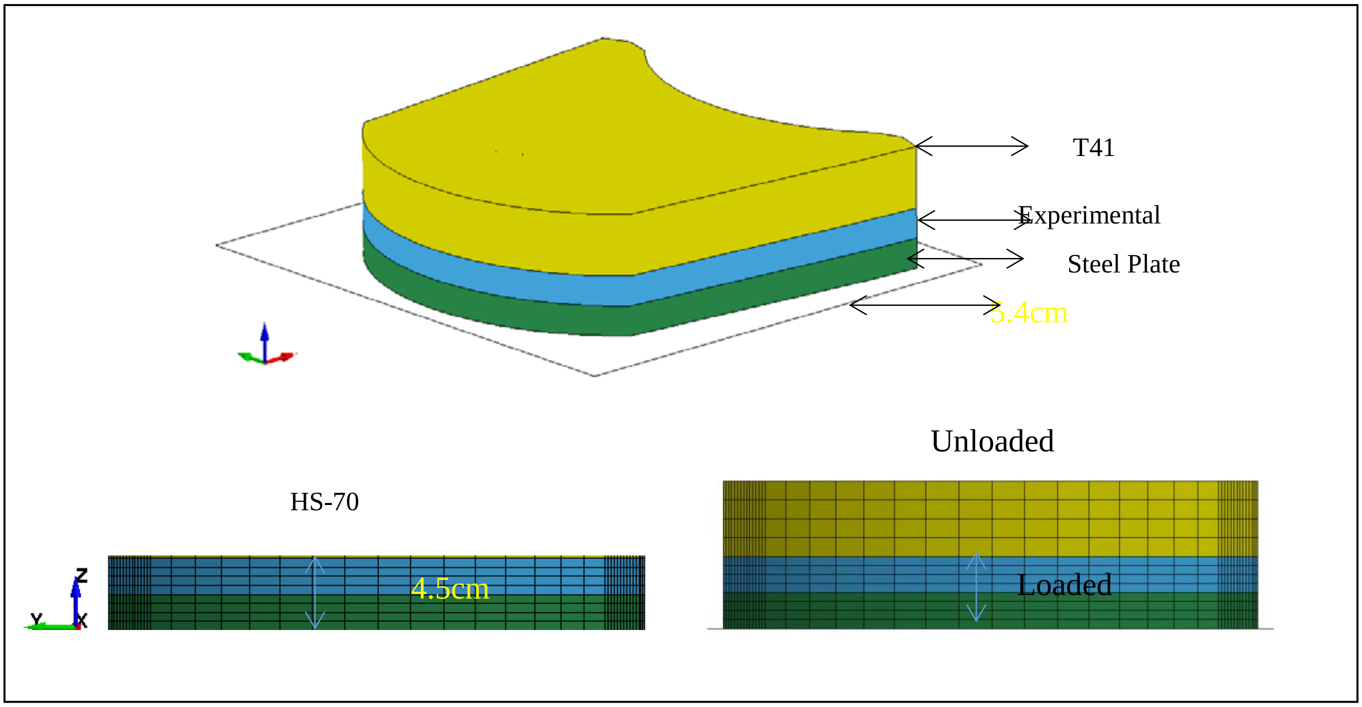


Figure 6: Steel Plate Compression Test

Modal Analysis: Experimental and Simulation

As a second means of verification of the model, a modal analysis was done comparing the experimental and simulation models. A random profile input with a peak of 0.17 g^2/Hz between 3-70 Hz was used on the cushion on the shaker table, as seen in Figure 7. Based on the cushion's response exhibited in Figure 8, the highest peak occurred at 16.50 Hz. While there are other peaks nearby it was highly likely that these were associated with shaker system, thus a best judgement was used to determine if a mode was present or not. A similar eigen-value analysis was performed on the simulation model, with the model yielding a mode at 16 Hz. Due to the nature of eigenvalue analysis employing geometrical and material properties in the calculation, an accurate modal analysis gives confidence in the geometry and material properties used in the simulation.

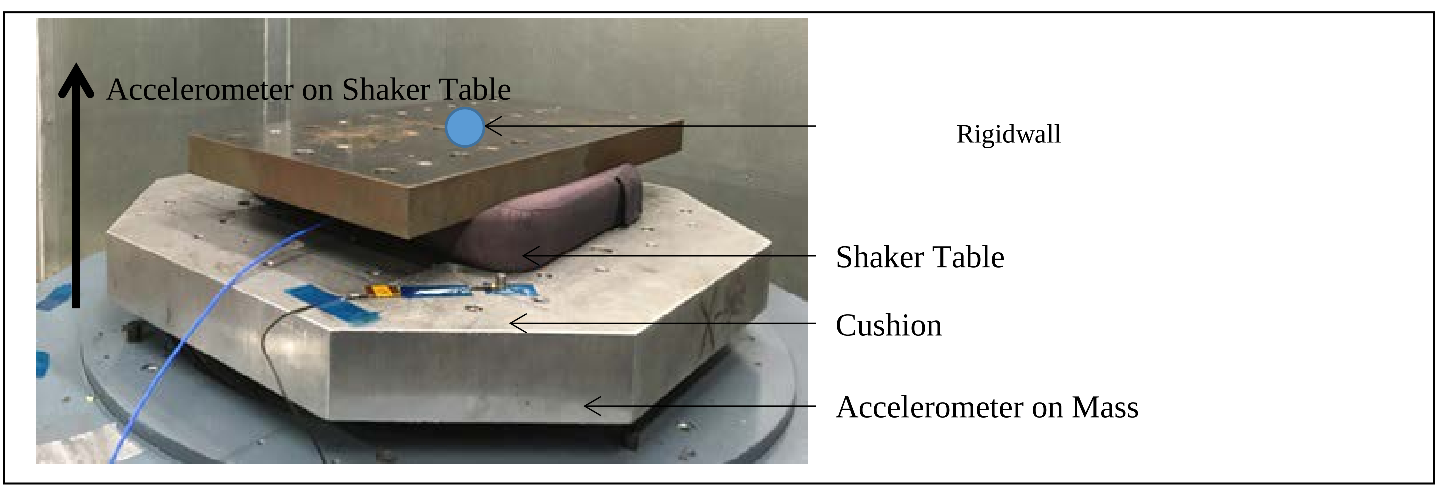


Figure 7: Shaker Table Setup

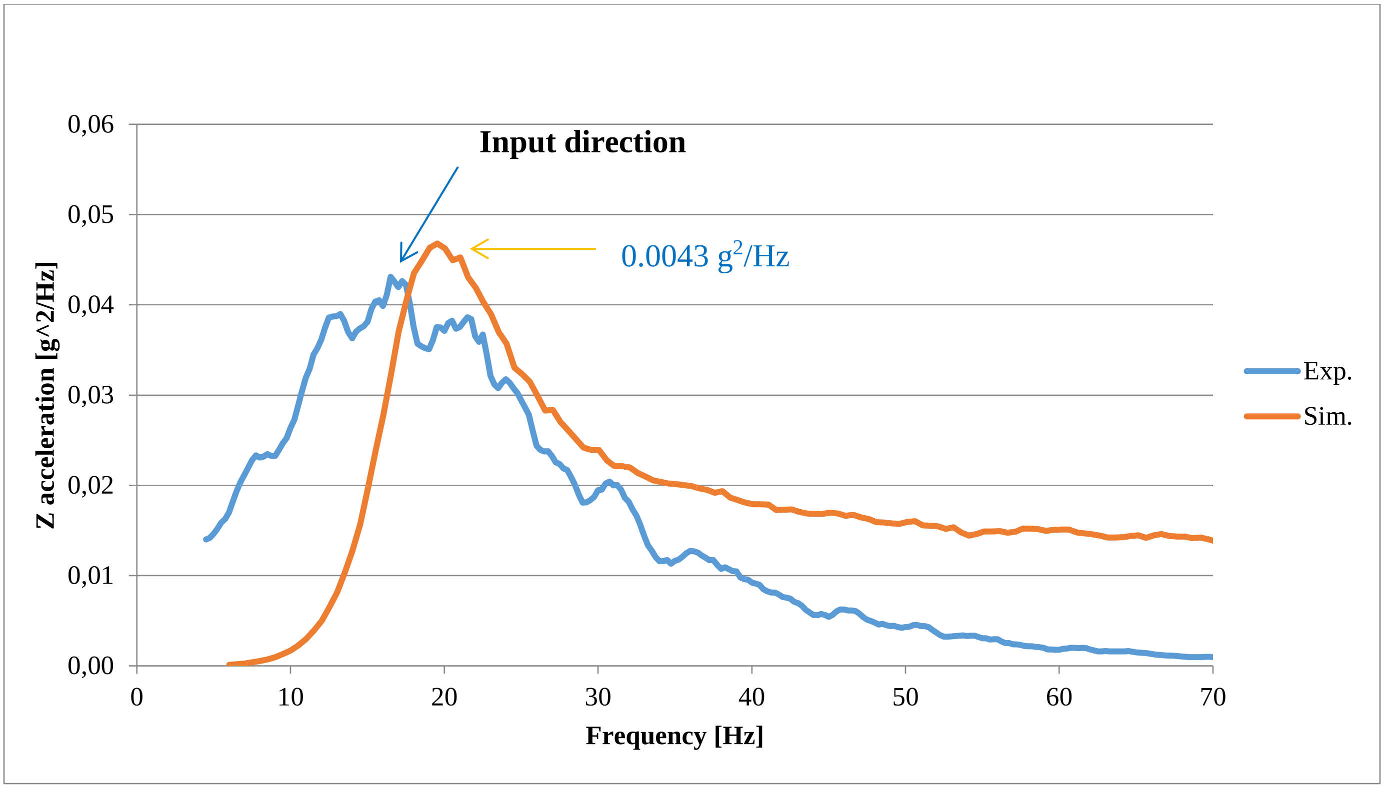


Figure 8: Random Profile Input Response

Modal Analysis: Experimental and Simulation

In order to obtain results closely aligned to those in the actual in-service environment, the steel plate was replaced with a dummy pelvis, shown in Figure 9. As the head, torso and extremities were not relevant to this simulation they were removed and their mass localized in the pelvis region; the pelvic model contained all the mass of the dummy model weighing 45 kg. Figure 9A shows the original dummy model, a 3B-Hybrid III taken from LS-DYNA [5], while Figure 9B show the pelvic region with the irrelevant extraneous parts removed. The pelvis model was modeled using 264 solid elements along with element formulation 1. Figure 10 shows local compression of the cushion due to the weight of the pelvis model.

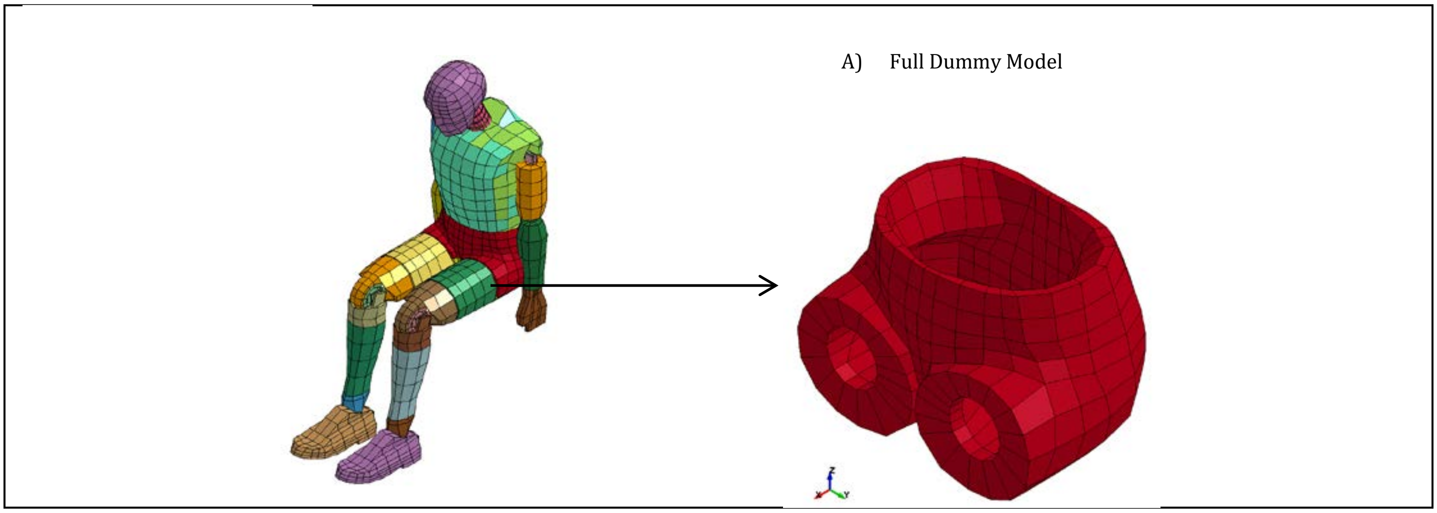


Figure 9: Dummy model

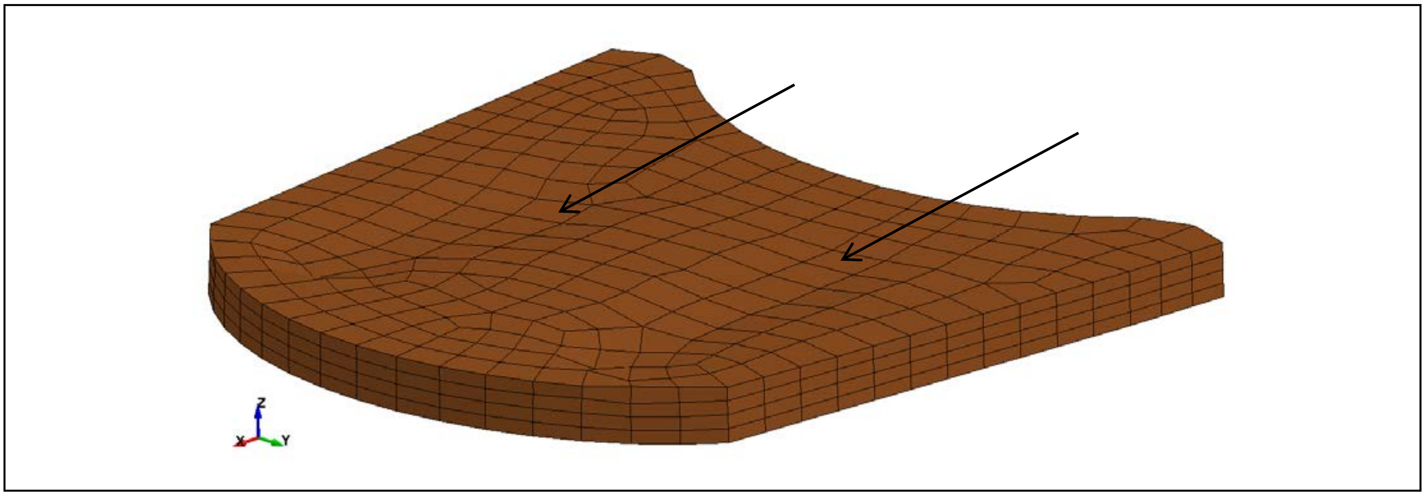


Figure 10: Localized Compression on the T41 Temperfoam Cushion

Shock Loading

The shock profile in Figure 11, was recorded in phase one of the project, was replicated on the NRC shaker with a dummy model seated on the cushion, Figure 12. The results were compared with the response of numerical model to the same shock profile. In LS-DYNA, the shock profile was modelled using the "Frequency Domain Response Spectrum" keyword which performs a response spectrum computation to obtain the peak response of a structure. In this case, the excitation profile was based on the experimental profile and applied as a base excitation in the normal direction on the cushion, with a damping ratio of 27%.

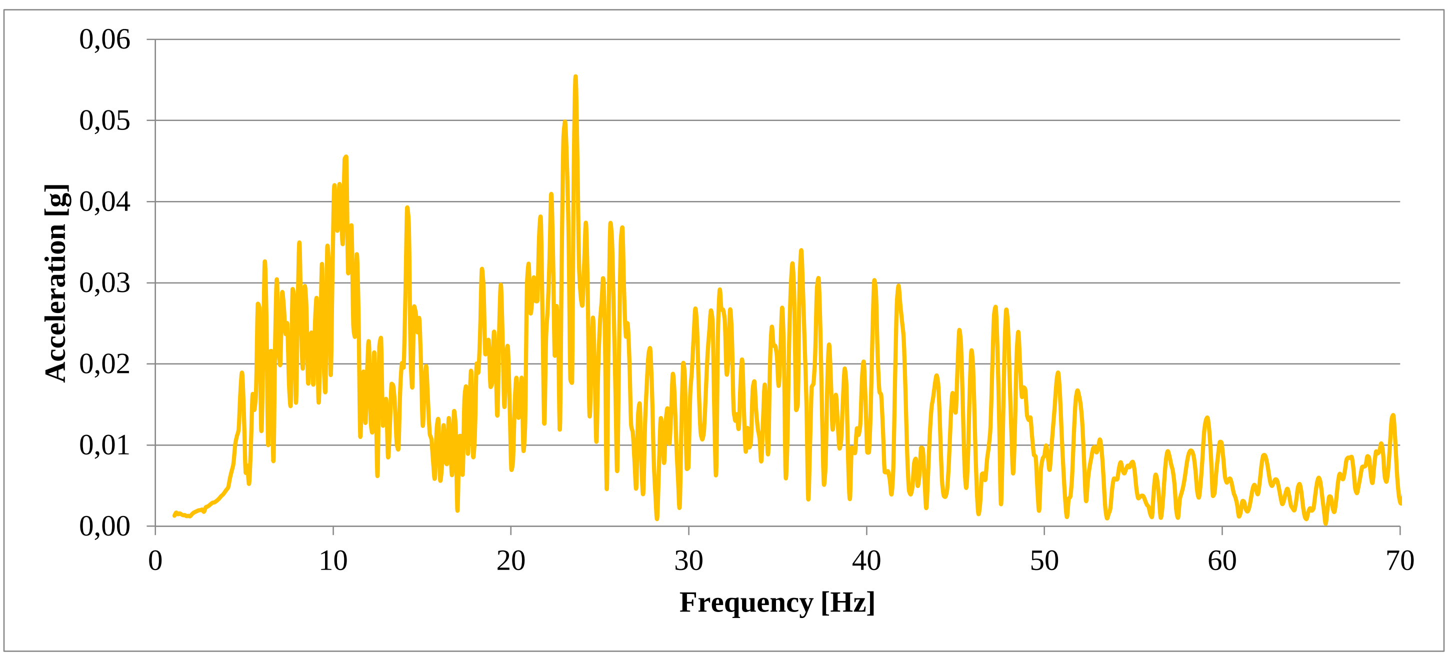


Figure 11: Input Profile – Shock Test

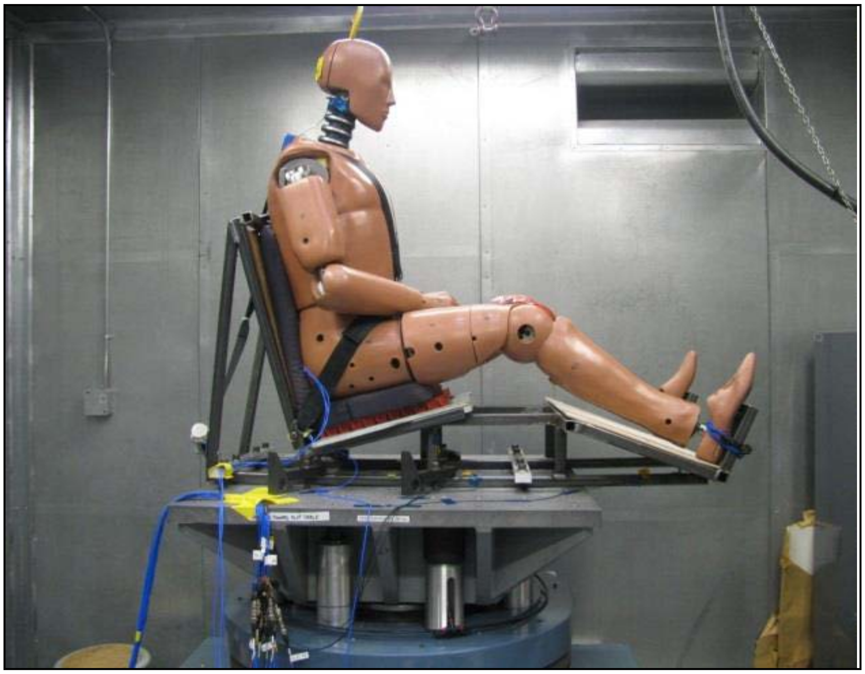


Figure 12: Shock Test with Dummy

The response profile of both the experimental test and the numerical simulation is show in Figure 13. The experimental profile reached a peaked value of 0.051g, while the pelvis reached a peaked of 0.054g, a difference of 5.9%. The two profiles remained similar with greater attenuation at the higher frequencies, likely because the damping coefficient is higher for the higher frequencies.

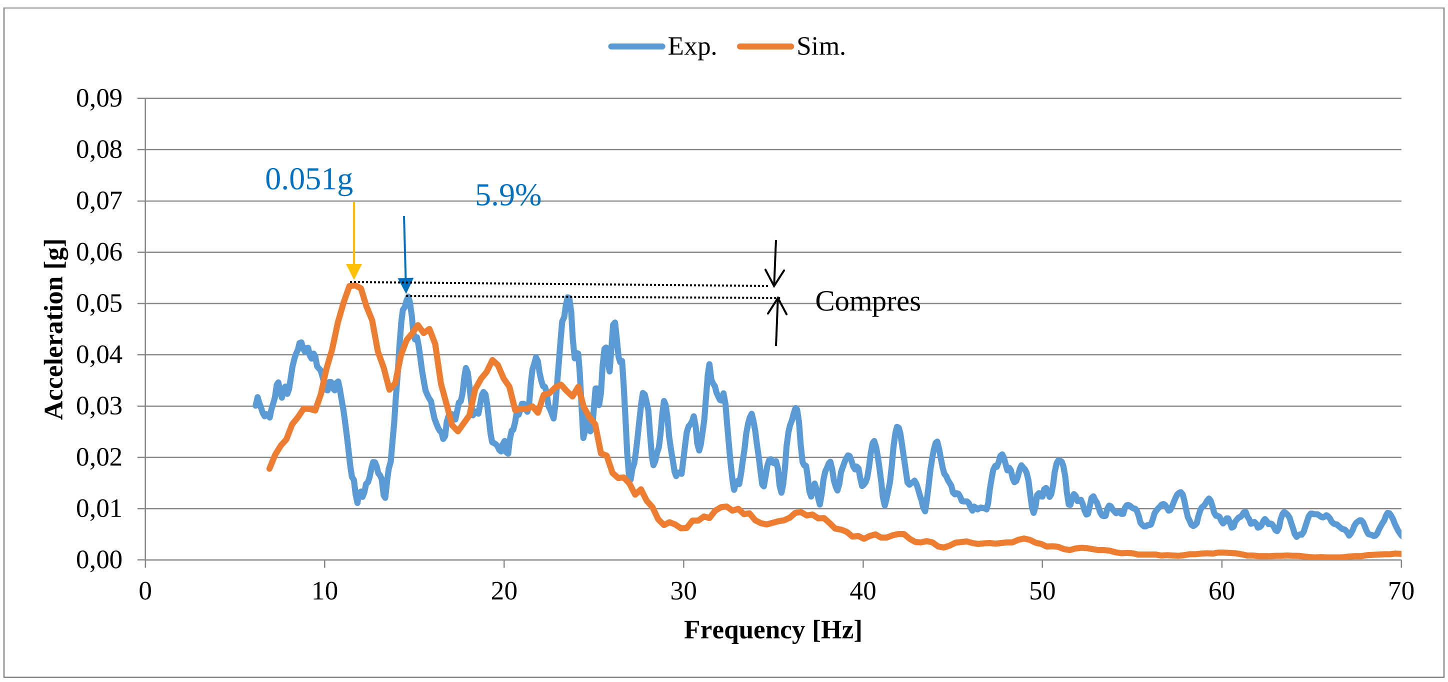
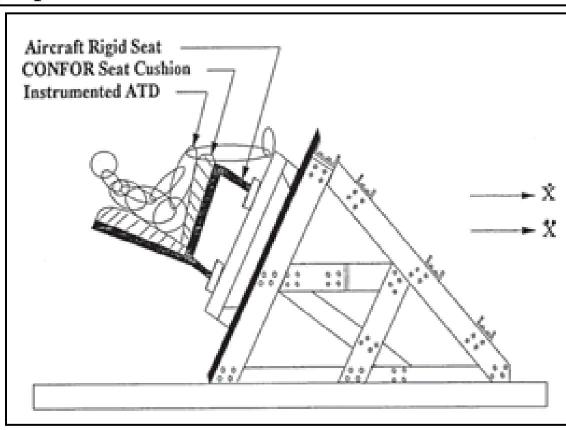


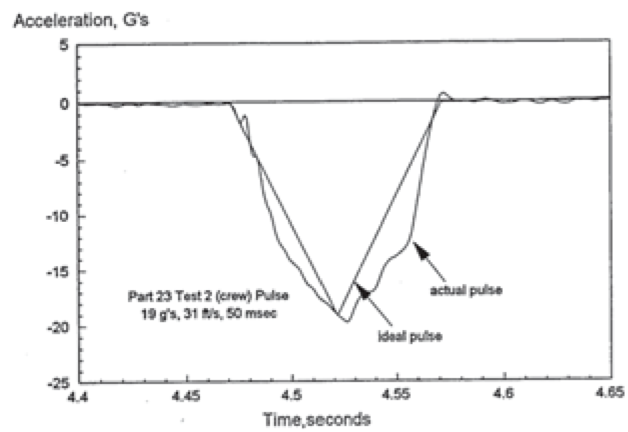
Figure 13: Shock Test Simulation Results on the Pelvis

The Effect of Cushion Thickness on Shock Response

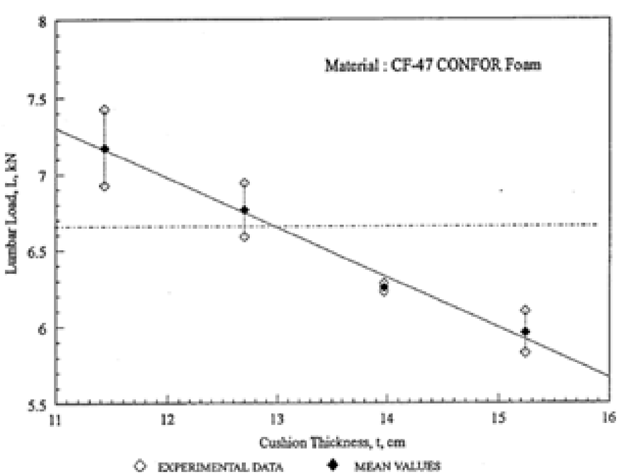
With a verified numerical model a study was conducted to study the effect of increasing the cushion thickness to mitigate shock loading on the pelvis based results from on the research paper [4]. A dynamic test consisting of a Hybrid II anthropomorphic test dummy was seated on the cushion which was inclined at 60° to the horizontal, as shown in Figure 15A. The seat was accelerated to velocity of 9.45 m/s at which time the brakes were applied and the apparatus achieved a deceleration profile of 19g over 50ms as shown in Figure 15B. This is consistent with the 14-Code of Regulations Part 23-Airworthiness Standard, Section 562 (b).1 standard for testing seat cushions. The results showed that increasing the cushion thickness reduced the loading experienced by the lower back, shown in Figure 15C. The experimental test discussed above was replicated in the simulation for a series of different Temperfoam thickness (1-5inch). A velocity was applied to the pelvis, which compressed the cushion and the acceleration experienced by the pelvis was monitored, Figure 16. The simulated acceleration response of the pelvis with varying thicknesses of the T41 Temper foam is shown in Figure 17. The acceleration response was shown to decrease with increasing in thickness of the T41 Temper foam. This demonstrated a consistent trending as that reported in the literature through crash impact tests [4]. With the T41 Temper foam thickness increasing, the shock acceleration response of the pelvic mass was observed to reduce significantly. The trending of the reduced shock response suggested that a thicker bottom cushion made of T41 Temper foam will provide enhanced shock load protection to the occupant in glider landing operations, however only up to a certain thickness.



15C:Results



0.054g



15B:Deceleration Profile

Figure15: 14-Code of Regulations Part 230Air wothiness Standard Test

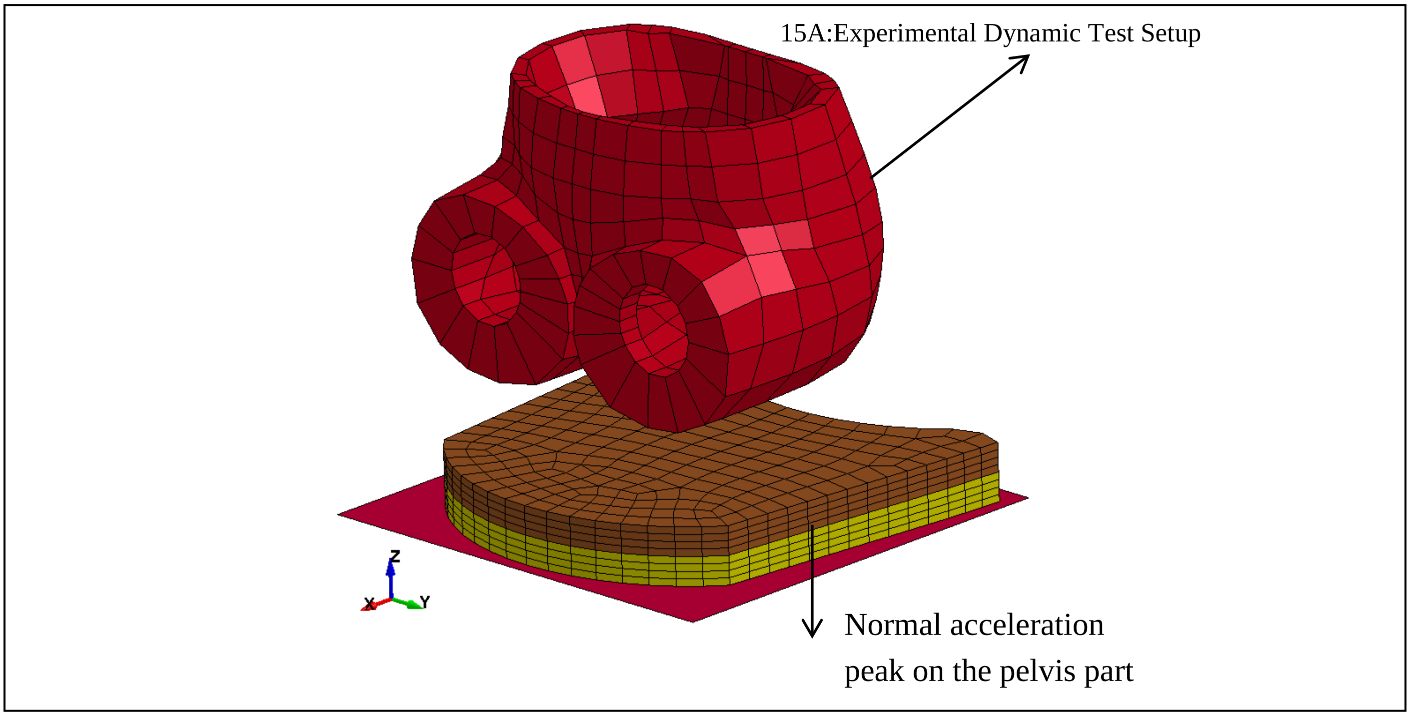


Figure 16: Deceleration Profile

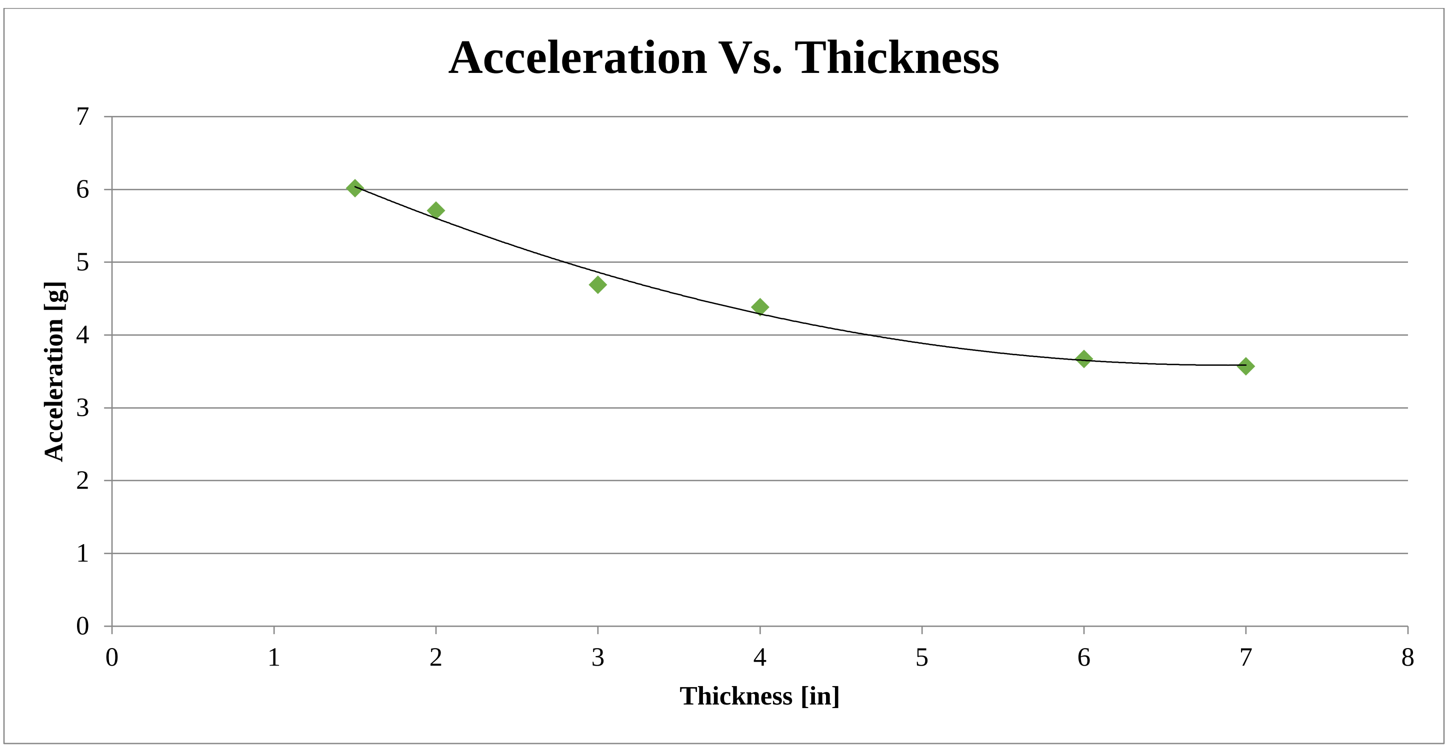


Figure 17: Deceleration Profile

Conclusion

The goal of the project was to numerically replicate the response of a glider seat cushion which was exposed to random and shock loading and to extend the numerical model to predicting maximum cushion thickness for reducing loading on the glider seat occupant. The seat cushion was compromised of two different layers of foam, a soft Temper foam and a stiffer Ethafoam, both housed concurrently in a cloth sack.

The model was first verified by a static compression tests along with a random vibration and shock loading. After which, the thickness of the softer foam was increased to determine its effectiveness at shock load mitigation shock of the lumbar region. The acceleration response was shown to decrease with increasing in thickness of the T41 Temper foam. This demonstrated a consistent trending as that reported in the literature through crash impact tests. The trending of the reduced shock response suggested that a thicker bottom cushion (T41 Temper foam) will provide enhanced shock load protection to the occupant in glider seat, however only up to a certain thickness.

References

[1] International Standards Organization, "Mechanical vibration and Shock - Evaluation of human exposure to whole-body vibration Part 1: General Requirements [ISO 2631-1:1997]," Genova, 1997.
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