TESTORI AERO SUPPLY

POLITECNICO MILANO 1863
DIPARTIMENTO DI SCIENZE E TECNOLOGIE AEROSPAZIALI

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SEAT CUSHION SUBSTITUTION ON LARGE TRANSPORT AIRCRAFT

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PROJECT DEVELOPMENT

The replacement of seat cushions on seats installed on aircraft required to comply FAR/CS 25.562 is one of the key areas of business of Testori Aero Supply (TAS).
TAS holds an EASA DOA (EASA.21J.350) and POA (IT21G.0014) with a consolidated experience in designing and manufacturing aircraft seat cushions.
The following constraints are well-known to the companies active in this market:

1. High costs and lead-times to procure test articles, especially the seats.
2. Lack of knowledge on the already certified seat design.
3. Difficult cooperation from seat manufacturers.

TAS has applied to participate to a European Commission programme for research and innovation named Horizon 2020 and has submitted the project **"Development of replacement method for all kind of 16g dynamically tested aircraft seat cushions"** for multilayer non monolithic cushions replacement.

TAS has developed the project in cooperation with Politecnico of Milan and the support of GEVEN, an Italian aircraft seats manufacturer, based on the principle contained in FAA report DOT/FAA/AR-05/5,I **Development and Validation of an Aircraft Seat Cushion Component Test-Volume I.**

The project has been accepted as innovative project eligible to receive a funding by the European Union, ref. to grant agreement number 711347 on January 2016.
Subsequently, TAS has signed with EASA (European Aviation Safety Agency) a TAC (Technical Advice Contract) to receive technical guidance during the project.

PROGRAM CERTIFICATION LIMITATIONS

TAS has decided, for the time being, to develop a means of compliance limited to economy class seats since TAS is willing to offer to the E/C passengers more comfortable cushions even in high density E/C Class.

TAS has decided to utilize an E/C seat model "PIUMA" manufactured by GEVEN SPA.

The PIUMA has a quite conventional design with aluminium structure and is already certified for installation on a wide range of large aircraft, such Airbus A320, A330 and Boeing B737 NGs.

SEAT CUSHION MATERIAL SELECTION CRITERIA

TAS, based on its experience in cushion manufacturing, has decided to use graphite-based foams of different density and having different indentation hardness:

- **"Hard foams":** having a density of approx. 65-70 kg/m^3, typically used as cushion lowest layer sustaining the loads at the contact with the seat pan (configuration D, F, H).
- **"Medium foams":** having a density of approx. 50 kg/m^3, typically used as intermediate layer between the seat cover and the hard layer in cushions with two layers (or directly above the "hard foam" layer in case of three layers cushions) (configuration A, E).
- **"Soft foams":** having a density of approx. 45-55 kg/m^3. The soft layer is located below the seat cover and is the first contact with the passenger. The aim of this foam is to improve passenger comfort and contribute to **Deep Vein Thrombosis (DVT)** prevention. The percentage in volume of this layer is normally 10% (configuration G, B, C).

CONFIGURATION	LAYER #1	%	LAYER #2	%	LAYER #3	%
A	FRMC65	70	FRM C55	20	FRM C45	10
B	FRMC65	70	FRM C55	20	FRM C55S	10
C	FRMC65	60	FRM C55	30	FRM C45	10
D	RTAS 9167B16	70	RTAS 9167B16	30		
E	RTAS 9167B16	70	RTAS 9167B16	20	FRM C55S	10
F	FLOATING	30	RTAS 9167B16	50	RTAS 9167B16	20
G	FRM C65	60	FRM C55	40		
H	FLOATING	60	FRM C45	40		

PROJECT DESCRIPTION

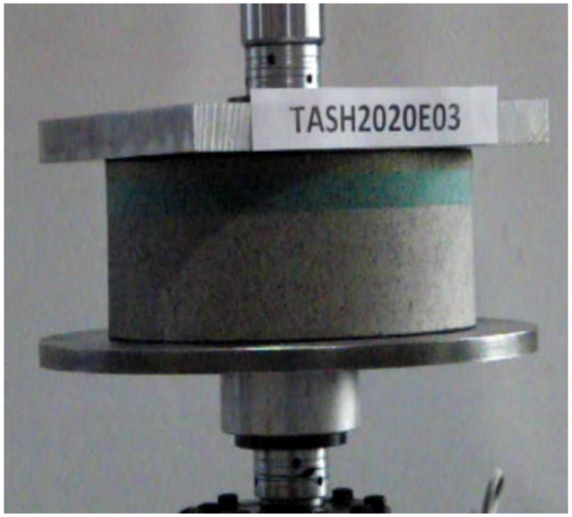
The target of the project is to set-up a procedure to assess the response of new CS-25 seat cushions, for retrofitting on existing seats, without carrying out a full seat dynamic test.

The basic ideas are as follows:

1. The seat, in its original configuration, has already been certified but the test results are in general not available.
2. Samples from the original cushion must be manufactured and tested.
3. Samples from the new cushion are tested.
4. Load responses from the two tests are compared by using a simplified dynamic analysis.

FULL SCALE 14 G DOWN SEAT DYNAMIC TEST

DYNAMIC COMPRESSION TEST



DYNAMIC COMPRESSION TEST

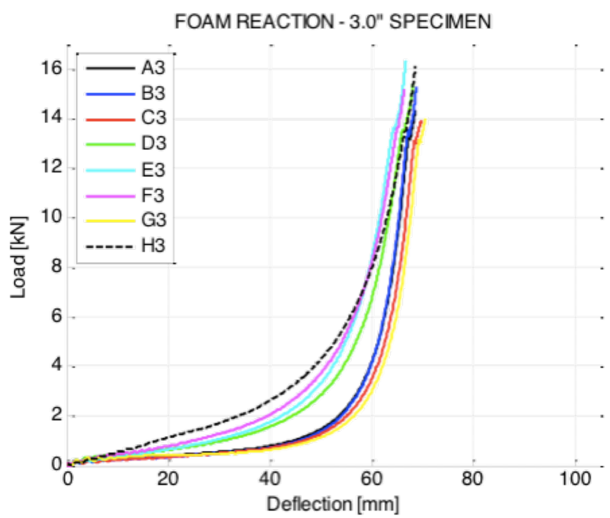
The test consists of a compression test applying a force of 15,000 N and travelling at a speed of 0.76 m/sec (33 inch/sec), up and down (up to 90% of the original thickness) as per FAA/DOT/AR-05 chapter 4.

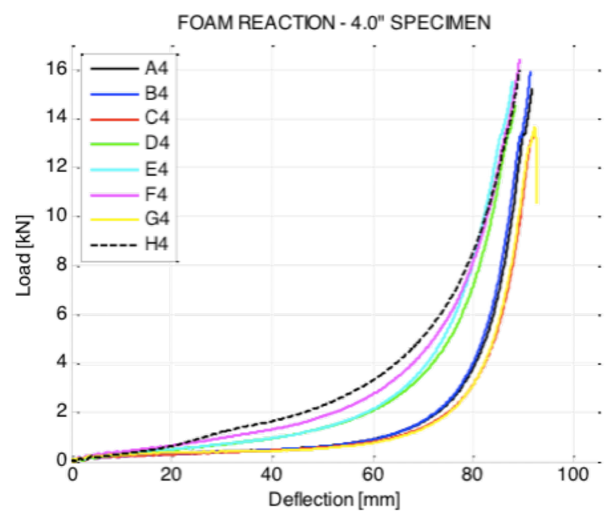
TAS has manufactured 20 multilayer cylindrical test specimen having 8” diameter and thickness equal to 2”, 3”, 4” and 4.5” for each type of selected foam for a total of approx. 640 specimens.

3” and 4” thickness specimens are considered more representative of the actual cushion geometry.

The figures below shows the average load-deflection curves for the specimens, considering that for each foam stratification and thickness 20 specimens were manufactured and tested, for possible scattering.

The curves are plotted on the same axes scales, for better comparison.





FULL SCALE 14 G DOWN DYNAMIC TESTS PERFORMED AT GEVEN FACILITIES (1/5)

A total of 13 full scale tests have been performed at Geven using an asymmetrical triple seat (PHASE 1) and a symmetrical triple seat (PHASE 2) based on an EASA commonly agreed program.

In **PHASE 1** full scale 14 g down dynamic tests have been conducted with PIUMA triple narrow seat (most critical configuration) equipped with foam composition C and D, considered one of the softer and one of the harder (DDD, CCC, DCC, CDD) in order to calibrate the model, plus an additional test to compare B and F(soft/hard) and validate once more the model.

In **PHASE 2** full scale 14 g down dynamic tests have been conducted with PIUMA symmetrical triple seat equipped with the remaining foam compositions (A, B, E, F G, H).

These data have been used as input for the model to validate the simulated peak of the lumbar load that would be measured by analysis of the dynamic compression data.

FULL SCALE 14 G DOWN DYNAMIC TESTS PERFORMED AT GEVEN FACILITIES (2/5)

Below are reported only few full scale 14 g down test reports, as example.

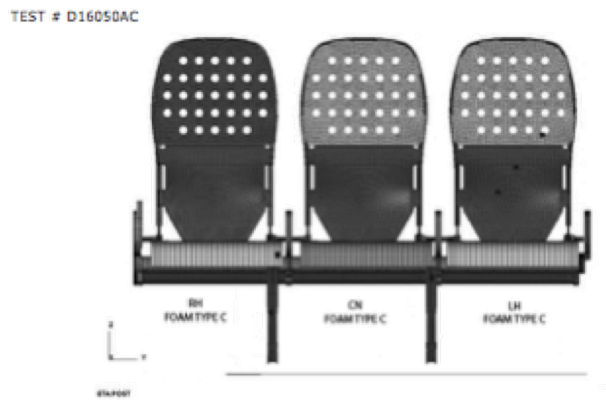


Fig. 5.1 – Unsymmetrical triple seat with symmetrical cushion installation, front view

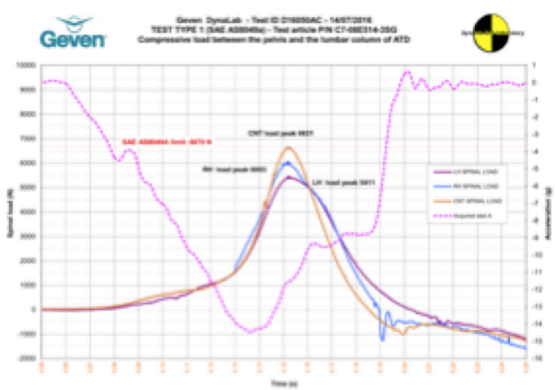


Fig. 5.2 – Sled acceleration and ATD's lumbar spine loads

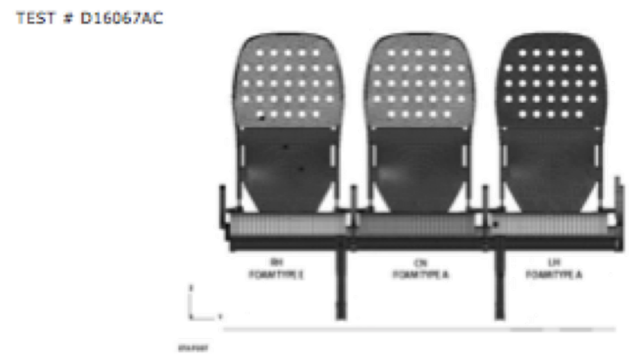


Fig. 5.9 – Symmetrical triple seat with unsymmetrical cushion installation, front view

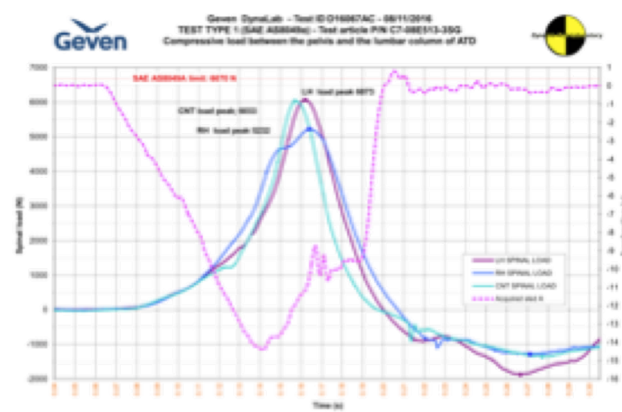


Fig. 5.10 – Sled acceleration and ATD's lumbar spine loads

FULL SCALE 14 G DOWN DYNAMIC TESTS PERFORMED AT GEVEN FACILITIES (3/5)

The test matrix main results relating to the dynamic tests are summarised in the table below.

REPORT TEST 14 G DOWN													
TRIPLE NARROW SEAT													
TEST	TEST ART.	TEST ID	DATA	SEAT P/N	LH CUSHION	CTR CUSHION	RH CUSHION	LH LOAD PEAK	CTR LOAD PEAK	RH LOAD PEAK	LOAD LIMIT	ACTUAL G PEAK
1	# 1 N	D16050	14/07/16	C7-08E514-3SG	C	C	C	5411	6631	6003	6670	-14.46
2	# 2 N	D16064	06/10/16	C7-08E513-3SG	D	D	D	5240	4986	4770	6670	-14.21
3	# 1 R	D16053	22/07/16	C7-08E514-3SG	D	C	C	4972	8189	6063	6670	-14.77
4	# 2 R	D16066	13/10/16	C7-08E513-3SG	D	D	C	5094	6480	5887	6670	-14.29
5	# 1 R	D17098	10/09/17	C7-08E514-3SG	B	F	F	5965	5300	5374	6670	-14.36
6	# 2 R	TEST NOT PERFORMED AS AGREED WITH EASA										
TRIPLE SYMMETRICAL SEAT												
TEST	TEST ART.	TEST ID	DATA	SEAT P/N	LH CUSHION	CTR CUSHION	RH CUSHION	LH LOAD PEAK	CTR LOAD PEAK	RH LOAD PEAK	LOAD LIMIT	ACTUAL G PEAK
7	#1 N	D16067	08/11/16	C7-08E515-3SG	A	A	E	6073	6033	5232	6670	-14.41
8	#2 N	D16071	24/11/16	C7-08E515-3SG	E	A	A	5781	6792	6185	6670	-14.40
9	#1 R	D16068	09/11/16	C7-08E515-3SG	E	E	B	6083	5834	6123	6670	-14.38
10	#1 R	D17059	04/05/17	C7-08E515-3SG	B	B	A	5760	7948	5925	6670	-14.28
11	#2 R	D16072	01/12/16	C7-08E515-3SG	B	B	E	6277	7330	6521	6670	-14.43
12	#2 R	D17062	12/05/17	C7-08E515-3SG	A	E	B	6147	6838	6396	6670	-14.30
13	#1 R	D17129	08/11/17	C7-08E515-3SG	H	H	G	5758	5794	6164	6670	-14,59
14	#1 R	D17130	09/11/17	C7-08E515-3SG	G	G	H	6821	7836	6731	6670	-14,82

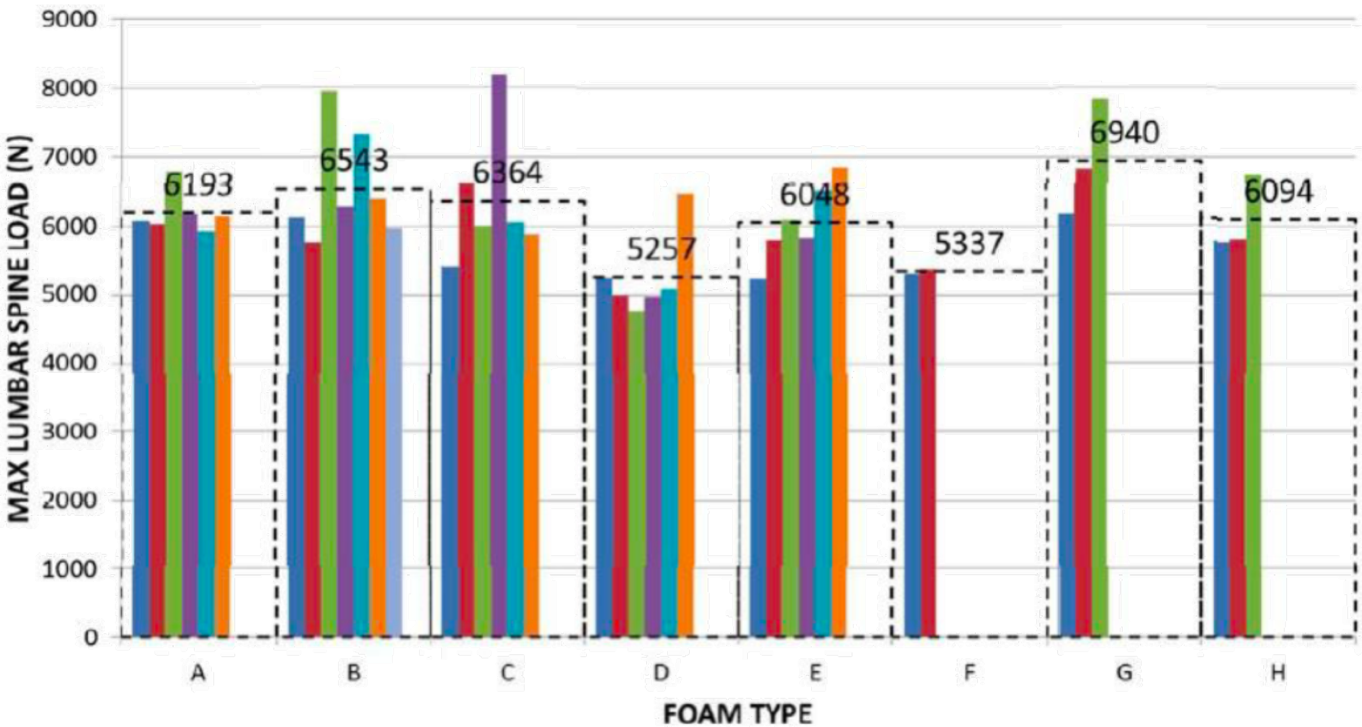
Legenda Test article: #1 = test article 1 #1N = test article 1 nuovo #1R = test article 1 ricondizionato

Tests D16050AC and D16053AC show the most relevant discrepancy; they were performed with the same seat P/N C7-08E514-3SG, non-symmetrical, and with the same type C foam in the centre and right hand seat cushions. While the right ATD lumbar spine loads are comparable (6,003 and 6,063 N respectively), the centre ATD loads are quite different (6,631 N and 8,189 N). Even considering a max load normalisation by using the acceleration peak, the difference remains significantly high.

FULL SCALE 14 G DOWN DYNAMIC TESTS PERFORMED AT GEVEN FACILITIES (4/5)

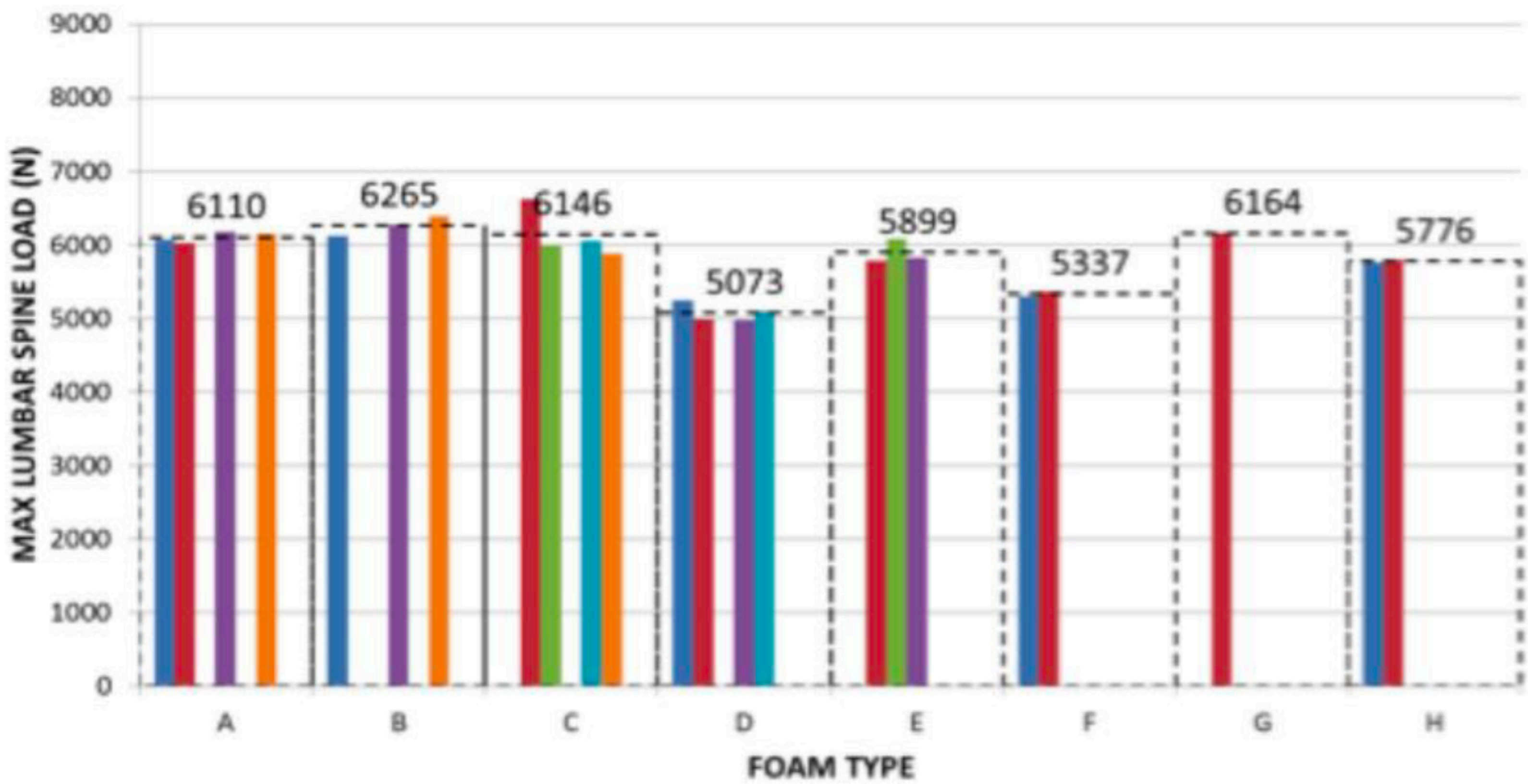
The test results show a scattering that suggests that some statistical approach could be tried to skip those results which may be interpreted as off-standard.

For this reason it has been decided to make a selection of the results based on a ±80% standard deviation band considering that only data with respect to the average are taken.

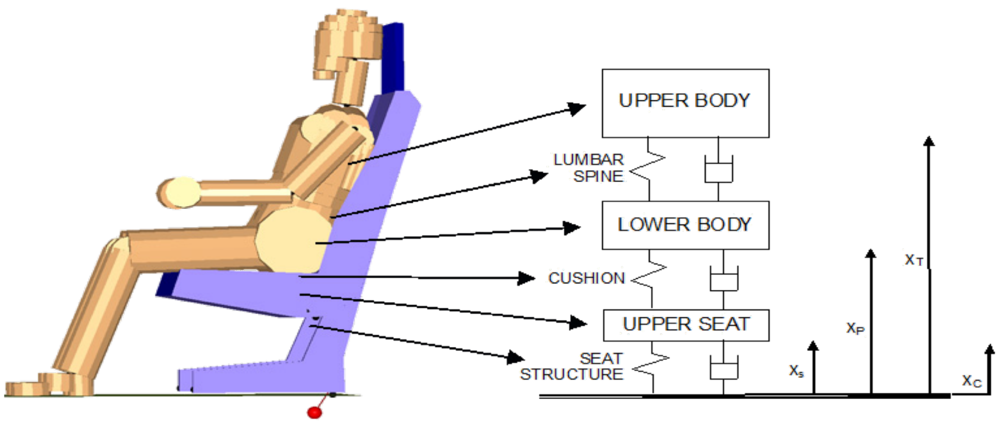


FULL SCALE 14 G DOWN DYNAMIC TESTS PERFORMED AT GEVEN FACILITIES (5/5)

In the table below are reported the data based on 80% standard deviation of the corresponding min and max lumbar spine loads.



POLITECNICO DI MILANO DATA ANALYSIS METHOD (1/2)



MuSIaC is the acronym od Multi-Scale Impact and Crash.

This is a code based on multi body formulation, developed by Politecnico di Milano for the numerical analysis of impact and crashes, including the occupant's biomechanics.

Its main applications are in the study of road safety barriers and attenuators, vehicle dynamics and aircraft crashworthiness.

A 3-degree-of-freedom model has been set-up; this may be considered a very simplified version of the MuSIaC model, which could be implemented with any programming language.

The upper body includes thorax, upper arms, part of the forearms, necks and head; its degree of freedom is represented by the coordinate x_T.

The lower body includes the pelvis and part of the upper legs; its degree of freedom is represented by the coordinate x_P (Pelvis) from the sled reference level.

The upper seat structure: its degree of freedom is represented by the coordinate x_S (Seat) from the sled reference level.

The sled finally is a reference kinematic body with assigned motion, input from the experimental test sled acceleration, like in the MuSIaC model.

Its coordinate x_C (Carriage) is then obtained by double integration of the experimental acceleration.

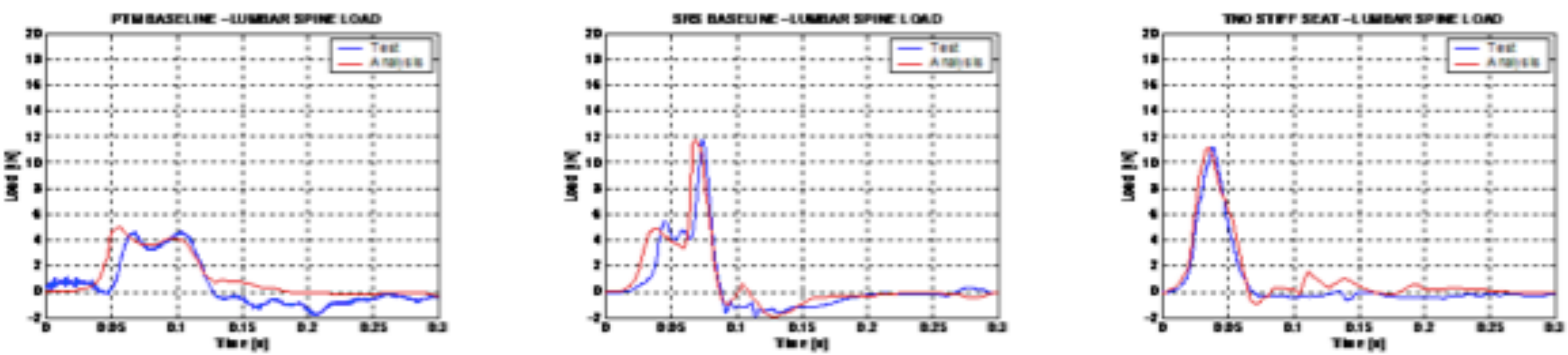
POLITECNICO DI MILANO DATA ANALYSIS METHOD (2/2)

A set of equations has been developed by Politecnico di Milano to solve the dynamics.

The main results concerning MuSIaC ATD and seat model validation program can be summarised by the plots shown in the picture below, where the experimental and numerical results are compared in terms of lumbar spine loads for two different kinds of seats:

- typical aircraft/helicopter energy absorbing seat
- fully rigid steel seat

The last one is of course significant for the ATD numerical model refinement, because in this case the dynamics doesn't depend on the seat response.

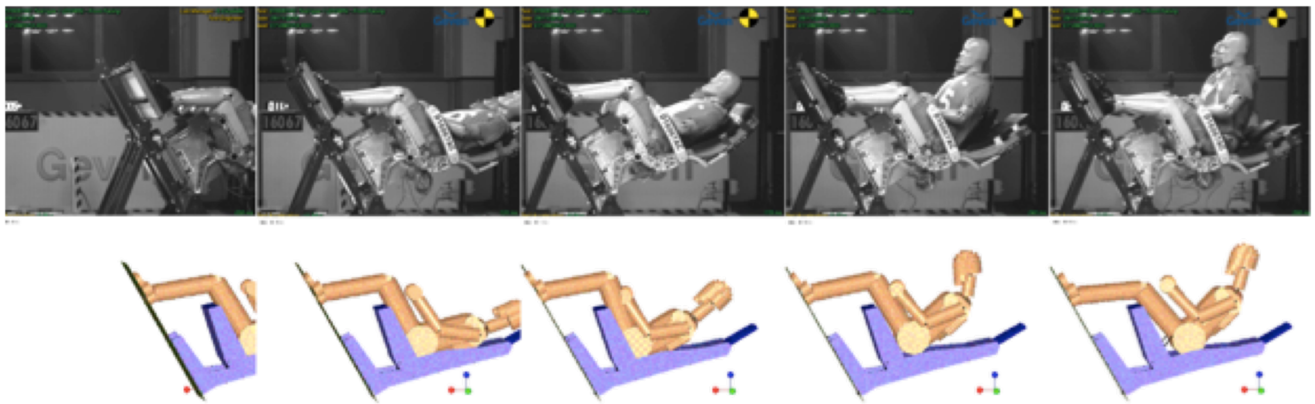


Lumbar spine loads in seat dynamic conditions respectively for a non-bottoming energy absorbing seat, a bottoming energy absorbing seat and a rigid seat

CASE STUDY: MUSIAC RESULTS FOR GEVEN TEST # D16067AC (1/2)

The following picture shows a sequence of frames taken from the high-speed camera film in Geven test # D16067AC and those taken, in the same times, from the MuSIaC simulation with a type A4 foam cushion.

Type E4 ATD response is hardy different from the visual point of view and then is not shown.



High speed video and MuSIaC numerical analysis frame comparison

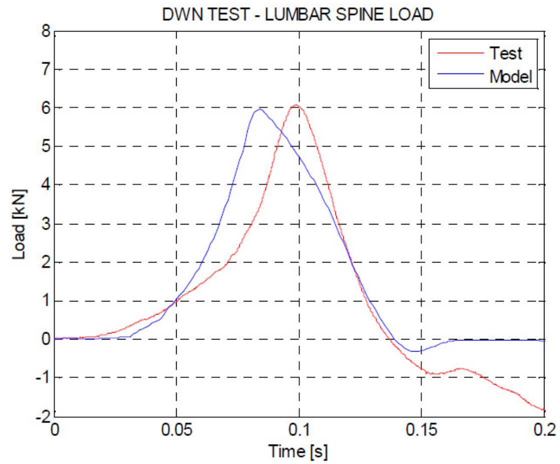
In the numerical model the floor kinematics is assigned by the sled acceleration file sampled during the test.

In the next page is reported the main output for this analysis, that is the lumbar spine load.

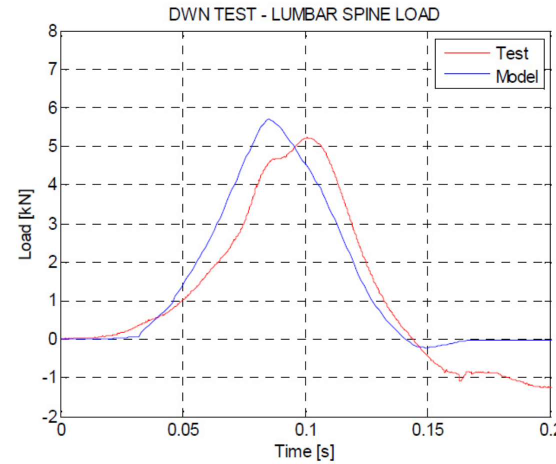
The correlation is acceptable even if some further investigation should be done to improve it.

The peak value is very well respected, but there is a slight anticipation of the max value obtained by numerical analysis and, most of all, the time extension of the curve from the numerical analysis is wider that the experimental test.

CASE STUDY: MUSIAC RESULTS FOR GEVEN TEST # D16067AC (2/2)



LH occupant – type A5 foam



RH occupant – type E5 foam

The results look satisfactory even if some differences can be pointed out.

For the LH passenger the peak value of the lumbar spine load is very well reconstructed by the multi-body analysis. The two curves show different shapes, probably due to the seat structure dynamics.

For the RH passenger there is more discrepancy in the lumbar spine peak value. This is significantly reduced, in the experimental test, by the introduction of a harder cushion E4 type. This is in agreement with current knowledge on the ATD/seat coupling: a harder cushion normally should minimise the relative velocity among the pelvis and the cushion itself during sled acceleration, then resulting in a reduced max contact force.

On the other hand, the irregularity shown by the experimental curve of the RH occupant spine load near the max value suggests that the seat structure had some additional deformation, perhaps a minor plastic response. This possible seat failure is not included in the multi-body model.

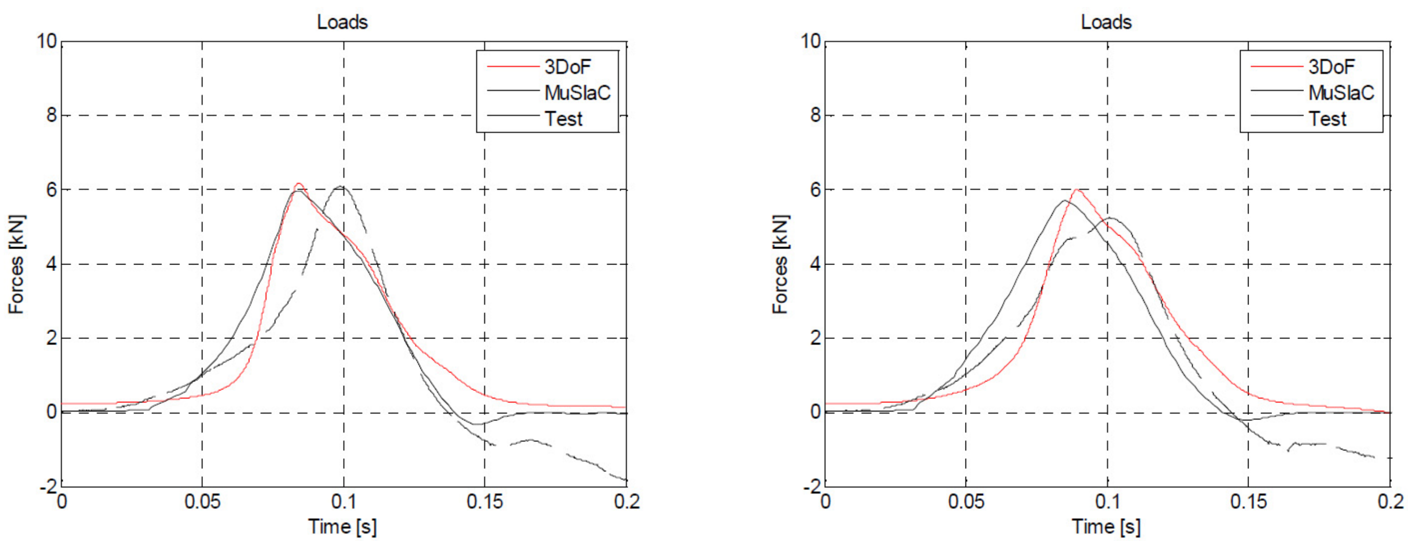
SIMULATION UTILIZING 3DOF MODEL (1/2)

A **simulation** of the same test has then been run using the **3DOF model.**

The lumbar spine load is calculated as a function of the spine deflection and rate of deflection using the biomechanical parameters of the multi-body MuSIaC ATD model.

Friction forces, whose contribution may be of interest, are calculated as Coulomb reactions. The cushion load is calculated by linear interpolation in the load-deflection curve obtained in the foam experimental tests.

The result obtained with the 3-DOF model are compared with the MuSIaC numerical simulations. The experimental tests, for both the LH occupant on type A4 foam cushion and RH occupant on type E4 foam cushion, are shown below.



The 3-DOF model, like the full multi-body model, is able to predict the trend of lumbar spine variation as a function of the cushion foam

SIMULATION UTILIZING 3DOF MODEL (2/2)

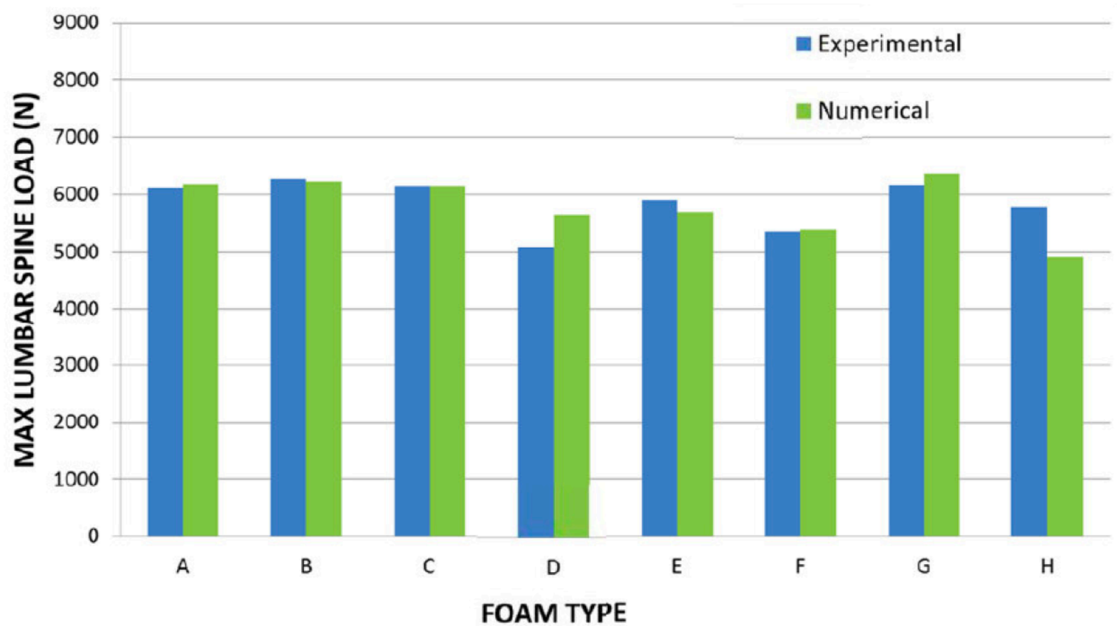
The 3-DOF model is applied for the analysis of the full set of the experimental tests.

In this analysis the sled acceleration is maintained equal to the D16067AC study case, because no significant differences are observed in the test campaign.

The seat stiffness is also maintained.

The foam reaction force is changed according to the foam type used.

The figure below shows the numerical results of lumbar loads compared to the average experimental results after the post-processing described in the previous pages: cutting off the values outside the 80% standard deviation band.



ADDITIONAL TEST PERFORMED AT POLITECNICO DI MILANO

Additionally, a full scale 14 g down comparison test has been performed in August 2017 at Politecnico di Milano test facility using the rigid seat equipped with already tested cushions A, B, C, D, E and production new F, comparing the data with the test results performed at GEVEN.

POSITION	LH		CTR		RH	
FOAM	A		B		C	
RIGID SYM SEAT	LOAD	6048	LOAD	6980	LOAD	7288
TEST GEVEN	Date	04/05/17	Date	04/05/17	Date	14/07/16
	Position	RH	Position	LH	Position	CTR
	Seat	Triple sym	Seat	Triple sym	Seat	Triple narrow
	LOAD	5925	LOAD	5760	LOAD	6631

POSITION	LH		CTR		RH	
FOAM	D		E		F	
RIGID SYM SEAT	LOAD	5393	LOAD	5693	LOAD	4923
TEST GEVEN	Date	06/10/16	Date	12/05/17	Date	New
	Position	LH	Position	LH	Position	CTR
	Seat	Triple narrow	Seat	Triple sym	Seat	Triple narrow
	LOAD	5240	LOAD	5781	LOAD	5300

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EASA MOC APPROVAL

EASA European Aviation Safety Agency

P-EASA.TAC.0049 Final Report

Final Report

Development of a Means of Compliance (MOC) alternative to seat dynamic testing for the replacement of non-monolithic seat bottom cushions

Document ref.	Status	Date
P-EASA.TAC.0049 Final Report	Released	26 /11/ 2018
Contact name and address for enquiries:	Enzo Canari enzo.canari@easa.europa.eu European Aviation Safety Agency [Department] Postfach 10 12 53 50452 Köln Germany	
Information on EASA is available at:	www.easa.europa.eu	

Authorisation :			
	Name	Signature	Date
Prepared	Enzo Canari	Enzo Canari	26/11/2018

TAS has signed with EASA (European Aviation Safety Agency) a TAC (Technical Advice Contract) P-EASA.TAC.0049 to receive technical guidance during the project.

TAS has followed EASA technical guidance and provided constant reports on the dynamic test data results for all the tests performed both real dynamic tests both simulated tests with the 3DOF model.

As conclusion of the project EASA has issued the Final Report approving the TAS Alternative Means of Compliance to seat dynamic testing for non monilithic bottom seat cushions

CONCLUSION (1/2)

In this paragraph are summarized all the activities performed by Testori Aero Supply (TAS) to demonstrate the possibility to replace multilayer seat cushion on seats certified in accordance with CS 25.562 requirements without performing a fully 14 g dynamic test, overcoming in this way the limitations as per AC 25.562-1B Appendix 3.

TAS has set a consulting contract with Politecnico di Milano to perform the dynamic compression tests developed by TAS on cylindrical foam specimen of different thickness in accordance with FAA/DOT/AR-05 Chapter 4 and to develop a mathematical method to correlate the data of the 14 g down dynamic test lumbar spine load with the dynamic compression test loads on the cylindrical foam specimen.

TAS has developed this project under EASA supervision, through a TAC-0049 and has obtained an EASA MOC (Means of Compliance) for the proposed replacement activities.

Based on the results provided in this report TAS considers acceptable to replace, on a seat certified in accordance with CS 25.562 requirements, the original cushion (in the following called item#1) with a new multilayer cushion (in the following called item#2) following the proposed procedure:

STEP 1 DYNAMIC COMPRESSION TEST

TAS will test 5 item#1 and 5 item#2 cylindrical specimens having thickness of 2, 3, 4, and a diameter of 8 inches representative of the seat cushion area under the occupant’s pelvis.

Tests will be conducted using a press at a speed around 760/800 mm/sec, up to 90% of the undeformed thickness.

CONCLUSION (2/2)

STEP 2 NUMERICAL ANALYSIS

The load deflection responses of STEP 1 item#1 and item#2 are input on the 3-DOG model and the resulting lumbar spine loads are compared.

If item#2 lumbar spine load is lower that item#1 lumbar spine load with a safety margin of 310 N, item#2 (the new cushion) can be considered eligible to replace item#1 (original cushion) without additional dynamic seat tests.

To summarize, the proposed project has the following advantages:

- It increases the safety of passengers: the possibility to replace old with new certified cushions at sustainable cost will allow any air operator to maintain the adequate quality of seats.
- It increases the comfort and wellness of passengers: it will allow the adoption of certified multilayer cushions also in low-cost flights, which may avoid circulatory and/or postural issues.
- It will save the operator the cost of replacing the whole seat, allowing the replacement of the worn-out cushions only (the cost will be reduced to 1/5 of the whole seat replacement).
- It will make the market of cabin interior providers more competitive.