Impact attenuator design validation with LS-Dyna

Contents

Introduction

During the development of this assignment, SolidWorks, Femap and LS-Dyna were used to model a composite safety enclosure and impact attenuators, mesh the resulting CADs and perform FEA to validate the design performance, respectively, where the performance comparison between different impact attenuator designs was the main objective, in order to improve understanding on automotive safety and energy absorption. FEA validation previous to real-world testing can have a significant impact on both manufacturing costs and waste, eliminating the need for unsuccessful prototypes (Fadiji & et al., 2018).

Deflection limits and load cases have been specified as part of the study case where a maximum allowable deflection of 5mm was imposed when a 1300kg mass impacted the enclosure at 13.86m/s for both frontal and side impact according to the EuroNCAP AE-MBD barrier test method (EuroNCAP, 2013).

In order to meet these limits, impact attenuators are mainly used in the automotive industry, as they reduce the risk of injury and absorb the impact forces (Itu & Vlase, 2023).

The dimensions of the impact attenuators were limited to the enclosure's surface, extruded by 500mm for the frontal impact and 200mm for the side impact. An iterative process was used to select the appropriate material and geometry for the attenuators.

To model the composite safety enclosure, the dimensions, materials and composite lay-ups from the previous assignment were used.

Procedure

An iterative process of academic research, CAD models development, FEA meshing and analysis, and simulation post-processing was used to develop this work [Figure 1].

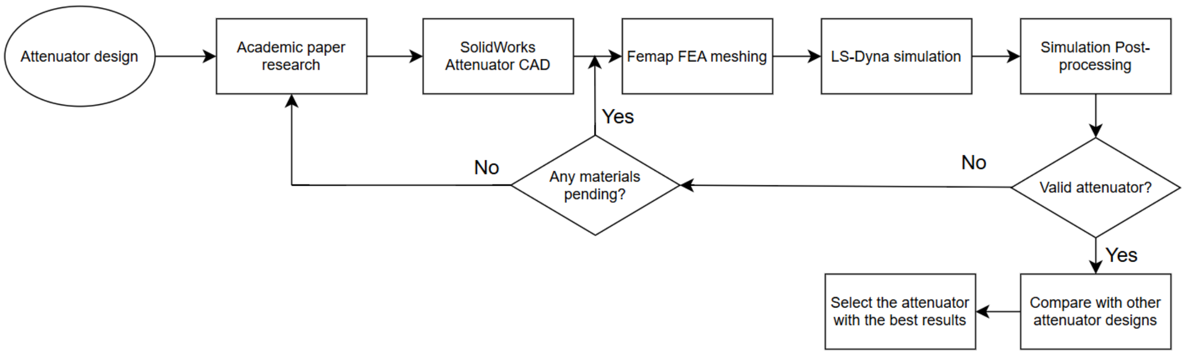


Figure 1. Attenuator design flow chart

To develop the attenuators, first, a CAD model of the enclosure was created [Figure 2]. This model had two front reinforcements and two side reinforcements, which defined the area of the front and side surfaces, which limit the size of the attenuator. Afterwards, the materials and composite lay-ups were defined in Femap.

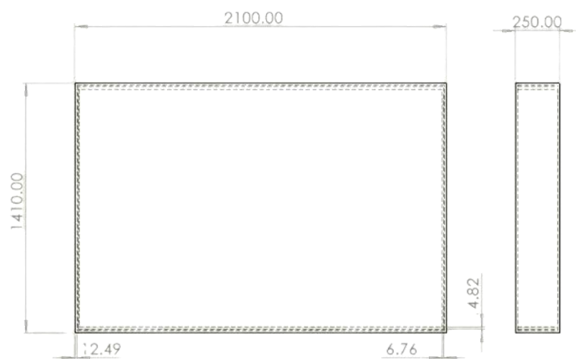


Figure 2. Enclosure CAD model utilized for the attenuator design

The composite layups for the enclosure were composed of Doucel 6101-T6 Aluminium Foam, HS0838-8020 and P173EBN-7, while the reinforcements were made of TC346 M46JB [Table 1]. Enclosure wall and reinforcements thicknesses are available on Table 2.

Table 1. Enclosure and reinforcements materials

Doucel 6101-T6 Aluminium Foam		
Material Type	1. LS-Dyna Isotropic	
Density	230	kg/m3
Young Modulus	4E+07	Pa
Poisson's Ratio	0.2	
Thickness	10.85	mm

HS0838-8020		
Material Type	54. LS-Dyna Enhanced Composite Damage	
Density	1200	kg/m3
Young Modulus A	6.86E+10	Pa
Young Modulus B & C	6.74E+10	Pa
Poisson's Ratio BA	0.04	
Poisson's Ratio CA & CB	0.0393	
Shear Modulus AB, BC & CA	3.9E+09	Pa
Compress Strength A	6.74E+08	Pa
Compress Strength B	6.36E+08	Pa
Tensile Strength A	9.35E+08	Pa
Tensile Strength B	8.76E+08	Pa
Shear Strength AB	8E+07	Pa
Ply thickness	0.2	mm

P173EBN-7, 3960		
Material Type	54. LS-Dyna Enhanced Composite Damage	
Density	1520	kg/m3
Young Modulus A	1.55E+11	Pa
Young Modulus B & C	8.27E+09	Pa
Poisson's Ratio BA	0.3	
Poisson's Ratio CA & CB	0.02	
Shear Modulus AB, BC & CA	5.7E+09	Pa
Compress Strength A	1.40E+09	Pa
Compress Strength B	2.83E+08	Pa
Tensile Strength A	1.68E+09	Pa
Tensile Strength B	5.29E+07	Pa
Shear Strength AB	2E+08	Pa
Ply thickness	0.074	mm

TC346 M46JB		
Material Type	54. LS-Dyna Enhanced Composite Damage	
Density	1640	kg/m3
Young Modulus A	2.59E+11	Pa
Young Modulus B & C	7.40E+09	Pa
Poisson's Ratio BA, BC & CB	0.01	
Shear Modulus AB, BC & CA	4.8E+09	Pa
Compress Strength A	1.06E+09	Pa
Compress Strength B	2.56E+08	Pa
Tensile Strength A	1.91E+09	Pa
Tensile Strength B	3.50E+07	Pa
Shear Strength AB	7E+07	Pa
Ply thickness	0.13	mm

Material type 1 is selected for the Aluminium Foam as this foam can be considered to present isotropic properties (Kumaran & Kumar, 2018).

Material type 54 is selected for the composite materials as these present orthotropic properties, additionally, this material type requires a reduced number of inputs compared to others (Feraboli & et at, 2011). Laminate plates are created for the front and back of the enclosure, sides, top and bottom of the enclosure and front and lateral reinforcements, specifying the laminate fibres direction on each property.

For the impactor, following the EuroNCAP AE-MBD barrier specifications, an aluminium 3003O is selected and is given the material type 20 “LS-Dyna Rigid” in order to reduce simulation time, as the impactor’s deformations are not the objective of the study. With a density of 2730kg/m^3, the impactor is modelled with volume of 0.47658m^3 to achieve a weight of 1301kg. A solid element is created for the impactor.

For the mesh, 3D solid, linear elements were created for both the impactor and attenuator, while the enclosure and reinforcements were meshed as 2D laminate plate elements, ensuring fast and reliable simulation results (Jensen, 2020).

As it’s been demonstrated that small cell sizes can lead to more inaccurate results (Fellows, 2017) while increasing the simulation run-time, a cell size of 0.02m is used for the enclosure and reinforcements, while a 0.1m cell size is used for the impactor and attenuator [Table 2].

The impactor’s required speed of 13.86m/s is added as a load to all the impactor’s nodes, while the enclosure’s rear nodes are fixed to prevent any movement when impacted. The impactor, attenuator, enclosure and reinforcements are each defined as a deformable region, in order to define the following contacts [Table 2]:

- Impactor to attenuator: The impact is defined as a contact with type “1. Automatic”.
- Attenuator to enclosure: The attenuator is glued to the enclosure utilising a type “11.Tied”.
- Enclosure to reinforcements: The reinforcements are in contact with the enclosure with type “1. Automatic”, ensuring that they aid to the enclosure’s stiffness, while allowing their own deformation.

Table 2. Femap model settings summary

Material types	
6101-T6 Foam	1. LS-DYNA Isotropic
HS0838-8020	54. LS-DYNA
P173EBN-7, 3960	Enhanced
TC346 M46JB	Composite Damage

Mesh properties		
Part	Type	Cell size
Impactor	3D Solid	0.1m
Attenuator		
Enclosure	2D Laminate plates	0.02m
Reinforcements		

Loads / Constrains		
Type	Definition	Where
Velocity Load	V(0,-13.86,0)	Impactor nodes
Constrain	Fixed	Enclosure's rear nodes

Regions	
Connector regions	Impactor
	Attenuator
	Enclosure
	Reinforcements

Connection properties			
Conection	Type	Source	Target
Impactor to attenuator	Contact / Automatic	Impactor	Attenuator
Attenuator to enclosure	Glue / Tied	Enclosure	Attenuator
Enclosure to reinforcements	Contact / Automatic	Enclosure	Reinforcements

Laminate lay-ups		
Enclosure	Front reinforcements	Side reinforcements
13: Thk=0.0002 Ang=45. Mt=6..HS0838, 8020 Prepeg (0.0002) 12: Thk=0.0002 Ang=-45. Mt=6..HS0838, 8020 Prepeg (0.0002) 11: Thk=7.4E-5 Ang=-45. Mt=7..P173EBN-7, 3960 Prepreg (0.074mm) 10: Thk=7.4E-5 Ang=45. Mt=7..P173EBN-7, 3960 Prepreg (0.074mm) 9: Thk=0.0002 Ang=0. Mt=6..HS0838, 8020 Prepeg (0.0002) 8: Thk=7.4E-5 Ang=45. Mt=7..P173EBN-7, 3960 Prepreg (0.074mm) 7: Thk=0.01085 Ang=0. Mt=3..Doucel 6101-T6 Aluminium Foam 6: Thk=7.4E-5 Ang=45. Mt=7..P173EBN-7, 3960 Prepreg (0.074mm) 5: Thk=0.0002 Ang=0. Mt=6..HS0838, 8020 Prepeg (0.0002) 4: Thk=7.4E-5 Ang=45. Mt=7..P173EBN-7, 3960 Prepreg (0.074mm) 3: Thk=7.4E-5 Ang=-45. Mt=7..P173EBN-7, 3960 Prepreg (0.074mm) 2: Thk=0.0002 Ang=-45. Mt=6..HS0838, 8020 Prepeg (0.0002) 1: Thk=0.0002 Ang=45. Mt=6..HS0838, 8020 Prepeg (0.0002)	52 Plies TC 346 M46JB 0 Degrees 6.76mm thickness	114 Plies TC 346 M46JB 0 Degrees 14.82mm thickness

Results

Frontal impact baseline

Firstly, reference simulations were carried out for a frontal impact without dampers. From the previous assignment, theoretical deformations of 17.32 mm were calculated for the frontal impact; however, when simulated, the deformation was found to be much greater [Figure 3], with a maximum deformation of 103.6 mm.

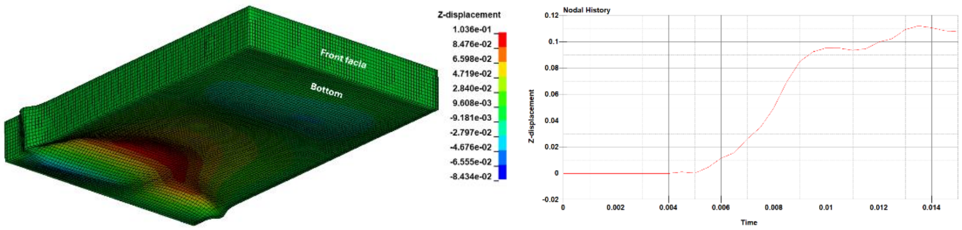


Figure 3. Front impact baseline

Frontal impact attenuators

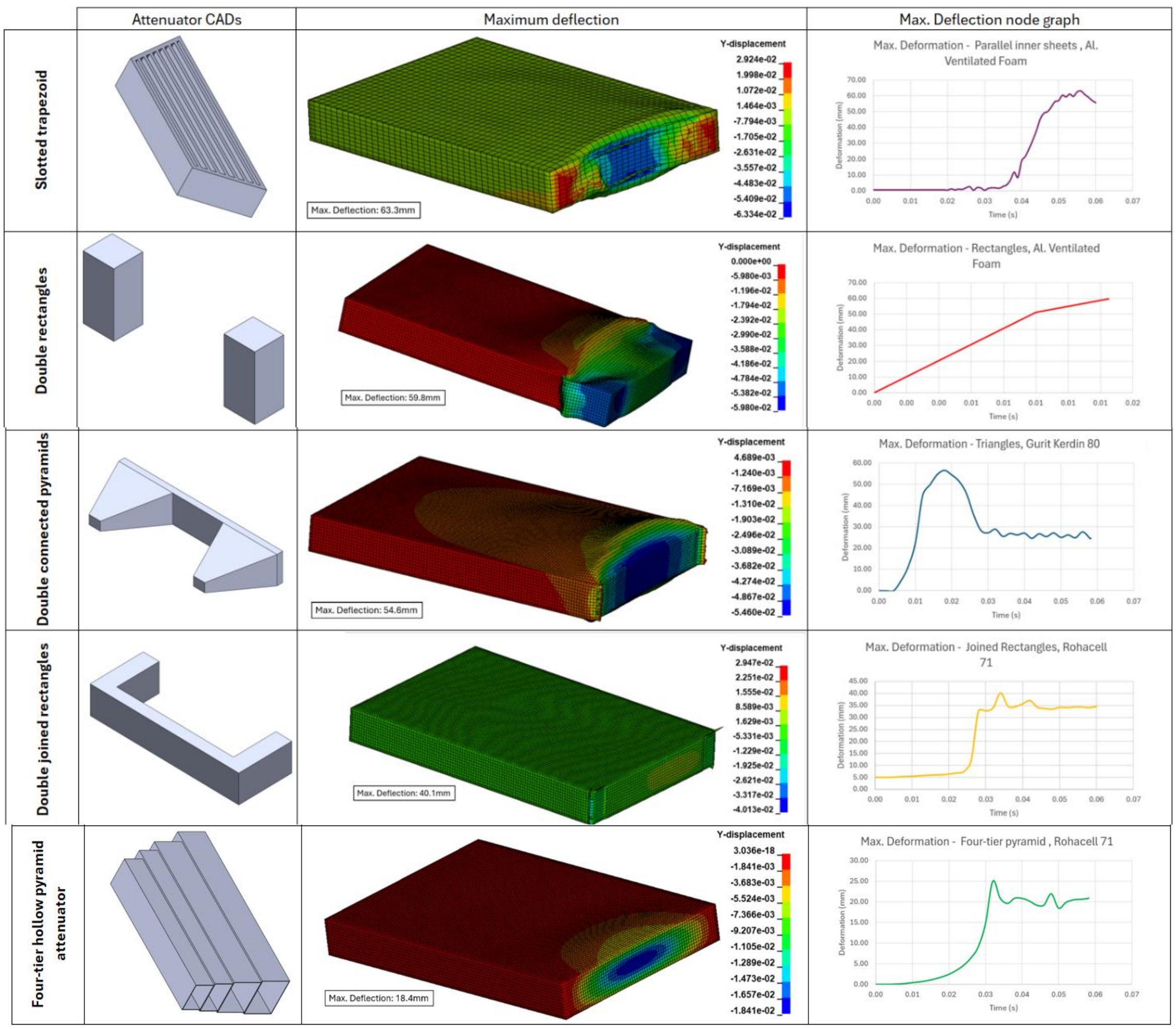


Figure 4. Front Impact Attenuators CAD and deflections

In order to solve this deformation, a combination of multiple isotropic foam and honeycomb materials and attenuator designs were investigated [Figure 4].

Concepts of solid and hollow attenuators were studied, and it was found that attenuators made of aluminium foam materials gave the best results, in particular Rohacell 71 IG-F aluminium (Rohacell, 2022), followed by a 6101-T6 foam (Hao et al., 2025).

Aluminium honeycombs and Nomex materials decreased in performance compared to aluminium foams, but were still a viable option. No performance improvements were observed when using solid aluminium attenuators as their high rigidity prevented them from progressive deformation, and thus, made them unable to absorb the impact energy.

As different geometries were tested, it was found that for this enclosure, where the reinforcements were close to the enclosure walls, attenuators that dissipated the energy outwards worked best. Solid attenuators, such as the shown rectangles or connected pyramids, reduced the impact velocity more abruptly than hollow attenuators, such as the four-tiered hollow pyramid (Wheatley & Zaeimi, 2022). The use of multiple perpendicular sheets of material also proved useful in reducing impact velocity, as seen in both the hollow pyramid and the slotted trapezoid (Boria, 2010).

Overall, the best front impact attenuator design tested was the four-tier hollow pyramid, made out of Rohacell 71 IG-F aluminium foam [Figure 4], reducing the enclosure’s deflection from 103.6mm to 18.4mm, although not meeting the 5mm deflection target, this still ensures the safety of the components inside the enclosure, as they are located further from the front facia of the enclosure.

Side impact baseline

Following the findings of the front impact attenuator tests, a side impact baseline simulation without attenuators was run. From the previous assignment, theoretical deformations of 17.1mm were calculated for the side impact, when simulated [Figure 5], the deflection calculated probed to be much more accurate than on the front impact, achieving a maximum deflection of 20.1mm.

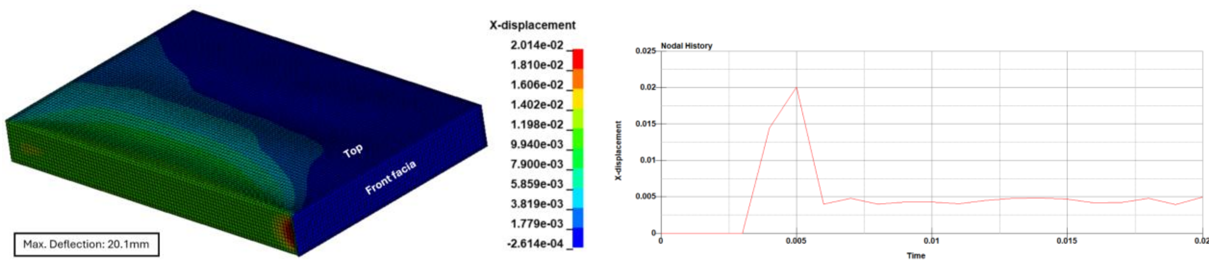


Figure 5. Side impact baseline

Side impact attenuator

As the four-tier pyramid proved to be the most efficient impact attenuator for the front impact, this attenuator was modified to fit the side area of the enclosure, reducing the maximum height to 200mm and extending the width to 2100mm.

Additionally, the impactor was also adapted to fit the side area of the enclosure, maintaining the 3003 aluminium used by the EuroNCAP AE-MDB barrier (EuroNCAP, 2013). Impactor dimensions were modified to be 2200mm length, 260mm width and 842mm depth, achieving a weight of 1300.38kg.

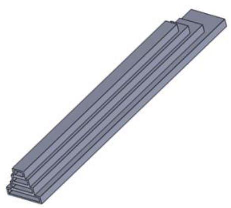
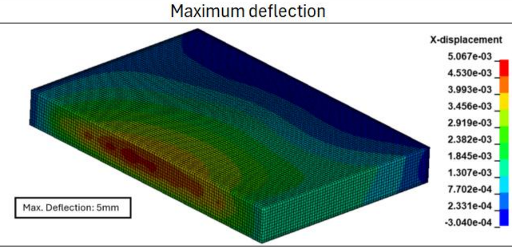
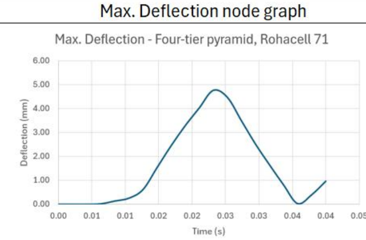
	Attenuator CADs	Maximum deflection	Max. Deflection node graph
Four-tier hollow pyramid attenuator			

Figure 6. Side impact attenuator CAD and deflection

The side impact attenuator was able to successfully reduce the deformation to the 5mm target imposed by the design specifications [Figure 5], utilising the same Rohacell 71 IG-F aluminium foam used for the best front impact attenuator.

Discussion

Given the simulation results, the side impact attenuator successfully achieved the 5 mm deflection target, while the front impact attenuator, although significantly reducing the deflection, still failed to meet the design specifications, achieving a deflection of 18.4 mm. This discrepancy between the experimental results and the theoretical analysis makes it necessary to investigate possible sources of error.

One of the first most significant errors is likely spurs from the theoretical assumption of isotropic material properties used in the simulation models (Kumaran & Kumar, 2018), as in reality, the aluminium foam displays orthotropic properties. Composite material behaviour under dynamic loading conditions (Feraboli & et at, 2011) can differ substantially from static properties, particularly in progressive failure mechanisms.

The presence of the material type 54 "LS-DYNA Enhanced Composite Damage" may imply that the simulations do not fully capture the complex strain-rate dependent behaviour of the composite materials, leading to unrealistic deformation predictions, as this material type's advantage against others lies in its simplification of the input data.

Additionally, simplification of contact definitions between components may have neglected critical interactions, affecting energy dissipation.

Although the reliability of the side impact results can appear to be higher than for frontal impact, given the closer alignment between theoretical calculations (17.1mm) and simulated results (20.1mm) in the baseline, the amount of ideal assumptions in the theoretical calculations makes this appear as an unrealistic result.

This work advances the understanding of impact attenuator designs, by evaluating progressive energy absorption for composite laminate structures. The findings align with the technical papers researched, demonstrating that hollow pyramidal structures with multiple perpendicular sheets provide optimal energy dissipation (Boria, 2010).

The value of this work lies in the methodical evaluation of multiple material and geometry combinations for safety-critical applications. The identification of aluminum foam as superior to honeycomb and Nomex alternatives, in particular Rohacell IG-F 71 and 6101-T6, provides practical guidance for the design of impact attenuators in similar applications. In addition, investigations were undertaken into solid aluminum attenuators which performed poorly due to insufficient progressive deformation.

Future work should focus on exploring variable density foams to optimize progressive crushing behaviour, validating simulation results with real-world tests, and implementing strain-rate dependent non-linear material models to improve simulation accuracy.

Word Count: 1842 words.

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