Designing Shock Absorbers for Nuclear Transport Packages

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1 Introduction

Across the world, radioactive sources are used for a variety of applications. From X-rays and radiotherapy in hospitals, to generation of heat in a nuclear power station. All these sources, however small or large, need to be transported to the point of use and away from there for eventual disposal or recycling. It is more often the case that when the sources are transported to the site, before use, they are not particularly radioactive, but after use they can pose a serious health hazard if not handled correctly. Special, specifically designed transport packages are manufactured and tested to ensure they meet the regulatory requirements for the transport of radioactive materials [1]. Part of the regulatory requirements is that the package withstands a 9m drop on to an unyielding target without loss of containment. The external shock absorbers of a transport package are designed to absorb the energy from this impact, as well as provide other functions not covered in this paper. This paper looks at methods to assist in the designing of these shock absorbers and how LSDYNA can be instrumental in the design and testing phase.

2 The Regulatory Requirements

The International Atomic Energy Agency (IAEA) define the requirements that every radioactive transport package must meet in “Regulations for the Safe Transport of Radioactive Material” [1]. This is reviewed and updated approximately every 3 years, but one item that hasn’t changed is the impact withstand requirements. There are numerous tests that must be passed, but the most onerous is usually that defined in Paragraph 727(a).

“For drop I, the specimen shall drop onto the target so as to suffer maximum damage, and the height of the drop, measured from the lowest point of the specimen to the upper surface of the target, shall be 9m. The target shall be as defined in para. 717”

Paragraph 717 states

“The target for the drop test specified in paras 705, 722, 725(a), 727 and 735 shall be a flat, horizontal surface of such character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase damage to the specimen.”

Thankfully, the requirement of Paragraph 717 is easily met using `*RIGIDWALL`. For information only, not covered in this report, some of the other tests require handling drops from a lower height, a drop from 1m on to a 150mm diameter mild steel bar (punch), crushing by a 500kg 1m x 1m mild steel plate dropped flat from 9m and a thermal test where the package must be subjected to an all engulfing fire of at least 800C for a period of 30 minutes. A lot of these tests are cumulative, i.e. the fire test usually comes after the 9m drop test and the 1m punch test.

3 Other requirements and limitations

Nuclear Transport Solutions (NTS) are the UK international nuclear transport company that deal with the majority of radioactive material transports across the UK and internationally. We own and operate a small fleet of specifically designed ships, trains and vehicles that can transport a wide range of nuclear packages. Some of the packages are designed and owned by NTS but we also transport third party packages. Within the UK we have a historical limitation. We were the first country in the world to build a rail infrastructure and as such our rail gauge is smaller that the majority of the world, and our bridges pose a limitation of the size of items that can be transported to certain areas of the UK. As you may imagine, the majority of the Nuclear sites are in remote areas and rail links to these areas are restricted by the rail gauge. The standard rail gauge dimensions are shown in Figure 1 alongside other countries standard gauges.

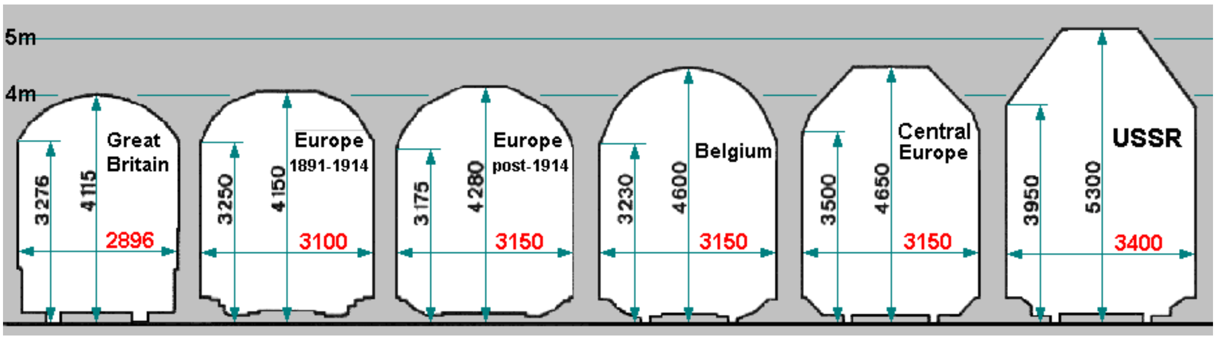

Fig.1: Rail gauge dimensions.

The slightly smaller W6a gauge, which exists on some of the remote lines is shown in Figure 2.

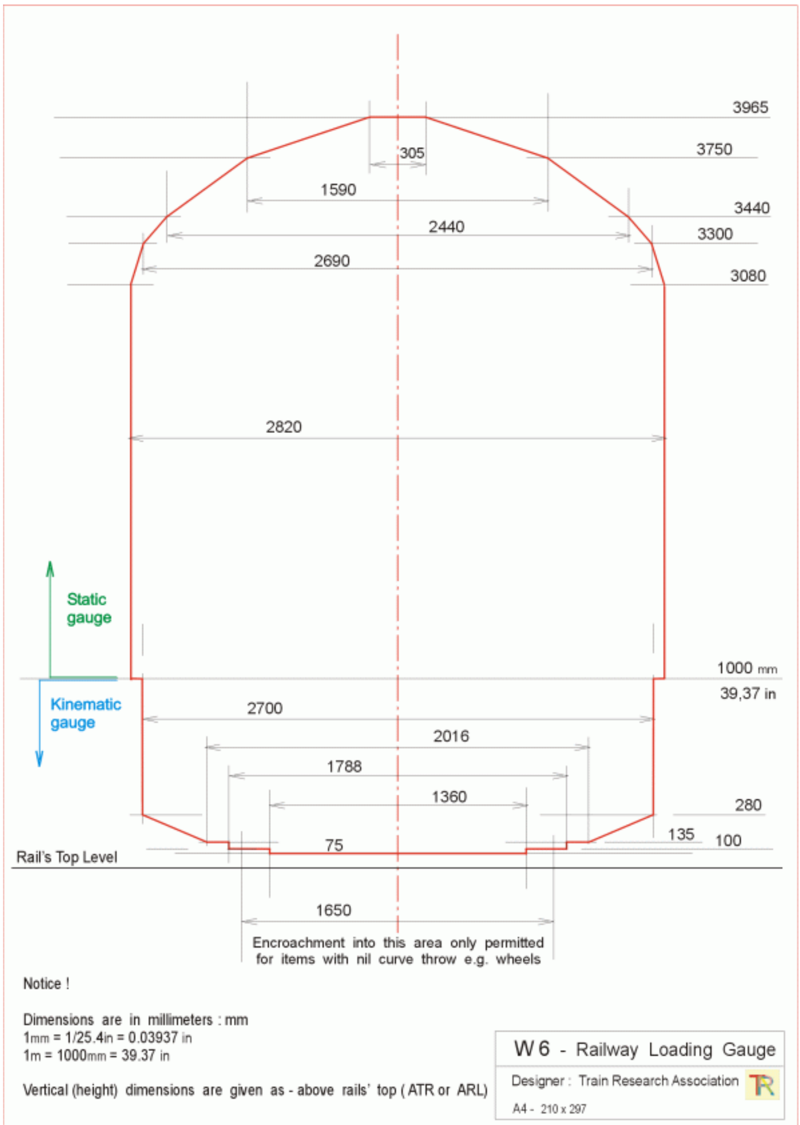

Fig.2: W6a rail gauge dimensions.

NTS are currently designing a package that, due to the dimensions of the contents and the radioactive shielding requirements, has to be approximately 2450mm wide. The maximum width for W6a is 2820mm leaving only 185mm either side. This space must also include a cover, which typically takes up around 100mm, therefore a shock absorber is required that is only 85mm deep. This is an extreme case as will be seen later in this report, but it indicates how creative we must be when designing for the UK infrastructure.

4 Typical types of shock absorbers

Shock absorbers, or impact limiters as some people call them, are devices that attach to, or form part of, the outside of the transport package. They act to absorb the energy of an impact to ensure that deformation of the containment boundary of the package is not breached. The three main types used are wood filled, metalic crushable fins and solid deformable metal upstands.

Fig.3: Three forms of shock absorbers

Where size is not an issue, it is typical to go for the wood filled shock absorbers. When space is limited, then metallic shock absorbers need to be used. The former will generally give better performance because the package travels further during the impact and hence decelerations and forces seen by the package are lower. Metallic shock absorbers are much harder to design as the requirement is to achieve the lowest acceleration by allowing the maximum amount of metal to be deformed.

5 Starting a design

There are a few key pieces of information needed before we can start to design the shock absorbers.

1. The overall dimensions of the transport package.
2. The maximum mass of the transport package.
3. The maximum size the package can be, usually driven by the rail gauge.

There are many other considerations, but these are the key three. The process is similar for most typical shapes of transport package, cylindrical, cuboid. To minimize effort, a spherical transport package would be best as we would only have to consider one orientation, all the others being the same. Sadly this is not the case for most transport packages and every orientation of impact has to be considered.

5.1 Cylindrical transport packages with wood filled shock absorbers

In the early stages it is assumed that the package has rotational symmetry and that the top and base can be assumed to be similar. For this case, I have created a piece of software that allows the user to enter the key information about the package including the key package dimensions, the proposed external dimensions of the shock absorber and the mass. The user can then select the type of wood and the wood grain orientation to be used in sections of the shock absorber. The code then generates, in a few seconds, the expected accelerations and knockbacks for all orientations. Knockback is the distance that the shock absorber has been deformed. A typical output is shown in figure 4.

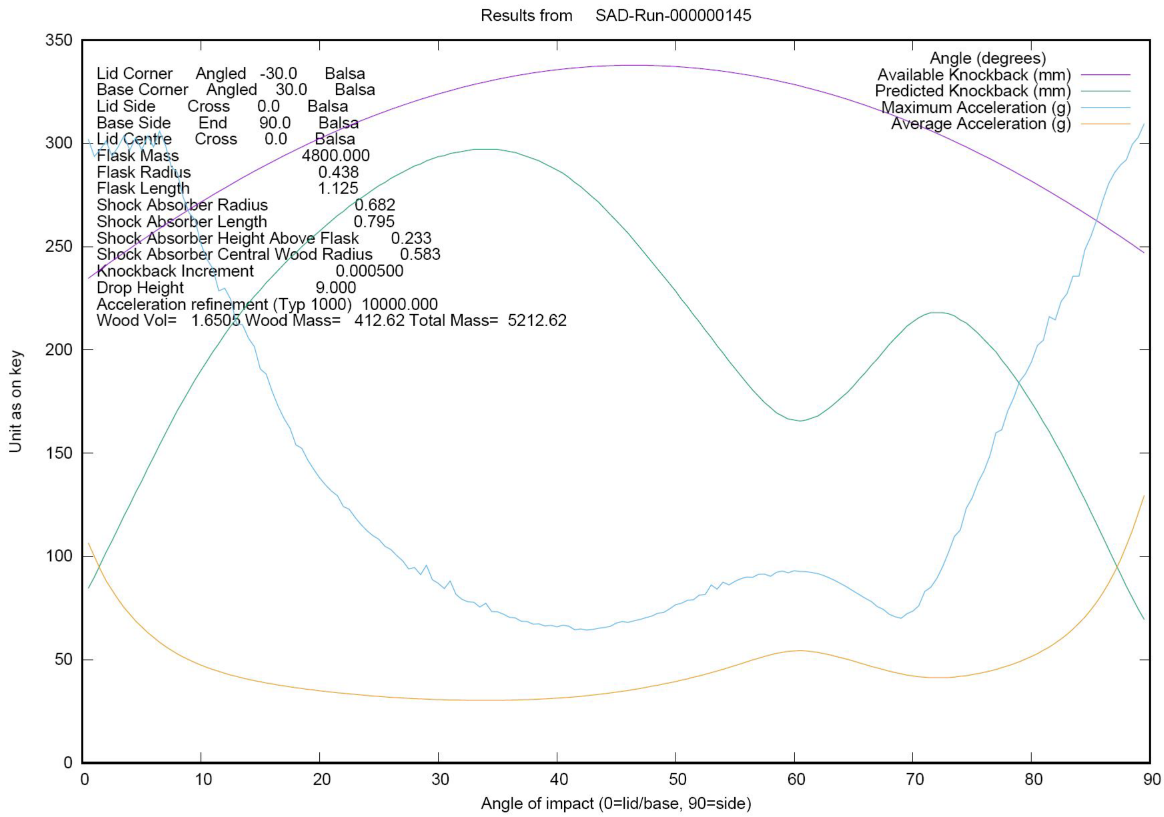

Fig.4: Typical output from SAD-Code

In this case, I have adjusted the orientation of the wood until the "Predicted Knockback" is below the "Available Knockback" for all orientations. This implies that the shock absorber design can potentially work and absorb all the energy such that the package itself does not strike the target. This is rudimentary, but it is a very quick way to determine typical sizes of a shock absorber. It is actually possible to enter other stress-strain curves into the SAD-Code which could represent buckling of metallic fins or crushing of metallic components. Once we have an idea of the shock absorber size, we would turn to LSDYNA to start preliminary analyses. This would involve a basic, possibly rigid, package with the shock absorbers modelled in sufficient detail to allow the compression of the wood to be predicted. Approximately 20 years ago a series of tests were completed on small samples of timber to produce stress-strain/volumetric compression curves that can be used in **`*MAT_HONEYCOMB`** or similar. I have yet to write a similar code that can be used for non-cylindrical packages

5.2 Transport packages with finned shock absorbers

Where space is limited, and wood filled shock absorbers will not be sufficient, it is likely that the design will use metallic fins to absorb the energy. There are some calculations which can give you approximate forces for the buckling or crushing of fins but these can be complex once you start to look at the interaction of fins. Therefore it is sensible to turn to LSDYNA at the start of this design process.

In a recent case a cuboid package, that needs to be 2450mm by 2450mm and weighs 65Te needed a shock absorber to be designed to protect the containment features. Namely it needs to ensure that the lid is not separated from the body following a 9m drop. This package also needs to fit in the W6a rail gauge with a cover leaving only 85mm for the shock absorber.

5.2.1 Stage 1 – A simple solid and shell model

The first stage is to ignore the lid and main body separation and just treat the entire package as a rigid body of 65Te. To this simple model, shell elements can be added to represent the fins. This gives a very simple method of adjusting the number of fins, the thickness of fins and of running multiple orientations. One example is show in Figure 5.

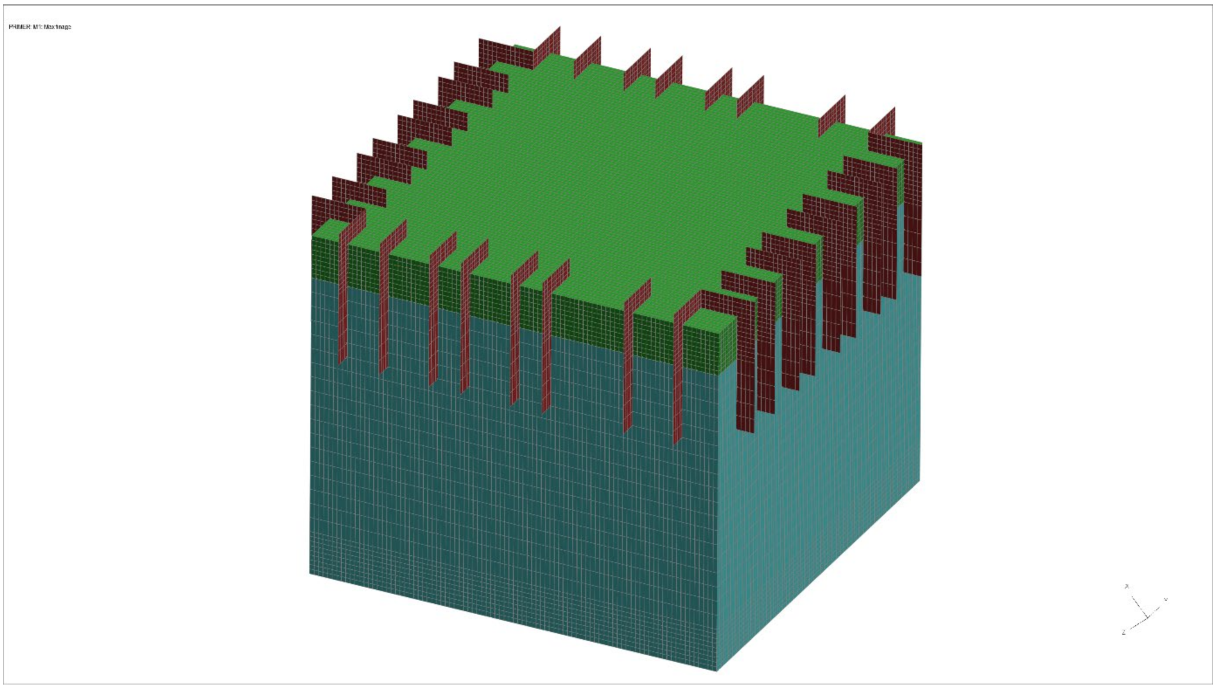

Fig.5: An example simple model using shell elements for fins.

In the above image, the focus is on impacts to the lid. This model can be used to determine if the fins work correctly and by using deformable materials for the package, interface forces can be determined between the body and lid. These analyses run in minutes on a high specification laptop, meaning variations can be made, tested and rejected or accepted very quickly. Some of the most useful information from this sort of analysis, is the internal energy of the fins. The example shown in Figure 6 is the internal energy for 20mm, 40mm and 60mm thick fins.

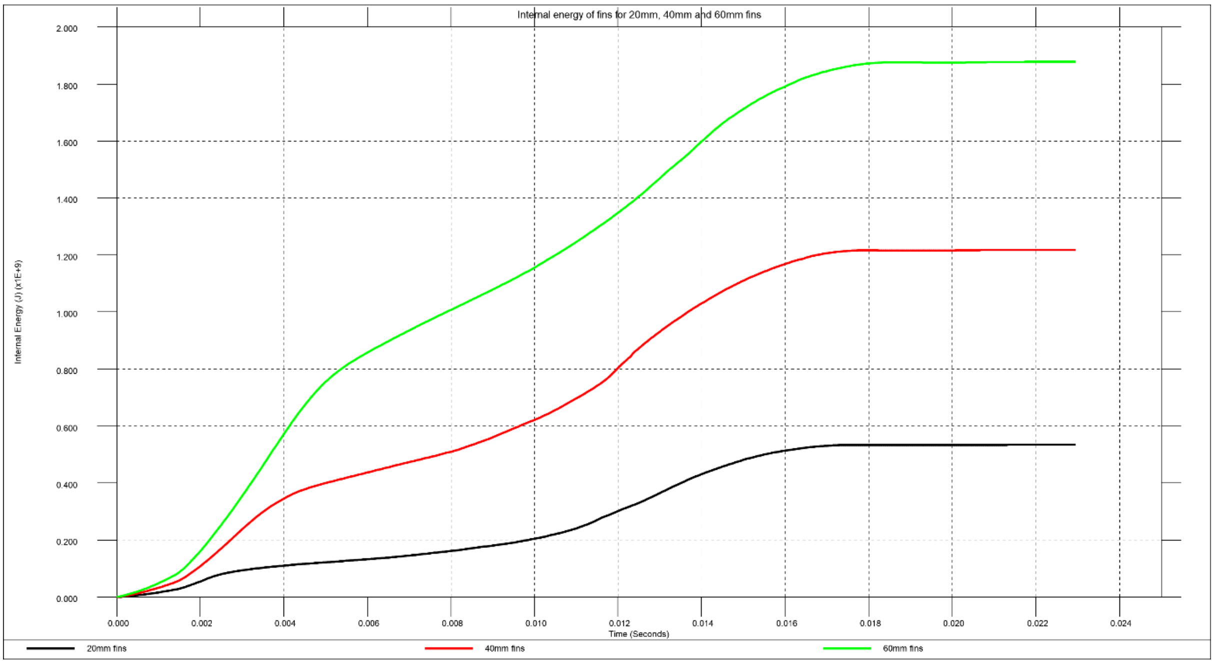

Fig.6: Internal energy absorbed by 20mm, 40mm and 60mm fins.

5.2.2 Stage 2 – More complex model

One of the key issues with cuboid packages is that almost every impact orientation is different. This is not the case with cylindrical impacts where the rotational symmetry means you need to only study a few orientations. One way to reduce the number of dissimilar orientations is to ensure that the same number of fins act for a range of orientations. In the simple example above, the number of fins involved can vary significantly as shown in Figure 7.

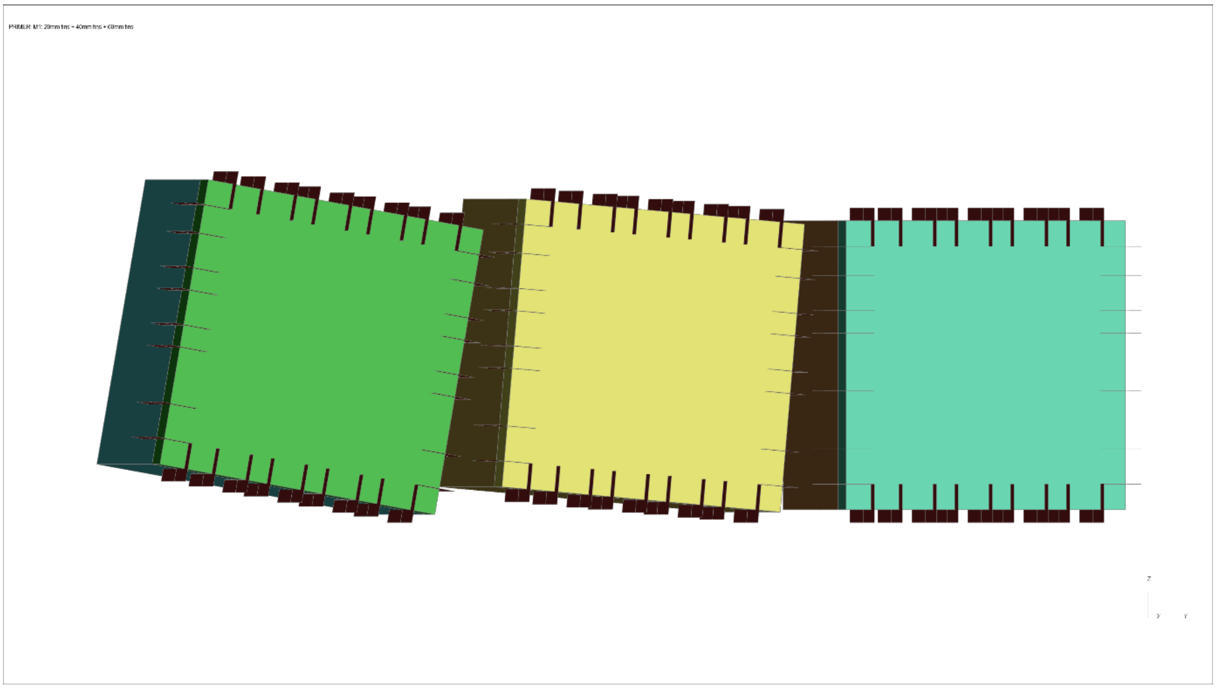

Fig.7: The number of fins involved against varying orientation.

For the three orientations shown, which only vary by 5 degrees between each, the number of fins that are deformed, before the package strikes the target, changes considerably. In the case of zero degrees, all nine fins are deformed, at a 5 degree rotation, 5 of the fins are deformed and for the 10 degree rotation only 2 are deformed before the package strikes the target. This causes significant difference in the energy absorbed by the fins.

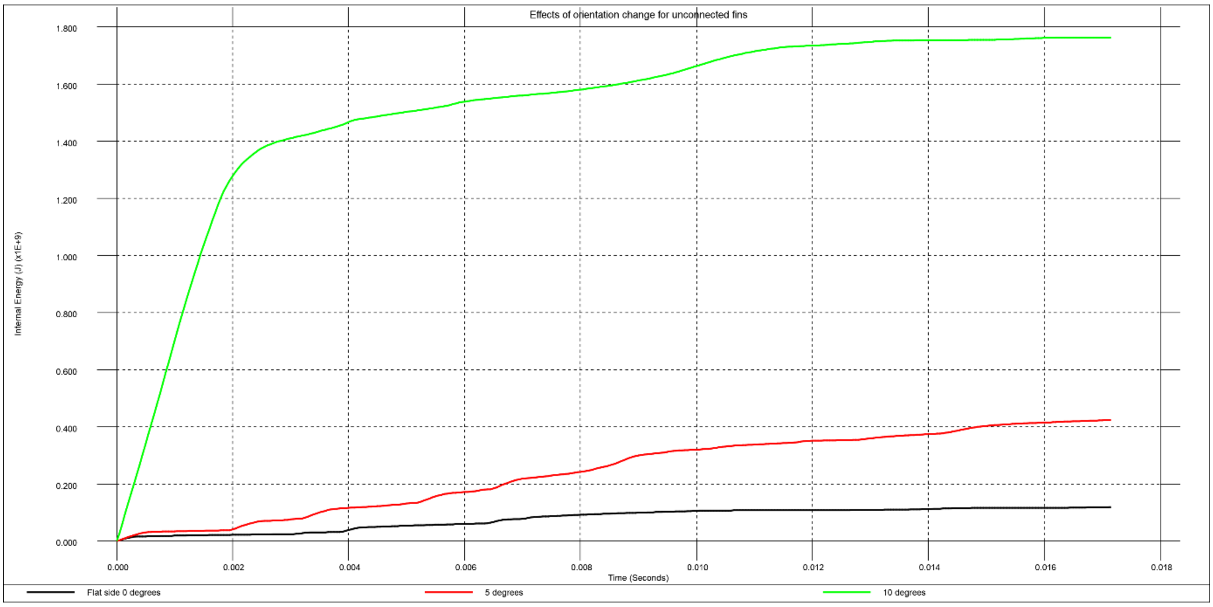

Fig.8: Internal energy for 3 different orientations.

To reduce this effect, the design is changed to ensure that all the fins are involved regardless of the orientation, as much as possible.

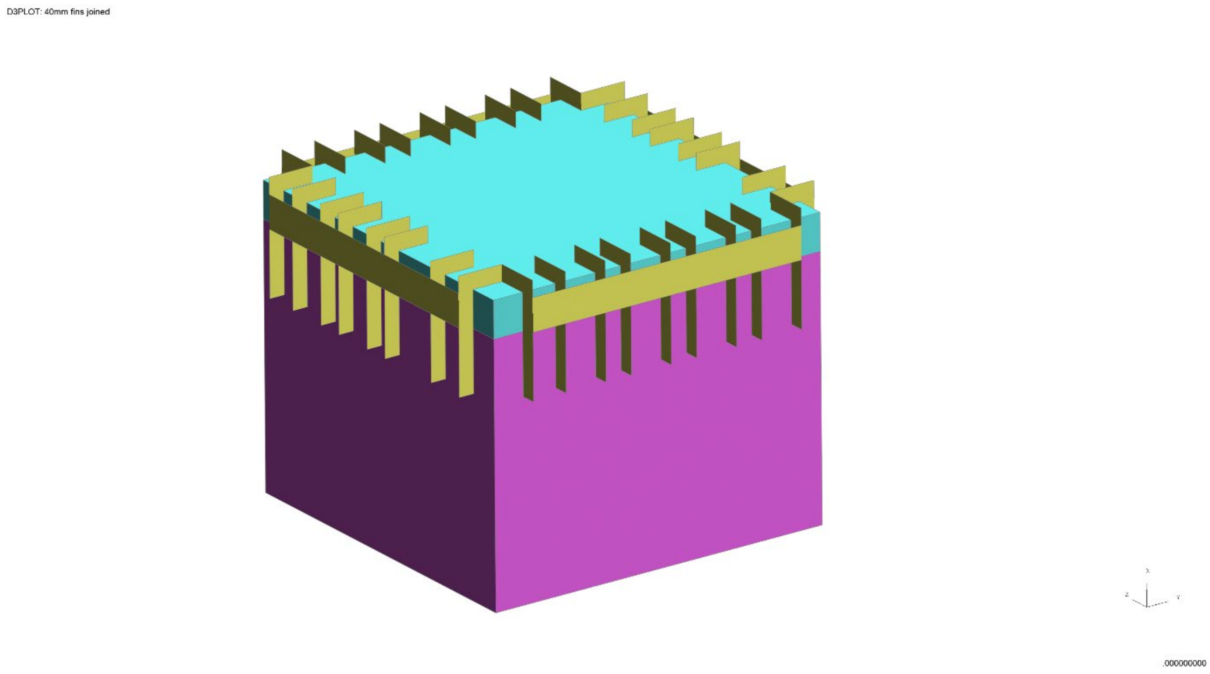

Fig.9: Simplistic connection of fins.

The internal energy plot, shown alongside the previous analysis, are shown in Figure 10.

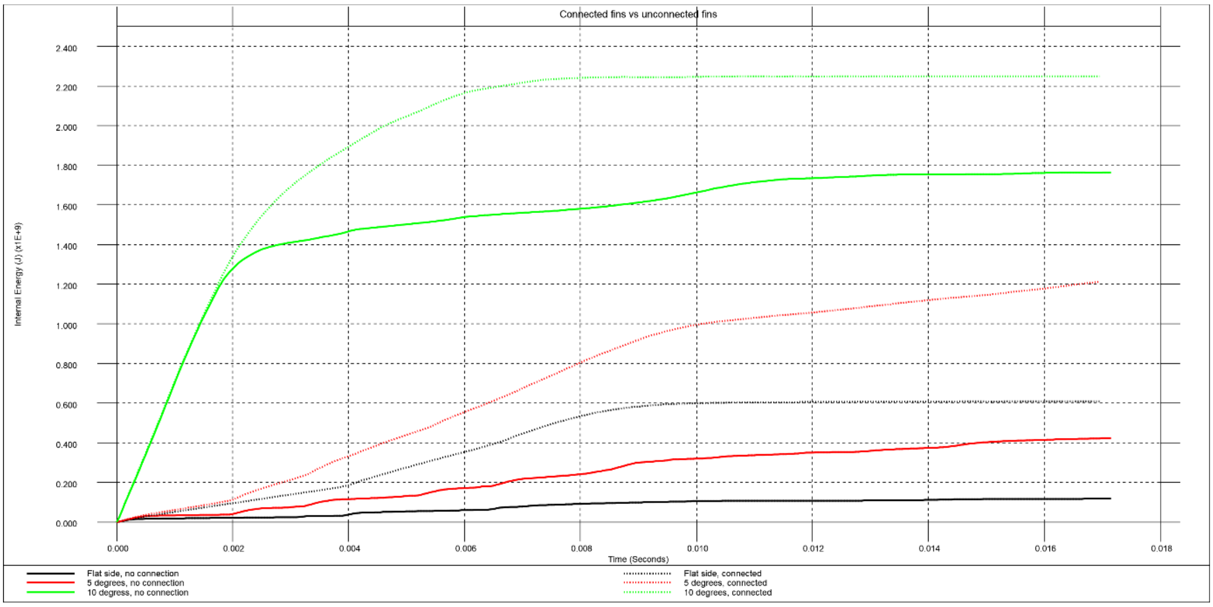

Fig.10: Comparison of internal energy for connected and unconnected fins.

It is clear that this makes a significant improvement. Further iterations can be made simple and quickly on this type of model. Making one change at a time and comparing key items, rather than trying to design the whole package in one go. This same approach can be used for cylindrical packages, introducing small changes on simple models that run quickly. This approach does not represent reality and does not attempt to. It provides the designer and analyst a quick way to suggest and accept or reject changes without having to go through the entire design process loop. It gives the analyst the ability to explore variations with freedom.

5.2.3 An alternative approach using submodelling

Where there are a lot of fins that may interact with each other, an alternative approach is to use submodelling or partial modelling. A relatively detailed model can be created of a single fin and this can be subjected to impacts at various orientations to obtain a set of force-displacement curves. These curves can then either be used directly for the behaviour of springs in a simple LSDYNA modell, or can be utilized in material models as stress-strain curves. In this way the simpler model of a fin can be modified and rerun quickly to provide information that can be fed into a slightly more complex model that still runs quickly.

6 Summary

You may ask, what is innovative and groundbreaking about this approach?
Why have you presented this at this conference?
My answer would be, not much is innovative, but it demonstrates a very important point that should be remembered by analysts across the various industries. As the ability to create and run massive LSDYNA model increases, it is always worth asking why?
Eventually the design does need all the detail, and the cuboid example presented above is currently shown in Figure 11 with a section of the outer fin connection removed for clarity.

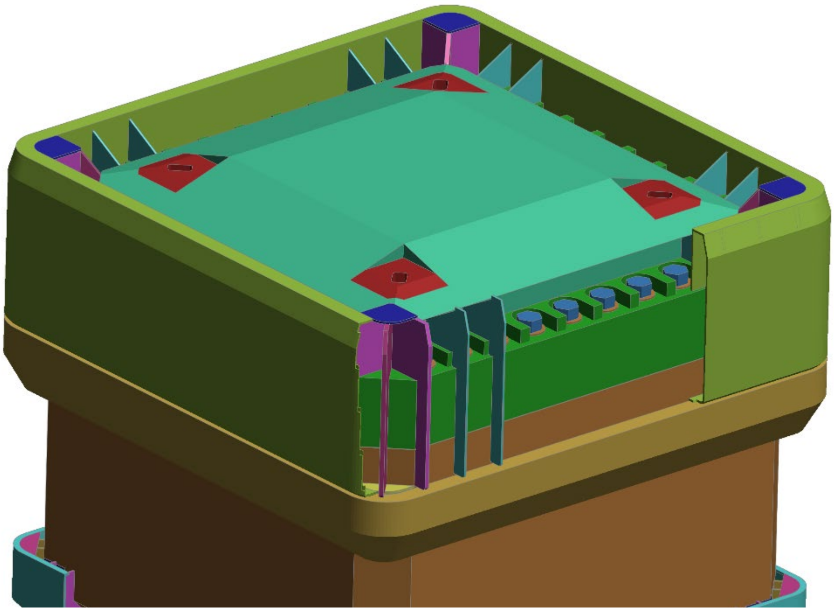

Fig.11: Current state of design with outer case transparent.

This model takes in excess of 12 hours to run a single orientation compared to 5 minutes during the development phase. With a simplified model, addressing one item at a time and understanding how it performs, the development cycle can be reduced. The use of LSDYNA is key to the development process and using it as a "comparative" tool rather than developing complex "all singing, all dancing" detailed models from the start provides even more power and understanding.

7 Literature

[1] International Atomic Energy Agency: Regulations for the Safe Transport of Radiative Material, 2018 Edition