

Advanced Physics - CSCs- 1910613

by Peter Robert Kenrick

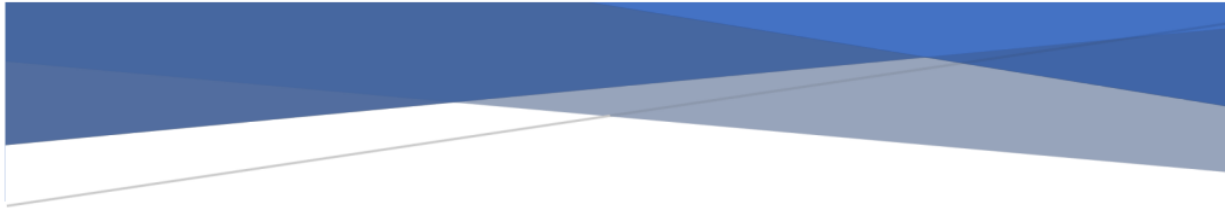
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IMPROVING A SHAPE CHARGE MODEL

Modifying a simulation to produce a better Jet

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Introduction

According to Walters and Zukas, Shape Charges are explosive devices which are used to cut holes into their target using the Munroe effect [1]. They use High Explosives which can be dangerous to handle, use and create. Creating Computer models of these detonations can provide a safe method of designing these devices.

The aim of this report is to take a given model of a Shape Charge and modify it to produce a better, more realist jet. This report will focus on making the model as realistic as possible rather than altering the design or materials to achieve this, however there are several recommendations at the end of this which do involve modifications. Abaqus [2] is the program being used and all screenshots in this report are from it.

Method

What is a Shape Charge?

According to Meyer and Homberg [3], a Shape Charge is an explosive with a hollowed-out space facing towards the target, lined with an inert liner which forms a high velocity jet (or in some cases an Explosively Formed Projectile) which can be used to cut into its target. The penetration, or effectiveness of the Shape Charge is dependent on several factors including the liner material, the liner dimensions (angle, width, size etc.)

They have uses in both military and civilian industries, such as mining [4] or the oil industry [5]. According to Walters and Zukas [1], Lined Shaped Charges have been used for military applications to provide extra penetration against armoured targets by detonating the Shaped Charge element when it is at the stand-off distance.

Materials used

The materials used to make a shape charge a pronounced effect on the design. Softer liner materials will not require as much energy to deform them. Typically, liners are made of copper which has some of the best properties required according to Wang et al [6], and is therefore the material used in the model for this report, specifically Annealed Copper [7].

The High Explosive used in the model is TNT. To model this, Abaqus can use what is known as the Jones Wilkens Lee (JWL) equation-of-state [8]. This represents the pressure to volume relationship. This is entered into the material properties in Abaqus along with a detonation point.

Stand off

One important thing to consider in the design of a Shaped Charge is the stand-off distance. This is the distance from the device to the target which is needed for the jet to form. For each variation of Shape Charge there is an optimum standoff value where the penetration is at its maximum [9].

What is Modelling

Modelling is creating a 3D simulation of a design on a computer or Computer Aided Design (CAD) according to Sarcar, Rao and Narayan [10]. This allows for the testing of a design without having to create a real-world prototype. There are several reasons for modelling ranging from cost to safety.

It is a useful tool for engineering as it allows designs to be tested for certain criteria such as failure modes. This means it's possible to determine how the design will likely fail can be redesigned to prevent this, for example, adding material or removing sharp edges. It can also be used to reduce

weight, if a model has a component which is not going to fail even if the thickness of the material is reduced, the designer can make it thinner and save on material costs or weight.

Bi and Wang [11] talk about the costs involved in manufacturing. Modelling can reduce costs by not having to machine or cast the design multiple times and perform test. This also aids in safety, for example, explosives are not easily made safe to work around. They can be modeled so people don't need to handle explosives to see roughly how the design will work.

Meshing

The mesh of this model will be using the Lagrangian method which according to Bi [12], is when a model is divided up into elements which can each deform which represent the material. These elements will take the input conditions at the beginning of each step of the simulation and calculate what happens to it. If the model were a metal bar restrained at one end and a force acting on the other, the elements would take the material properties of the bar and the force acting on it to determine the stresses, strains, deflection, and other properties at each point. Once this has been done for the first step, the elements would take their new locations and values and perform the next calculations.

The size of the mesh is determined by the user and can be modified to increase or decrease the size, and therefore number, of the elements (or vice versa). A larger mesh means each element covers more volume in the model and it becomes less accurate. This is due to the element calculating the averages of the values inside. With the metal bar example, if the element was the thickness of the bar, it would be trying to show both compressive and tensile forces where the bar flexes. If this is split into two elements over the thickness, they will each show their relevant value. If the element number is increased further this will show a gradient of values across the bar.

Increasing the number of elements in a simulation will necessarily increase the time it takes to run as the number of calculations performed will increase. There comes a point where increasing the resolution of the elements doesn't add enough additional accuracy to warrant the increase in time. This can be compensated by something called a mesh bias. This is where the element size changes to have greater concentration of elements in an area of interest (determined by the user). Bias can be seen in the difference between Figure 1 and Figure 2, Figure 1 has no bias and the elements are evenly spread. Figure 2 has a high bias towards the top of the cone, this is where the jet forms in a Shaped Charge and is therefore of interest to this model.

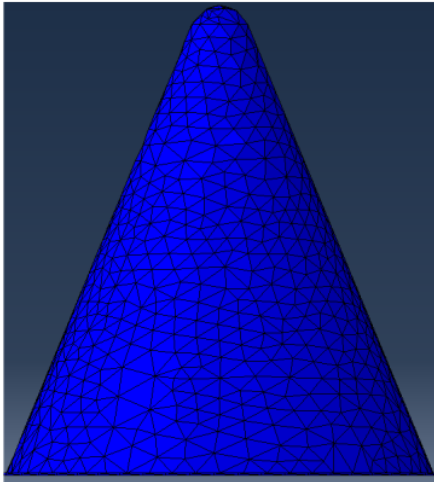


Figure 1 – 2nd Model – Even mesh

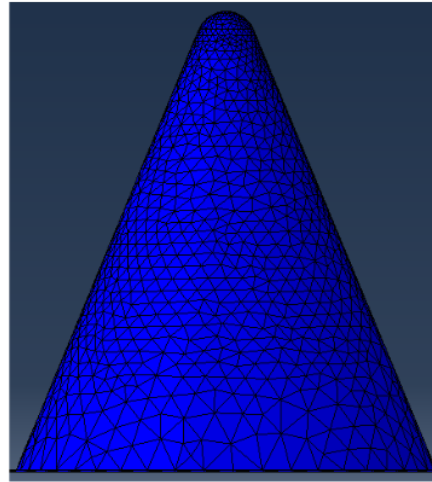


Figure 2 – 3rd Model – Biased mesh

Improving the model

The original model used for this report is a crude, coarsely meshed model of a typical Shape Charge in Abaqus. Several changes were made to the model to improve it:

- Altering the copper properties from the original given in the model to an Annealed Copper with more detail [7].
- Altering the model to use a thinner liner; during the first few runs it was noticed that the liner did not seem to be collapsing down into a jet. In his report, Manuel [13] describes the optimized liner to be $0.01D$ where D is the inside cone diameter at the widest point.
- Finally, the mesh of the model was improved; the bias around areas of interest were improved to give a better result in said areas while not increasing the calculation time of the simulation.

Running the simulation

Having generated the model, assigned the materials to each part within the model, constrained it, and applied the mesh, the simulation can then be run. This simulation was set up to run for 200 steps and a total of 1×10^{-4} seconds.

Results

Detonation

In the following images (Figure 3 & Figure 4), it shows the detonation wave in the model after 13 frames (approx. $6.5E-6$ seconds). Table 1 shows that there is a greater pressure in the more finely meshed model. This shows that the calculations being performed in the original model are different from the more finely meshed model. Improving the mesh further should result in different results again however the increase in accuracy might not be worth the computational time the simulation takes.

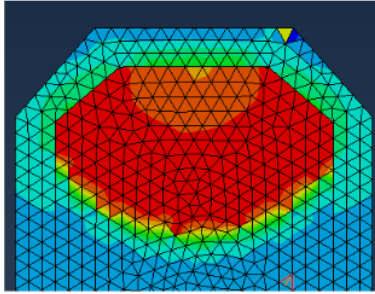


Figure 3 - Original Model

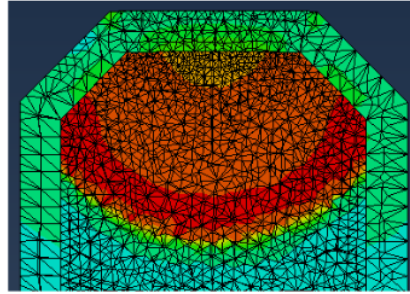


Figure 4 - Final Model

Original Model	Finer Mesh Model
+2.182e+09	+2.385e+09
+1.941e+09	+2.087e+09
+1.700e+09	+1.790e+09
+1.458e+09	+1.493e+09
+1.217e+09	+1.195e+09
+9.762e+08	+8.979e+08
+7.350e+08	+6.005e+08
+4.939e+08	+3.032e+08
+2.527e+08	+5.773e+06
+1.161e+07	-2.916e+08
-2.295e+08	-5.890e+08
-4.707e+08	-8.864e+08
-7.118e+08	-1.184e+09

Table 1 - Detonation Pressure - Frame 13

Compression of the Liner

The following images will show the difference in the liners. All the simulations ran for 200 frames, screenshots were taken at 50, 100, 150 and 200 frames to compare.

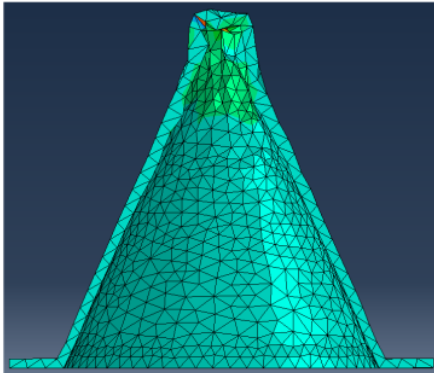


Figure 5 - 1st Model @ 50 frames

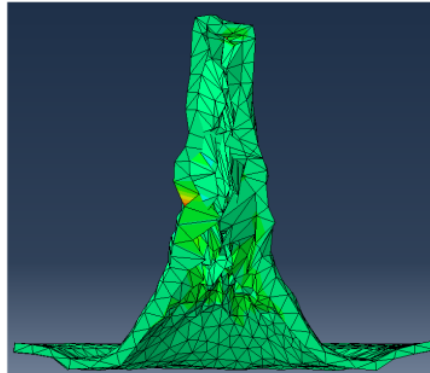


Figure 6 - 1st Model @ 100 frames

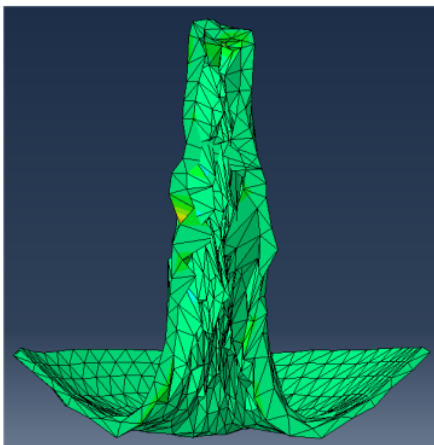


Figure 7 - 1st Model @ 150 frames

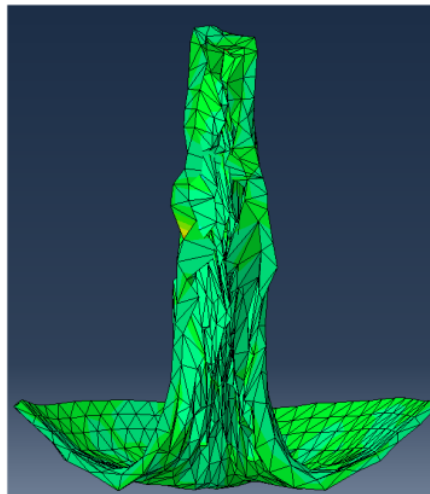


Figure 8 - 1st Model @ 200 frames

Figure 5, Figure 6, Figure 7, and Figure 8 show the original model given for the report with improved material properties at the 4 steps. In this model, the cone collapses down but does not seem to become a jet. This should have started forming between 50 and 100 frames as the cone collapses down and becomes a liquid. A gap can still be seen within this model inside the collapsed section of the cone.

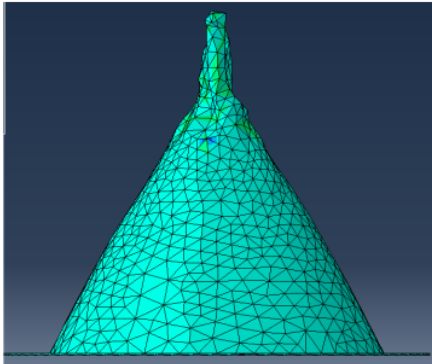


Figure 9 - 2nd Model @ 50 frames

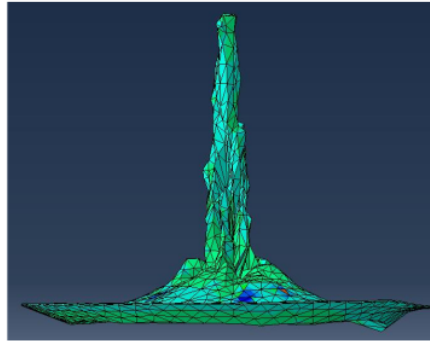


Figure 10 - 2nd Model @ 100 frames

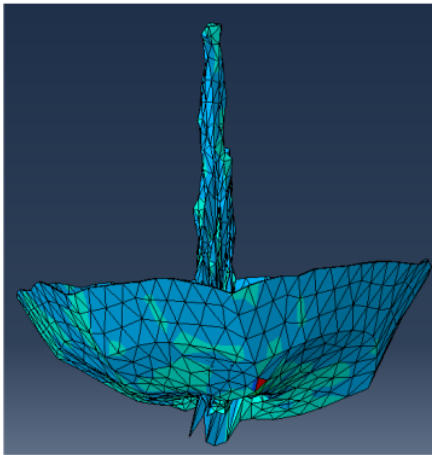


Figure 11 - 2nd Model @ 150 frames

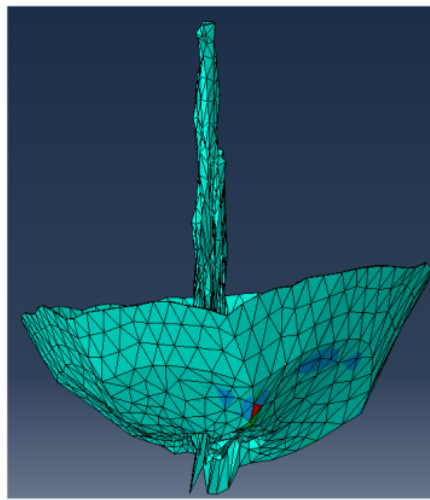


Figure 12 - 2nd Model @ 200 frames

Figure 9, Figure 10, Figure 11, and Figure 12 show the modified model where the thickness of the cone was reduced in an attempt to improve the jet. It is easy to see that Figure 10 is far more compressed than the original model in Figure 6. It can also be seen in Figure 11 and Figure 12 that there is some distortion of the elements in the direction the jet should be traveling.

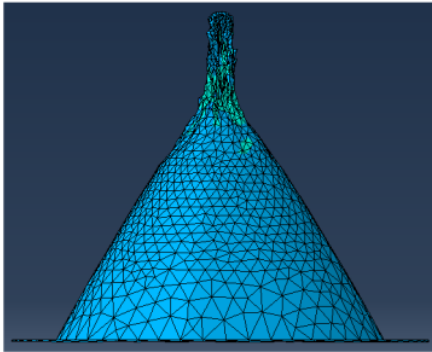


Figure 13 – 3rd Model - @ 50 frames

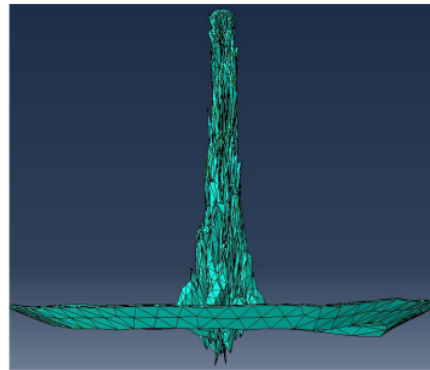


Figure 14 – 3rd Model - @ 100 frames

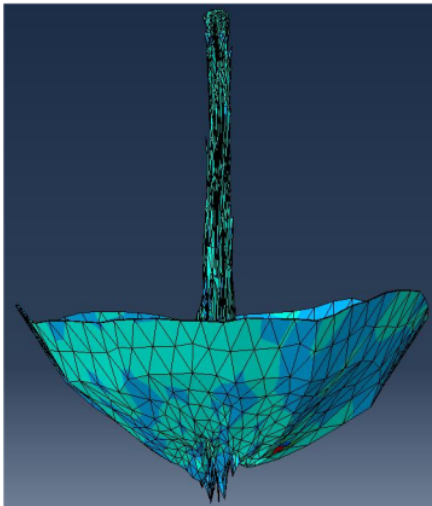


Figure 15 – 3rd Model @ 150 frames

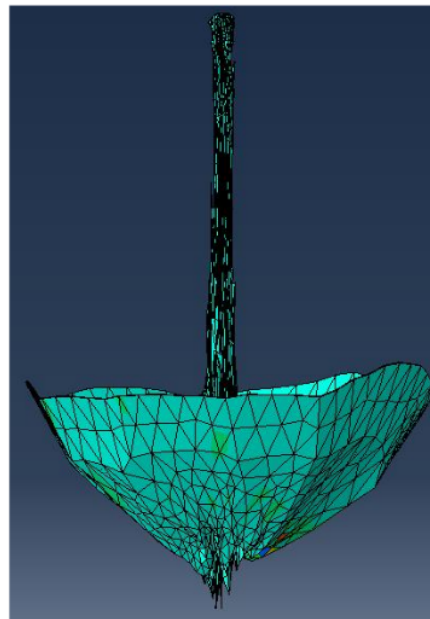


Figure 16 – 3rd Model @ 200 frames

Figure 13, Figure 14, Figure 15, and Figure 16 show the model with a better mesh and mesh bias. This model seems to become the most compressed of the three after the first 100 frames (Figure 14). It also shows the distorted elements much earlier indicating the jet formation.

Conclusion

In conclusion, the modifications made to the model resulted in a slightly better jet forming in the model.

The altered model which has a thinner liner than the original model had the largest effect on the simulation. It can be clearly seen that there is little to no jet forming in the original model (Figure 8) but in the 2nd and 3rd model, something can be seen to be forming out of the base.

Improving the mesh and improving the copper's properties did influence the performance of the model, this can be seen by the jet forming earlier than the 2nd model. It also changed how much the cone was compressed leading to the elongation of the cone in its final state to be considerably longer than the 1st and 2nd models.

Recommendations

Below is a list of recommendations which could be pursued after this report. Some of these are changes to the model/simulation which would aide in the understanding this report started:

Different Materials

The materials for the liner or HE (High Explosive) could be changed, this would provide different results potentially giving a better jet. Wang et al [6] investigate the simulation of varied materials for the liner.

More Realistic Model

There are several ways to create a more realistic model, all of which would require a much better understanding of Abaqus.

One way is the constraints used. As can be seen in the screenshots from Abaqus, if the constraints are not right it will create odd points of distortion. A better restrained model will act more like it would in the real world.

Another is to improve the material properties. This has already been started in this report by improving the copper. Improving the material properties gives the simulation more information to determine how the model should react given the inputs.

Angle of cone

Altering the angle of the cone can lead to different results, if the aim of the design is to have a specific stand-off, then the angle can be adjusted to achieve this at the cost of cutting ability. Vigil [13], has authored a report where they analysed the effects of different variables of Shaped Charges to find an optimum design.

Detonation wave

There are several ways to modify the detonation wave, this could be to alter the location of the detonator, or to increase the number of detonators. Another way would be to put voids or obstructions in the HE to alter the path of the wave.

Better mesh/bias

This report has already covered improving the mesh and the bias of the mesh however, with more time, and more powerful computer it would be possible to make a finer mesh which will inevitably produce more accurate results (assuming the model has been defined and constrained properly). Molinari [14] talks about adaptive meshing which attempts to remove the problem of heavily distorted elements.

Lagrangian and Eulerian Models

The method of modelling used in this report as stated above is Lagrangian. Something to consider when looking at the modelling is which type of model to use. Two of the types of models are Lagrangian and Eulerian. In the report Lagrangian modeling is used, however using a Eulerian model will show the simulation from a unique perspective. Whereas Lagrangian tracks each element, in Eulerian the mesh is stationary, and it is the concentration of the contents which is computed [15].

Stand-off distance/Penetration

Another aspect which could be investigated would be the stand-off distance vs penetration of the jet. This would require a fully working model and a longer simulation run time.

Comparison to real-world simulation

Producing and testing a real-world example of the model will be good to validate the simulation. If the simulation matches the actual model, it can be confirmed that the model is realistic enough to make predictions.

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